URANIUM RESOURCES IN NEW MEXICO

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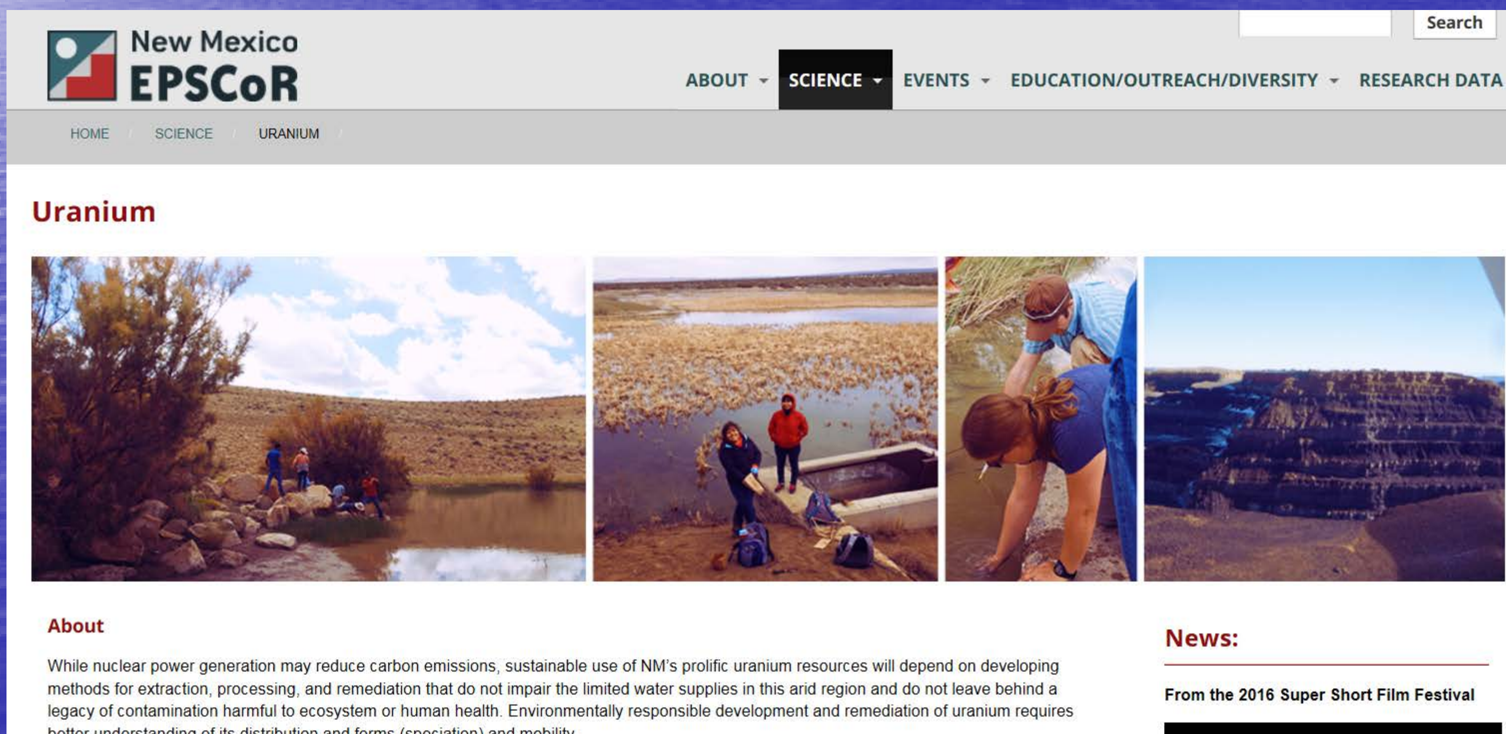
Purpose

- Describe the uranium industry in New Mexico, with emphasis on Grants uranium district
- Poster on "Uranium Resource Potential in New Mexico"
- Session later this morning, our keynote speaker, and many posters

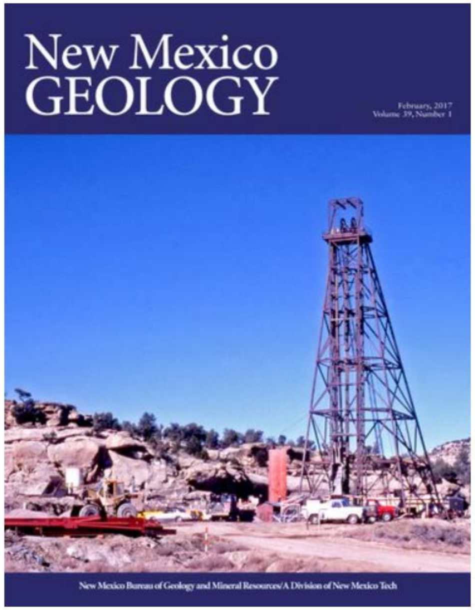
Why are we discussing uranium now?

- Near the end of a 5 year study as part of the EPSCoR program https://www.nmepscor.org/science/uranium



Why are we discussing uranium now?

- January 2016, three-day workshop to discuss topics associated with in situ recovery (ISR) of uranium
- Two special editions of New Mexico Geology
- This NMGS Spring Meeting "*Uranium in New Mexico: the Resource and the Legacy*"
- Grants uranium district is a world class deposit and there will be production in the future



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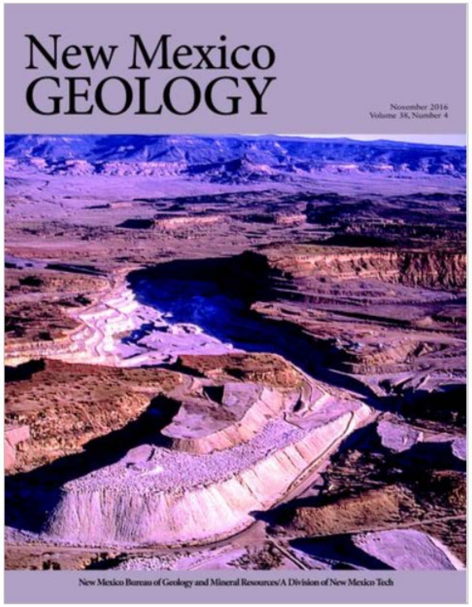

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WHY IS URANIUM IMPORTANT?

WHERE IS URANIUM FOUND IN NEW MEXICO?

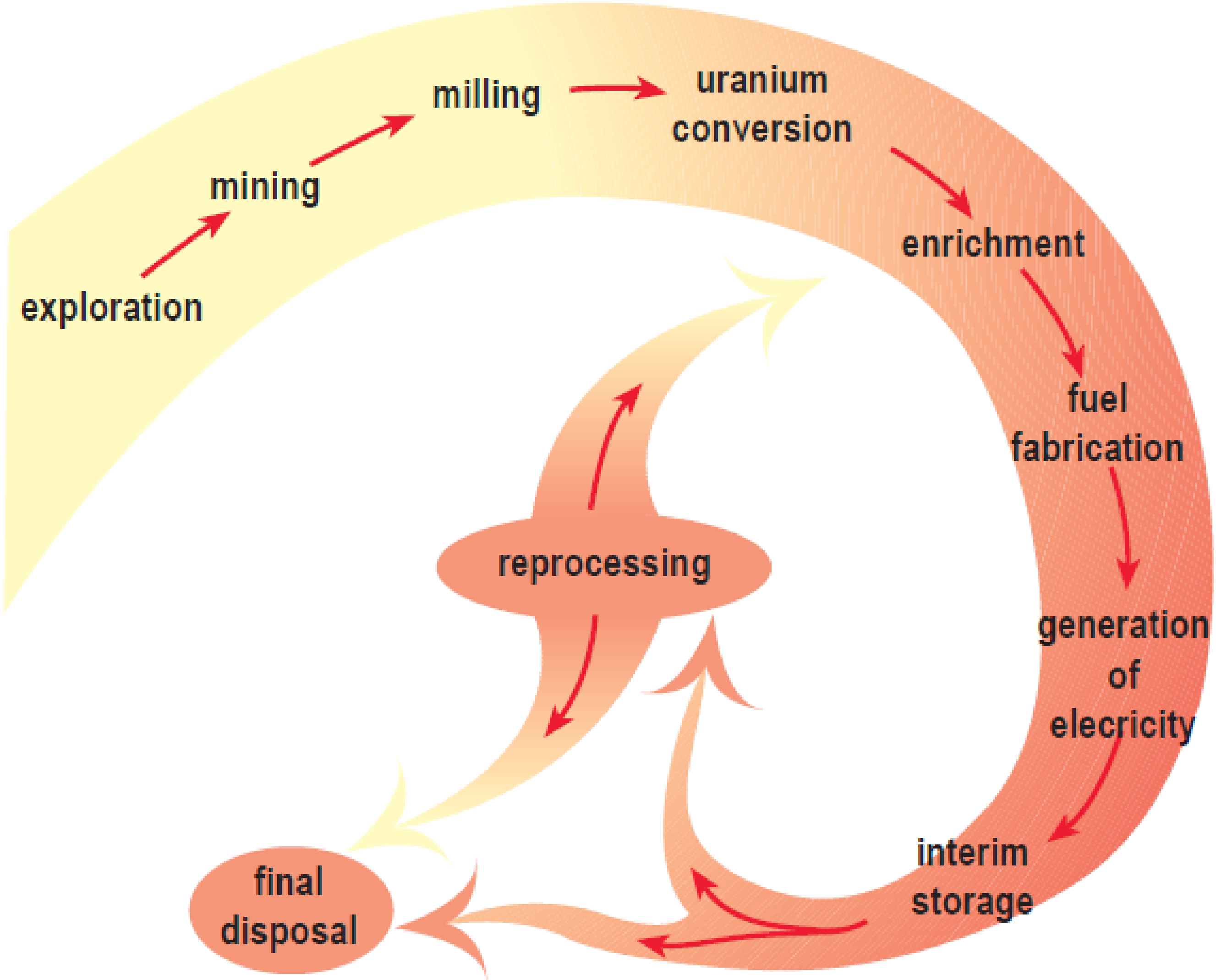
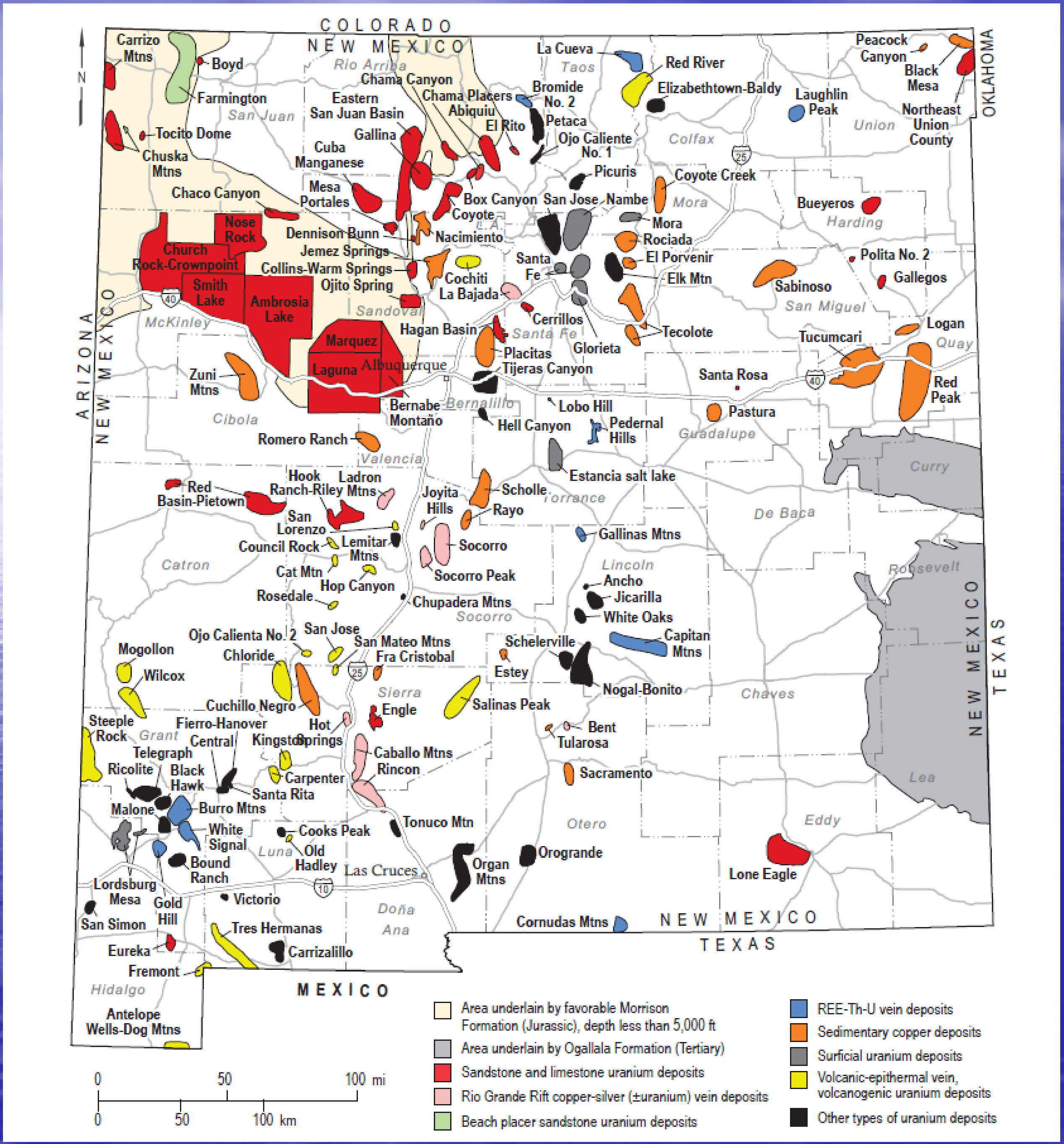


Figure 3. The nuclear fuel cycle (www.eia.gov/energyexplained/index.cfm?page=nuclear_fuel_cycle, accessed 7/27/15).



URANIUM MINING DISTRICTS IN NEW MEXICO

(McLemore, 2017; McLemore and Chenoweth, 1989, in press)

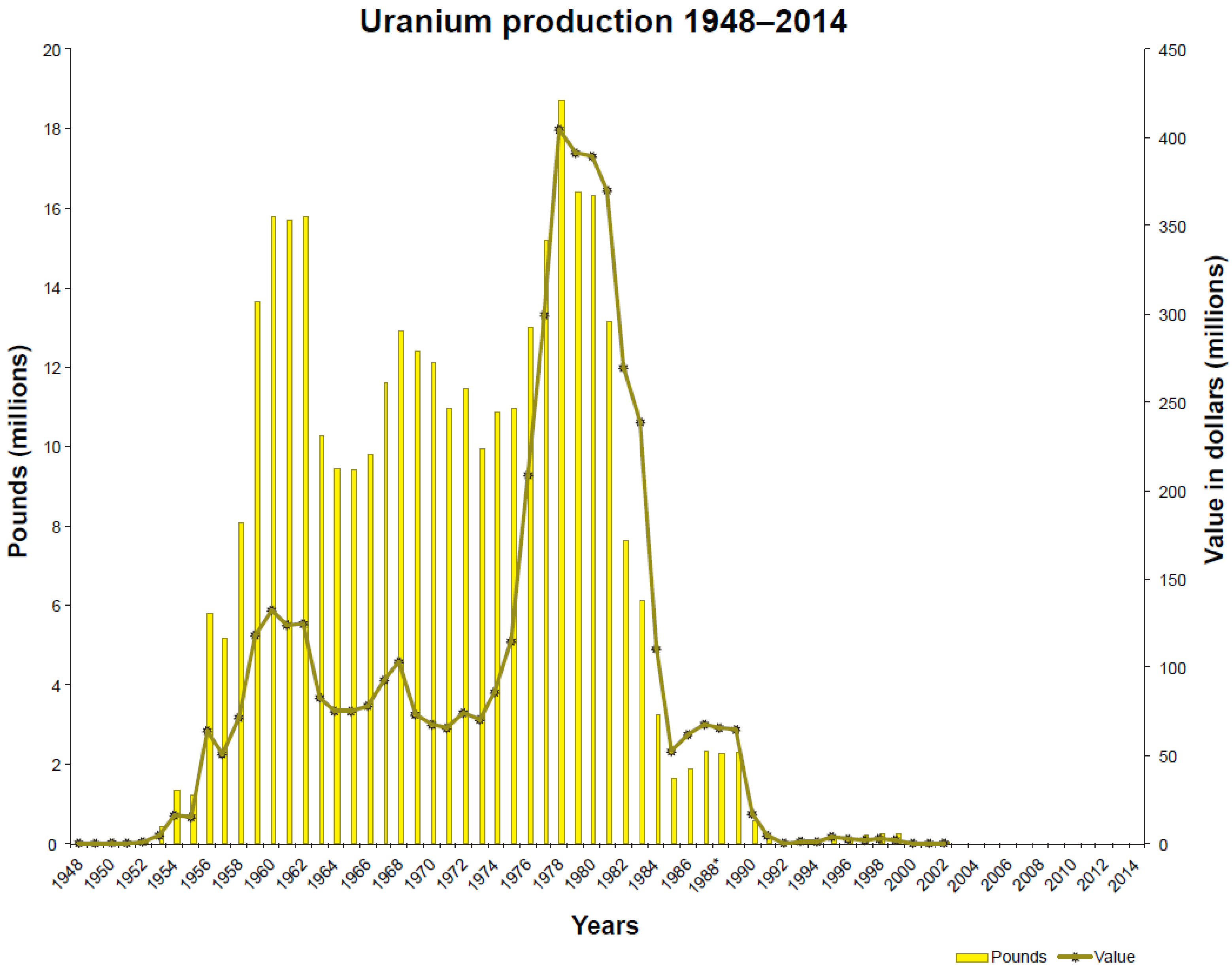


FIGURE 5. Uranium production in New Mexico from 1948 to 2002.

McLemore and Chenoweth (1989), McLemore (2017)

Table 1. Estimated total production of major commodities in New Mexico, in order of estimated cumulative value (data from USGS, 1902-1927; USBM, 1927-1990; Kelley, 1949; Northrop, 1996; Harrer, 1965; USGS, 1965; Howard, 1967; Harben et al., 2008; Energy Information Administration, 2015; New Mexico Energy, Minerals and Natural Resources Department, 1986-2015). Figures are subject to change as more data are obtained.

Commodity	Years of production	Estimated quantity of production	Estimated cumulative value
Natural Gas	1921-2014	>73 trillion cubic feet	$160 billion
Oil	1922-2014	>6.1 billion barrels	$115 billion
Coal	1882-2013	>1.27 billion short tons	>$21 billion
Copper	1804-2013	>11.5 million tons	>$20.6 billion
Potash	1951-2013	112,054,218 short tons	>$15 billion
Uranium	1948-2002	>347 million pounds	>$4.7 billion
Industrial minerals**	1959-2013	40,276,083 short tons	>$2.6 billion
Aggregates***	1997-2013	>666 short tons	>$2.5 billion
Molybdenum	1951-2013	>176 million pounds	>$852 million
Gold	1931-2013	>3.2 million troy ounces	>$463 million
Zinc	1848-2013	>1.51 million tons	>$337 million
Silver	1903-1991	>118.7 million troy ounces	>$279 million
Lead	1848-2013	>367,000 tons	>$56.7 million
Iron	1883-1992	>6.7 million long tons	>$23 million
Fluorspar	1883-1962	>721,000 tons	$12 million
Manganese	1909-1978	>1.9 million tons	$5 million
Barite	1883-1963	>37,500 tons	>$400,000
Tungsten	1918-1965	113.8 tons (>60% WO_3)	na
Niobium-tantalum	1940-1958	34,000 pounds of concentrates	na

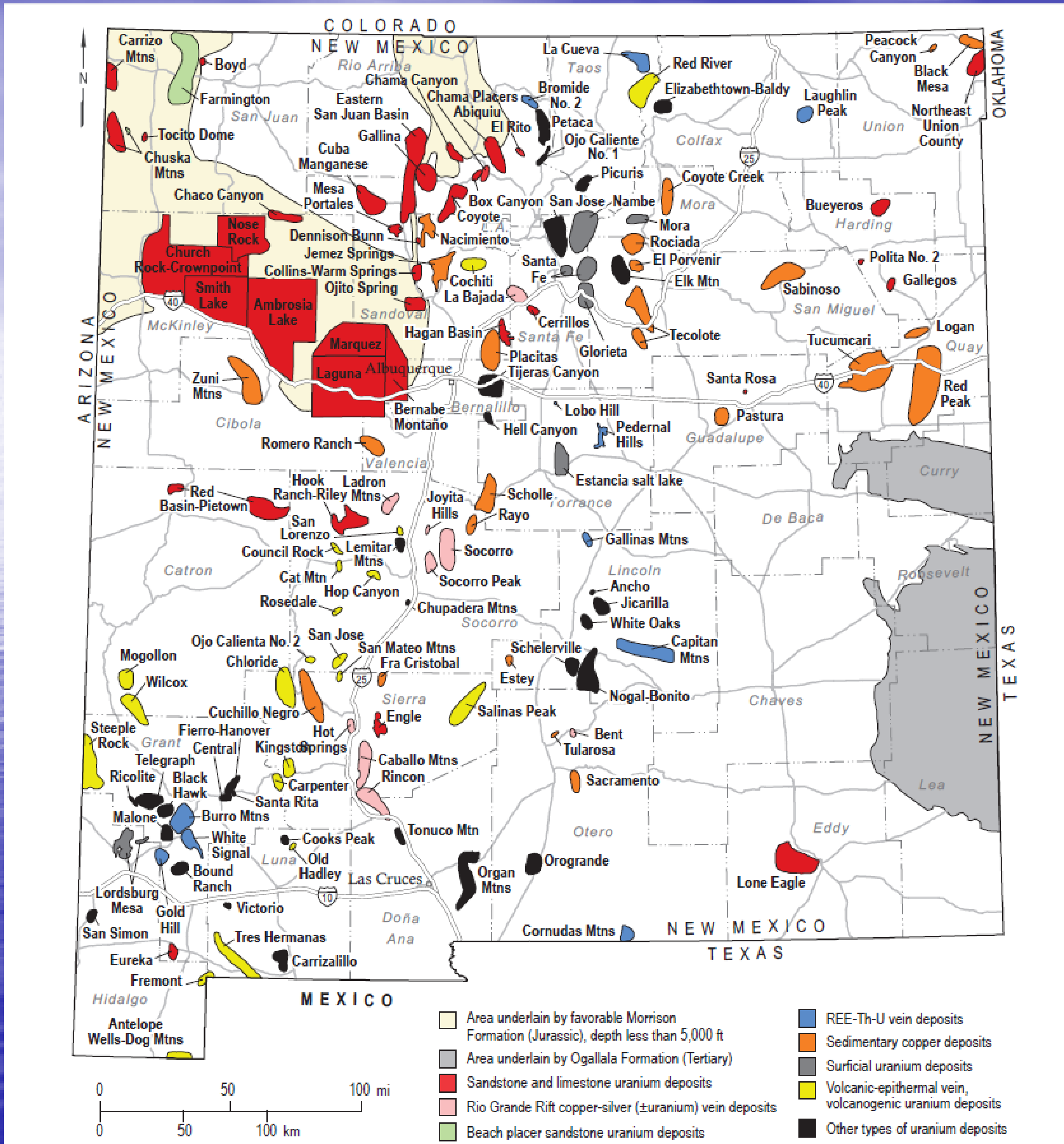
McLemore et al. (in press)

Table 1. Uranium production from 1947–2002 by type of deposit from New Mexico (McLemore and Chenoweth, 1989, 2003; production from 1988–2002 estimated by the authors). Type of deposits refers to Table 2. Total U.S. production from McLemore and Chenoweth (1989) and Energy Information Administration (2010).

Type of deposit	Production (lbs U_3O_8)	Period of production (Years)	Production total in NM (%)
Primary, redistributed, remnant sandstone uranium deposits (Morrison Formation, Grants district)	330,453,000[1]	1951–1988	95.4
Mine water recovery (Morrison Formation, Grants district)	9,635,869	1963–2002	2.4
Tabular sandstone uranium deposits (Morrison Formation, Shiprock district)	493,510	1948–1982	0.1
Other Morrison Formation Sandstone uranium deposits (San Juan Basin)	991	1955–1959	—
Other sandstone uranium deposits (San Juan Basin)	503,279	1952–1970	0.1
Limestone uranium deposits (Todilto Formation[2], redominantly Grants district)	6,671,798	1950–1985	1.9
Other sedimentary rocks with uranium deposits (total NM)	34,889	1952–1970	—
Vein-type uranium deposits (total NM)	226,162	1953–1966	—
Igneous and metamorphic rocks with uranium deposits (total NM)	69	1954–1956	—
Total in New Mexico	348,019,000[1]	1948–2002	100
Total in United States	**927,917,000[1]**	**1947–2002**	**NM is 37.5 of total U.S.**

[1]Production rounded to the nearest 1,000 pounds. There has been no uranium production in New Mexico since 2002. [2]Todilto Formation (Cather et al., 2013).

McLemore and Chenoweth (in press)



URANIUM MINING DISTRICTS IN NEW MEXICO

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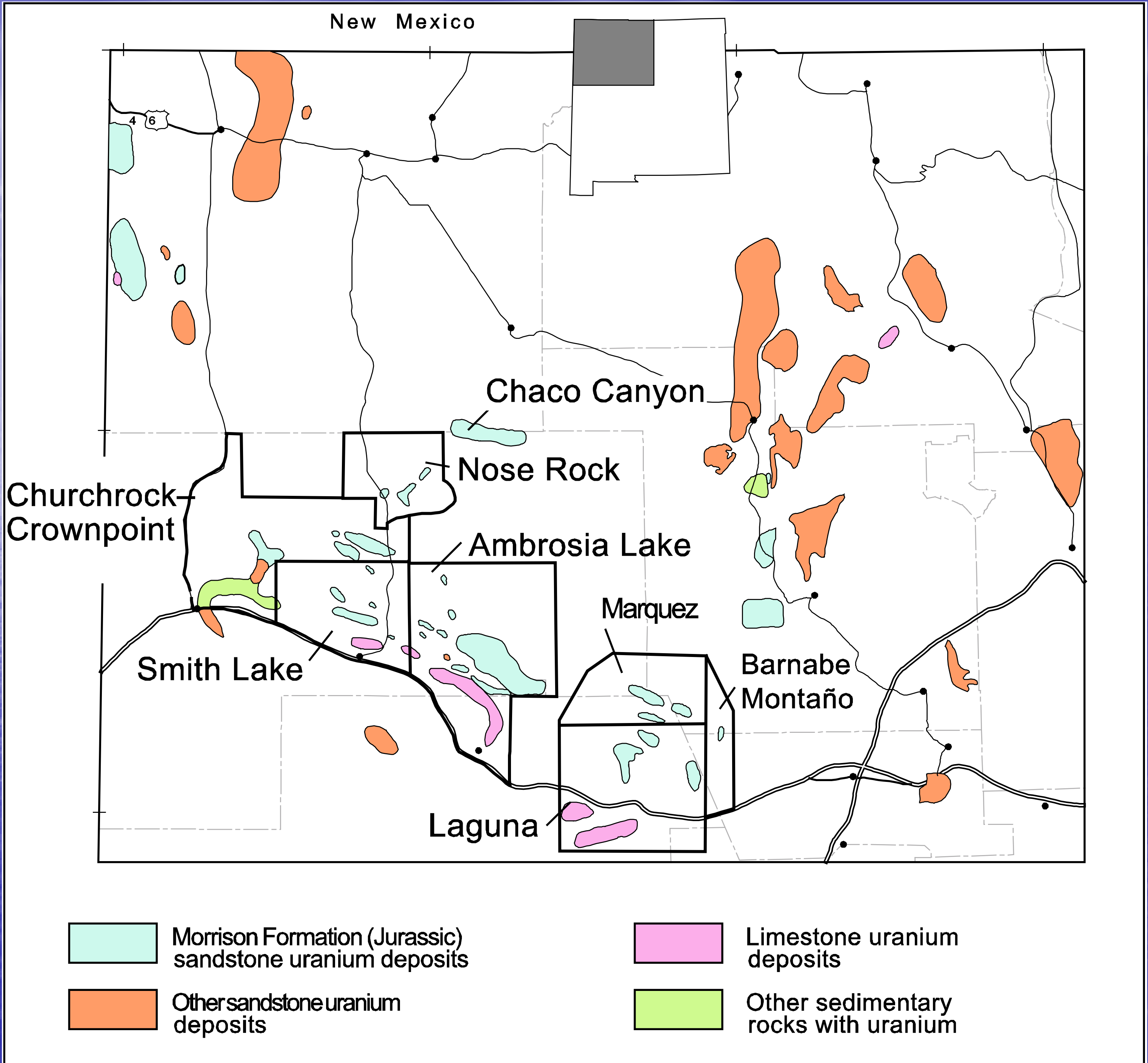


New Mexico
Chaco Canyon
Nose Rock
Churchrock-
Crownpoint
Ambrosia Lake
Marquez
Smith Lake
Barnabe
Montaño
Laguna
4
6
Morrison Formation (Jurassic) sandstone uranium deposits
Limestone uranium deposits
Other sandstone uranium deposits
Other sedimentary rocks with uranium

New Mexico is
2^{nd} in the US in uranium reserves 15 million tons ore at 0.277% U_3O_8 (84 million lbs U_3O_8) at $30/lb (DOE)

Historical Production from the Morrison Formation in Grants District

- ~348 million lbs of U_3O_8 from 1948-2002
- Accounting for 97% of the total uranium production in New Mexico
- More than 30% of the total uranium production in the United States
- 7th largest district in total uranium production in the world

Grants district

- ~348 million lbs of U_3O_8 have been produced 1948-2002
- ~409 million lbs of U_3O_8 historic resources have been reported by various companies
- Probably another ~200 million lbs of U_3O_8 remain to be discovered
- The district contained more than 900 million lbs U_3O_8

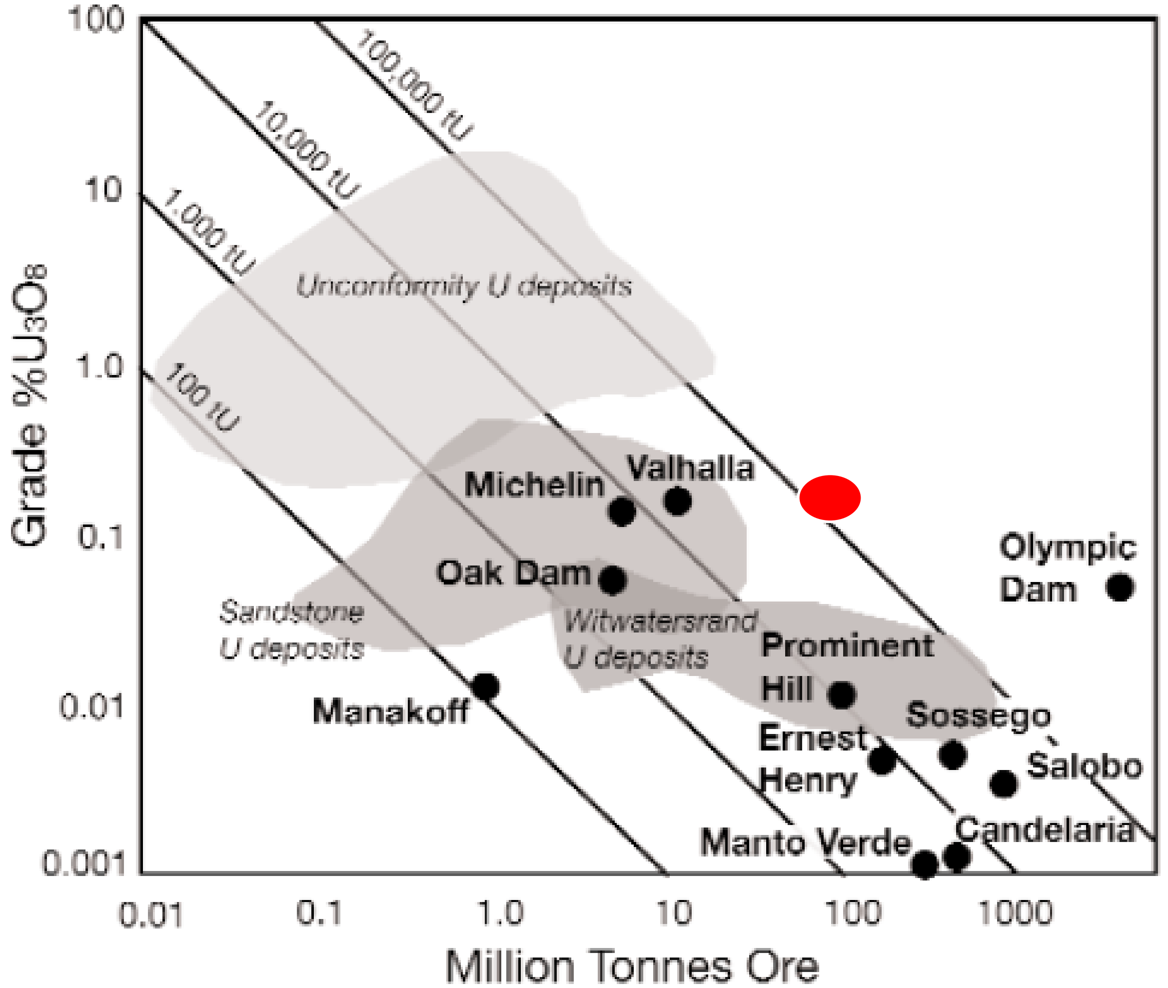


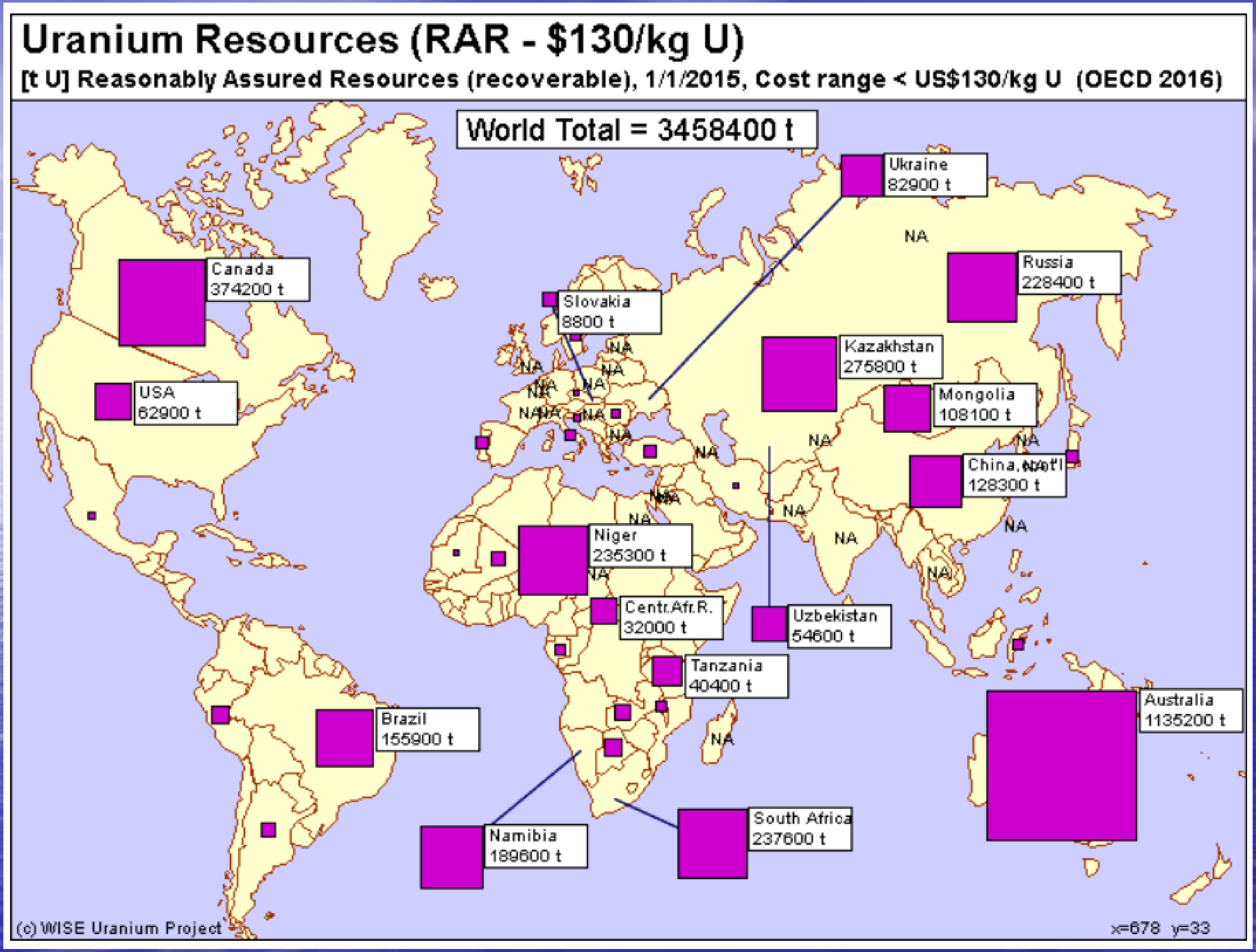
FIG. 1. Grade vs. tonnage plot for uranium in iron oxide-copper-gold (IOCG) deposits and prospects in relationship to the fields for unconformity-related uranium deposits, sandstone-hosted uranium deposits, and Witwatersrand uranium deposits (data from Dahlkamp, 1993). The IOCG deposits have a broad range of uranium contents. Although the giant Olympic Dam deposit has a relatively low uranium grade, it is currently the world's largest uranium producer.

Hitzman and Valenta, 2005, *Economic Geology,* v. 100, pp. 1657–1661

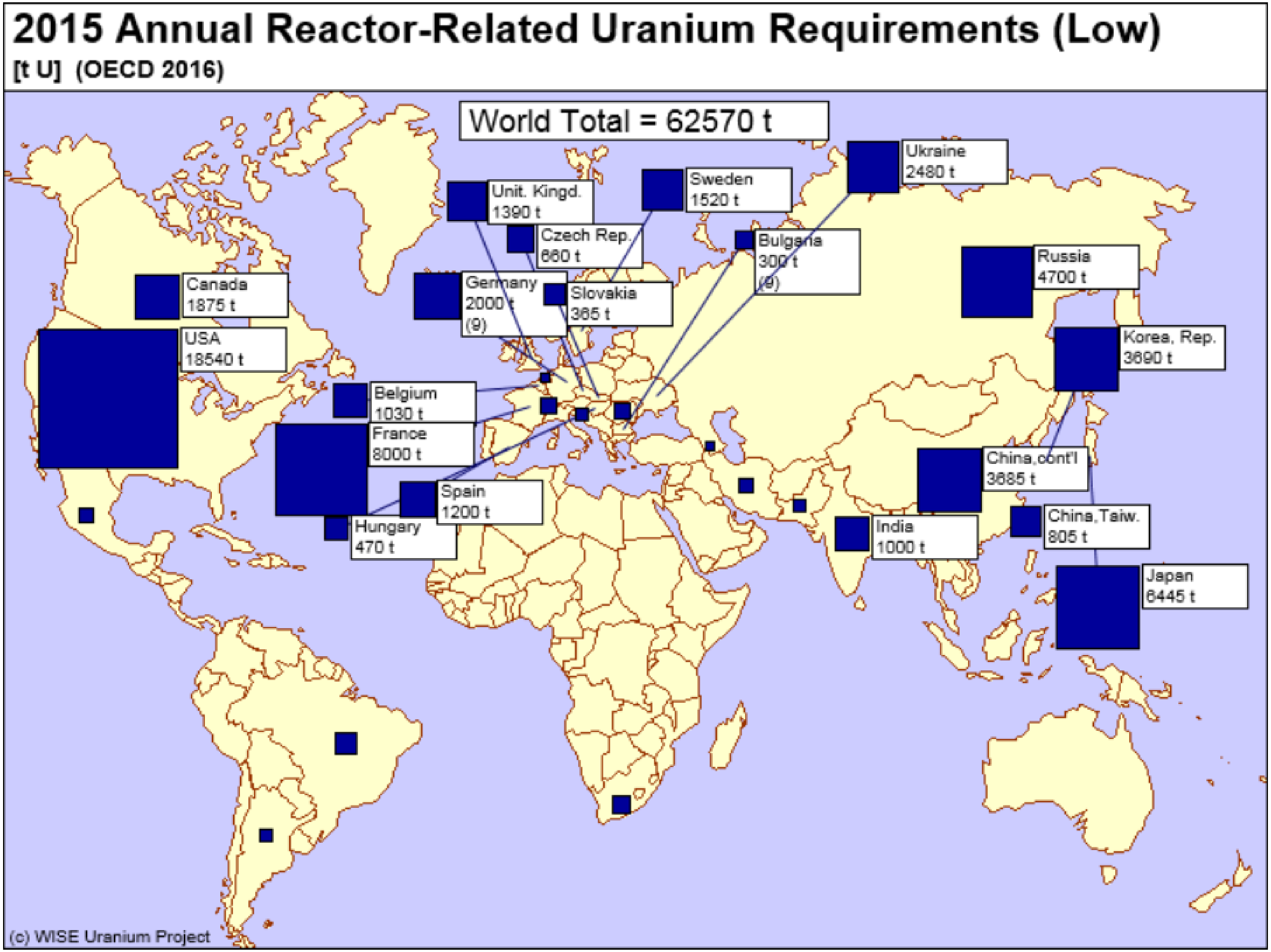
Grants district (V.T. McLemore estimate)

Why did uranium production cease in New Mexico?

- Three Mile Island produced a public perception in the U.S. that nuclear power was dangerous.
- **At the same time, NM uranium deposits in production were decreasing in grade by nearly half.**
- Significant changes were beginning to occur that would increase the cost of mine and mill reclamation as well as future permitting in the U.S.
- **More attractive, larger, higher grade uranium deposits in Canada, Australia, and Kazakhstan were discovered.**
- Large coal deposits were found throughout the U.S. that could meet the nation’s energy needs.



Resources in NM are from DOE which are significantly lower than what industry has identified (http://www.wise-uranium.org/img/uresw.gif)



t = metric tonne · NA = Data not available

http://www.wise-uranium.org/umaps.html?set=anrq

- There is sufficient uranium reserves to meet the current reactor demand.
- In order for NM deposits to oce again be economic—
  - Must build new reactors to increase demand.
  - Wait for reserves at other localities to be depleted by production.
  - Decrease cost of production.

Importance of sandstone uranium deposits in the Grants district

- Major mining companies abandoned the districts after the last cycle leaving advanced uranium projects.
- Inexpensive property acquisition costs includes $$ millions of exploration and development expenditures.
- Availability of data and technical expertise.
- Recent advances in in situ recovery and heap leaching makes sandstone uranium deposits attractive economically.

Geology

Sandstone uranium ore deposits

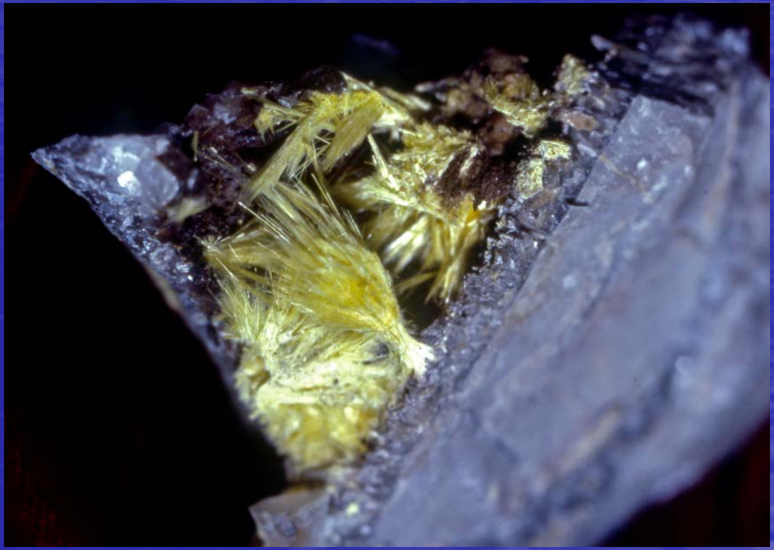
- Epigenetic concentrations of uranium minerals that occur as uneven impregnations and minor massive replacements in fluvial, lacustrine, and deltaic sandstones
- Low to medium grade (0.05 - 0.6% U_3O_8)
- Small to medium in size (ranging up to a maximum of 50,000 tons U_3O_8)
- Uraninite and coffinite primary minerals

Sandstone uranium deposits

- Medium- to coarse-grained sandstones
  - Includes mudstones through conglomerates
- Uranium precipitated under reducing conditions
  - Carbonaceous materials (detrital plant debris, amorphous humate, marine algae)
  - Hydrocarbons (petroleum, H_2S)
  - Pyrite or other sulfides
  - Interbedded basic volcanics with abundant ferro-magnesian and other minerals (eg chlorite, zeolite, Ti oxides)
  - Interface of reducing/oxidizing fluids

Uranium ore

- Uraninite and coffinite are primary minerals
  - Urano-organic complexes
  - Secondary uranium minerals
- Fine-grained
- Occupy intergranular spaces
- Locally replace fossil wood and bones
- Typically follow bedding, but rarely cross cuts bedding
- Well defined boundaries, but gradations are common



Geochemical signature

- U, V, Mo, Se, locally Cu, Ag, Cr, Ra.
- Anomalous radioactivity from daughter products of U.
- Low magnetic susceptibility in and near tabular ores.

AGE

from McLemore (2011)

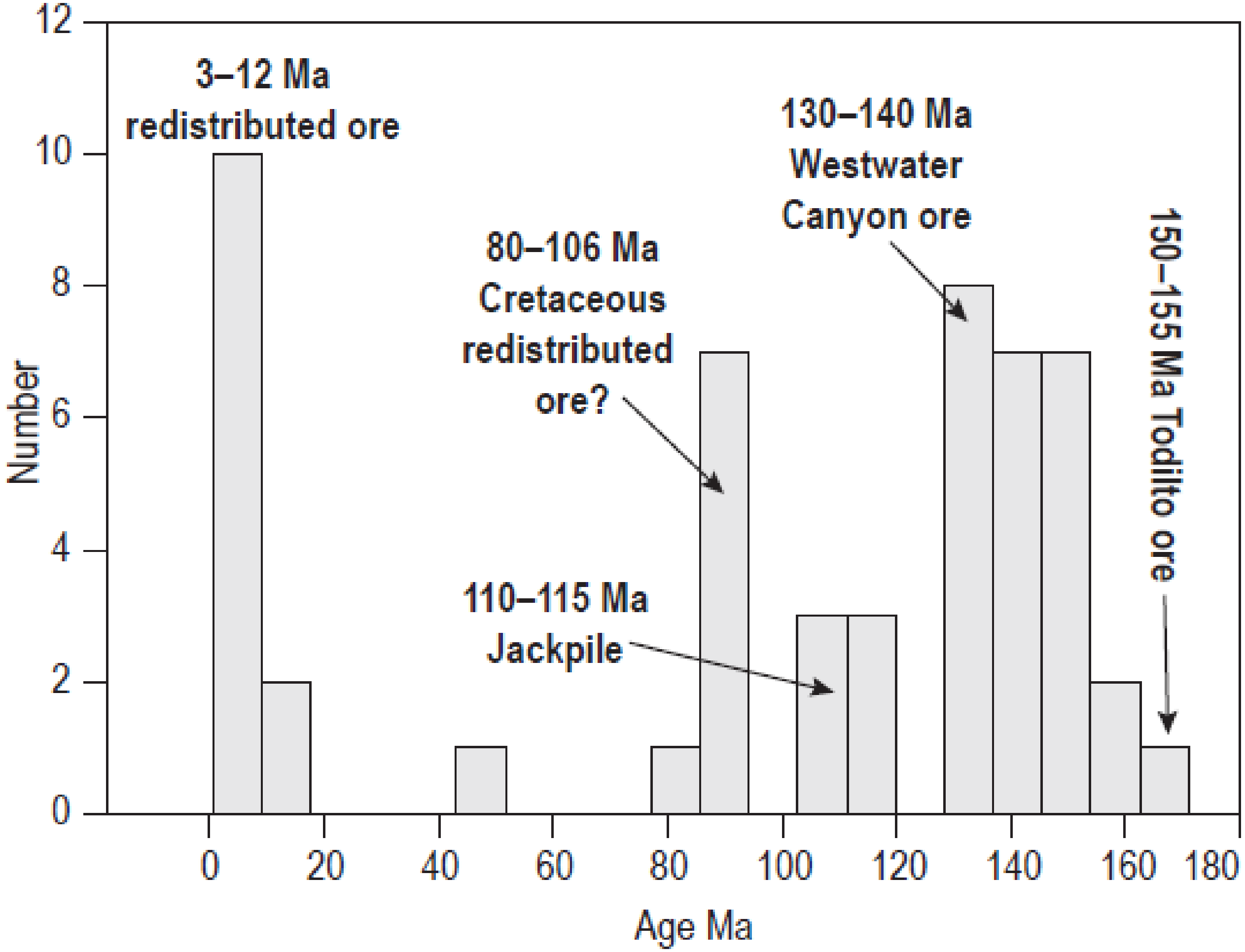
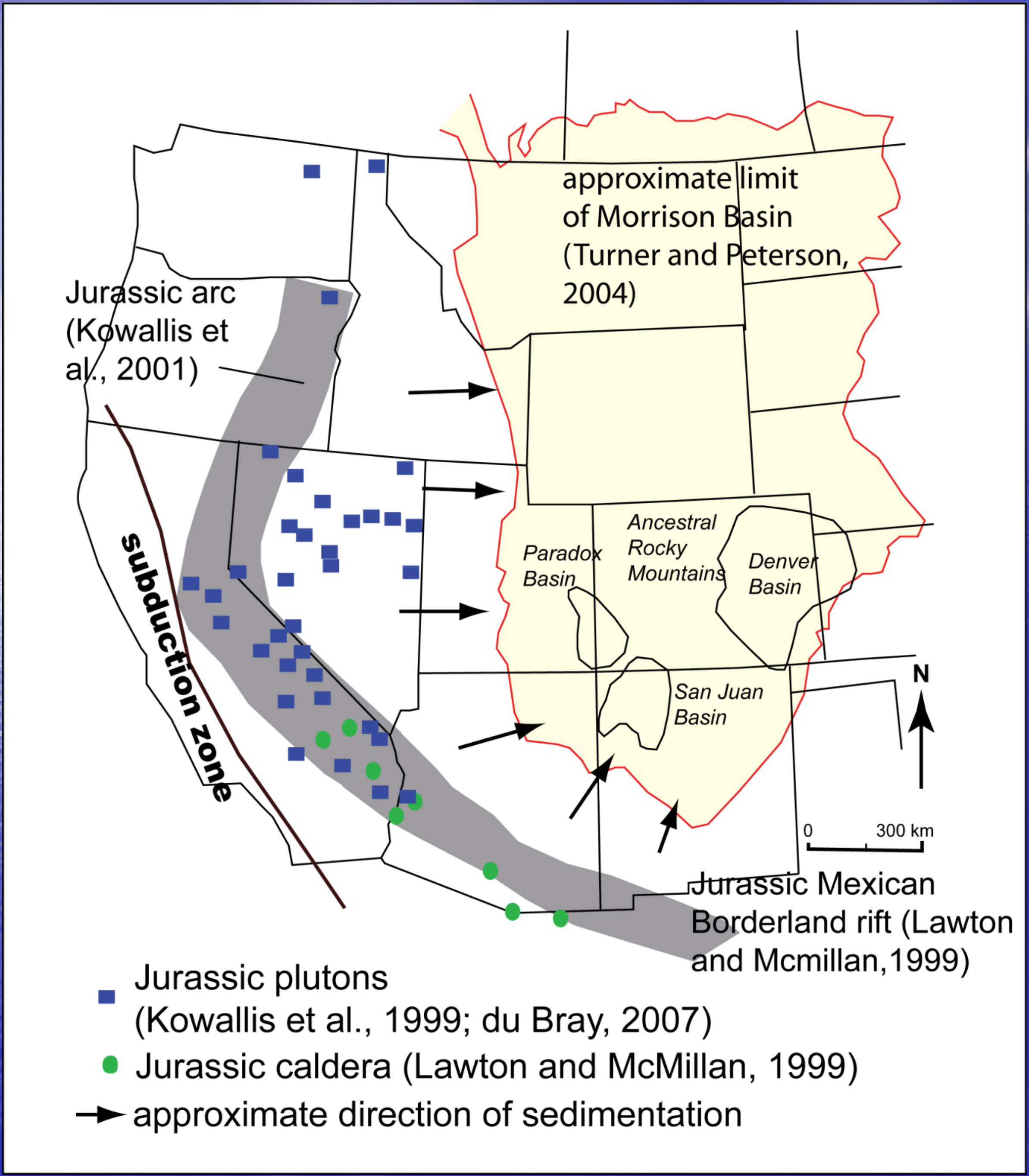


Figure 15. Age determinations of Grants district mineralization (McLemore, 2011). Includes Pb/U, K/Ar, Rb/Sr, and fission track dates from Miller and Kulp (1963), Nash and Kerr (1966), Nash (1968), Berglof (1970, 1989), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983) and is summarized by Wilks and Chapin (1997).



POTENTIAL SOURCE

from McLemore (2011)

Methods of uranium recovery

- Conventional mining and milling
  - Higher grade deposits
  - Mineralogy and lithology determine if it is acid or alkaline leach
  - No mills in NM, although there are plans underway for at least 1 mill in the Grants district
- In situ recovery
  - Typically roll front deposits
  - Mineralogy and chemistry important
  - Mo and V interferes with recovery of U

Past ISR in New Mexico

- Mobil at Crownpoint
- UNC-Teton at Section 23
- Grace Nuclear at Hook's Ranch
- Section 13 north of Seboyeta and Church Rock
- Anaconda at Windwhip, part of the Jackpile Paguate mine)
- Mine water recovery from Ambrosia Lake and other mines

Challenges to uranium mining in New Mexico

- **More attractive, larger, higher grade uranium deposits in Canada, Australia, and Kazakhstan are being produced.**
- Permitting for new ISR and especially for conventional mines and mills will take years to complete in New Mexico.
- Numerous geological and technical issues need to be resolved.
- Closure plans, including reclamation must be developed before mining or leaching begins. Modern regulatory costs will add to the cost of producing uranium in the U.S.

Challenges to uranium mining in New Mexico

- 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.
- 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 future requirements.

SUMMARY

- Sandstone uranium deposits have played a major role in historical uranium production
- Although other types of uranium deposits are higher in grade and larger in tonnage, sandstone uranium deposits will someday again become a significant player
  - As ISR and heap leach technologies improve cutting production costs
  - As demand for uranium increases world-wide increasing the price of uranium

FUTURE WORK

- Refine our estimates of uranium resource/reserve potential in the state
- Detailed mineralogy studies (XRD and electron microprobe)
- Define the origin of distribution of primary verses redistributed deposits in the San Juan Basin
- Geochemical characteristics of naturally-occurring groundwater that oxidized, remobilized, and redeposited primary tabular or “trend-type” uranium deposits in the Grants district
- Study of clay species in the mineralized zones, and their impacts not only on porosity and permeability characteristics during uranium extraction