THE GRANTS URANIUM DISTRICT: SOURCE AND DEPOSITION

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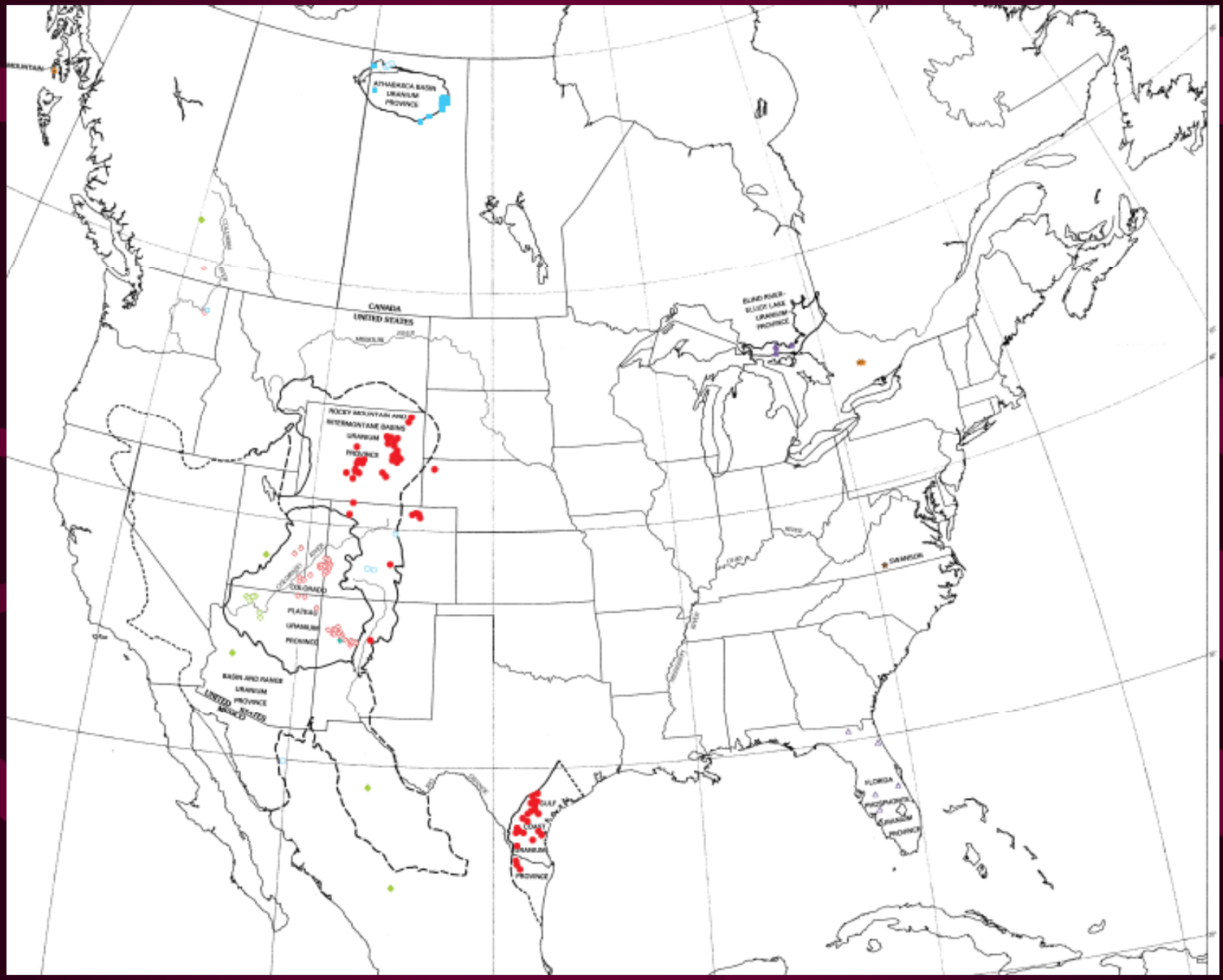
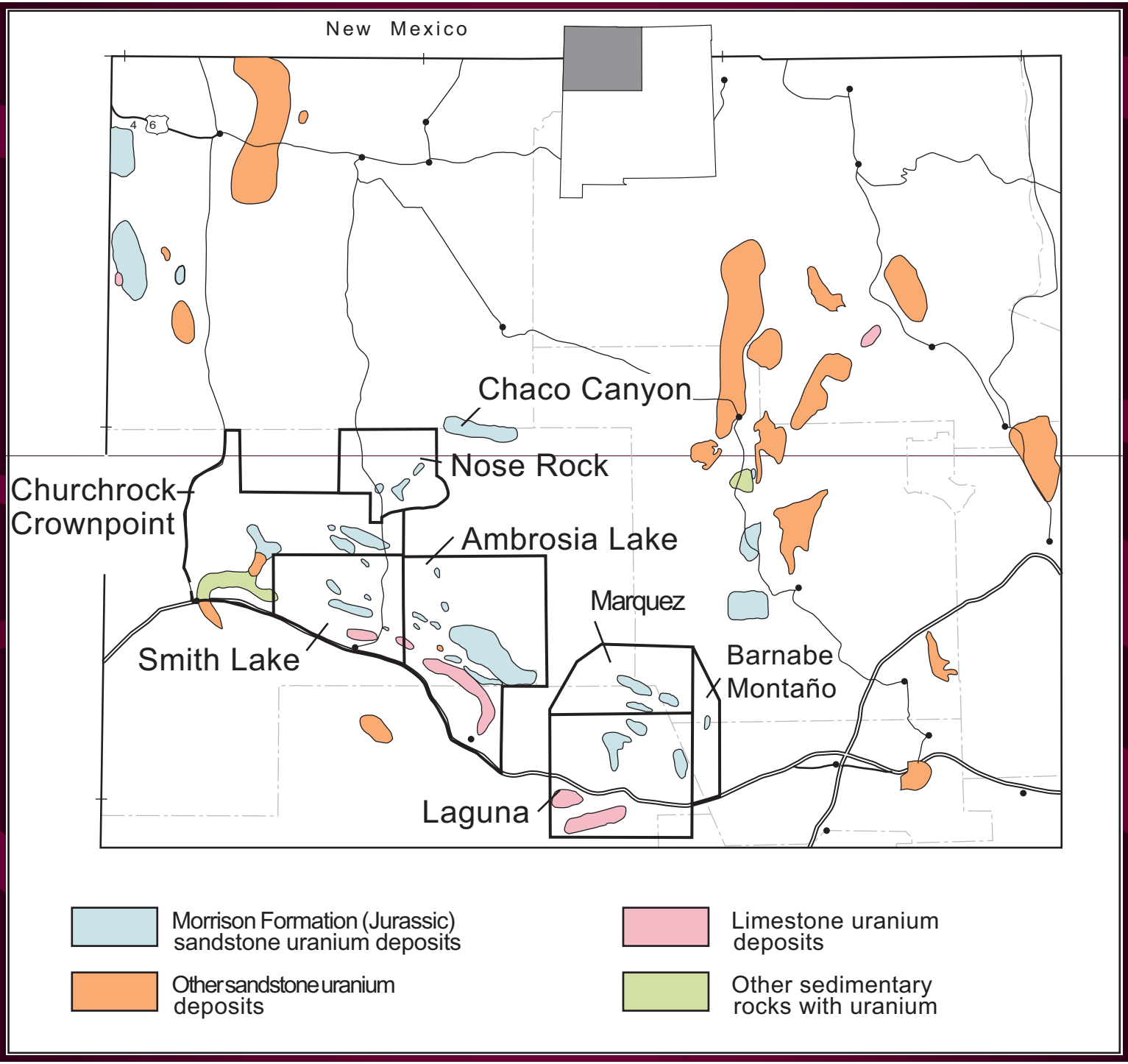
OUTLINE

- Introduction
- Description of the Grants uranium deposits
- Age of the deposits
- Source of uranium
- How did the deposits form?
- Comments and conclusions
- Future research

INTRODUCTION


ATHABASCA BASIN URANIUM PROVINCE
CANADA
UNITED STATES
ROCKY MOUNTAIN AND INTERMONTANE BASINS URANIUM PROVINCE
COLORADO PLATEAU URANIUM PROVINCE
BASIN AND RANGE URANIUM PROVINCE
GULF COAST URANIUM PROVINCE
FLORIDA PHOSPHORITE URANIUM PROVINCE
BLIND RIVER-ELLIOT LAKE URANIUM PROVINCE


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

Historical Production from the Morrison Formation in Grants District

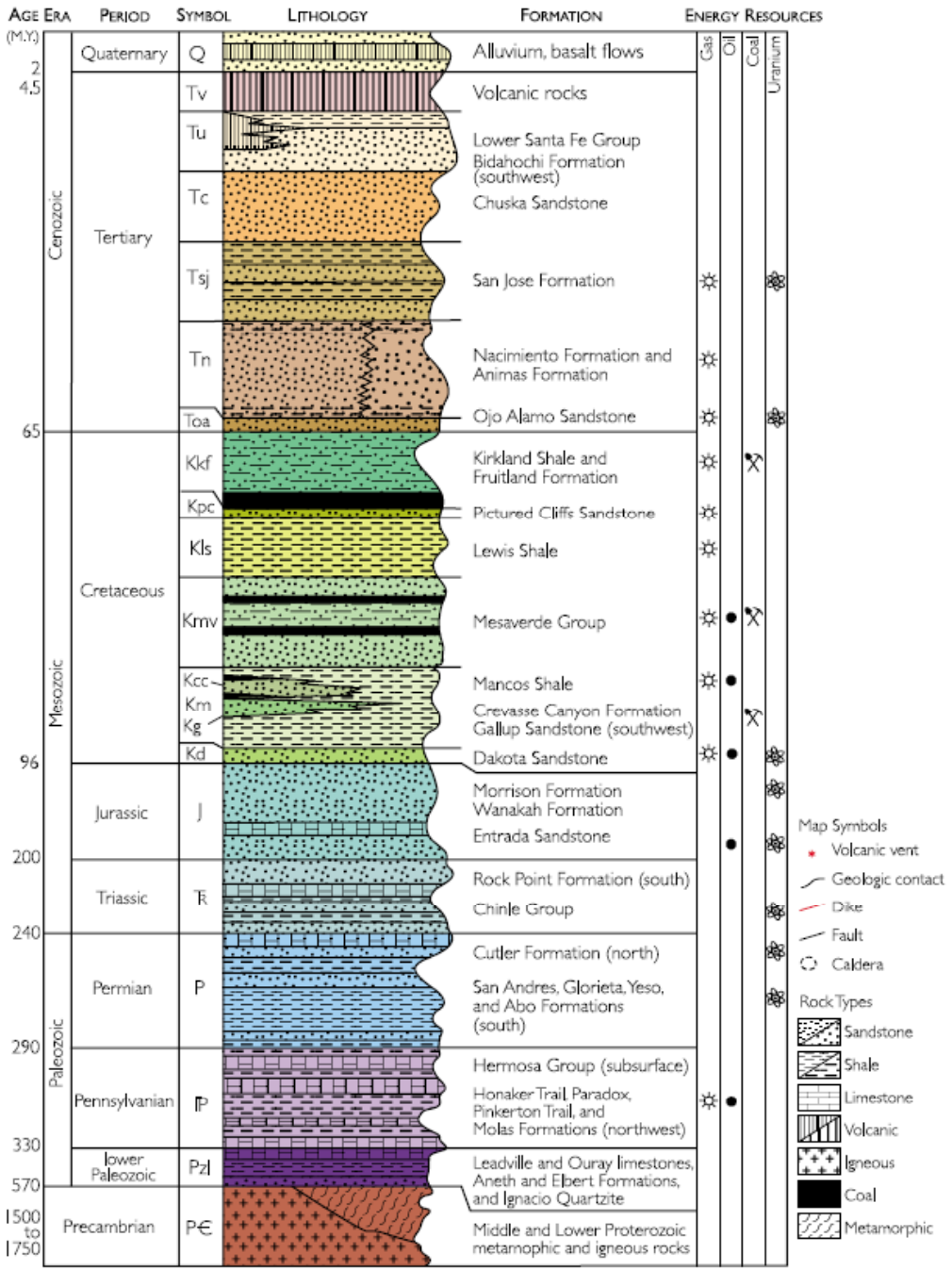
- 340 million lbs of U_3O_8 from 1948-2002
- Accounting for 97% of the total uranium production in New Mexico
- More than 30% of the total uranium production in the United States
- 4^{th} largest district in total uranium production in the world

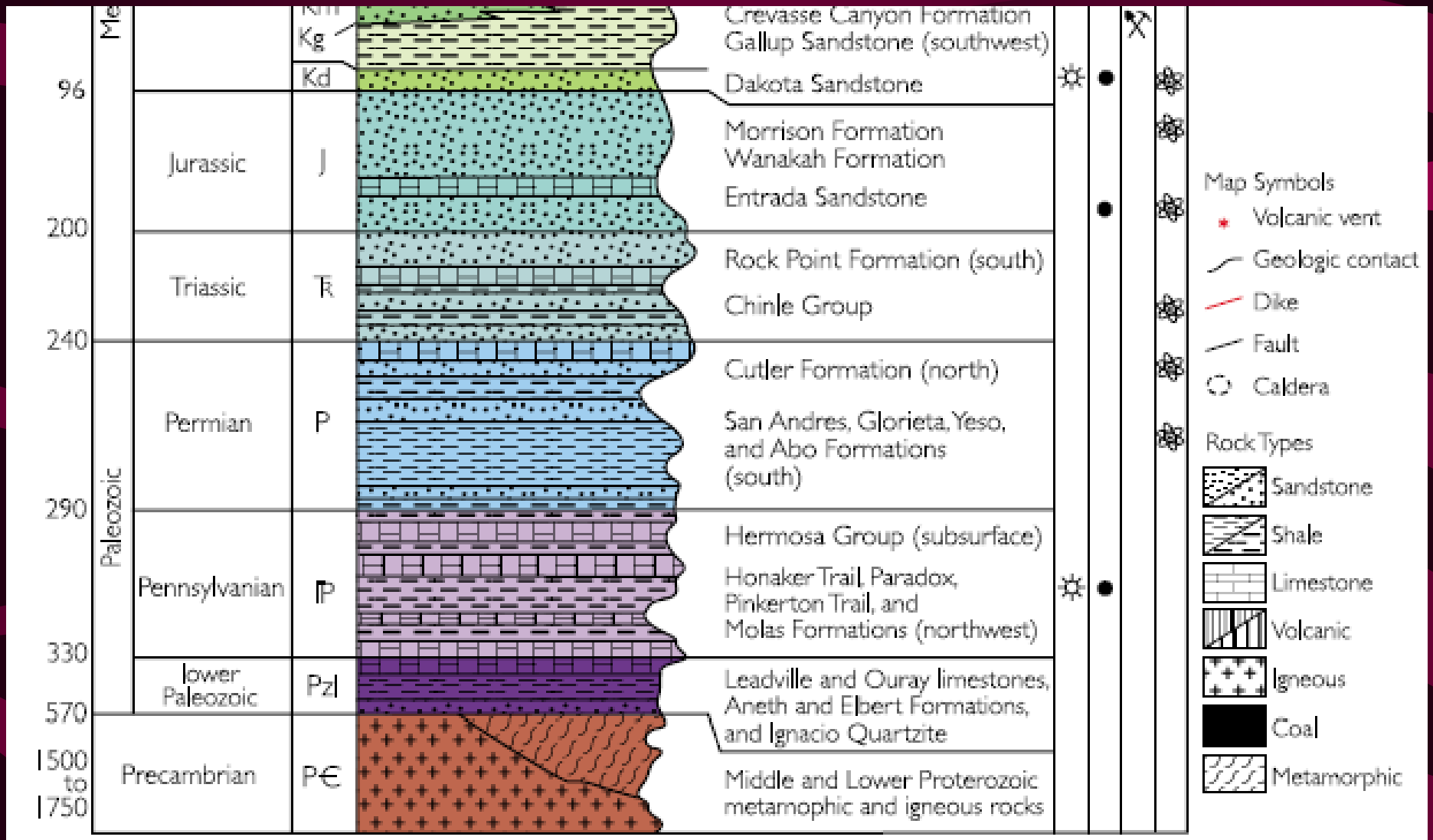
New Mexico is 2nd in uranium reserves 15 million tons ore at 0.277% U_3O_8 (84 million lbs U_3O_8) at $30/lb (2003)

Grants district

- 340 million lbs of U_3O_8 have been produced 1948-2002
- ~360 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

DESCRIPTION OF THE GRANTS URANIUM DEPOSITS


AGE ERA
PERIOD
SYMBOL
LITHOLOGY
FORMATION
ENERGY RESOURCES
(M.Y.)
Gas
Oil
Coal
Uranium
2
4.5
65
96
200
240
290
330
570
1500 to 1750
Cenozoic
Mesozoic
Paleozoic
Quaternary
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
lower Paleozoic
Precambrian
Q
Tv
Tu
Tc
Tsj
Tn
Toa
Kkf
Kpc
Kls
Kmv
Kcc
Km
Kg
Kd
J
Tr
P
IP
Pzl
P€
Alluvium, basalt flows
Volcanic rocks
Lower Santa Fe Group
Bidahochi Formation (southwest)
Chuska Sandstone
San Jose Formation
Nacimiento Formation and Animas Formation
Ojo Alamo Sandstone
Kirkland Shale and Fruitland Formation
Pictured Cliffs Sandstone
Lewis Shale
Mesaverde Group
Mancos Shale
Crevasse Canyon Formation
Gallup Sandstone (southwest)
Dakota Sandstone
Morrison Formation
Wanakah Formation
Entrada Sandstone
Rock Point Formation (south)
Chinle Group
Cutler Formation (north)
San Andres, Glorieta, Yeso, and Abo Formations (south)
Hermosa Group (subsurface)
Honaker Trail, Paradox, Pinkerton Trail, and Molas Formations (northwest)
Leadville and Ouray limestones, Aneth and Elbert Formations, and Ignacio Quartzite
Middle and Lower Proterozoic metamorphic and igneous rocks
Map Symbols
Volcanic vent
Geologic contact
Dike
Fault
Caldera
Rock Types
Sandstone
Shale
Limestone
Volcanic
Igneous
Coal
Metamorphic


Crevasse Canyon Formation
Gallup Sandstone (southwest)
Kg
Kd
Dakota Sandstone
96
Jurassic
J
Morrison Formation
Wanakah Formation
Entrada Sandstone
200
Triassic
Tr
Rock Point Formation (south)
Chinle Group
240
Permian
P
Cutler Formation (north)
San Andres, Glorieta, Yeso, and Abo Formations (south)
290
Pennsylvanian
IP
Hermosa Group (subsurface)
Honaker Trail, Paradox, Pinkerton Trail, and Molas Formations (northwest)
330
lower Paleozoic
Pzl
Leadville and Ouray limestones, Aneth and Ebert Formations, and Ignacio Quartzite
570
1500 to 1750
Precambrian
P€
Middle and Lower Proterozoic metamophic and igneous rocks
Paleozoic
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Sandstone
Shale
Limestone
Volcanic
Igneous
Coal
Metamorphic

Primary Tabular Deposits in Westwater Canyon Member

- Less than 2.5 m thick
- Grades exceed 0.2% U_3O_8
- Sharp boundaries
- Locally offset by Laramide (Late Cretaceous)-Tertiary faults
- Black to dark gray because of the associated humate
- Also called primary, trend, prefault, black banded, channel, blanket ore

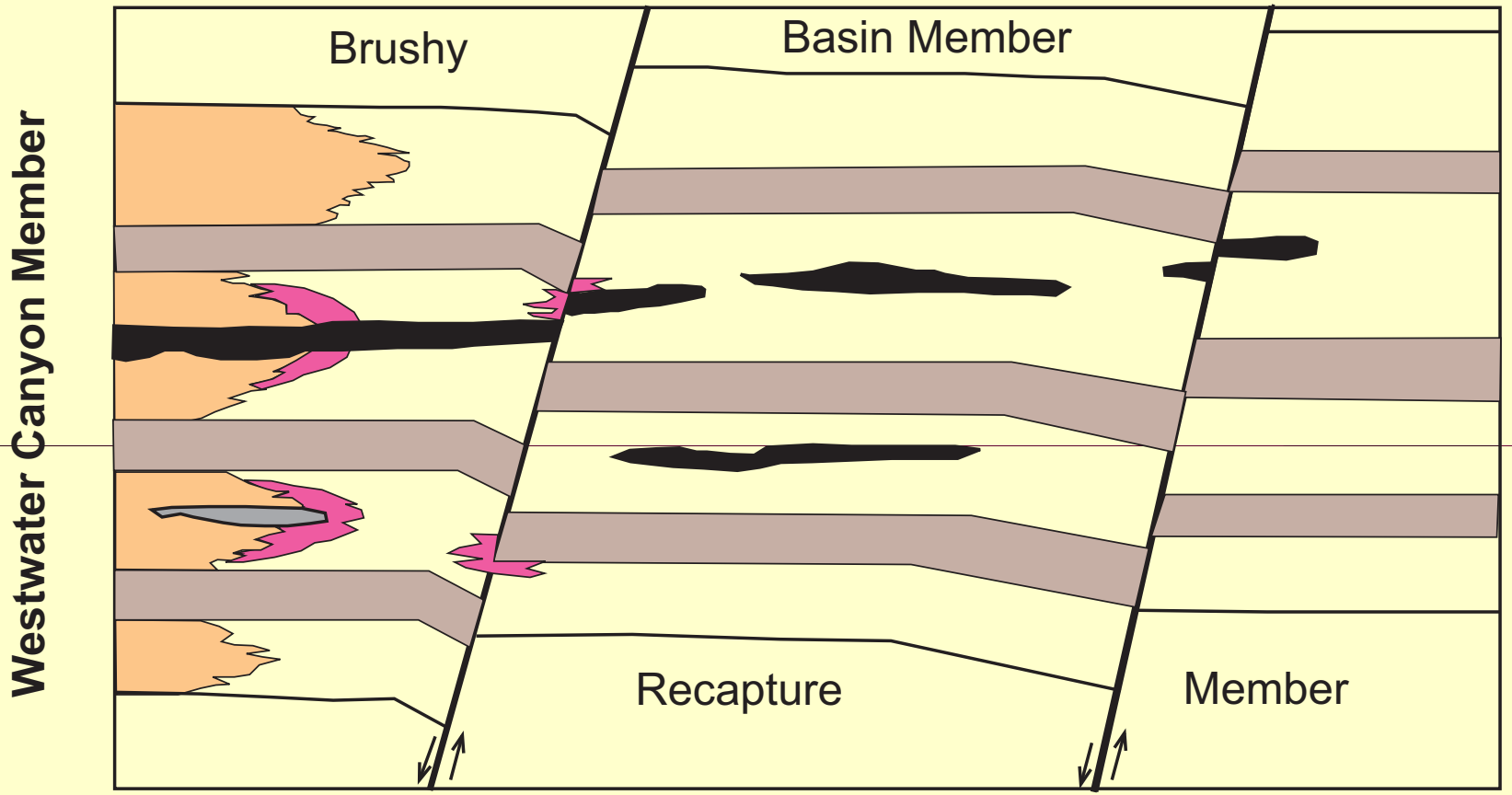

6
3

Redistributed Deposits in Westwater Canyon Member, Dakota Sandstone

- 3-46 m thick
- Grades less than 0.2% U_3O_8
- Commonly localized by faults
- Form roll front geometries locally
- Diffuse ore to waste boundaries
- Dark, brownish gray to light gray
- Also called postfault, stack, secondary, roll front ore

Remnant-primary sandstone uranium deposits

- Surrounded by oxidized sandstone
- 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
- Also called ghost ore bodies

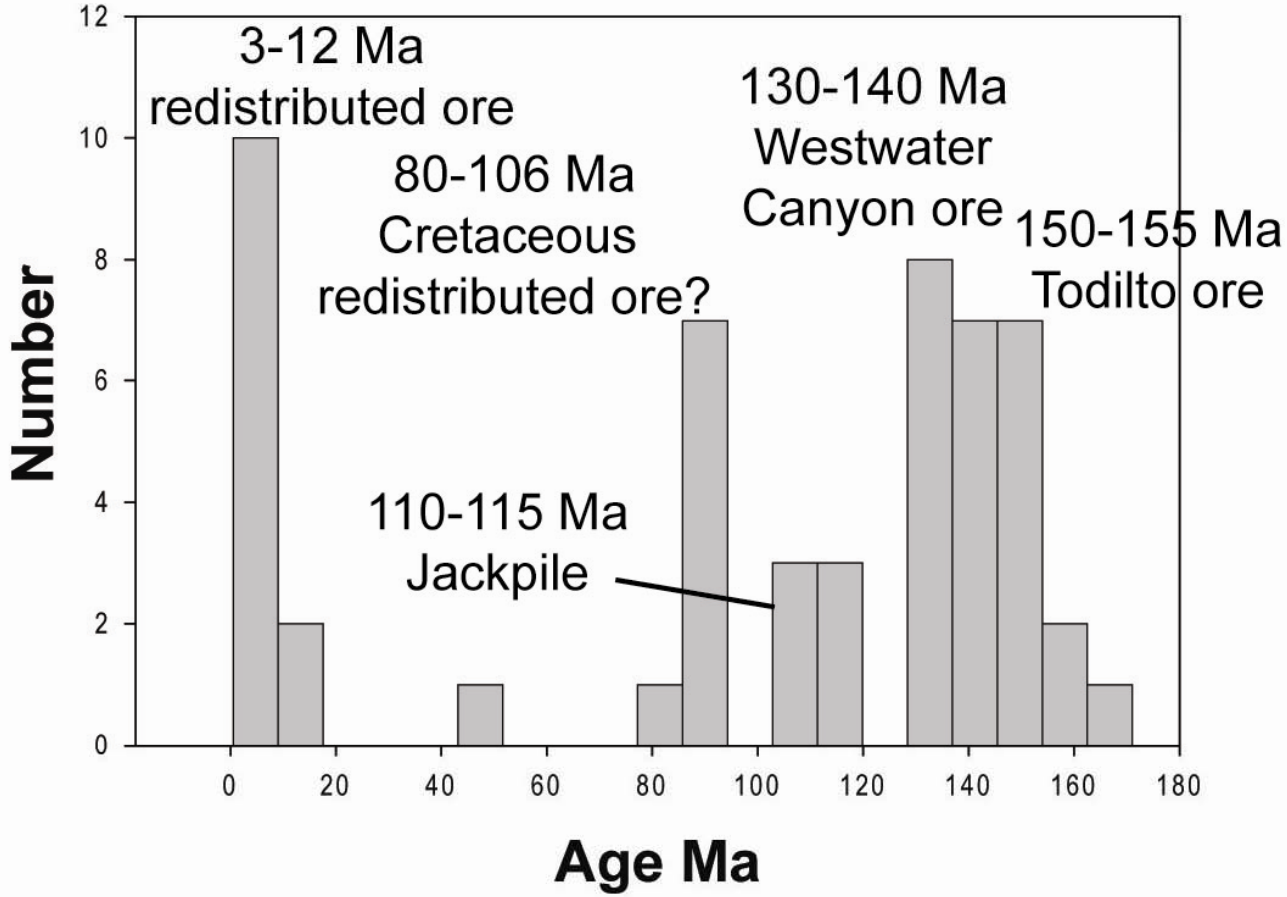

Westwater Canyon Member
Brushy
Basin Member
Recapture
Member
reduced sandstone
oxidized sandstone
primary uranium ore
redistributed uranium ore
remnant primary ore
shale

AGE OF THE DEPOSITS

Possible episodes of primary uranium mineralization

- Early Jurassic (Todilto at 150-155 Ma, U/Pb, Berglof, 1992)
- During and soon after deposition of the Westwater Canyon sandstones
  - 148 Ma (Rb/Sr, Lee and Brookins, 1978) deposition age of Westwater Canyon Member
  - 130-140 Ma based on U/Pb data and Rb/Sr and K/Ar ages of clay minerals penecontemporaneous with uranium minerals
  - Jackpile Sandstone is younger at 110-115 Ma (Lee, 1976)

Age determinations of Grants district mineralization



Includes Pb/U, K/Ar, Rb/Sr, and fission track dates from Miller and Kulp (1963), Nash and Kerr (1966) , Nash (1968), Berglof (1970, 1992), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983).

Possible episodes of redistributed uranium mineralization

- During the Dakota time (Late Cretaceous, 80-106 Ma??????)
- During the present erosional cycle (which started in late Miocene or early Pliocene)
  - Secondary Todilto uranophane yields U/Pb ages of 3 to 7 Ma (Berglof, 1992)
  - Redistributed (stack) ore and an oxidized uranium mineral (uranophane) at Ambrosia Lake have late Tertiary U/Pb ages of 3 to 12 Ma

SOURCE OF URANIUM

The primary uranium deposits are associated with humates. Therefore we need to understand the origin of the humates as well as the uranium.

Origin of humates

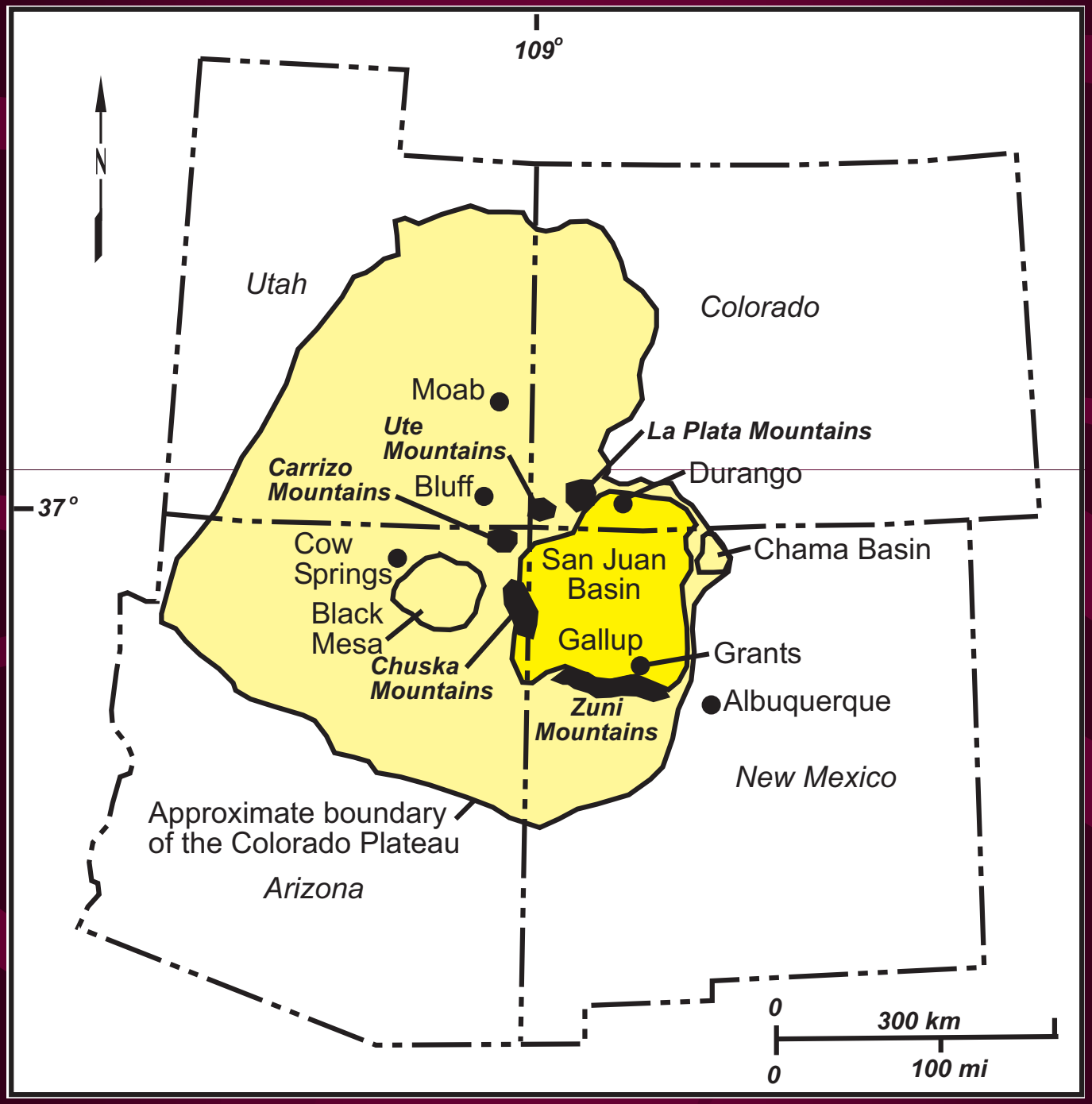
- Organic matter, not petroleum derived
  - Plant debris incorporated into the alluvial fans at the time of deposition
  - Plant material associated with the overlying lacustrine units
  - Dakota and pre-Dakota swamps (????)
- Locally it is detrital (L-Bar deposits)
- At most places, humates were deposited just after the sandstones were emplaced but before the uranium
- Brushy Basin contains little organic material

There is no consensus on details of the origin of the Morrison primary sandstone uranium deposits

- Ground water derived from a granitic highland to the south
- Ground water derived from a volcanic highland to the southwest (Jurassic arc)
- Alteration of volcanic detritus and shales within the Brushy Basin member (Lacustrine-humate model)
- Older uranium deposits
- Combination of the above

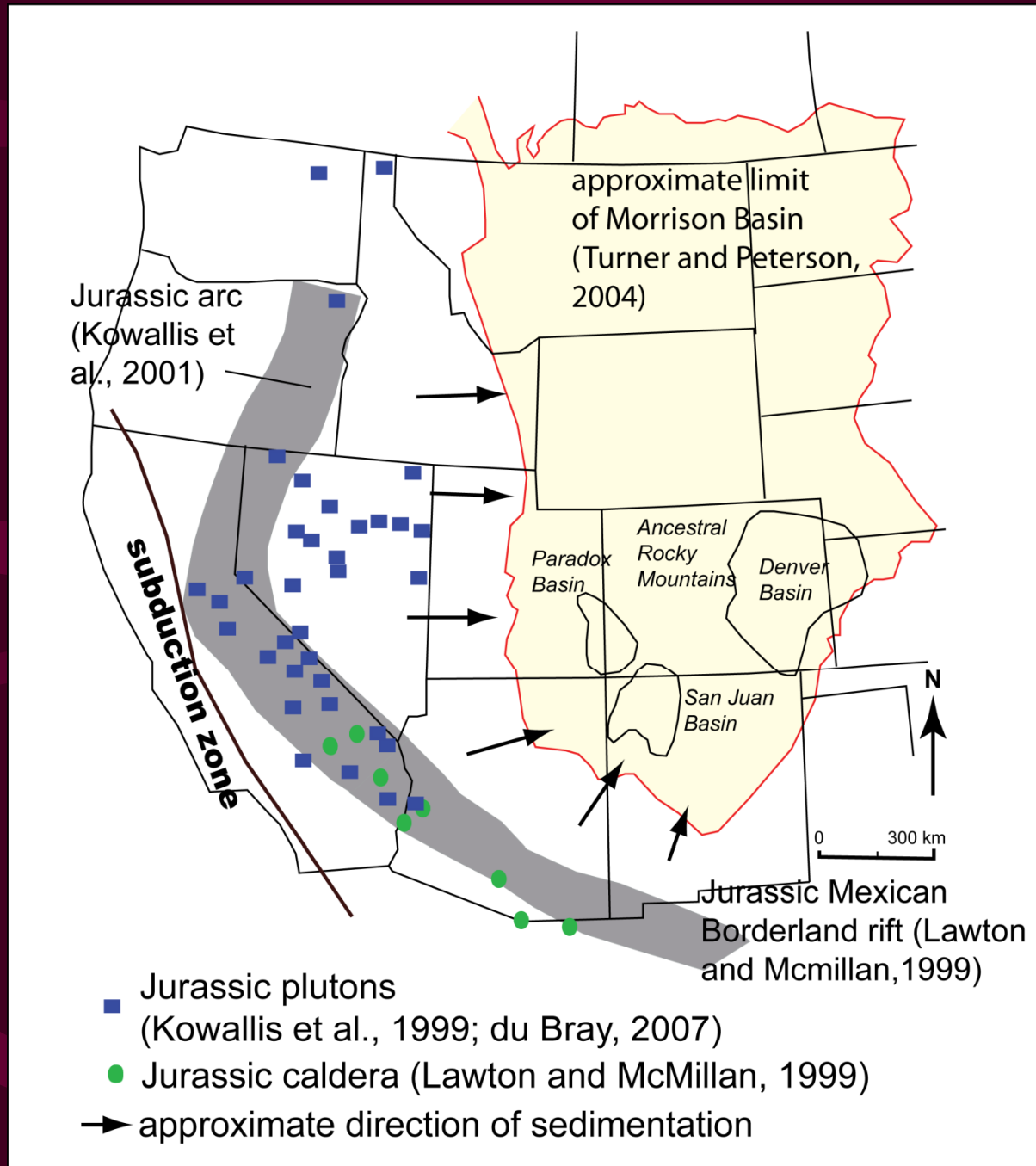
Granitic highland

- Zuni Mountains
- High heat flow (2-2.5 HFU; Reiter et al., 1975)
- Precambrian granites in the Zuni Mountains contain as much as 11 ppm (Brookins, 1978)


109°
N
Utah
Colorado
Moab
Ute Mountains
La Plata Mountains
Carrizo Mountains
Bluff
Durango
37°
Cow Springs
San Juan Basin
Chama Basin
Black Mesa
Gallup
Grants
Chuska Mountains
Albuquerque
Zuni Mountains
New Mexico
Approximate boundary of the Colorado Plateau
Arizona
0
300 km
0
100 mi

Volcanic highland

- Jurassic volcanic and plutonic rocks in the southwest
- Meteroic water dissolves uranium from volcanic and plutonic rocks and transport into the San Juan Basin


approximate limit of Morrison Basin (Turner and Peterson, 2004)
Jurassic arc (Kowallis et al., 2001)
subduction zone
Paradox Basin
Ancestral Rocky Mountains
Denver Basin
San Juan Basin
N
0
300 km
Jurassic Mexican Borderland rift (Lawton and Mcmillan,1999)
Jurassic plutons (Kowallis et al., 1999; du Bray, 2007)
Jurassic caldera (Lawton and McMillan, 1999)
approximate direction of sedimentation

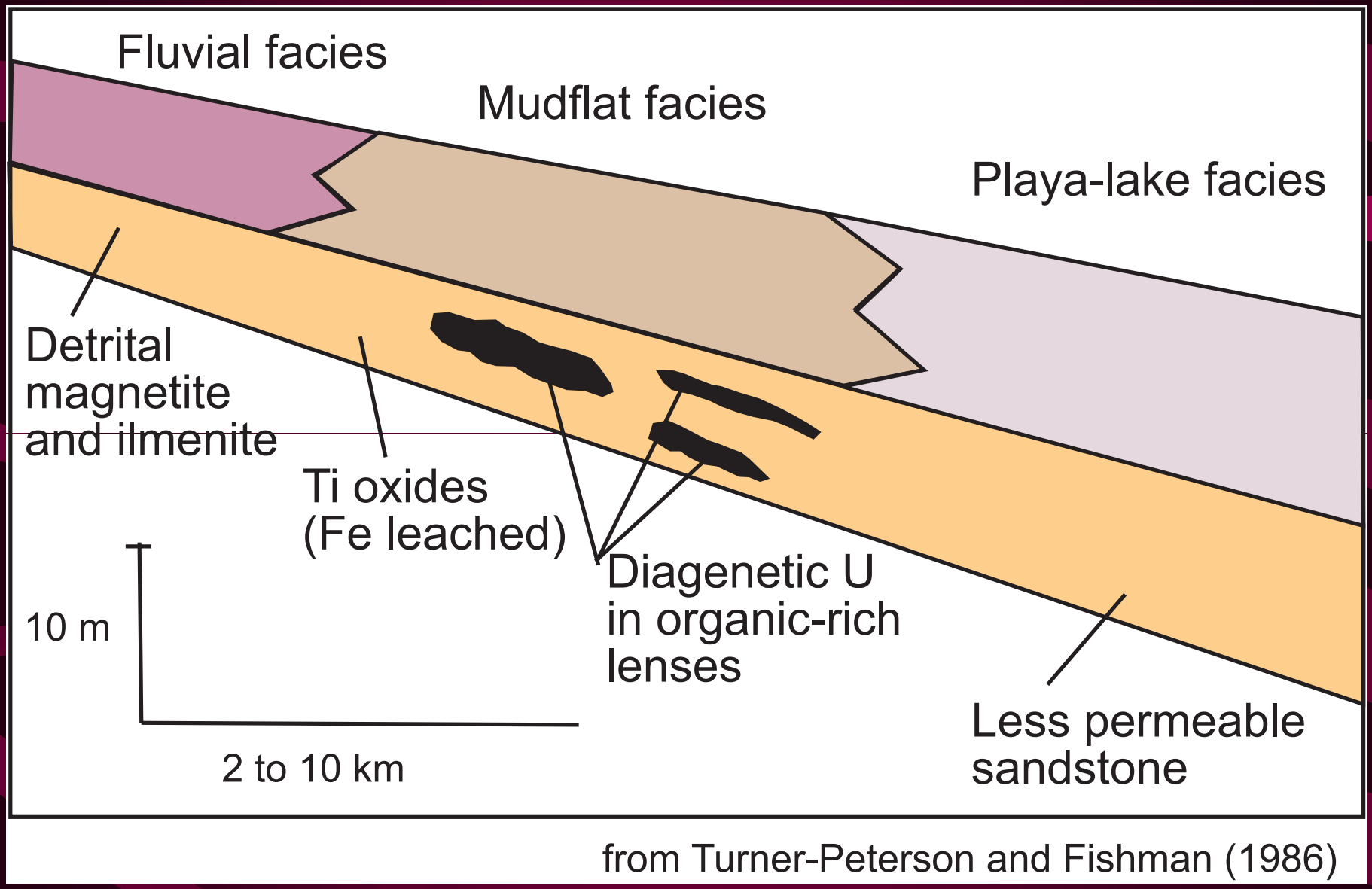
Alteration of volcanic detritus and shales

- Ash fall and other volcanic detritus erupts from the volcanic arc and deposits into the San Juan Basin
- Mechanical weathering of the volcanic arc deposits detritus into the San Juan Basin
- Subsequent weathering of the ash fall deposits immediately after deposition and during diagenesis releases uranium

HOW DID THE DEPOSITS FORM?

Lacustrine-humate model

- Ground water was expelled by compaction from lacustrine muds formed by a large playa lake
- Humate or secondary organic material precipitated as a result of flocculation into tabular bodies
- During or after precipitation of the humate bodies, uranium was precipitated from ground water



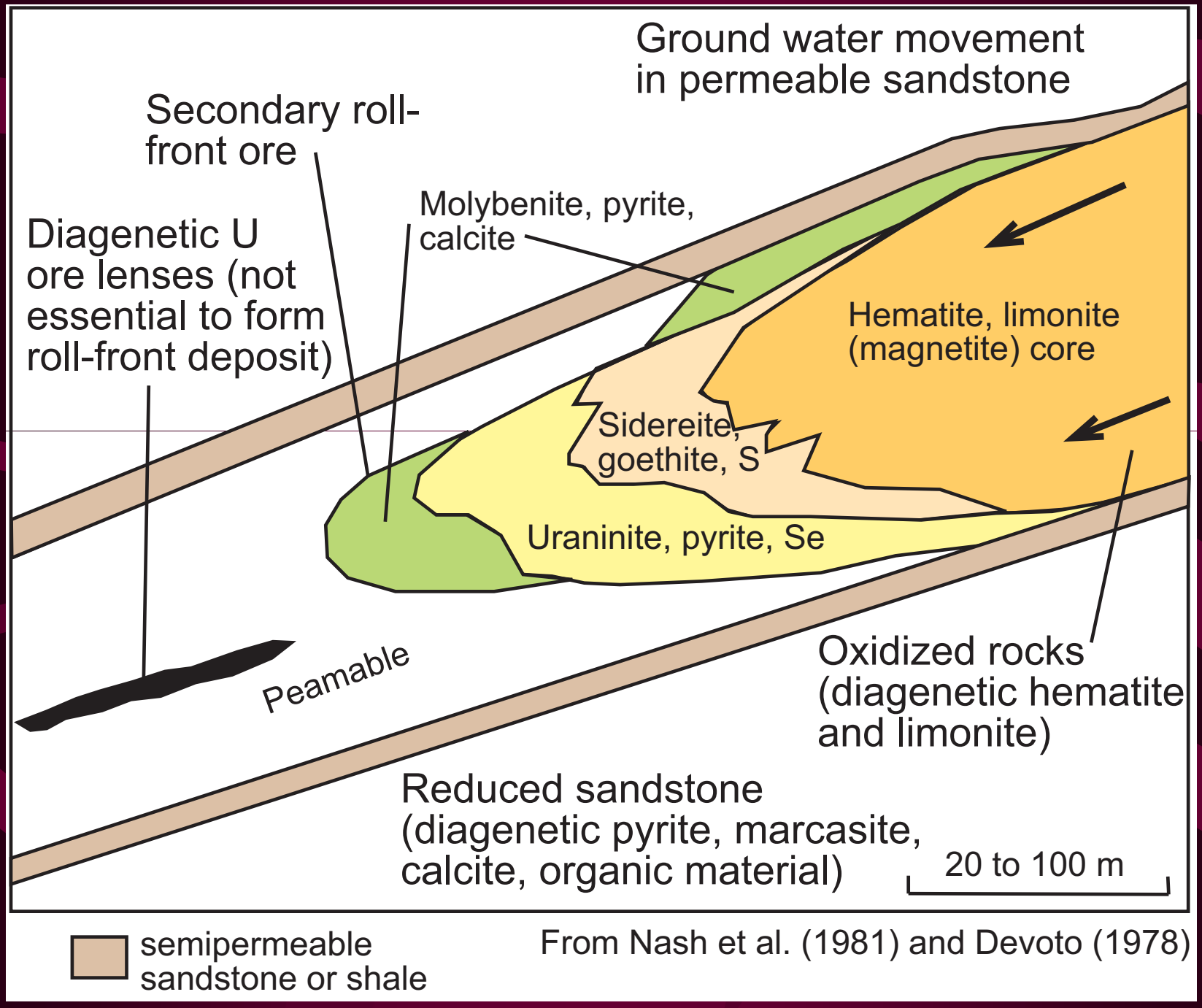
from Turner-Peterson and Fishman (1986)

Brine-interface model

- Uranium and humate were deposited during diagenesis by reduction at the interface of meteoric fresh water and basinal brines or pore water
- Uranium 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
- Ground-water flow was impeded by upthrown blocks of Precambrian crust and forced upwards
- These zones of upwelling are closely associated with uranium-vanadium deposits

Roll-front uranium deposits

- After formation of the primary sandstone uranium deposits, oxidizing ground waters migrated through the uranium deposits and remobilized some of the primary sandstone uranium deposits
- Uranium was reprecipitated ahead of the oxidizing waters forming redistributed or roll front sandstone uranium deposits
- Evidence suggests that more than one oxidation front occurred in places (Cretaceous and a Tertiary oxidation front)


Ground water movement
in permeable sandstone
Secondary roll-
front ore
Molybenite, pyrite,
calcite
Diagenetic U
ore lenses (not
essential to form
roll-front deposit)
Hematite, limonite
(magnetite) core
Sidereite,
goethite, S
Uraninite, pyrite, Se
Peamable
Oxidized rocks
(diagenetic hematite
and limonite)
Reduced sandstone
(diagenetic pyrite, marcasite,
calcite, organic material)
20 to 100 m
semipermeable
sandstone or shale
From Nash et al. (1981) and Devoto (1978)

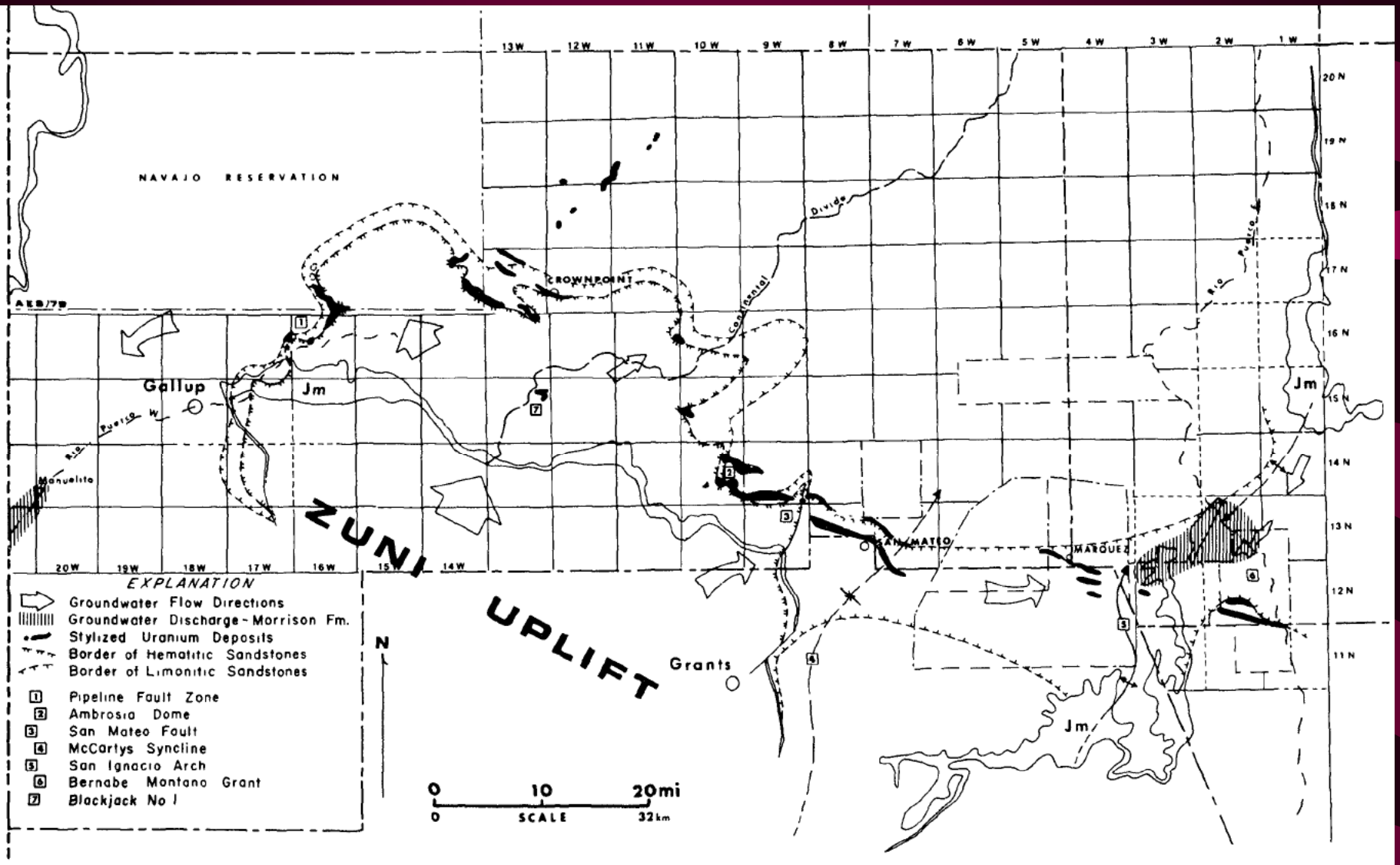


FIGURE 4. Map showing distribution of Tertiary-Quaternary oxidation in sandstone of Westwater Canyon Member, Morrison Formation. See Saucier (11), from which this figure is taken, for full discussion of details shown on map.

COMMENTS

- None of the uranium mills remain in the Grants region.
- Current plans by some companies are to mine uranium by ISR or heap leaching.
- Most conventional mining of uranium will require shipping to an existing mill in Utah or Colorado or licensing and building a new mill in New Mexico.
- The Navajo Nation has declared that no uranium production will occur in Indian Country.

CONCLUSION

- Grants district primary uranium deposits formed shortly after deposition coincident with Jurassic arc volcanism to the southwest
- Grants district redistributed uranium deposits formed during periods when oxidizing ground waters could enter the mineralized sandstones and remobilize the older primary uranium deposits
  - During the Cretaceous Dakota deposition ?????
  - During the mid-Tertiary to modern erosional cycle

FUTURE RESEARCH

- More age determinations
- Better understanding of the regional Jurassic tectonics
- Geochemical analyses of the Jurassic sediments and ore deposits
- Determining the age of remobilization or redistributed deposits