Uranium Mining & Milling in New Mexico: Past Activities & Environmental Challenges

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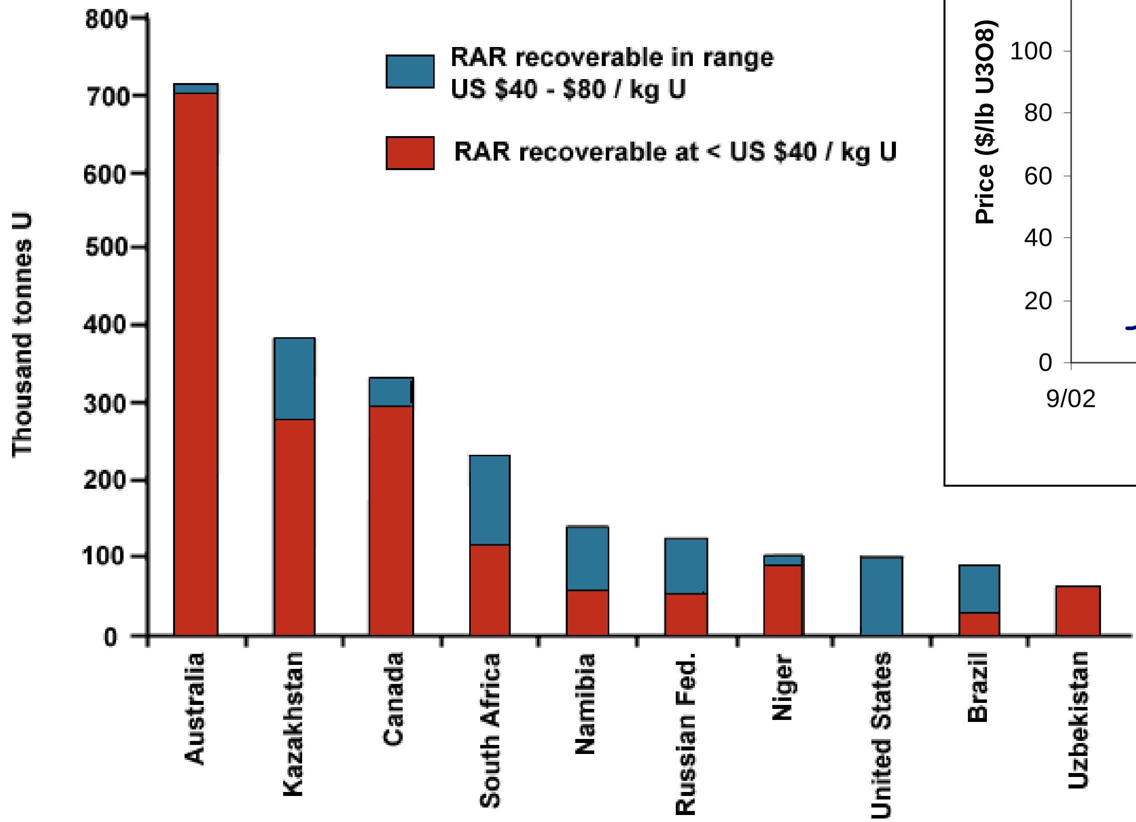
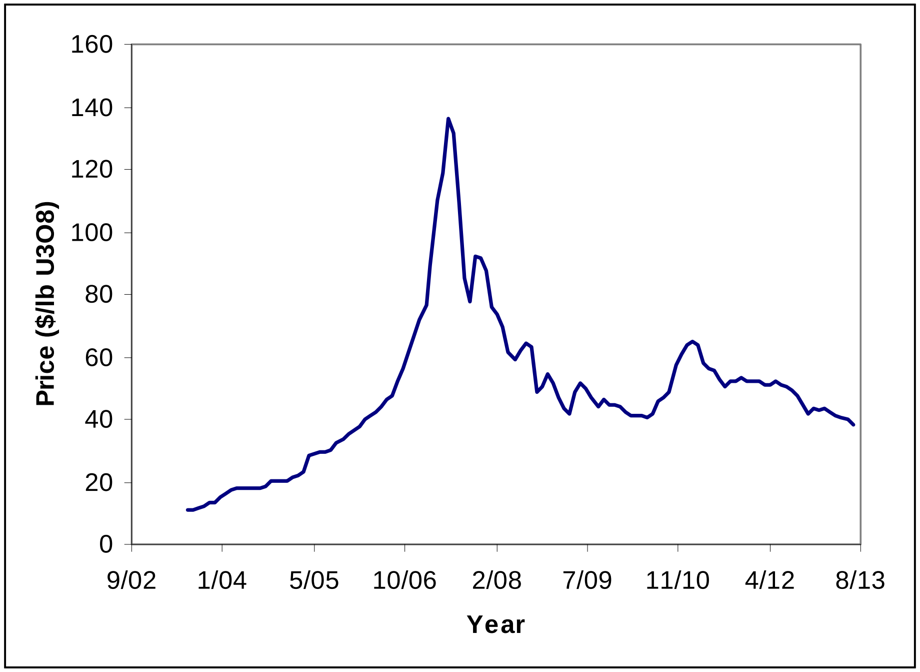
Introduction

- Historically NM produced ~50% of U.S. domestic production
- There is value in understanding past successes and challenges to establish basis for evaluating future development
- Objective:
  - Summarize history of U mining & milling in NM
  - Discuss mining & milling technologies used in the past
  - Consider environmental challenges

World U Resources

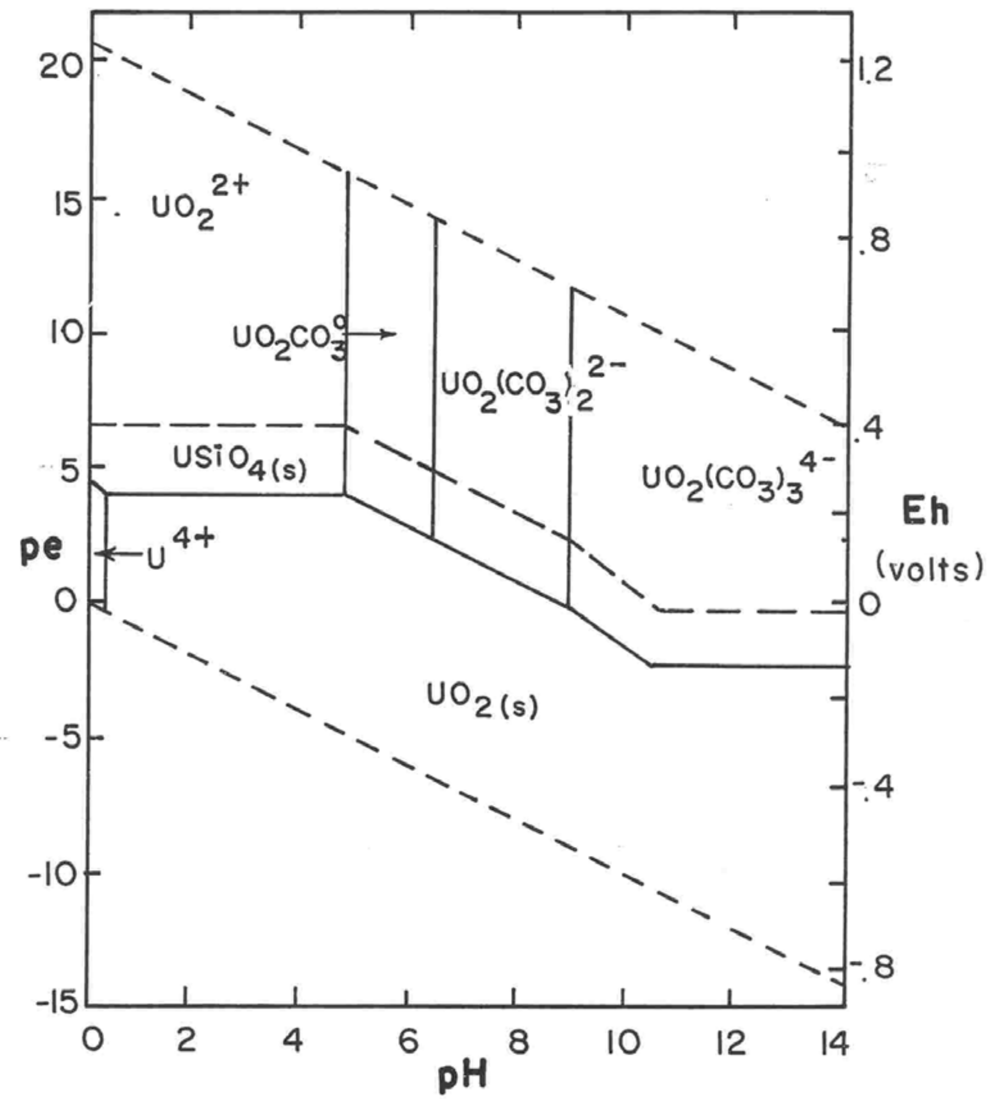
- NM has ~350 M lbs @ $50/lb
- 38% of US supply





U Mineralogy

- Two oxidation states
  - U(VI)
  - U(IV)
- Common U minerals
  - $UO_{2(s)}$ - Uraninite
  - $USiO_{4(s)}$ - Coffinite



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U Minerals (Devoto, 1978)

- There're a LOT!!
- Often associated with other metals

OXIDES

Becquerelite, $7UO_3 \cdot 11H_2O$
Billietite, $BaO \cdot 6UO_3 \cdot 11H_2O$
Cerianite. CeO_2
Clarkeite, $(Na,K,Ca,Pb)U_2O_7 \cdot nH_2O$
Curite, $PbO \cdot 8UO_3 \cdot 4H_2O$
Epi-ianthinite, hydrated uranyl oxide
Fourmarierite, $PbO \cdot 4UO_3 \cdot 5H_2O$
Ianthinite, $2UO_2 \cdot 7H_2O$(?)
Masuyite, $UO_3 \cdot 2H_2O$
Richetite, hydrated oxide of U and Pb(?)
Schoepite, $2UO_3 \cdot 5H_2O$
Thorianite, ThO_2
· Uraninite, UO_2
Uranospherite, $(BiO)(UO_2)(OH)_3$(?)
Vandenbrandeite, $Cu(UO_2)O_2 \cdot 2H_2O$
Vandendriesscheite, $PbO \cdot 7UO_3 \cdot 12H_2O$

FLUORIDES

Schroeckingerite, $NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$

CARBONATES

· Andersonite, $Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$
Bayleyite, $Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$
Liebigite, $Ca_2(UO_2)(CO_3)_3 \cdot 10H_2O$
Rabbittite, $Ca_3Mg_3(UO_2)_2(CO_3)_6(OH)_4 \cdot 18H_2O$
Rutherfordine, $(UO_2)(CO_3)$
Schroeckingerite, $NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$
Sharpite, $(UO_2)(CO_3) \cdot H_2O$(?)
Studtite, hydrated carbonate of U(?)
Swartzite, $CaMg(UO_2)(CO_3)_3 \cdot 12H_2O$
Unnamed mineral of Bignand (1954), Ca, U, hydrated carbonate
Voglite, $Ca_2Cu(UO_2)(CO_3)_4 \cdot 6H_2O$(?)

SULFATES

Johannite, $Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$
Uranopilite, $(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$
Zippeite, $2UO_3 \cdot SO_3 \cdot 5H_2O$
Peligotite (=johannite?)

MOLYBDATES

Umohoite, $(UO_2)(MoO_4) \cdot 4H_2O$

ARSENATES

Abernathyite, $K_2(UO_2)(AsO_4)_2 \cdot 8H_2O$
Kahlerite, Fe $(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Metazeunerite, $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Novacekite, $Mg(UO_2)_2(AsO_4)_2 \cdot 8\text{–}10H_2O$
Troegerite, $H_2(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Uranospathite, $Cu(UO_2)_2(AsO_4,PO_4)_2 \cdot 16H_2O$(?)
Uranospinite, $Ca(UO_2)_2(AsO_4)_2 \cdot 10H_2O$
Walpurgite, $Bi_4(UO_2)(AsO_4)_2O_4 \cdot 3H_2O$
Zeunerite, $Cu(UO_2)_2(AsO_4)_2 \cdot 10\text{–}16H_2O$

PHOSPHATES

$(PO_4)_2 \cdot 10\text{–}12H_2O$
$(PO_4)_2 \cdot 8H_2O$
,U,Pb,) (PO_4,SiO_4)
$)_6(PO_4)_4(OH)_6 \cdot 10H_2O$(?)
$)_3(PO_4)_2(OH)_4 \cdot 3H_2O$
$)_2(PO_4,VO_4)_2 \cdot 8H_2O$(?)
$O_2)_2(PO_4)_2 \cdot 8H_2O$
$UO_2)_2(PO_4)_2 \cdot 8H_2O$
a $(UO_2)_2(PO_4)_2 \cdot 8H_2O$
) (PO_4)
) $(PO_4)_2 \cdot H_2O$
$(UO_2)_4(PO_4)_2(OH)_4 \cdot 7H_2O$
$(PO_4)_2(OH)_2 \cdot 7H_2O$
$)_2(PO_4) \cdot 16H_2O$
$(PO_4)_2 \cdot 8\text{–}10H_2O$
$)_2(PO_4)_2 \cdot 10\text{–}H_2O$
$O_2)_2(PO_4,AsO_4)_2 \cdot 16H_2O$(?)

VANADATES

$(VO_4)_2 \cdot 1\text{–}3H_2O$
$(VO_4)_2 \cdot 6H_2O$(?)
a $(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$
$5V_2O_5 \cdot 16H_2O$
$_2(VO_4)_2 \cdot 8\text{–}10H_2O$(?)
$O_2)_2(VO_4)_2 \cdot 5\text{–}8H_2O$
H_2O

SILICATES

$(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$
,U,Pb) (PO_4,SiO_4)
$(OH)_{4x}$
$Cu(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$
nyl silicate

$SiO_3)(OH)_2$
$\cdot UO_3 \cdot 2SiO_2 \cdot 4H_2O$
$O_2)_2(SiO_3)_2(OH)_2 \cdot 6H_2O$
$O_4)_2(OH)_2 \cdot 5H_2O$
e,etc.) (SiO_4)
U,Ce,etc.) $(SiO_4)_{1-x}(OH)_{4x}$
$)_2(SiO_3)(OH)_2 \cdot 5H_2O$

NTALATES-TITANATES (MULTIPLE OXIDES)

,Ta,Ti$)_3O_9 \cdot H_2O$
e,Th,Y$)_2Ti_2O_{16}$
Y,U,Ca,Zr,Th) $(Ti,Fe,V,Cr)_3(O,OH)_7$
$O_3 \cdot 2FeO \cdot 24TiO_2$(?)
n,Ca$)_2Ta_2O_6(O,OH,F)$
,Sn,rare earths,U,Nb,Ta,Ti
$NaCaNb_2O_6F$

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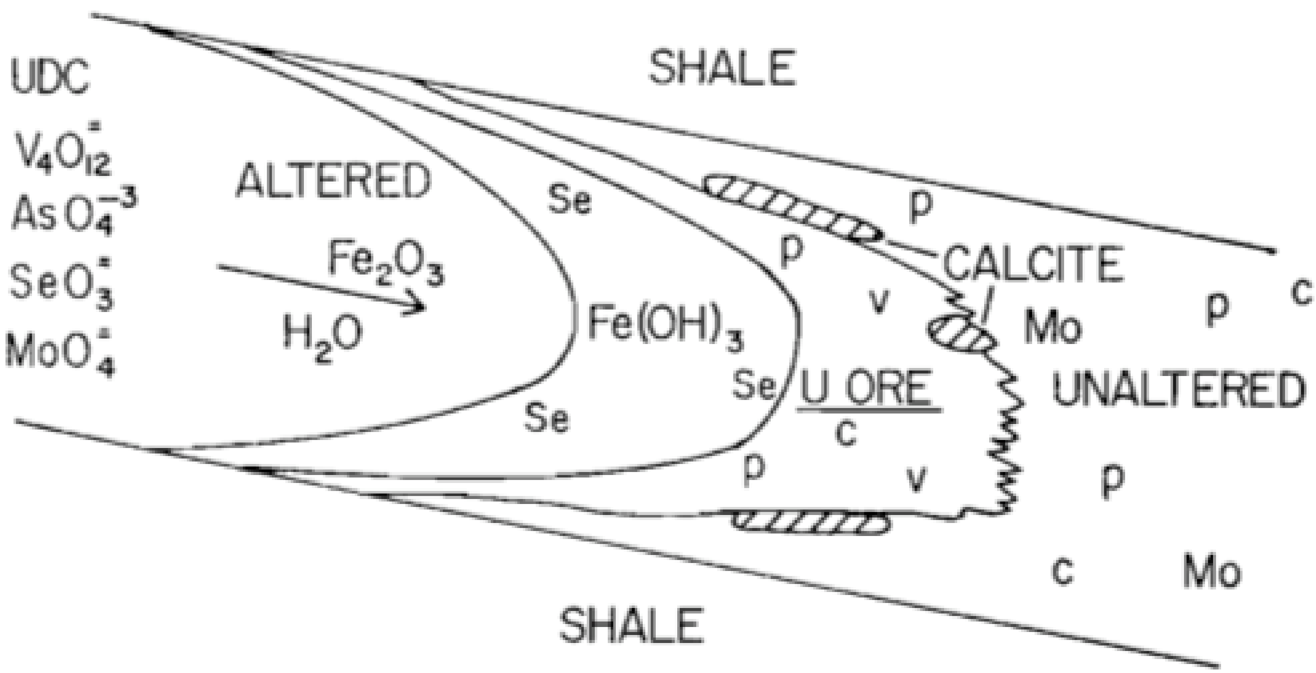
Types of U Ore Deposits (Devoto, 1978)

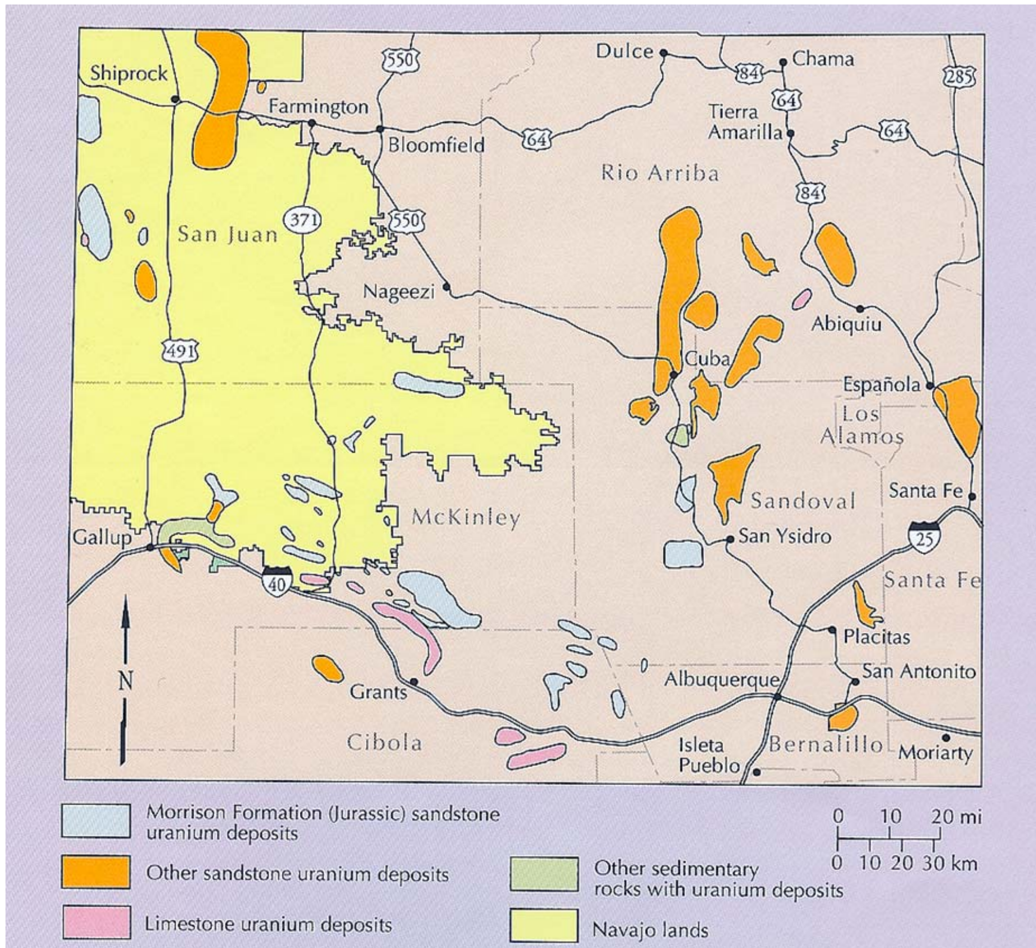
- Magmatic & igneous rocks
  - Crustal abundance ~2 ppm
  - Associated with granites & similar rocks
  - Some vein formation - felsic igneous & metamorphic rocks (Schwartzwalder Mine)
- Sedimentary environments
  - Depositional (syngenetic) - placer & marine deposits
  - Diagenetic (epigenetic) - ground water transport & deposition
    - Weathering & transport as U-carbonate
    - Deposition in reducing zone - Roll front deposits
    - With Organic C, Mo, V, S,e As, S, $CaCO_3$, feldspars, Fe-Mg Silicates

Diagram of Roll Front Deposit



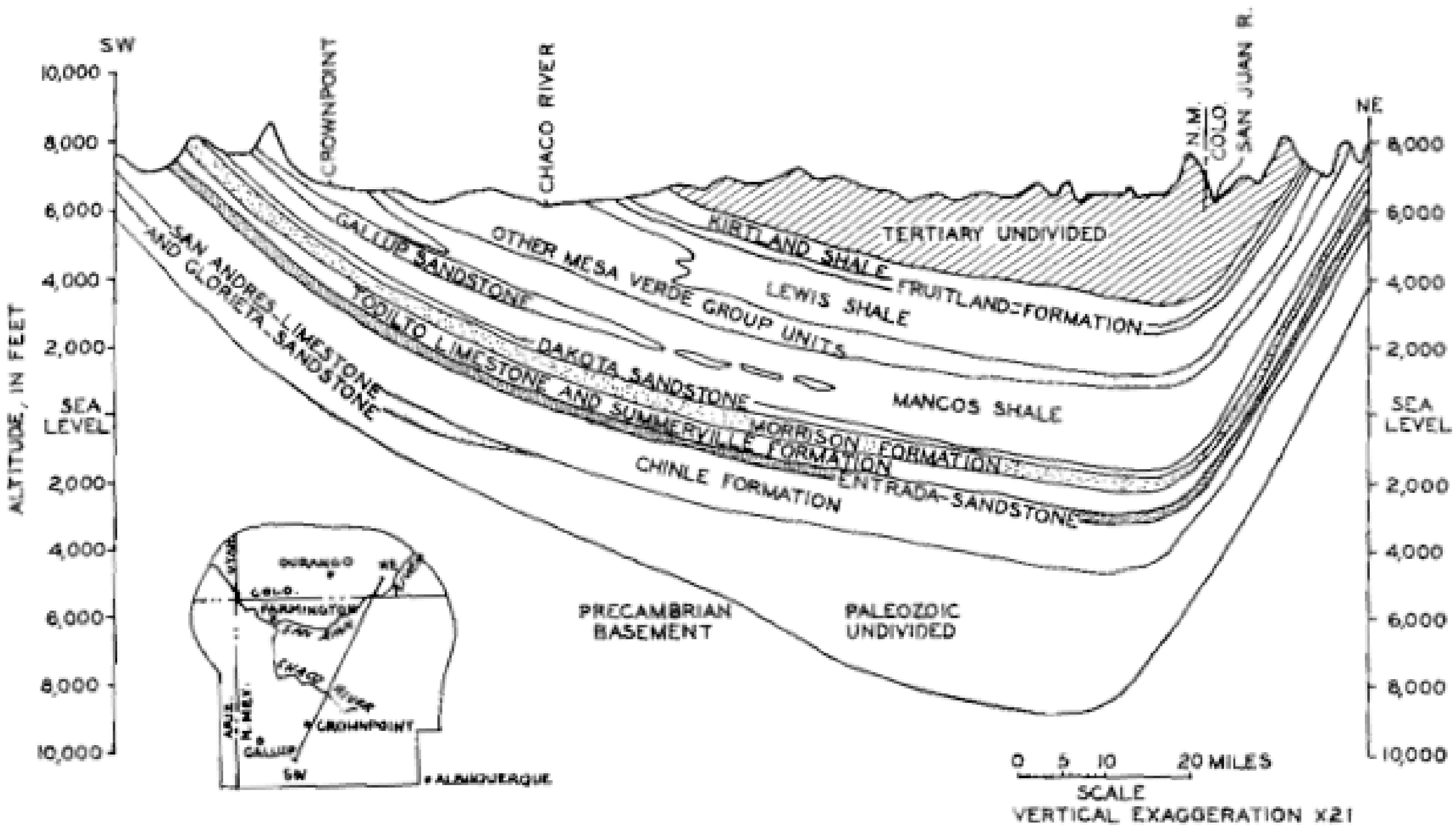
U Resources in Grants Mineral Belt

(McLemore, 2007)



Geologic occurrences of uranium in northwest New Mexico. Most of New Mexico's uranium reserves, and virtually all past production, are in this region.

General Cross Section of San Juan Basin



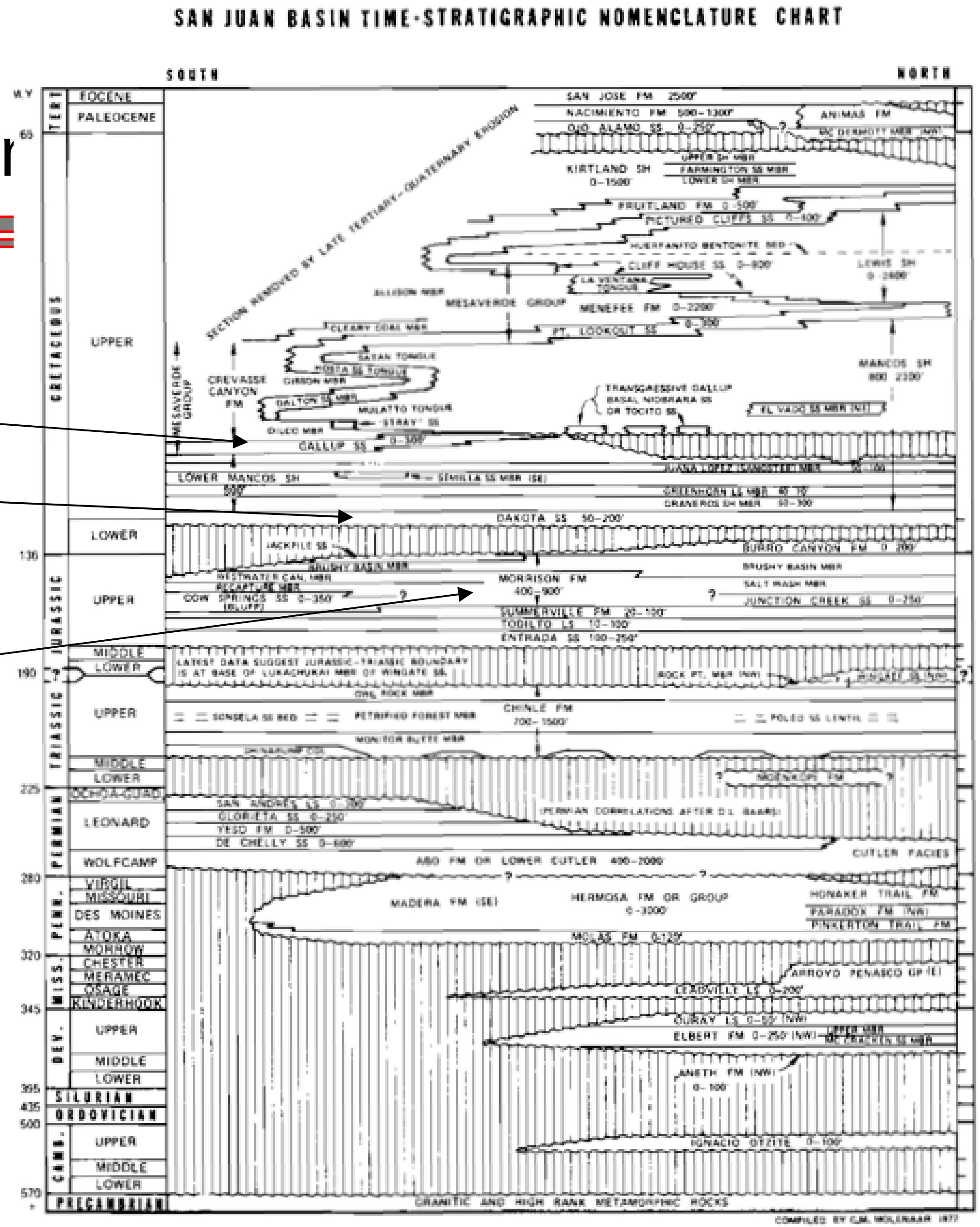
GENERALIZED GEOLOGIC SECTION SHOWING MAJOR AQUIFERS

Geologic Cross Section
(SJBRUS, 1981)

Gallup Sandstone

Dakota Sandstone

Morrison Formation

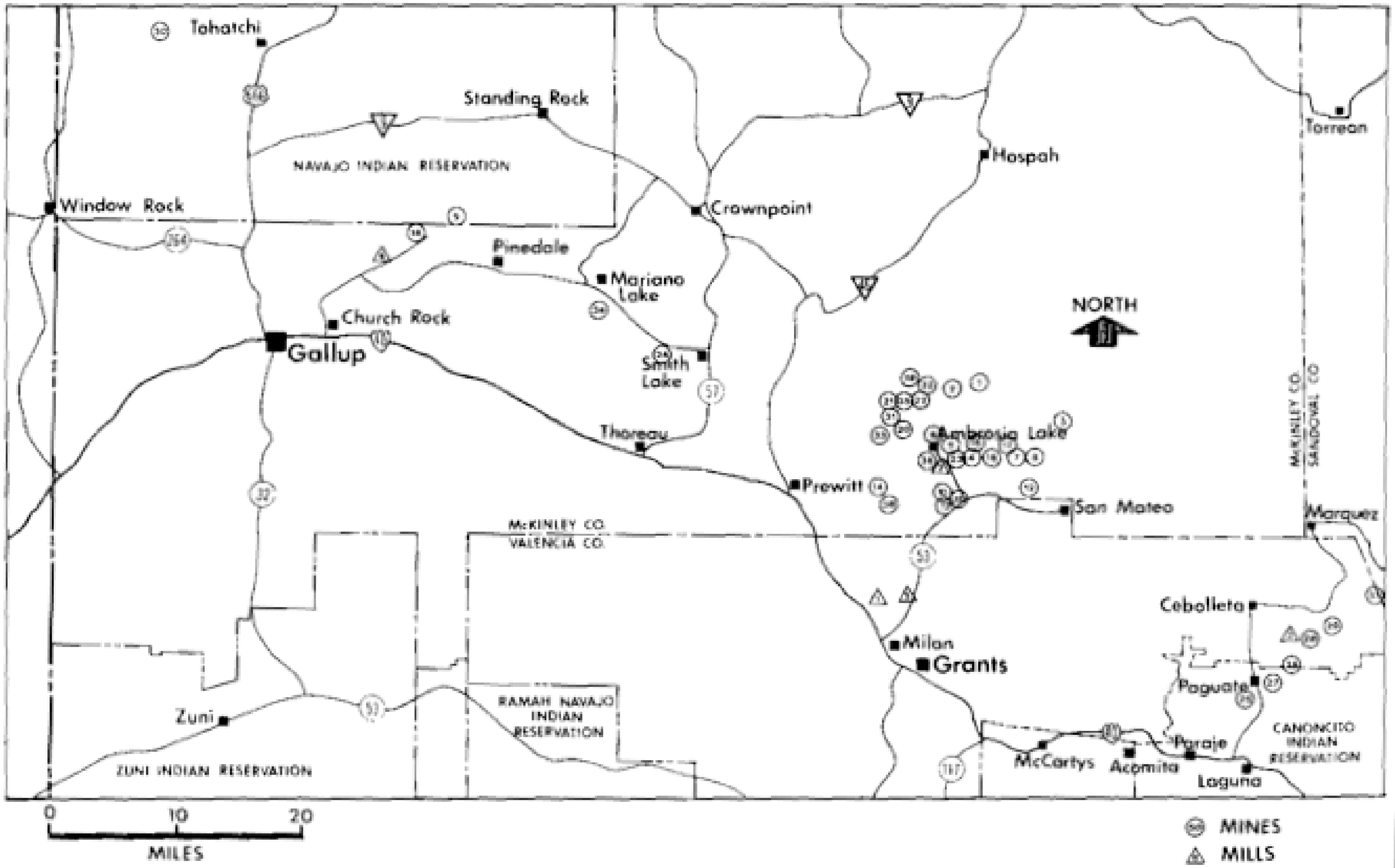


Source: USGS

Figure III-3

Formation Absent

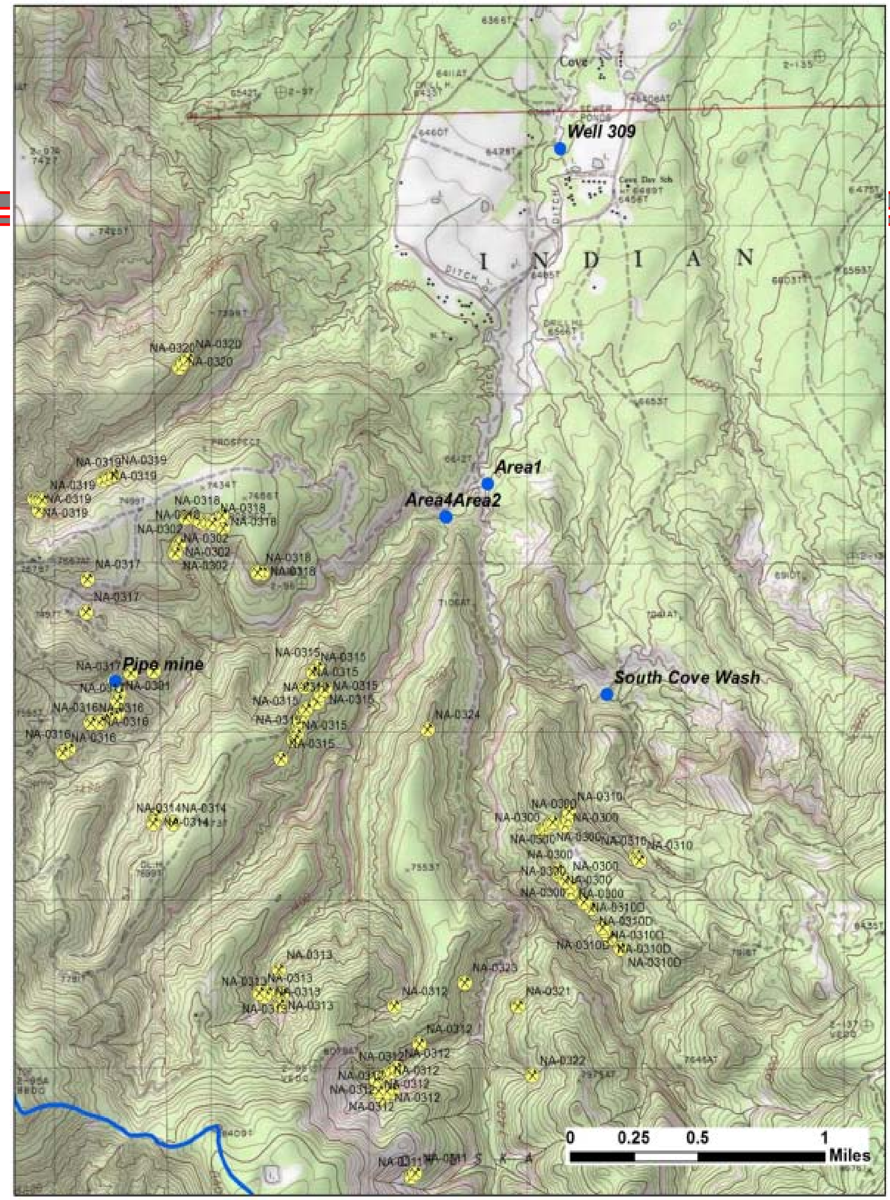
Mines & Mills in 1980 (SJBRUS, 1981)



EXISTING
MILLS & MINES

U Legacy in Navajo Nation

- Summarized in "Health and Environmental Impacts of Uranium Contamination in the Navajo Nation", DOI, EPA, NRC, DOE, IHS (2008)
- >500 mine sites, 4 mill sites
- Widespread contamination of soil & water



Mines near Cove, AZ (Lameman-Austin)

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Uranium Resources in NM

- Discovered in 1950 by Navajo sheepherder - Paddy Martinez
- In 1979 NM produced ~50% of nation's supply of U
  - 38 mines
  - 6 mills
  - ~7,000 employees
  - Then:
    - Three Mile Island (3/28/79)
    - Churchrock tailings dam failure (8/16/79)
      - 370,000 m^3 of tailings solution
      - 1,000 tonnes of tailings
      - Contaminated 110 km of Rio Puerco of the west
  - Now:
    - No mines or mills operating in NM

Major Proposed U Mine Projects in NM

(http://www.wise-uranium.org/uousanm.html)

Name	Principal Company	Resources (tones U_3O_8)
Cebolleta Project	Neutron Energy, Inc.	8,023[b]
Churchrock – Strathmore	Strathmore Minerals Corp.	3,313[a]
Churchrock – HRI	Hydro Resources, Inc.	7,154[b]
Crownpoint – ISL	Hydro Resources, Inc.	5,885[a]
Crownpoint Section 19/29	Tigris U Corp	4,373[a]
Hosta Butte	Tigris U Corp	4,030[a]
La Jara Mesa	Laramide Resources Ltd.	2,791[a]
Marquez Project	Strathmore Minerals Corp	2,545[a]
Mt. Taylor Mine	Rio Grande Resources	38,500[c]
Roca Honda	Strathmore Minerals Corp.	5,591[a]

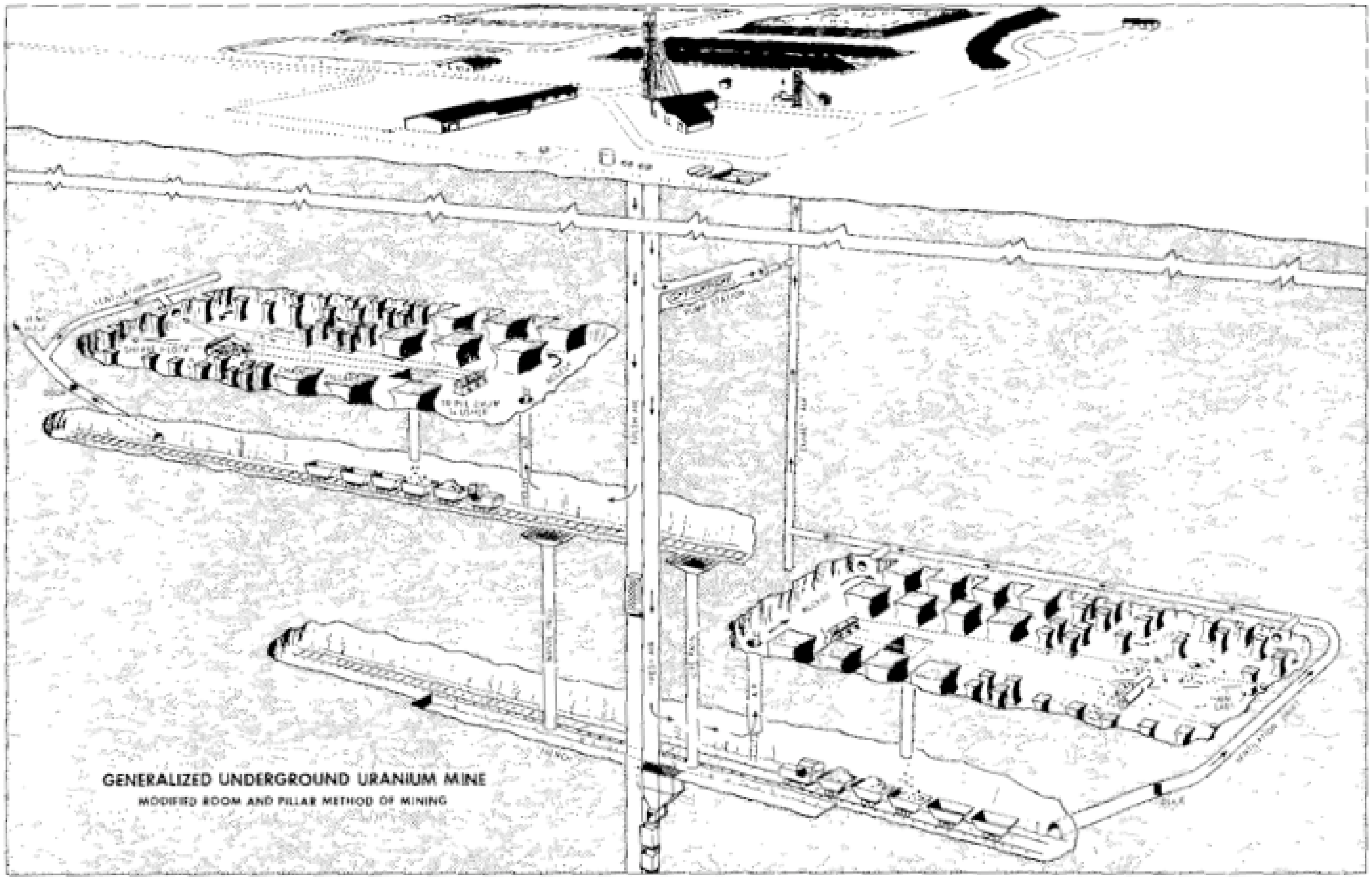
Notes:
a – Indicated reserves
b – Probable reserves
c – Not specified

U Mining

- Conventional mining
  - Open pit mine - Laguna Jackpile Paguate Mine
  - Underground mining
- Requires mine dewatering - up to 3,000 gal/min
- Large power requirements for ventilation (Palo Verde nuclear generating station)

- In situ leach (ISL) mining
  - Practiced in So. TX, & WY
  - Little impact on ground water resources
  - Little surface disturbance
  - Difficult to restore aquifer quality

Method of Underground Mining (SJBRUS, 1981)



Underground Images

Average Water Quality of the Puerco River

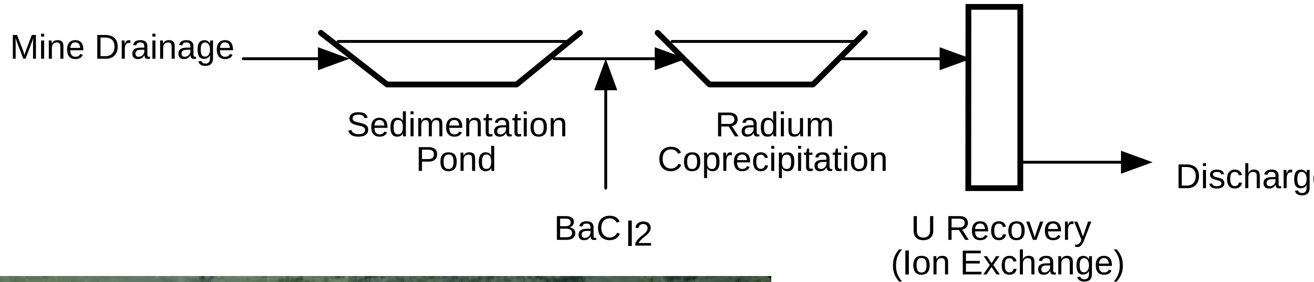
	Concentration (mg/L)		
Constituent	**1978**	**1979**	**SDWA Std**
Ba	.016	0.125	2.
NO_2^- & NO_3^-	2.0	6.6	10.0
Se	.025	.010	0.05
SO_4^{2-}	204.	201.5	250*
TDS	627.	609	500*
U	0.63	0.40	0.03

* - Recommended maximum concentration

Average Weighted Concentration of Mine Water Discharges

Constituent	1975	1978
Flow	9.27 Mgal/d	13.5 Mgal/d
TDS	-	911
Se	0.059	.088
U	9.83	0.694
V	0.73	0.033
Ra-226	92.8 pCi/L	

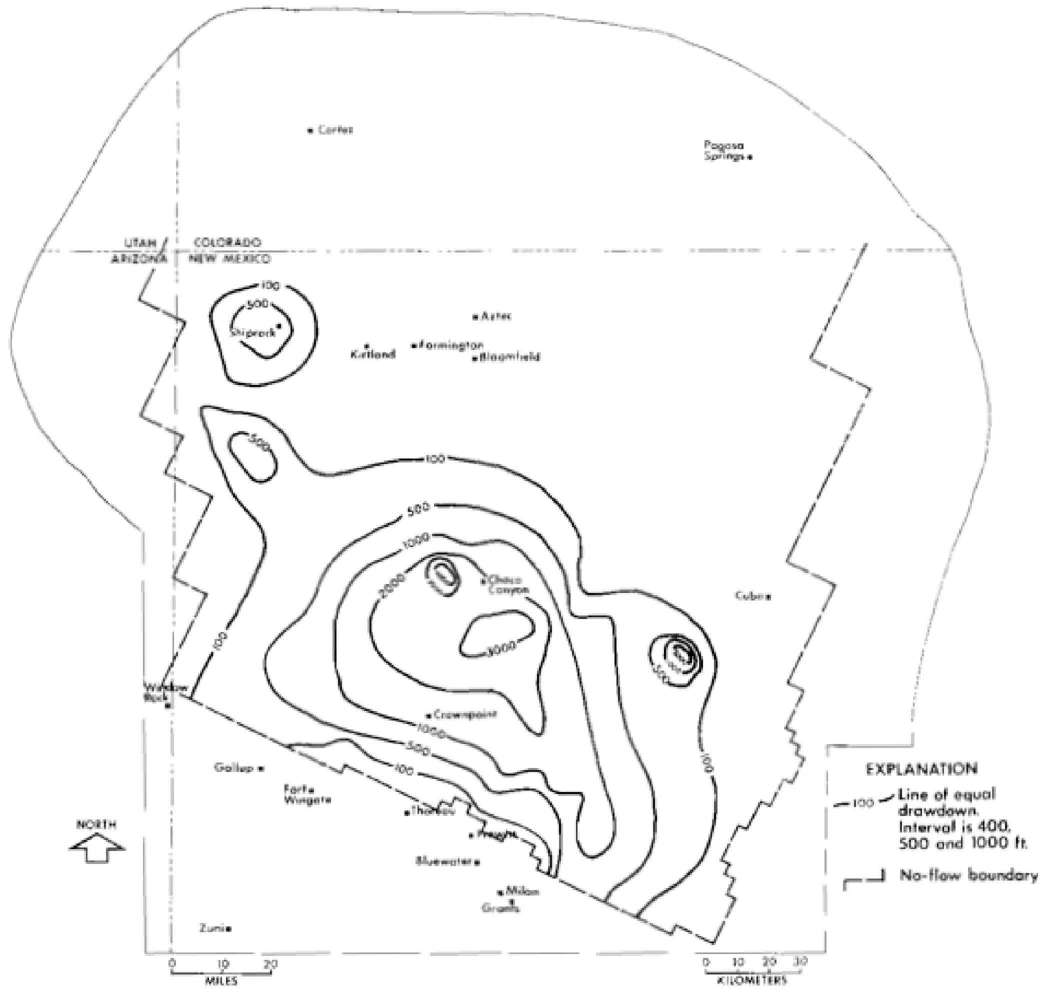
Mine Water Treatment



Major Aquifers in San Juan Basin

Aquifer	Thickness (ft)	TDS (mg/L)
Alluvium	0-100	200-9,200
Kirtland Shale	0-1,500	700 – 4,000
Gallup Sandstone	0-500	300 – 4,000
Dakota Sandstone	0-250	300-59,000
Morrison Formation	50-800	170-5,600

Impact on Ground Water Resources (SJBRUS, 1981)



MODELED DRAWDOWN IN THE MORRISON FORMATION
FOR THE YEAR 2000 USING THE
MID PROJECTED LEVEL OF URANIUM MINING

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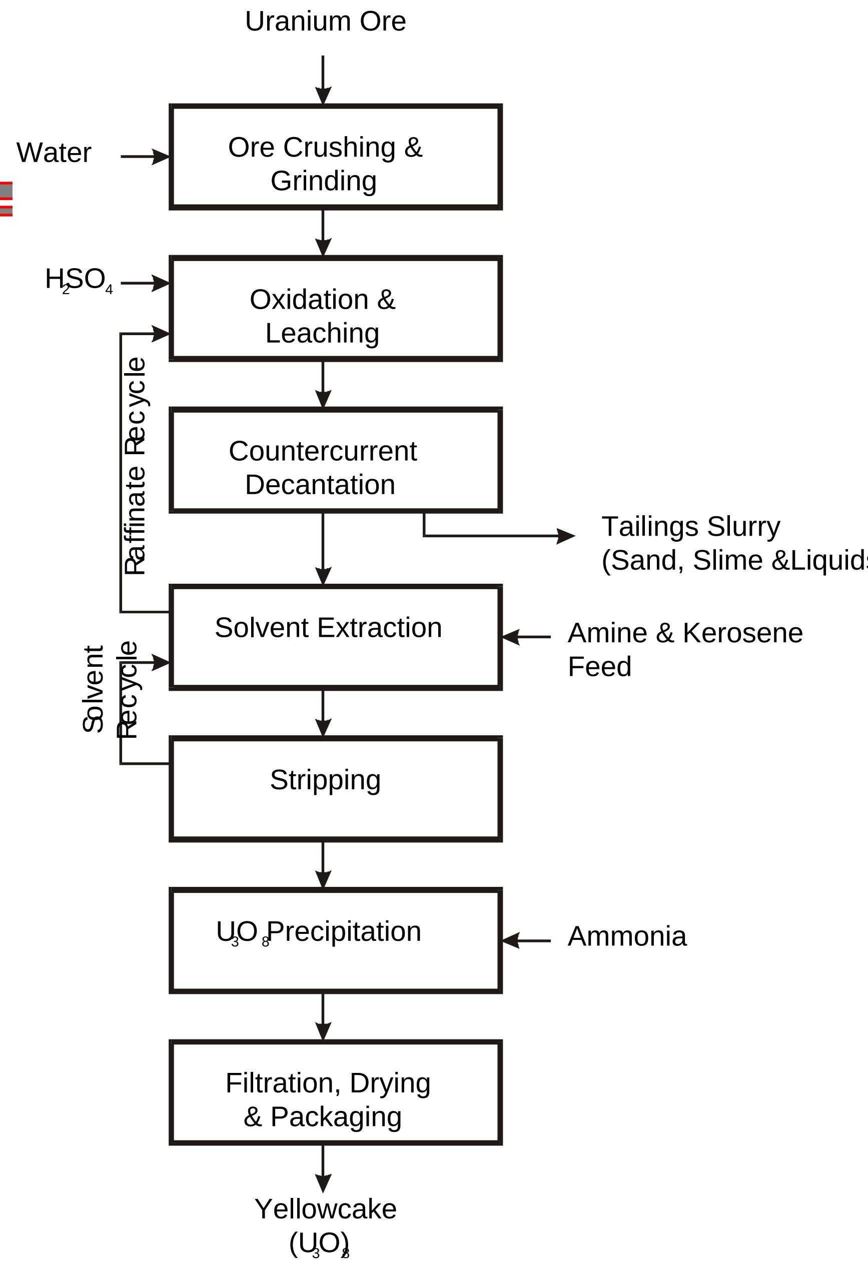
U Milling

- Acid (or alkaline) leach process
  - Oxidize U(IV) to U(VI)
  - Dissolve in acid (or base)
  - Recover by solvent extraction or IX
  - Precipitate as U_3O_8
- Acid leach - low Ca in ore (pH > 10)
- Alkalinie leach - high Ca in ore (pH < 2)



Kerr McGee
U Mill Tailings
(1980)

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Uraniu

Kerr McGee/Quivira
(Oct.2012)

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U Mill Tailings – Homestake
(1980)

Homestake Mill Tailings Pile
(Oct. 2012)

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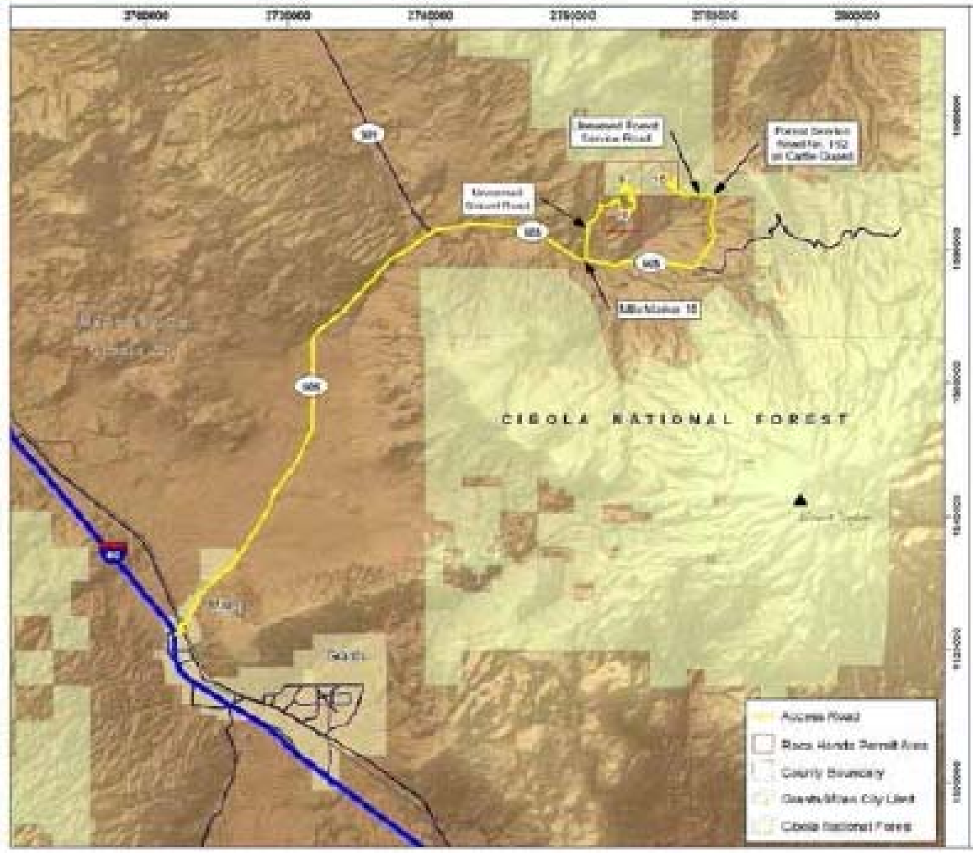
Mill Tailings Decant Water Quality

Constituent	SDWA MCL (mg/L)	4 Acid Mills in NM	1 Alkaline Mill in NM
As	.010	1.3	5.0
Mo		0.9	98.0
NH_3 (as N)		400.0	16.0
Se	.050	29,700.	8,400.
U	.030	74.0	14.0
TDS	500.	39,800.	25,400.
pH		1.05	10.1
Ra-226 (pCi/L)	5.	70.0	58.0
Gross-α (pCi/L)	15.0	38,000.	6,700.

Roca Honda Mine

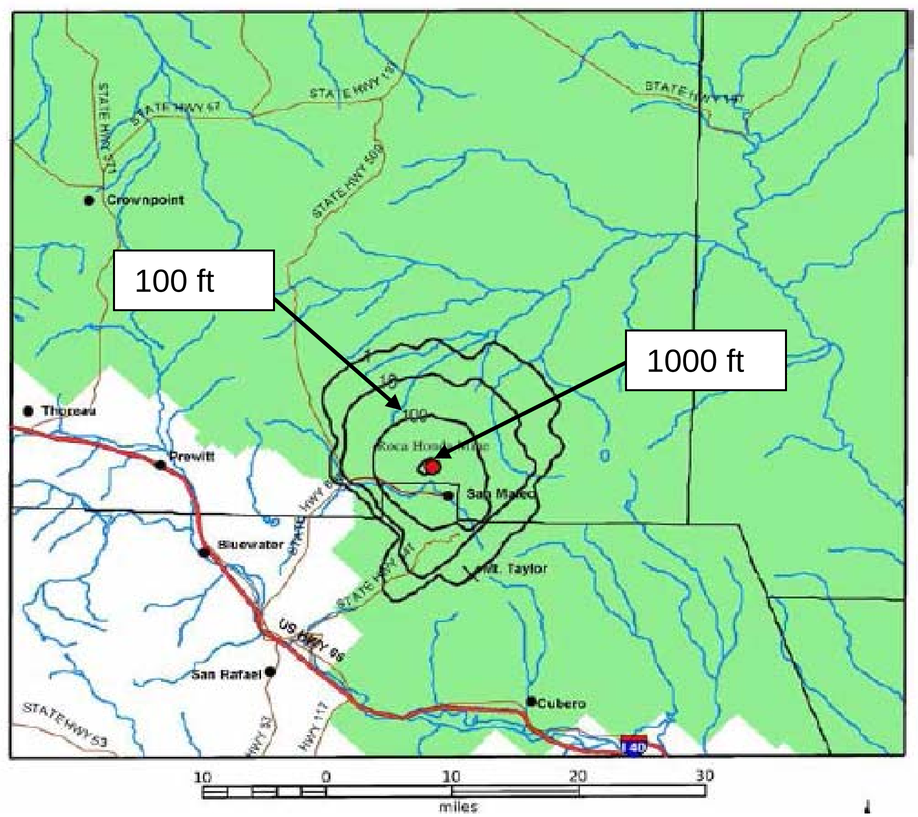
(Draft EIS - http://www.fs.fed.us/nepa/nepa_project_exp.php?project=18431)

- Proposed underground mine on Forest Service property
  - Ore depth 1,650 – 2,650 ft
- Mining period of 18-19 yrs
- ~25 dewatering wells to produce 4,000 gal/min (6,400 AF/yr)
  - Possible reuse for pastures
  - Discharge to arroyo
- Issues: Water, vegetation, wildlife, culture, socioeconomic, health, safety, environmental justice, etc.

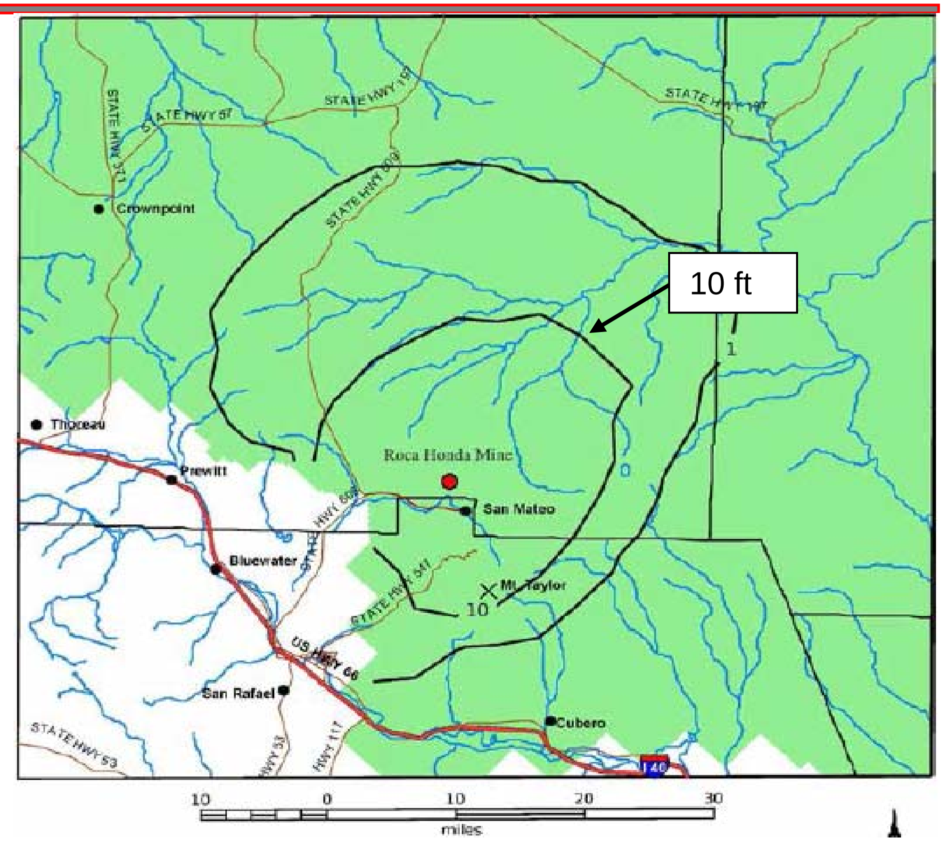


Roca Honda Mine Dewatering Impacts

(DEIS)



At end of project



After 100 years

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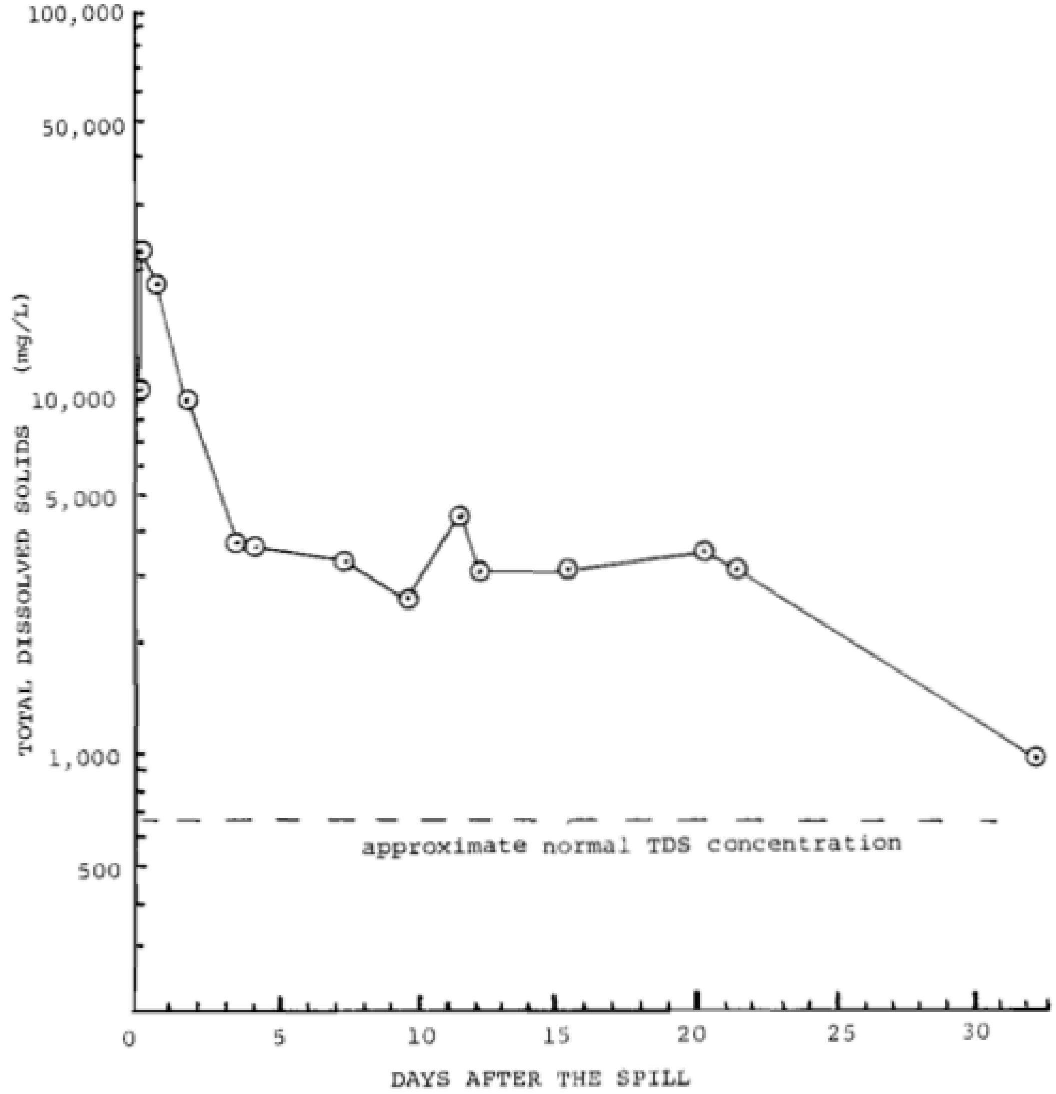
Churchrock Tailings Dam Failure



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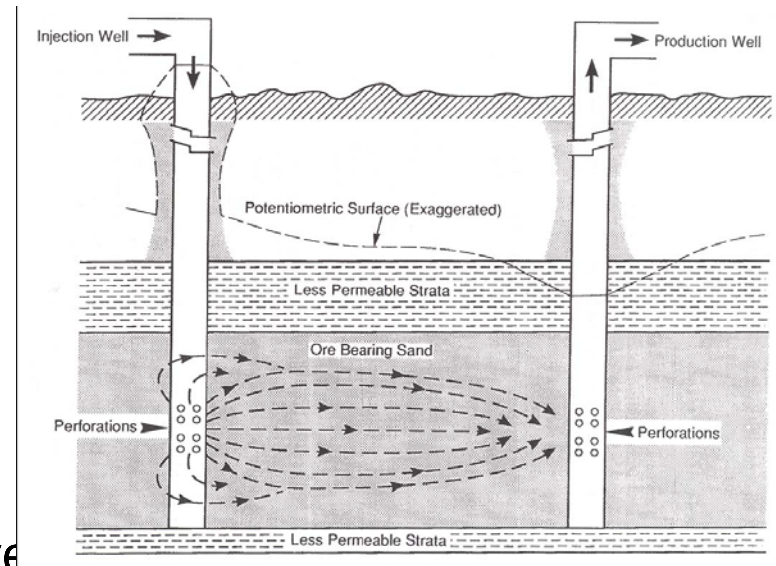
In Situ Leach/Recovery Mining of U (ISL/ISR)

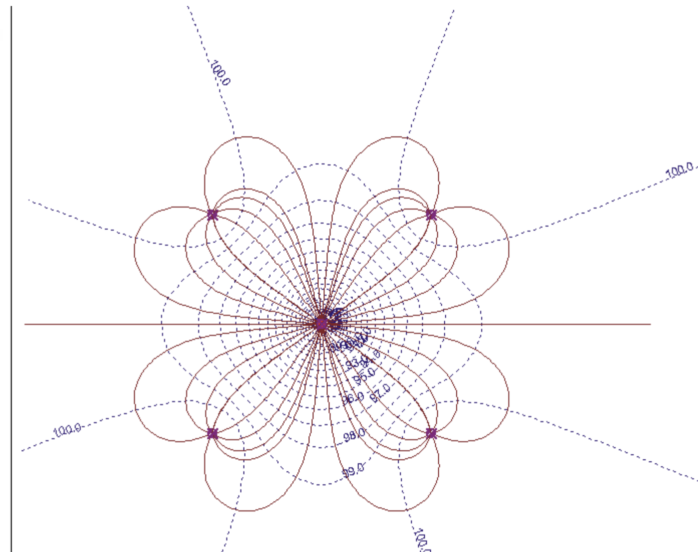
- ISR began in 1974 in TX.
- Typical ISR mines are relatively small (< 1000 ton/yr)
- 26% of world U production
- Criteria for ISR
  - Confined aquifer
  - Sandstone
- May do alkaline ($pH > 8$) or acid ($2.5 < pH < 3$) leach depending on Ca content
  - High Ca content (calcite) suggests alkaline leach

World Nuclear Association web site

ISL/ISR Technology

- Circulate oxidizing solution through ore deposit





- Recove
- Recycle leachate

ISR Technology

(Pelizza, 2007)

- ~30 licensed facilities in US - NB, WY, TX,
- Pelizza claims that pre-mining ground water quality at ISR sites do not meet SDWA criteria due to U, Ra, Rn & gross alpha. Data for Duval County, TX

Parameter	**Avg. Conc.**	**EPA MCL**
U (ug/L)	488	30
^{226}Ra (pCi/L)	215	5.0
^{222}Rn (pCi/L)	207,133	300
Gross Alpha (pCi/L)	865	15

Chemistry of ISR

- Oxidation by O_2 from U(IV) to U(VI):
  $UO_2 + 2H^+ + 1/2\ O_2 = UO_2^{2+} + H_2O$
  $UO_2^{2+} + 2HCO_3^- = UO_2(CO_3)_2^{2-}$
- Lixiviant = leaching solution
- Raffinate = leaching solution containing dissolved U

- U(VI) recovered by ion exchange (R = resin sites)
  $2R\text{-}Cl + UO_2(CO_3)_2^{2-} = R_2\text{-}UO_2(CO_3)_2 + 2Cl^-$

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Yellowcake Processing

- U is eluted from loaded resins with salt (NaCl) to provide concentrate
- HCl is added to destroy carbonate complex

$UO_2(CO_3)_2^{2-} + 4H^+ = UO_2^{2+} + 2H_2CO_3$

- UO_2^{2+} (uranyl ions) oxidized with H_2O_2

$$UO_2^{2+} + H_2O_2 + xH_2O = UO_4 \cdot xH_2O$$

  - Most commonly written as U_3O_8 - yellowcake
- Yellowcake is washed, filtered & dried.
- Can also recover U via NH_3 precipitation

1980 NM Mine Dewatering Act

(New Mexico Statutes 72-12A)

- Assigns jurisdiction to State Engineer – Mines must obtain permit to dewater
  - Must show non impairment to existing water rights
- Right of replacement – If mining impairs water resource, mine can replace the water right ("cure the impairment")
  - Deepen existing wells or drill new wells
  - Provide alternate source of supply
  - Applicant has right of condemnation, subject to OSE jurisdiction, in order to cure impairment
- No water rights may be established solely by mine dewatering

Mine Dewatering Act - 2

- Replacement may use reclaimed mine water, but must posses a water right for this water.
- Responsibility extends beyond life of mine for as long as impairment exists

Ground Water Restoration

- Generally goal is to meet pre-mining water quality criteria. In south TX water does not meet SDWA, hence relaxed pressure to achieve SDWA criteria
- Restoration involves circulating clean water through formation. May use RO treated water.
- In NM the U bearing formations have high quality water. State is requiring restoration to background. Not clear that it can be achieved.

Research Opportunities in U Development

- ISL
  - Geochemistry of U ores & development of better extractants
  - Subsurface characterization & ore delineation
  - Subsurface hydraulics & modeling
  - Aquifer restoration technologies
- Conventional mining & milling
  - Management of mine water supplies
  - Development of environmentally friendly milling process
  - Liquid & solid waste management technologies

Thoughts

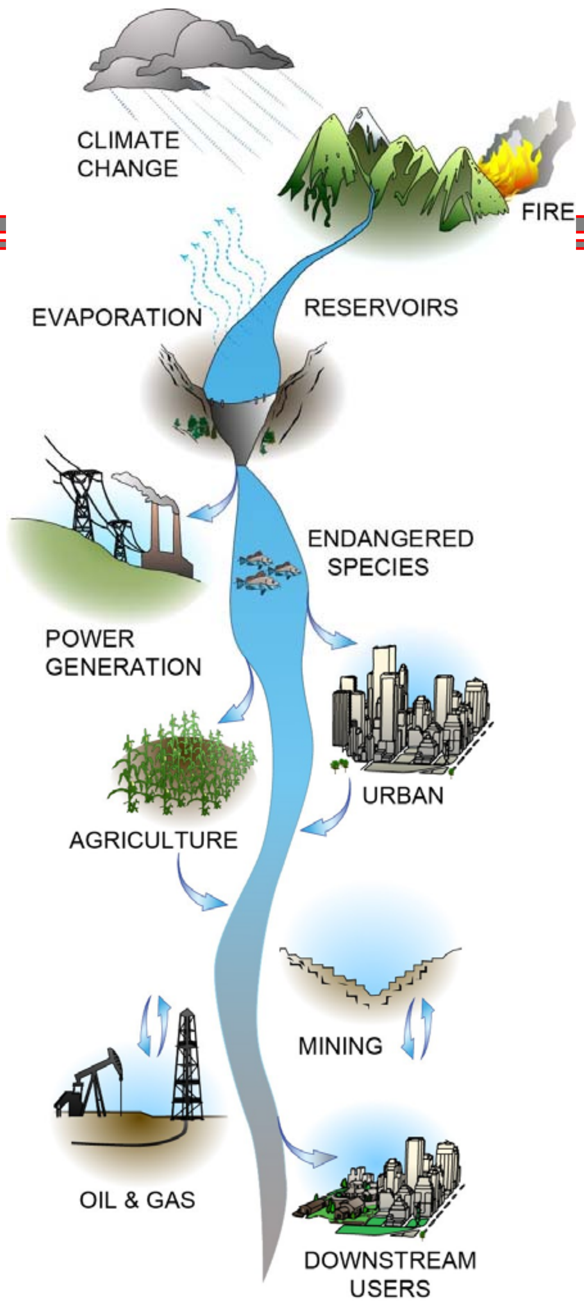
- Enormous U reserves in NM
- Historic mining caused major health problems and significant environmental impacts
  - Legacy impacts
  - Most of mill tailings piles have been stabilized
- Future U development must be safe and with little/no threat to health or the environment:
  - Health issues
  - Water quantity impacts
  - Water quality impacts
  - (And soil & air quality)
- New knowledge & technology can support responsible mining

Recommendations

- Update 1980 San Juan Basin Regional Uranium Study
  - Impacts to environment, economy & socio-cultural values
- Understand legacy contamination
  - Nature of contaminants, extent of contamination, fate & transport of contaminants
  - Impacts on human health & the environment
- Waste management
  - Impact on water resources
  - Identify remediation strategies
- Research new mining & milling technologies
  - Minimize impacts of future projects

UNM & State University Activities

- UNM Center for Water & the Environment
  - Interdisciplinary center focused on NM water issues
  - Major emphasis on water-energy-arid environments
- NM EPSCoR – “Energize NM”
  - NSF funded project
  - $4M/yr for 5 years
    - Uranium development & challenges
    - Osmotic power from produced water
    - Geothermal resources
    - Photovoltaic development
    - Algal biofuels development
    - Economic & Socio-Cultural interactions



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Questions?

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