North Dakota Geological Survey

Mineral Resources of North Dakota:

Uranium

Western North Dakota contains several areas of known radioactive mineral deposits. Investigations done from the late 1940s to the late 1970s discovered several large areas of increased radioactivity in Bowman, Slope, Stark, Billings, and Golden Valley counties. Uranium and other radioactive elements were often found associated with beds of lignite. These low grade ore deposits often ranged from 0.005 to 0.2 percent uranium. It is theorized by many geologists that these radioactive elements were released during the alteration of volcanic glass. These radioactive elements were then leached by groundwater into the underlying rocks until a change in pH and or Eh caused them to precipitate, often in a coal or organic-rich lenses in sandstone. Early on it was noted that radioactive lignites often were overlain by sandstones.

Beginning in 1956, a few hundred tons of uraniferous lignite was shipped from North Dakota to processing plants. The mills were set up to process uraniferous sandstones and had difficulty processing the low grade ore lignites. Beginning in 1962, this problem was rectified by burning the uraniferous lignite in pits at the mine site, often by burning the bed in place after the overburden had been removed. The process reportedly took from 30 to 60 days and diesel fuel and old tires were often mixed with the lignite to assure that it would burn sufficiently. The ash from the mines was then sent to Belfield or Griffith where it was further reduced by burning in kilns. The resulting ash was then shipped to mills in South Dakota, Colorado, and New Mexico. At least seven, and possibly as many as fourteen uraniferous lignite mines operated in the state. Records were poorly kept for a number of reasons including national security and most were relatively small short lived operations. Mining was discontinued in 1967 after total production of approximately 85,000 tons of ore resulting in 270 tons of "yellow cake" (U_3O_8). Renewed interest in uranium in the mid 1970s resulted in a number of uranium investigations centered in the Chalky Buttes (Slope County) and Gascoyne (Bowman County) areas. The accident at the Three Mile Island nuclear plant in 1979 effectively halted all uranium exploration in the United States. It has been estimated that North Dakota contains a mineable reserve of 480,000 pounds of U_3O_8 at an $8.00 per pound market price. The uranium reserves of North Dakota represent far less than 1 percent of the total U.S. reserves.

In recent years, the uranium deposits of North Dakota have been investigated as potential health hazards rather than as potential mineable commodities. Concern has been expressed for human or livestock consumption of moderate to high levels of uranium in groundwater in some areas of southwestern North Dakota. Elevated radon levels near these deposits is also a concern. These mines operated without any reclamation laws and the open pits were left when the sites were abandoned. In the 1980's and early 1990's, the North Dakota Public Service Commission reclaimed these sites for health reasons by burying the most radioactive material in the bottom of the pits and leveling the surface. Studies have also been conducted by the Department of Energy into the spread and potential health risks of radioactive dust that spread from the uraniferous lignite burn sites, both at the mines and the Belfield and Bowman kiln sites.

Known areas of uranium occurrence within 200 feet of the surface in western North Dakota. This information was plotted from radioactive spikes on gamma logs on file with the North Dakota Geological Survey.

Conglomerates, sandstone, and bentonite of the Chadron Formation in the Chalky Buttes, Slope County. Geologists speculate that these volcanic-rich rocks were the source for the uranium found concentrated in the underlying strata. Alteration of the glass shards to clay is thought to be responsible for releasing uranium to groundwater which leached the radioactive elements into the underlying rocks.
(Photo by E. Murphy, NDGS).

Open burning near Belfield (Slope County) of uraniferous lignite to produce an ash concentrate.

A portion of the old Fritz uraniferous mine located southwest of Belfield in Slope County. The photograph was taken in 1991, shortly before the mine site was reclaimed by the North Dakota Public Service Commission. Water with a low pH and high uranium content has ponded at the base of one of the mine pits. (Photo by E. Murphy, NDGS).

Selected References for North Dakota Uranium

Beroni, E.P. and Bauer, H.L., Jr., 1952, Reconnaissance for unaniferous lignites in North Dakota, South Dakota, Montana, and Wyoming: United States Atomic Energy Commission, Technical Information Service Extension, TEI-123, 93 p.

Denson, N.M., Bachman, G.O., and Zeller, H.D., 1959, Uranium-bearing lignite in northwestern South Dakota and adjacent states: United States Geological Survey Bulletin 1055-B, p. 11-57.

Denson, N.M. and Gill, J.R., 1965, Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston Basin - a regional study: United States Geological Survey Professional Paper 463, 75 p.

Karsmizki, K.W., 1990, U3O8, Uranium industry context statement: prepared for UNDAR-West by Western History Research, Bozeman, Montana, 79 p.

Moore, G.W., Melin, R.E., and Kepferle, R.C., 1959, Uranium-bearing lignite in southwestern North Dakota: United States Geological Survey Bulletin 1055-E, p. 147-166.

Noble, E.A., 1973, Uranium in coal, in Mineral and water resources of North Dakota: North Dakota Geological Survey Bulletin 63 p. 80-85.

Uranium Maps (/ndgs/uraniummaps/)

URANIUM IN NORTH DAKOTA

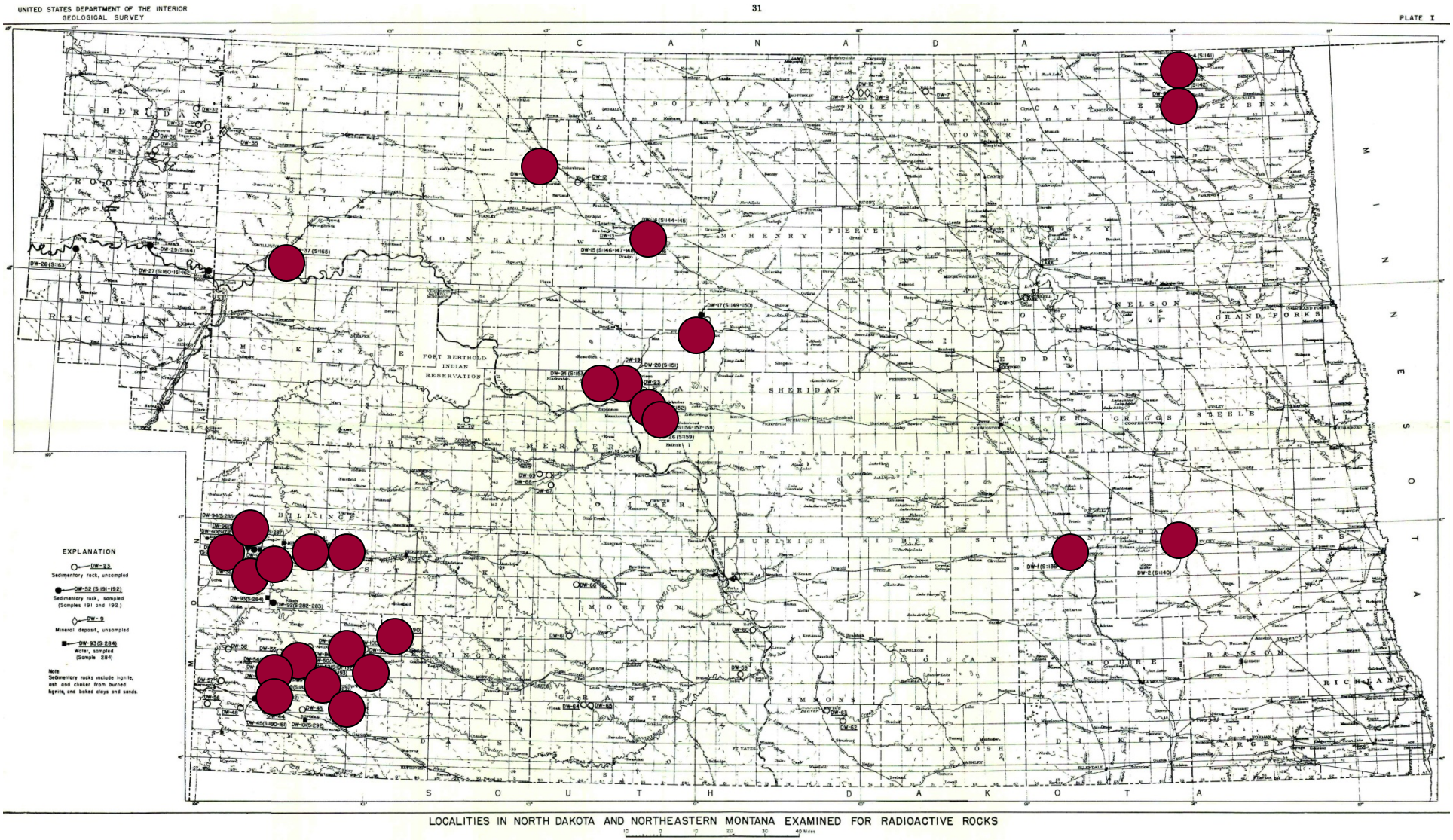
Edward C. Murphy

GEOLOGICAL INVESTIGATIONS NO. 184
NORTH DAKOTA GEOLOGICAL SURVEY
2015

Authors Note: Unfortunately, little or no information was recorded at the state level regarding uranium exploration and mining due to national security and the lack of state oversight. In 1990, Ken Karsmizki compiled a 79 page report for UNDAR-West entitled U_3O_8 *Uranium Industry Context Statement, a* good source of information for early uranium mining in North Dakota. For this presentation, I supplemented Karsmizki's report and information from the Abandoned Mine Lands Division of the North Dakota Public Service Commission with information garnered from discussions with geologists involved in the uranium mining in North Dakota in the 1960s as well as those involved in uranium exploration in the state during the 1970s.

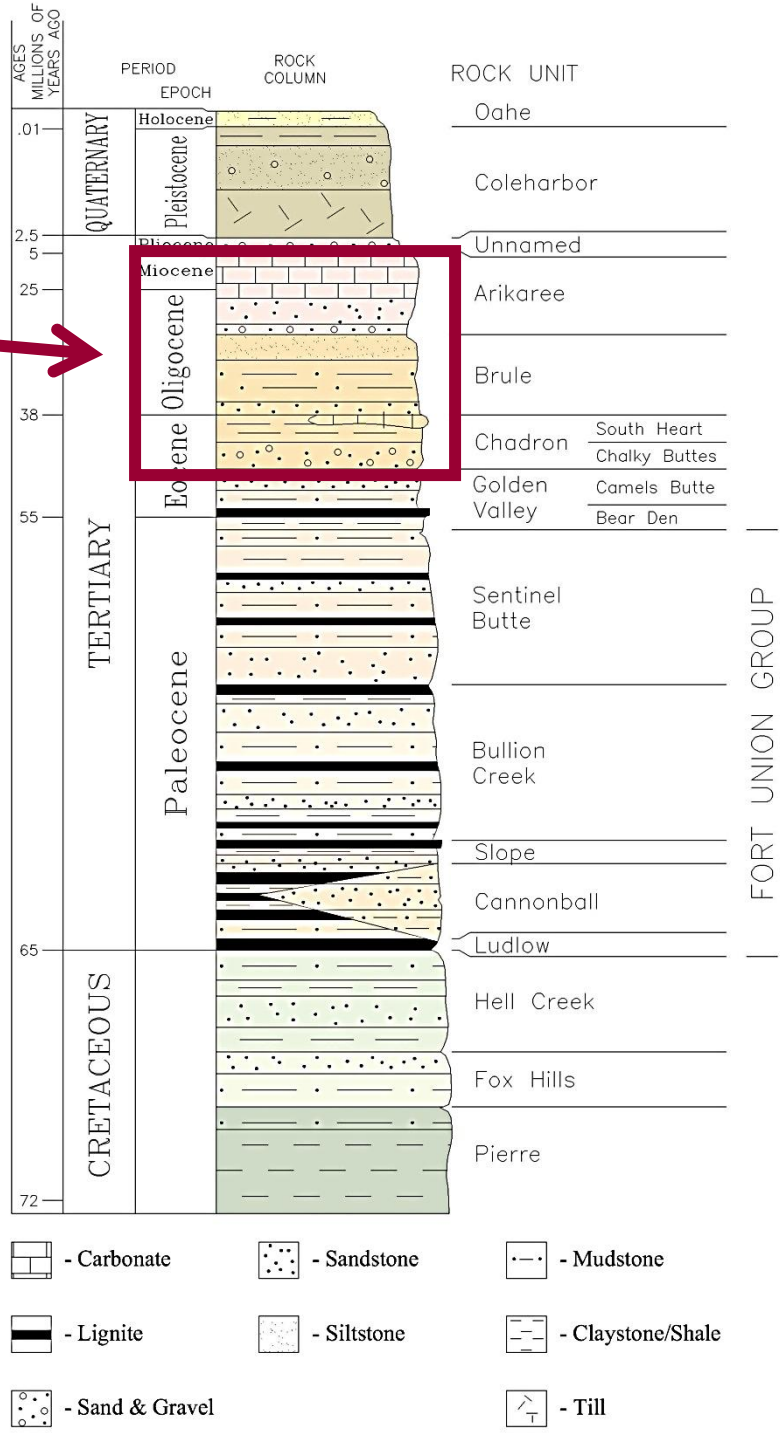
Variations on this PowerPoint were presented to 1,100 people in Belfield, Bismarck, Bowman, Dickinson, and Mandan between 2008 - 2012.

Uranium in North Dakota, North Dakota Geological Society, Bismarck, February 22, 2008.
The Proposed ISL Uranium Rules for North Dakota, Public Informational Meeting, Belfield, March 10, 2008.
Uranium in North Dakota, Golden Kiwanis, Bismarck, April 30, 2008.
Uranium in Western North Dakota, Dickinson Rotary Club, July 9, 2008.
Uranium in Western North Dakota, EmPower Group, Bismarck, December 12, 2008.
Uranium in Western North Dakota, Bismarck Rotary Club, January 12, 2009.
Uranium development in Western North Dakota, North Dakota Chapter of the Wildlife Society, Mandan, February 11, 2009.
Uranium in Southwestern North Dakota, North Dakota Earth Science Teachers Conference, Bismarck State College, March 6, 2009.
Uranium in North Dakota, Bowman County Economic Development Association, December 14, 2010.
Mineral Potential of Southwestern North Dakota, Bowman, January 23, 2012.
Energy Resources of the Williston Basin, Soil Conservation Districts Annual mtg, Bismarck, November 19, 2012.



In 1948 and 1949, Wyant and Beroni (1950) collected 82 samples from 86 localities (red dots) – the first reported widespread uranium exploration to take place in North Dakota.

Source rocks for uranium deposits



Arikaree Fm.

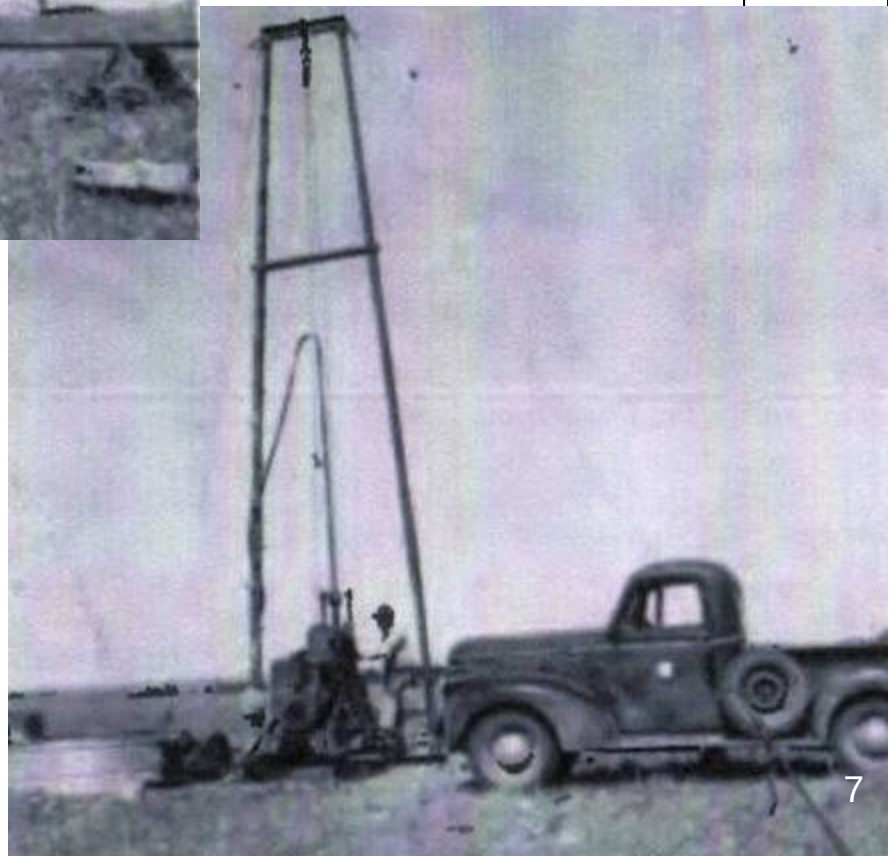
White River Group

Sentinel Butte Fm.

The Arikaree and White River rocks are typically only found preserved on the major buttes in western North Dakota. Chadron rocks overlie this massive sandstone (Golden Valley Formation) at Bullion Butte in Billings and Golden Valley counties.

Chadron claystones and conglomerates overlie the 75-foot-thick sandstone caprock (Golden Valley Formation) on Square Butte, Golden Valley County.

Fifty feet of Chadron claystone overlies the sandstone caprock (Golden Valley Fm) on Sentinel Butte in Golden Valley County.



Uranium exploration in North Dakota, South Dakota, Montana, or Wyoming in the 1940s and 1950s.

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no.238

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Geology - Mineralogy

This document consists of 104 pages, plus 3 figures. No. 43 of 58 copies, Series A.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

RESULTS OF CORE DRILLING OF URANIUM-BEARING LIGNITE DEPOSITS IN HARDING AND PERKINS COUNTIES, SOUTH DAKOTA, AND BOWMAN COUNTY, NORTH DAKOTA *

By

Howard D. Zeller

Should include a statement to the effect that this area was drilled in 1951 by the U.S.G.S. and that the results are in Chapter C.

October 1952

Trace Elements Investigations Report 238

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to to an unauthorized person is prohibited by law.

* This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission

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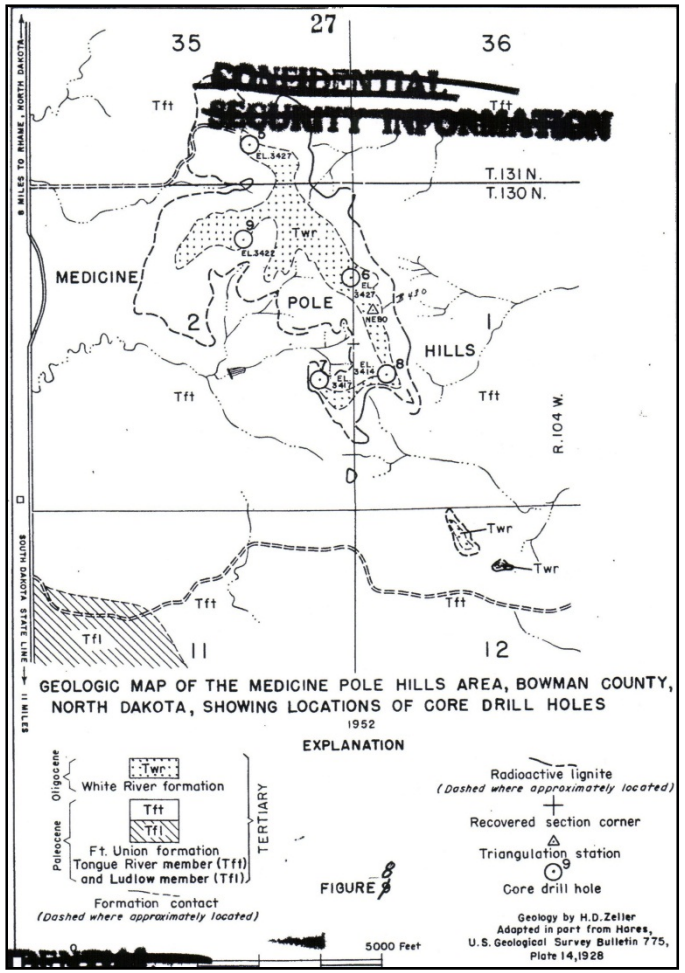
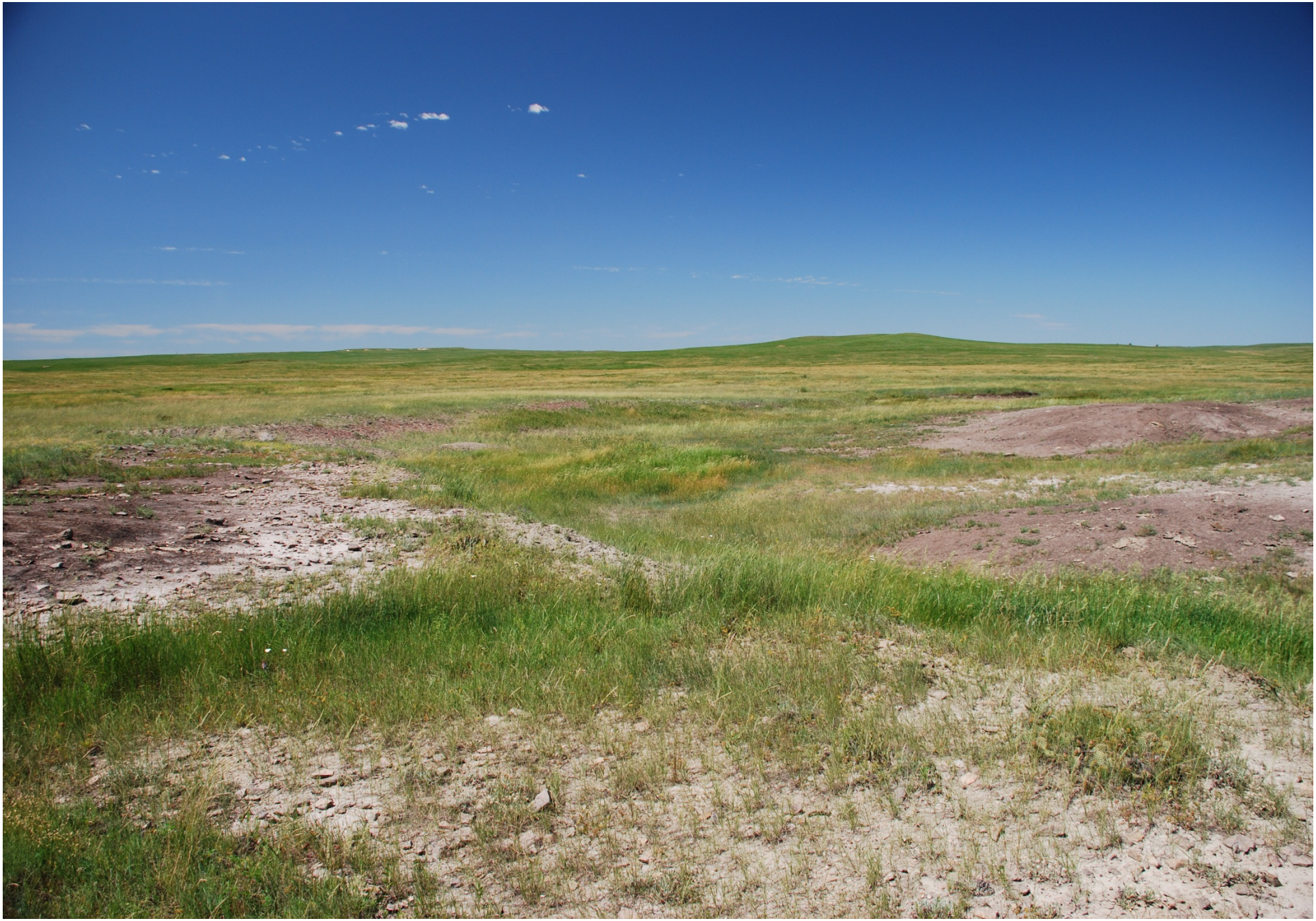
Early uranium reports were sometimes restricted in distribution due to security concerns.



An old uranium test pit east of the Kinley Plateau in Billings County. A number of test pits were excavated in North Dakota during the 1950s. The uraniferous lignite was sent to processing sites in New Mexico and Colorado to determine the best means of removing the uranium from the coal.



An old uranium test pit in north-central Billings County.

URANIUM MINES IN NORTH DAKOTA

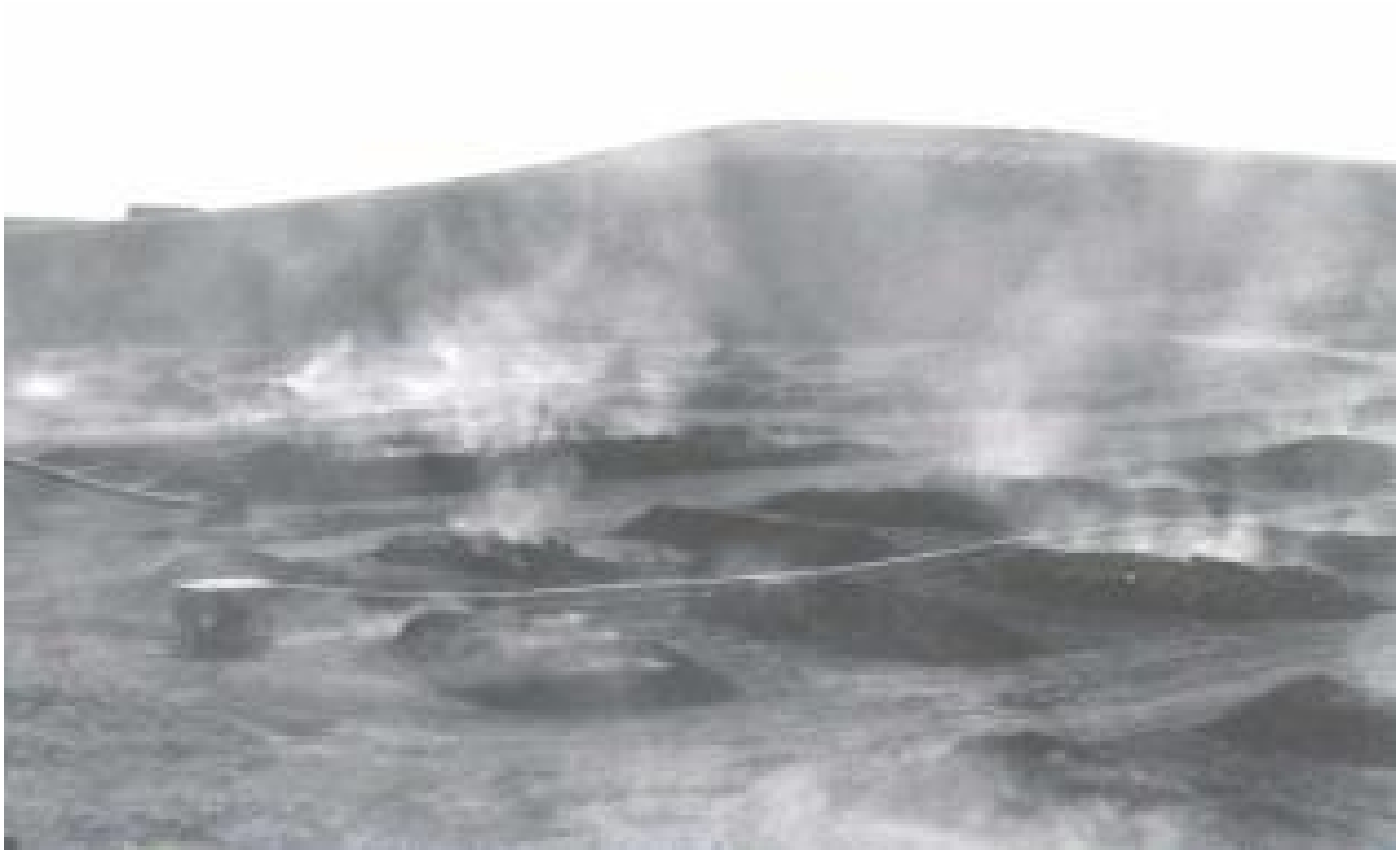
Mining took place in North Dakota between 1962 – 1967.

Mine records were poor to nonexistent.

No state agency had jurisdiction over the mines at the time – the ND Geological Survey subsurface minerals program did not come into existence until 1968.

ND had somewhere between 9 – 14 uranium mines.
Some of these sites may have been large test pits.

Mining was centered in the Belfield area and included:
- Billings County
- Stark County
- Slope County
- Golden Valley County



Uraniferous lignite was burned in the mine pit or in a rotary kiln in Belfield. The uraniferous lignite was placed in piles, covered with old tires, doused in diesel fuel, ignited, and left to smolder for a couple of months. This is believed to be the Fritz Mine and is the only photograph of a burn that I have been able to locate.

MINERAL COMPANIES ACTIVE IN NORTH DAKOTA: 1950s and 60s

- **Union Carbide Corporation**
- **Kerr-McGee**
- **Kermac Nuclear Fuels Corporation**
- **Susquehanna-Western Incorporated**
- **Geo Resources Exploration Incorporated**
- **Manidon Mining Company**
- Uranco Mining and Exploration Company
- Minerals Mining Company
- Westinghouse
- Ohio Oil Company
- Landis-Gress-McCann-Getting Uranium Association

URANIUM PROCESSING PLANTS

- Rifle, Colorado
- Ambrosia Lake, New Mexico (Kermac Nuclear Fuels Corp.)
- Edgemont, South Dakota (Mines Development Inc.)
- Riverton, Wyoming (only a small amount believed to be sent to this plant from North Dakota)

The uraniferous lignite was burned in the mine or in a kiln to reduce it to uraniferous ash -- a volume reduction of approximately 90%. The ash was then sent to one of these four plants where it was processed into uranium oxide (yellow cake).

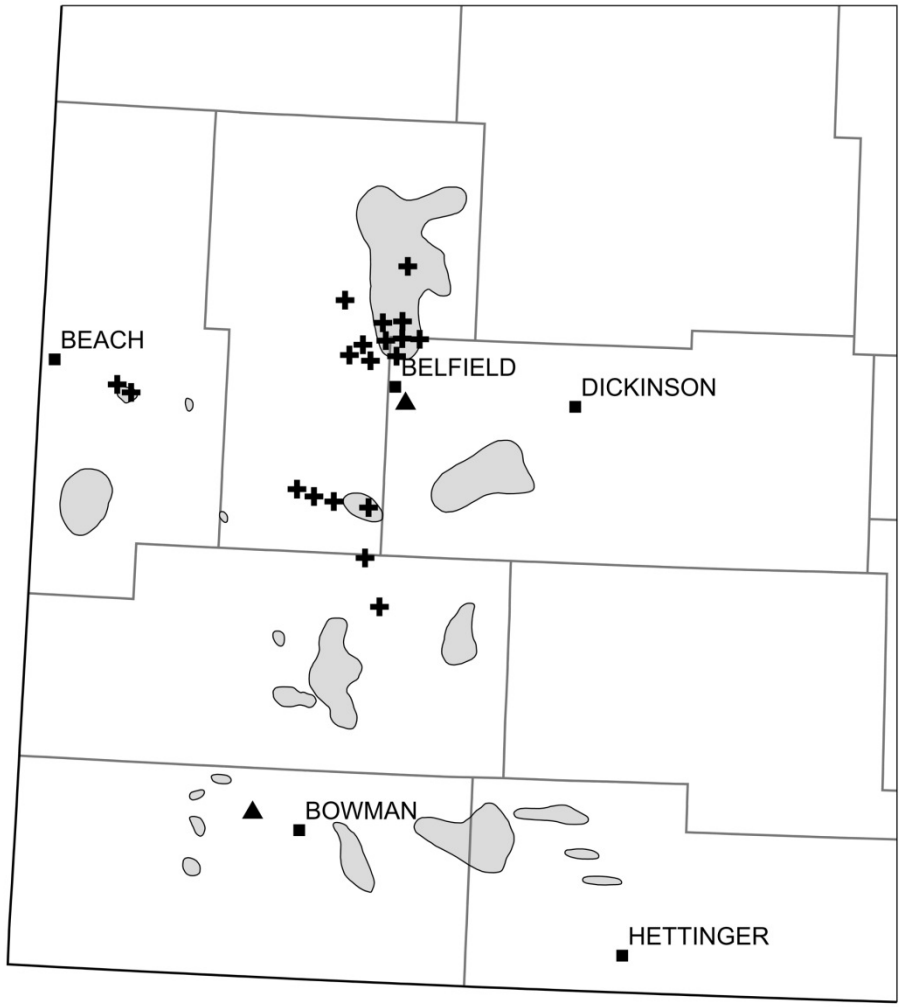
ND ROTARY KILNS

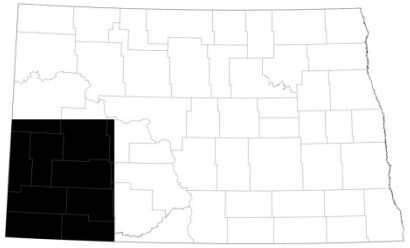
1964 -- 1967

- Union Carbide Corporation’s plant at Belfield – one rotary kiln.
- Kermac Nuclear Fuels Corporation's plant at Griffin – three rotary kilns.

One of the Griffin rotary kilns was moved to Lehigh in Stark County to make clay aggregate. Today, this equipment still contains elevated levels of radioactivity.

URANIUM MINES IN NORTH DAKOTA



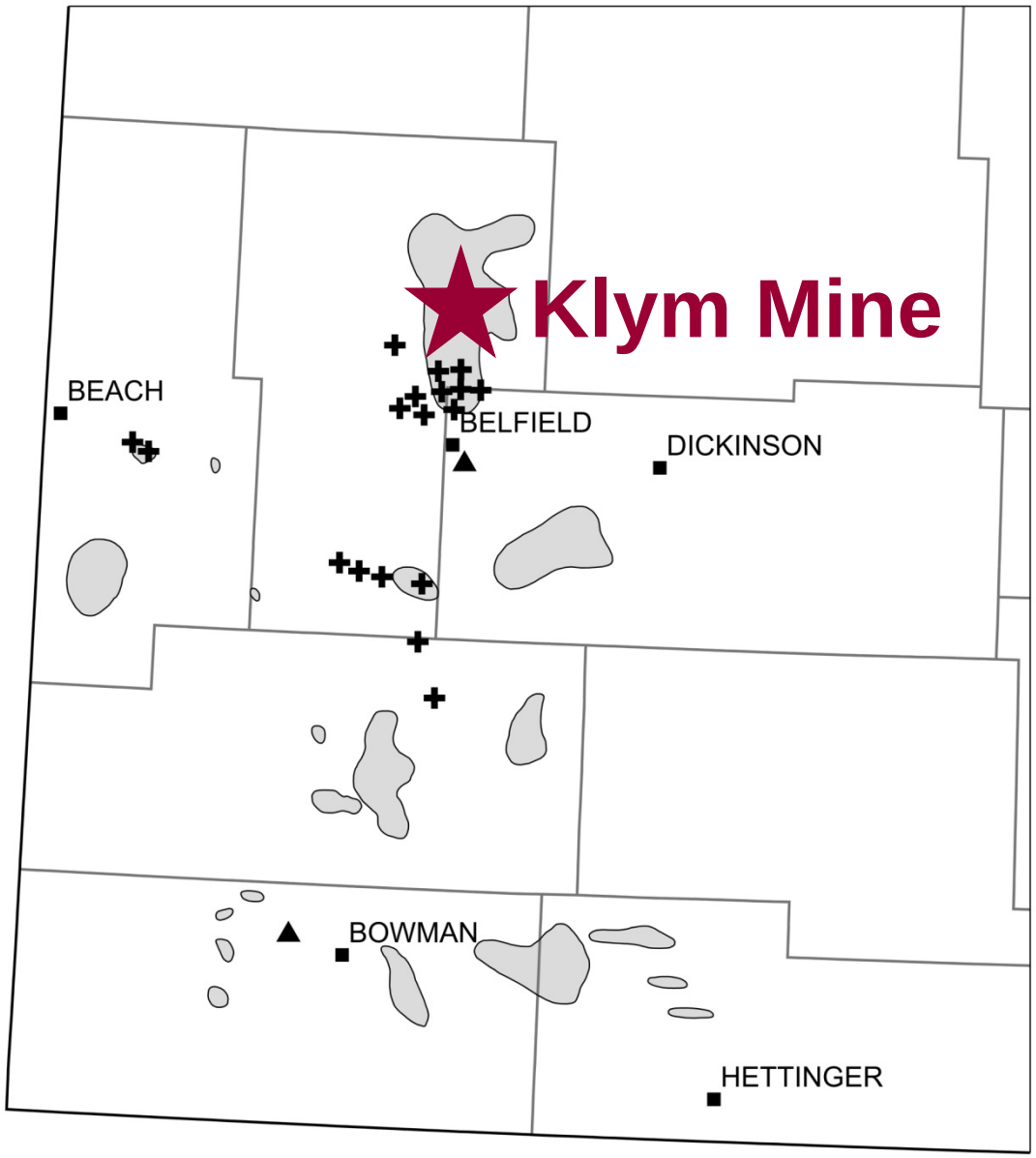


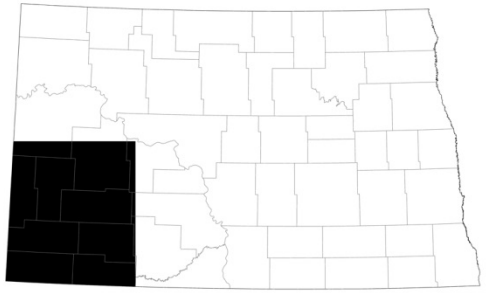
Abandoned Uranium Mine

Rotary Kiln

Uranium Deposit

Nine to 14 uranium mines operated in North Dakota in the 1960s. A half dozen or more of the sites plotted here may have been test pits rather than mines.





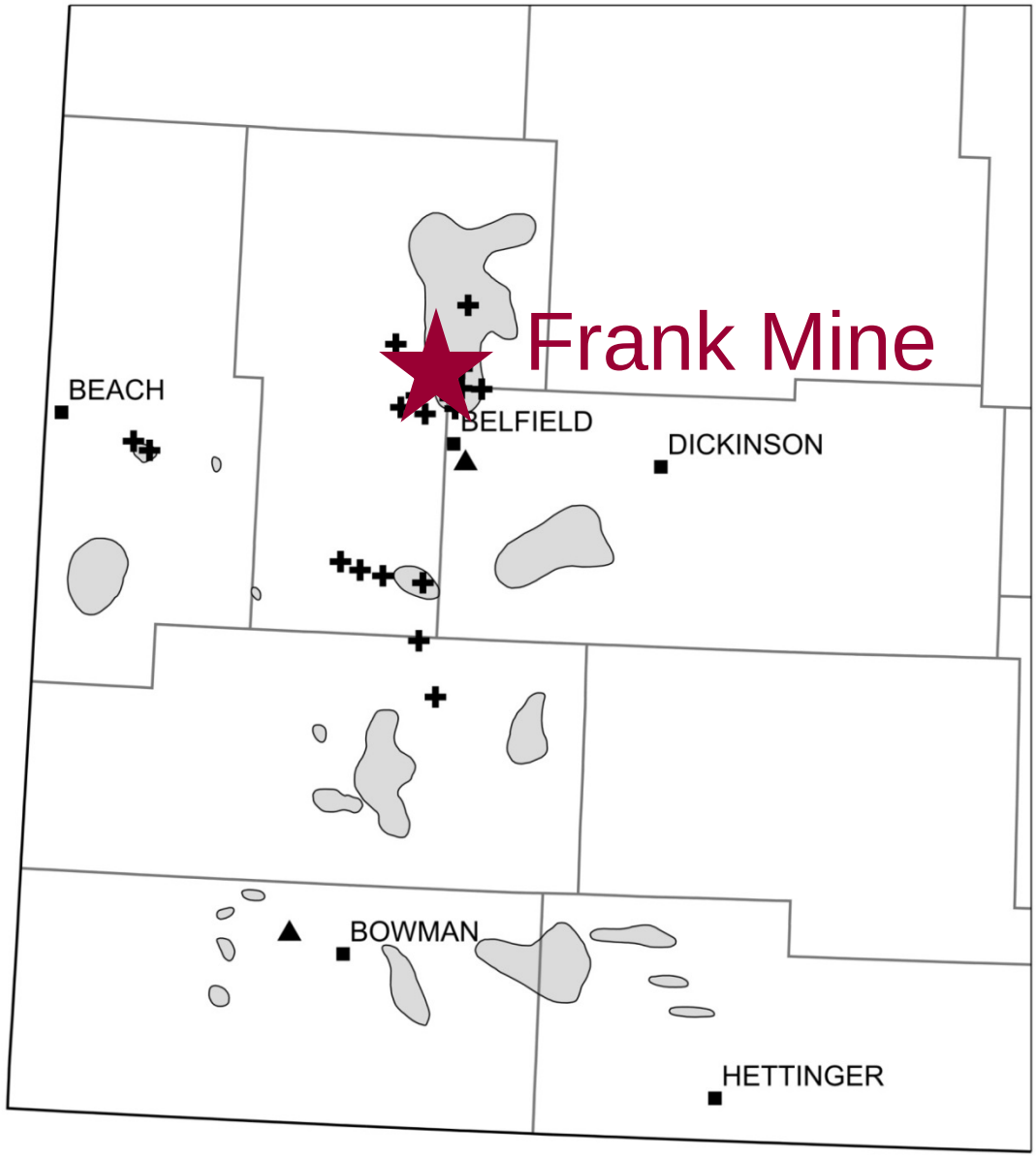
Abandoned Uranium Mine

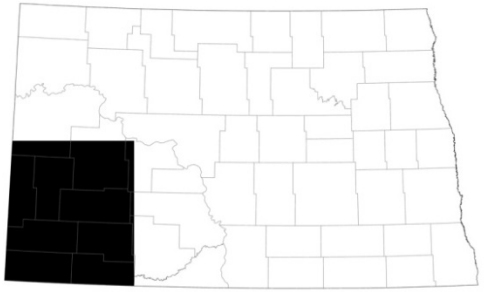
Rotary Kiln

Uranium Deposit

Susquehana-Western mined this site from 1967-1968. Mined about 25,000 tons of uraniferous lignite. Reportedly burned lignite on site and shipped the ash.

The Klym Mine in Billings County. The site was reclaimed in 1990.





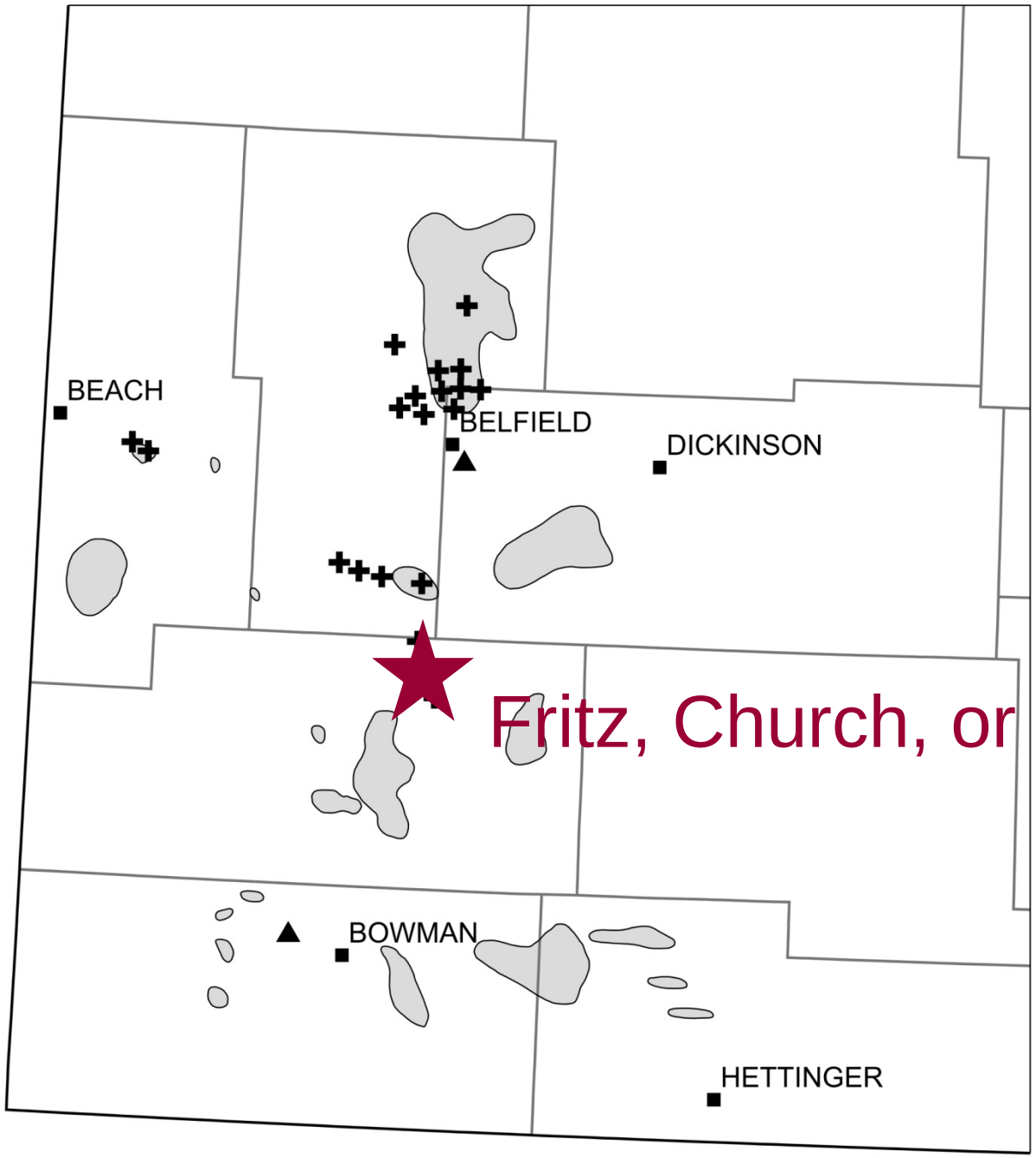
Abandoned Uranium Mine

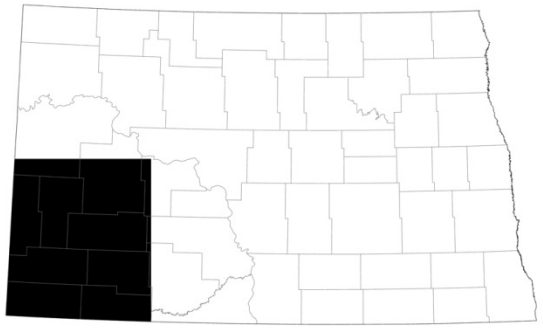
Rotary Kiln

Uranium Deposit

Union Carbide produced about 50,000 tons of uraniferous lignite from the Frank Mine. This production figure may also include the Luptak, Palaniuk, Safratowich, Hecker, Rodowski, and Lindo mines.

In the distance, a portion of the reclaimed Frank Mine in Stark County. The mine was reclaimed in 1989. Photograph taken in 2007.





Abandoned Uranium Mine

Rotary Kiln

Uranium Deposit

Fritz, Church, or Hurick Mine

The Church or Fritz Mine in Slope County operated from 1962-1967 with test pits as early as 1956. The mine site covered approximately 155 acres. This is an oblique aerial photograph of the Frtiz Mine taken by the ND Public Service Commission in 1990.

URANIUM ALLOCATIONS

1952-1962: The Atomic Energy Commission (AEC) grants U_3O_8 allocations on individual properties in the western U.S.

Late 1950s: The original allocations in North Dakota are granted on leased properties drilled by Ohio Oil.

Early 1960s: Marathon Oil proves properties in North Dakota.

1963: Marathon drops most of the leases (allotments remain with the mineral owners).

1963: Union Carbide and the other companies lease a number of the properties that contain allocations.

1967: The AEC allows companies to consolidate their allocations. Companies leave ND to locate closer to processing centers.

ATOMIC ENERGY COMMISSION CHANGES RULES IN THE MIDDLE OF THE GAME

In 1967, AEC allowed companies to obtain their allotted amount of uranium from any deposit. As a result, companies immediately stopped mining their more expensive holdings that were further from the uranium processing centers.

UNION CARBIDE

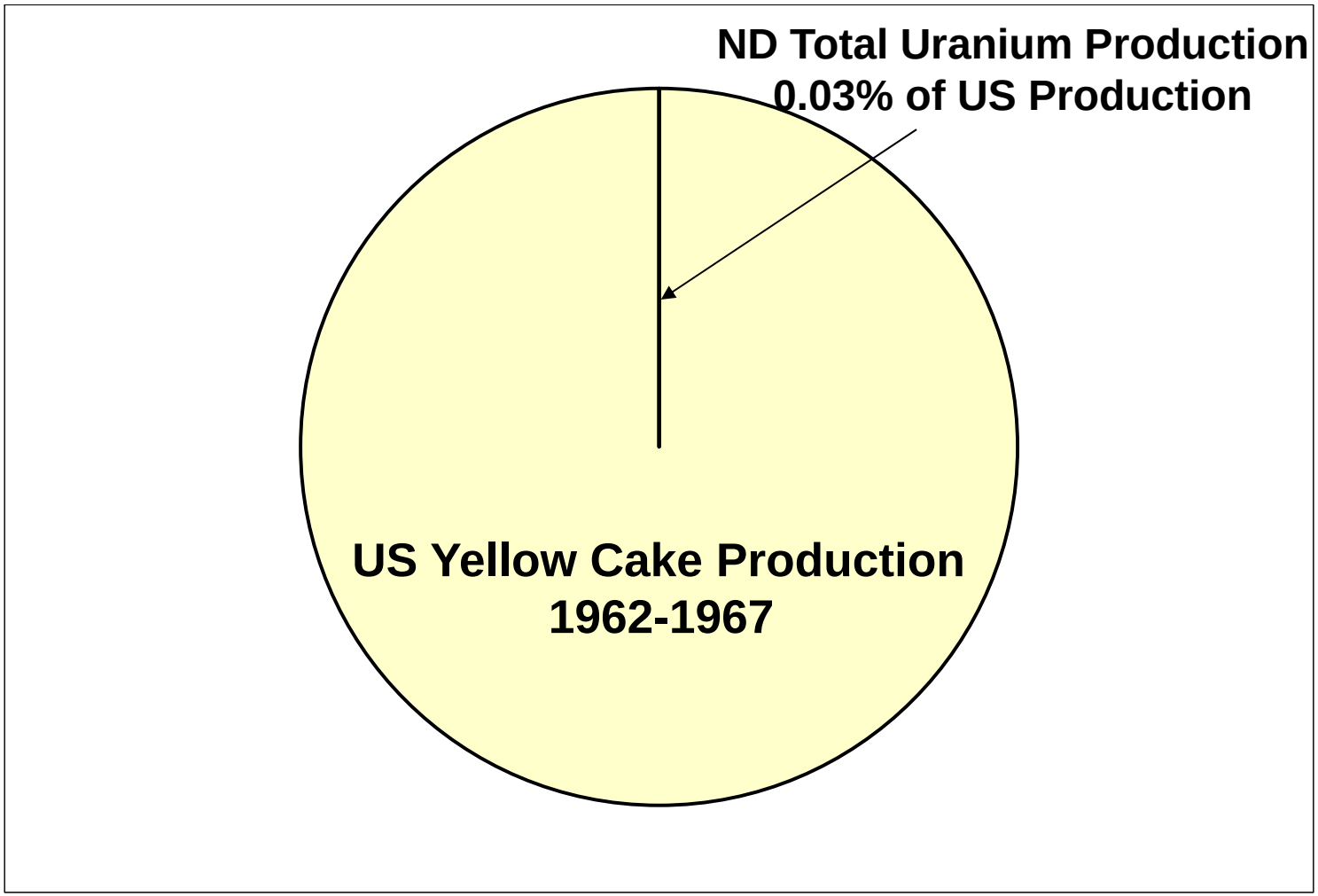
- **Frank Mine** (Luptak, Palaniuk, Safratowich, Hecker, Rodokowski, and Lindo)
  - *50,000 tons of lignite*
- **Others**

Talkington, Smith, Johnson, Munkries, and Howie (GeoResources) Mines.

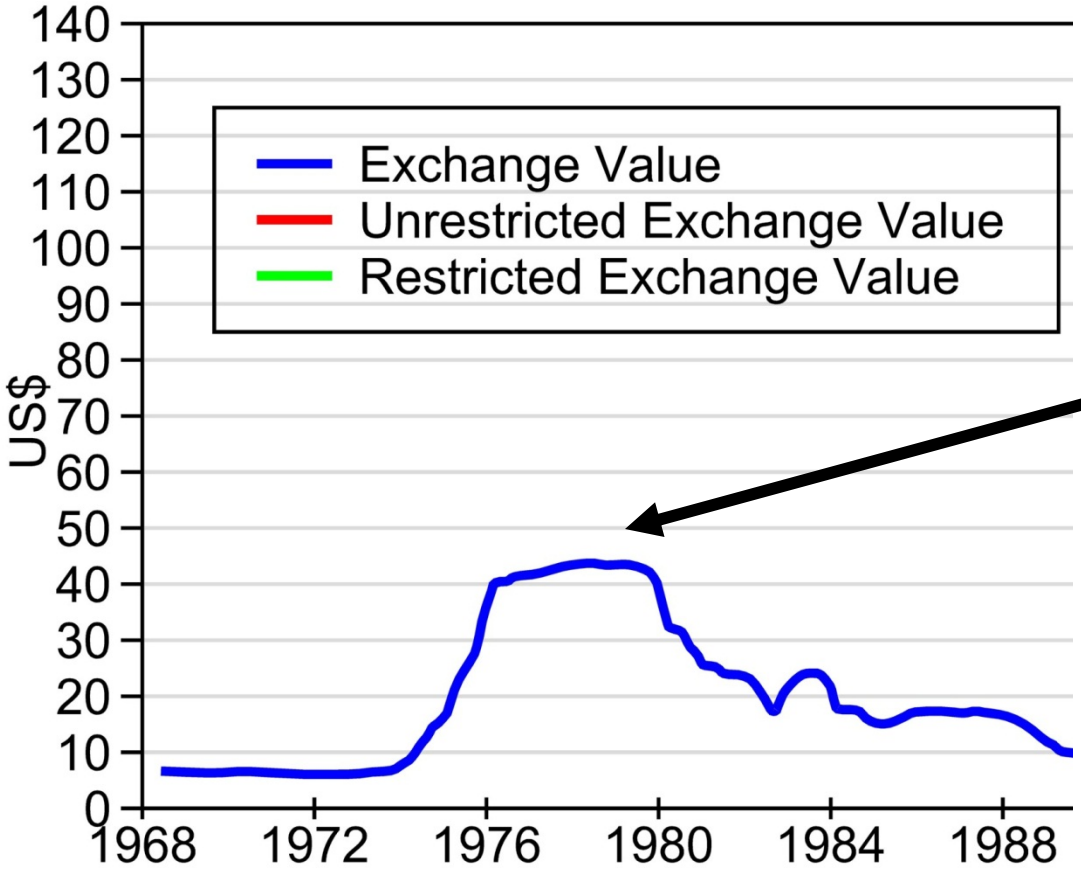
SUSQUEHANA WESTERN

- **Fritz Mine**
  - *40,000 tons of lignite*
- **Klym Mine**
  - *25,000 tons of lignite*

85,000 tons reported



592,288 (ND) vs 1,800,000,000 (US) pounds of yellow cake

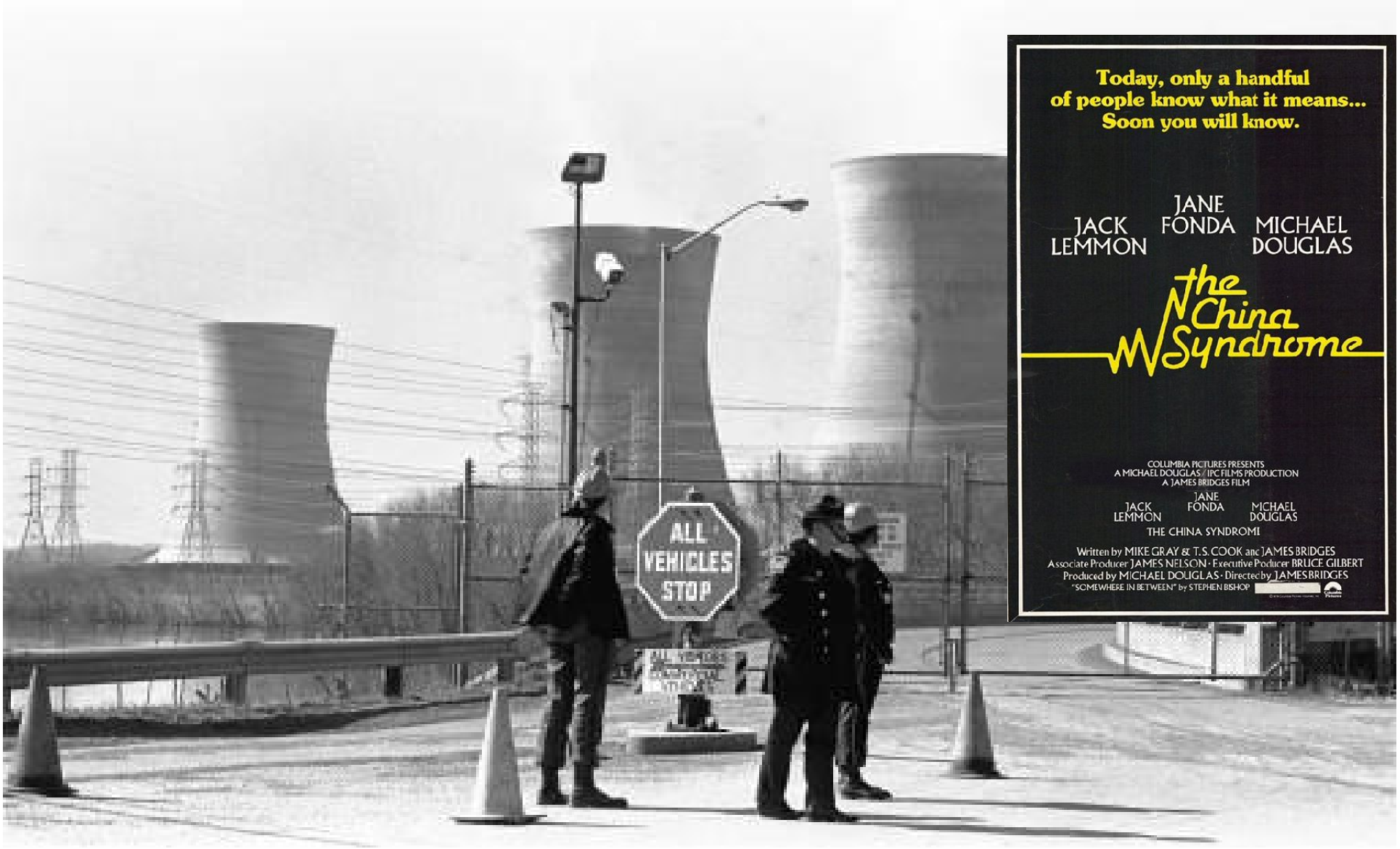


Uranium exploration in North Dakota 1976-1979

Some of the uranium exploration that was conducted in the 1970s focused on the Chalky Buttes in Slope County.

MINERAL COMPANIES ACTIVE IN NORTH DAKOTA: 1976-1980

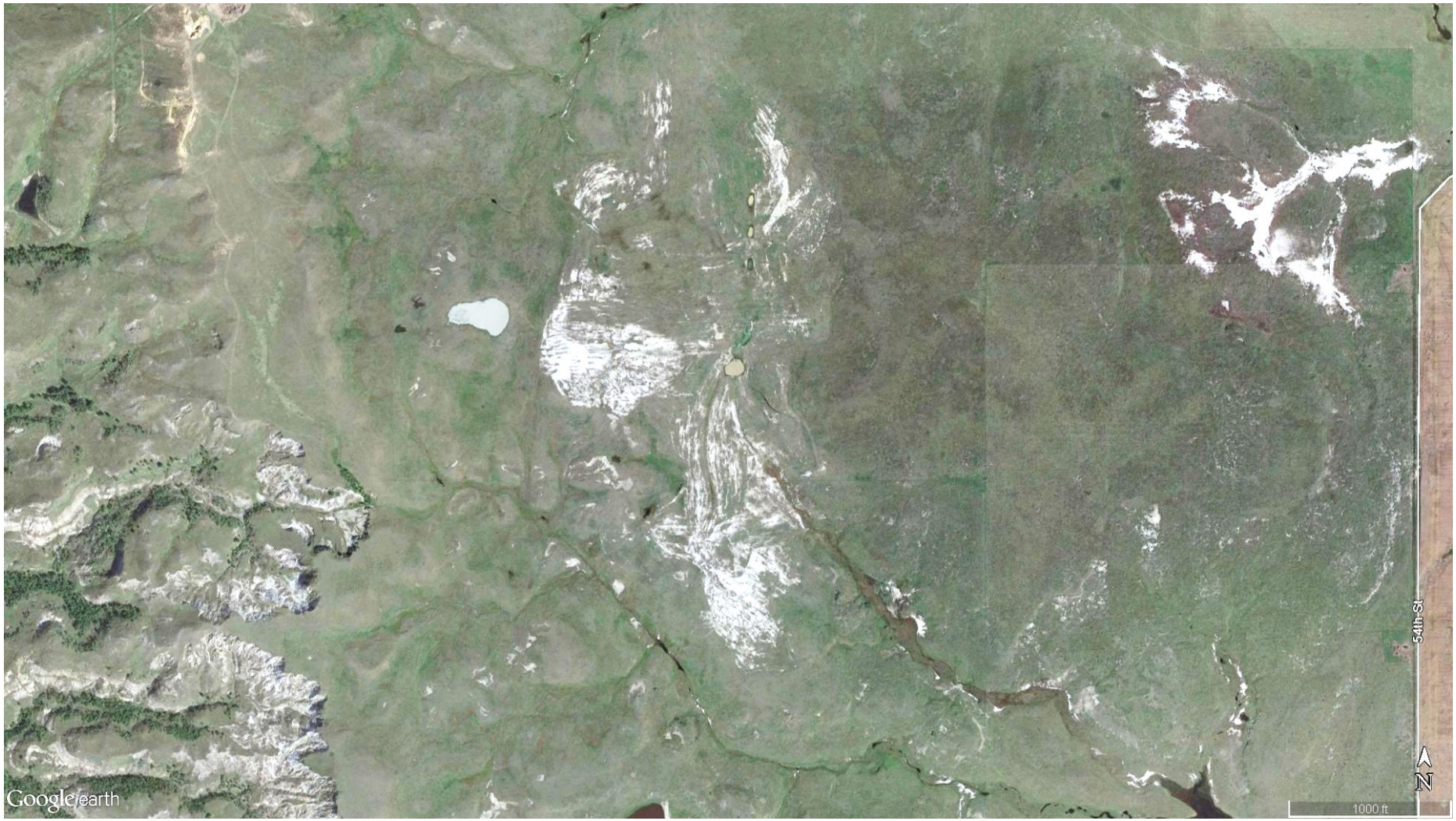
- Minatome Corporation
- North American Coal
- Power Resources Corporation
- Urex, Incorporated
- Framco
- BurWest (Burlington Northern Minerals)
- H&H Services
- Uranerz USA, Incorporated
- Rocky Mountain Energy Company
- Erda-Bendix Field Engineering Corporation
- John J. Simmons
- Gulf Mineral Resources Company
- Exxon Minerals Company, USA



The accident at the Three Mile Island nuclear power plant in Pennsylvania and the release of the movie *The China Syndrome* in 1979 brought uranium exploration to a standstill in the US.

Because neither the federal government nor the state of North Dakota had reclamation laws in effect at the time of uranium mining, more than 450 acres of uranium mine pits and spoils were left unreclaimed in Billings, Slope, and Stark counties in 1967. This photograph of the old unreclaimed Fritz Mine was taken 1986.

FRITZ MINE



The Fritz Mine (center of photograph) was reclaimed in 1992 with funds from the Abandoned Mine Lands Program of the North Dakota Public Service Commission.

A photograph looking north-northeast to the reclaimed Howie or Schwartz Mine that had been operated by GeoResources in Billings County. The mine was reclaimed in 1981.

GRIFFIN AND BELFIELD URANIUM ROTARY KILN SITES

The sites operated from 1964 – 1967.

In 1978, the Uranium Mill Tailings Radiation Control Act (UMTRCA) was created to cleanup inactive uranium processing sites and in 1979, the U.S. Department of Energy (DOE) developed the Uranium Mill Tailings Remedial Action project (UMTRA).

In 1979, the Belfield and Griffin sites were placed on the UMTRA list of sites to be cleaned up.

In the 1980s, the radioactivity and potential health risks of both of these sites were studied by DOE contractors.

The DOE studies concluded there are approximately 186,400 cubic yards of radioactive ash-contaminated soils between the two sites (31.7 acres containing 58,000 yd^3 at Belfield and 71.1 acres containing 128,400 yd^3 at Griffin).

There are no stockpiles of contaminated sediment at either site. The average depth of contaminated soil at Belfield is 1.1 feet and 1.2 feet deep at the Griffin site (DOE reports refer to Griffin site as the Bowman site).

GRIFFIN AND BELFIELD URANIUM ROTARY KILN SITES

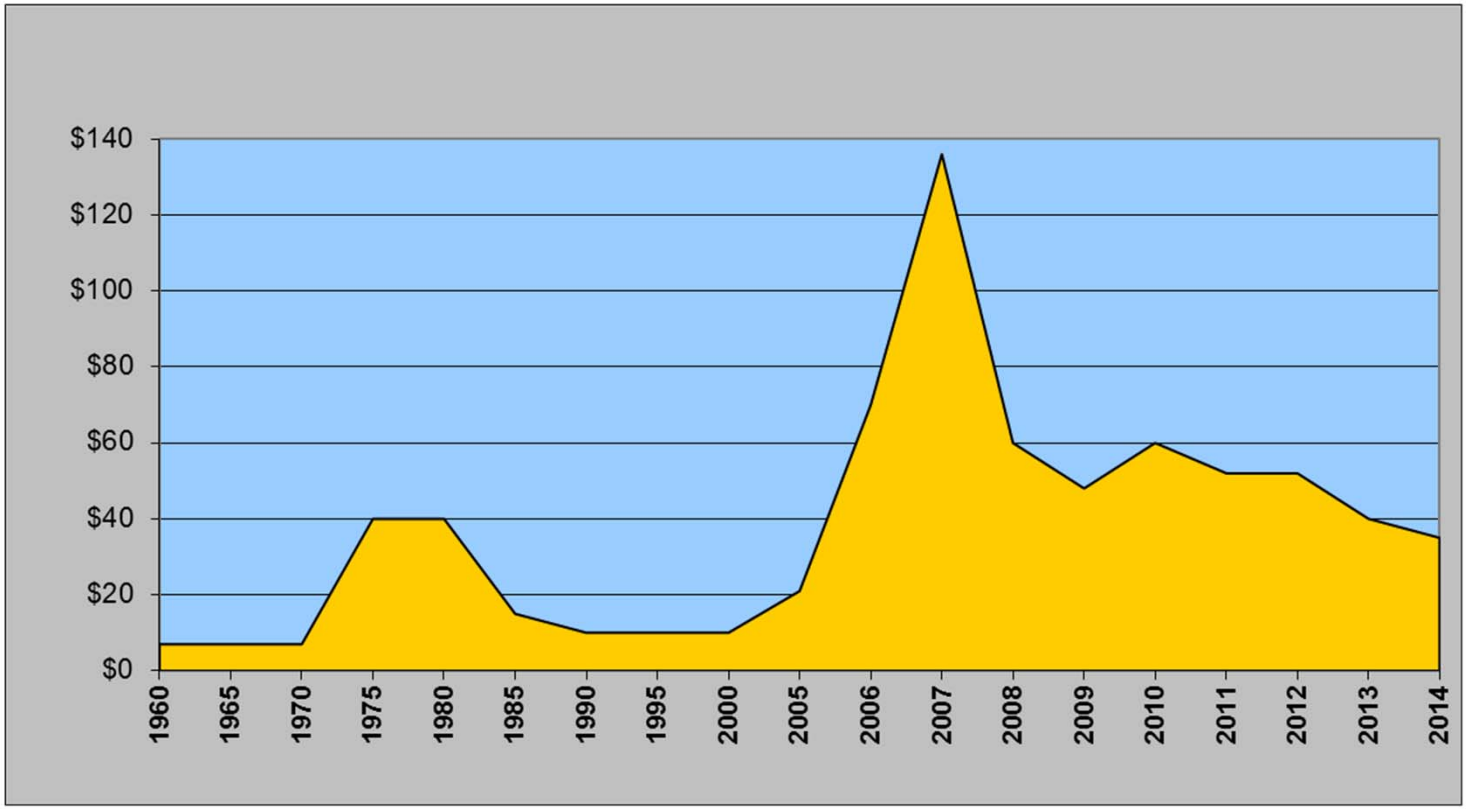
DOE concluded contamination was the result of the dispersion of the radioactive smoke and dust from the kilns as well as the spilling of radioactive ash during handling between the kiln and railroad cars. Radioactive dust and ash were further dispersed at these sites by wind and water. In addition, pore water in the unsaturated zone beneath the sites contained elevated levels of uranium and associated metals.

DOE proposed removing the 58,000 yd^3 of contaminated soil from Belfield, hauling it to Griffin, and constructing a cell at the Griffin site that would hold all 186,400 yd^3 of contaminated soil. Total cleanup was estimated at $44.23 million (in 1995 dollars). Under UMTRCA, the state of North Dakota was responsible for 10% of project costs or $4.423 million.

In 1995, the state of North Dakota requested both sites be dropped from UMTRCA because the state did not believe the low health risks the sites posed warranted the $4.4 million the state would have to pay for their cleanup.

DOE agreed to remove the sites from UMTRCA in 1995 because; 1) the sites posed a low risk to the public and the environment, 2) North Dakota declined to pay the 10% cost share because of the low risk, and 3) neither the Nuclear Regulatory Commission nor the Environmental Protection Agency objected to the sites being taken off the list.

PRICE PER POUND OF YELLOW CAKE (U_3O_8)

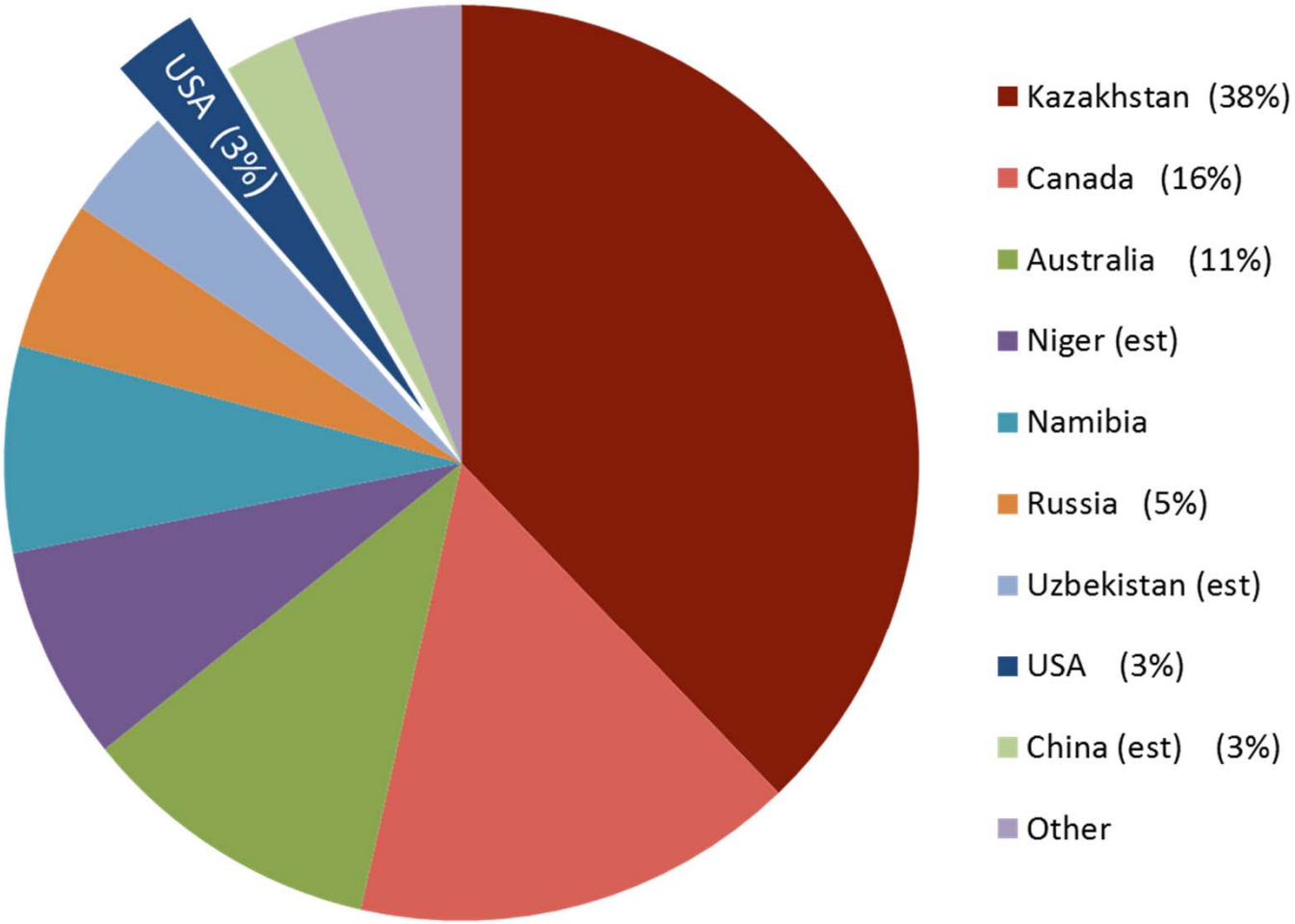


Throughout the 1960s the price for yellow cake was around $7 per pound. The price hit $40 in the 1970s while North Dakota was undergoing a surge in uranium exploration and dropped in 1979 as a result of the accident at the Three Mile Island nuclear power plant. The price for yellow cake peaked at $134 per pound in 2007 as higher volumes of fuel generated from recycled nuclear warheads and uranium stockpiles adverted a tightening of worldwide fuel stocks that had been predicted for nuclear power plants.

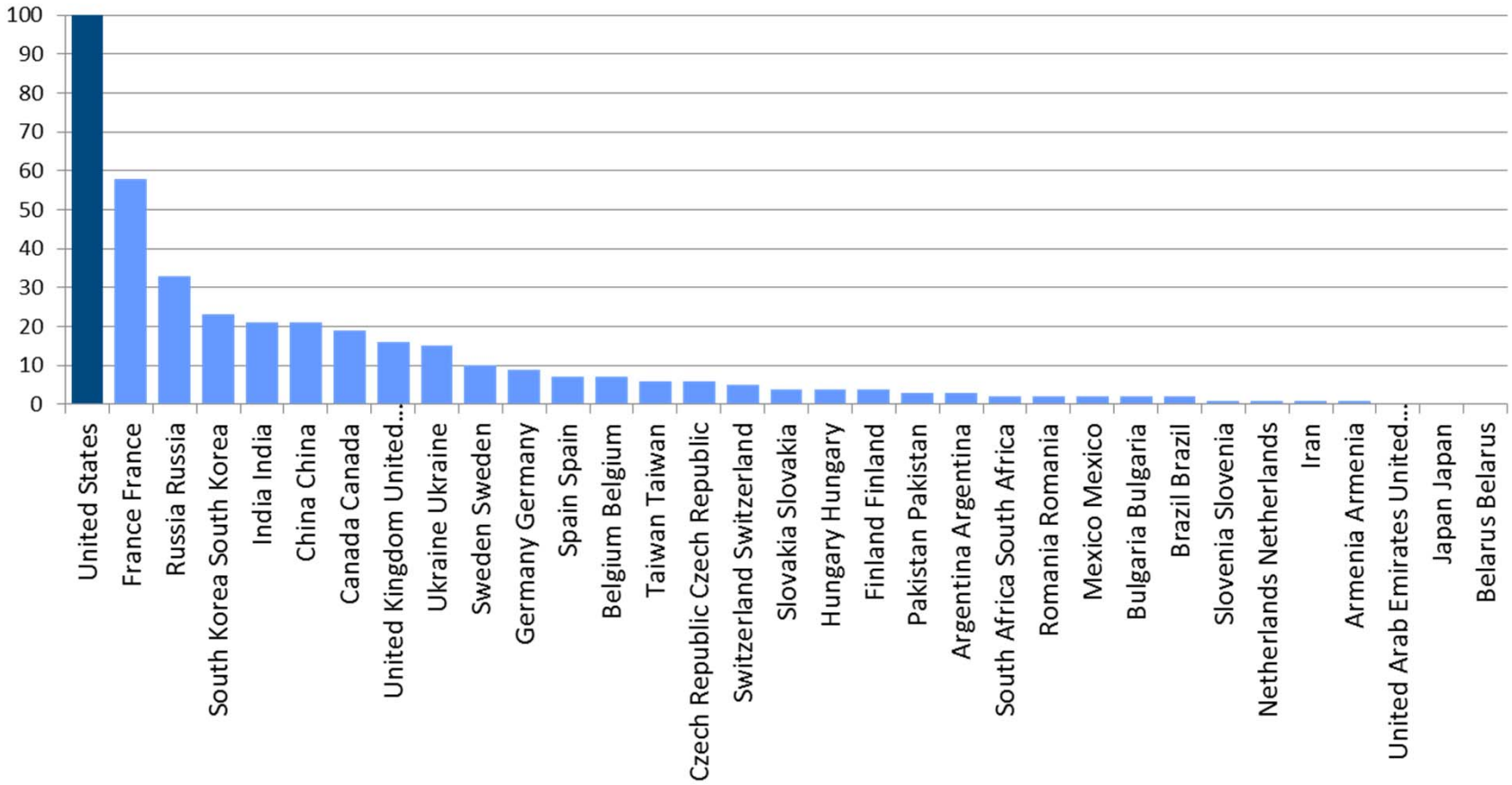
Formation Resources geologists collecting drill samples in an area just to the north of the old Fritz mine in Billings County. This 2008 photograph was taken looking to the southeast with West Rainy Butte in the background.

2013 URANIUM PRODUCTION

70,000 Tonnes of U_3O_8

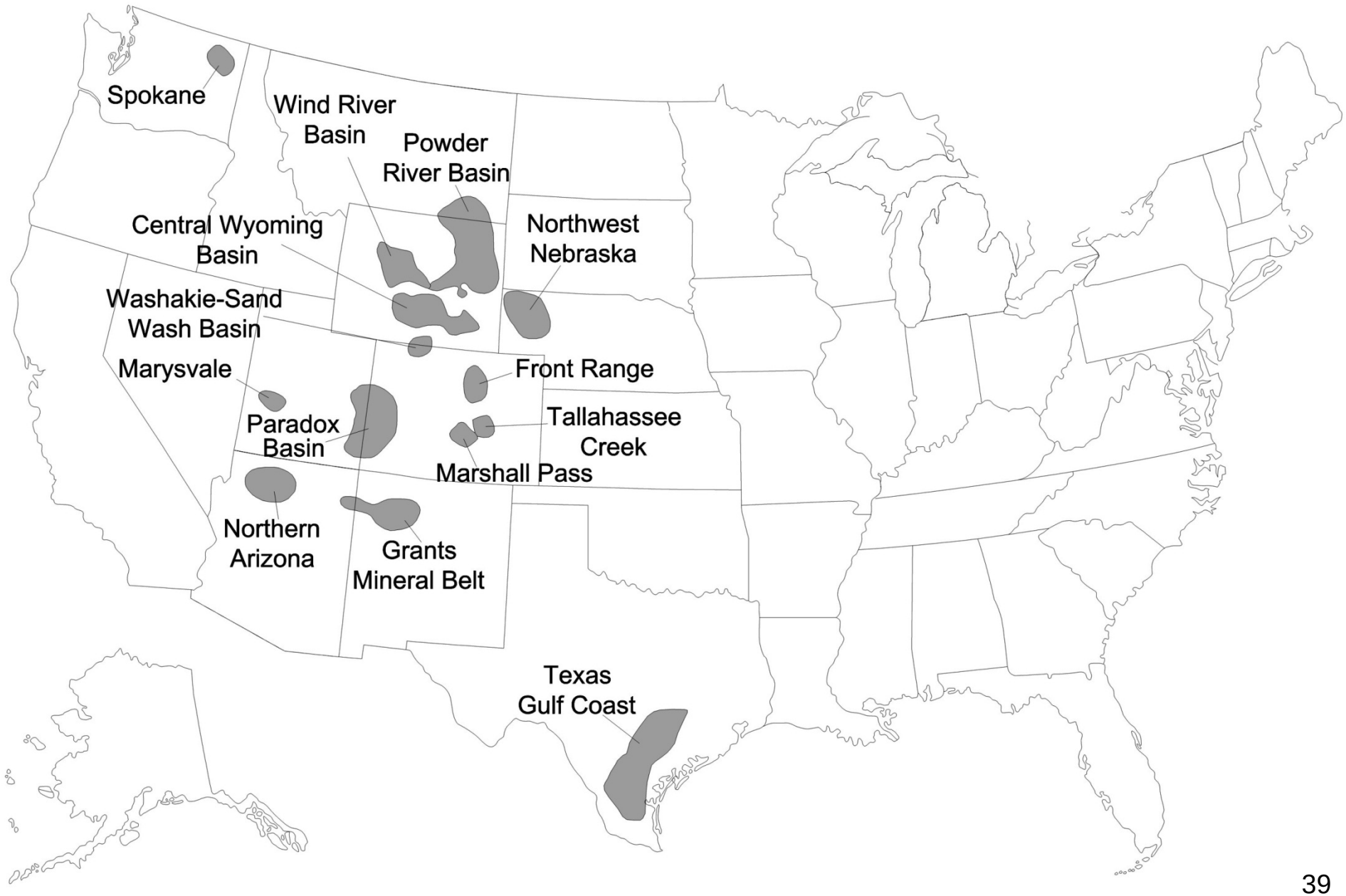


NUCLEAR REACTORS BY COUNTRY



The United States has 100 nuclear reactors, 26% of the operational reactors in the World. China has 21, with another 26 or so under construction.

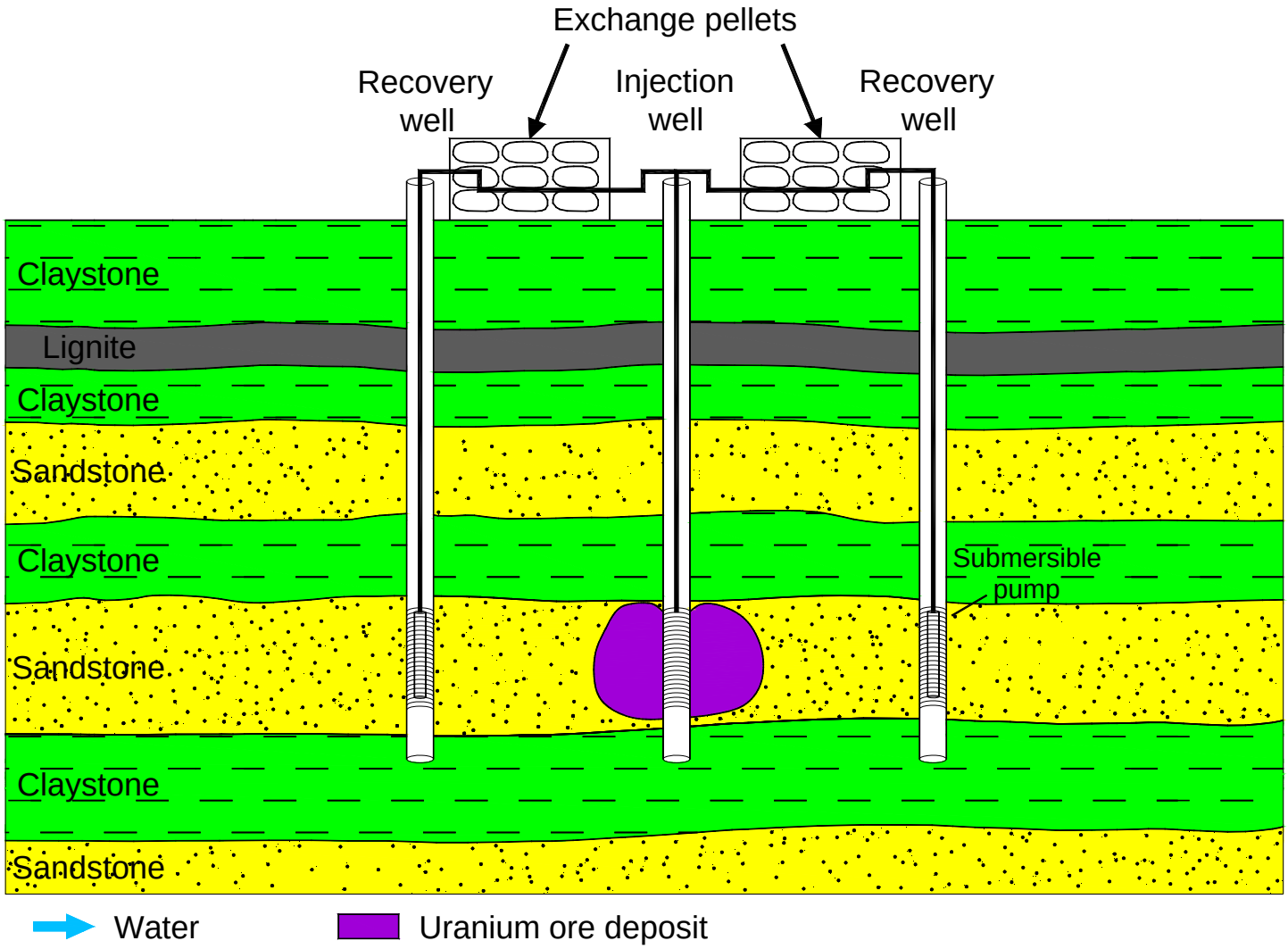
Major U.S. Uranium Reserves



URANIUM TIMELINE IN NORTH DAKOTA

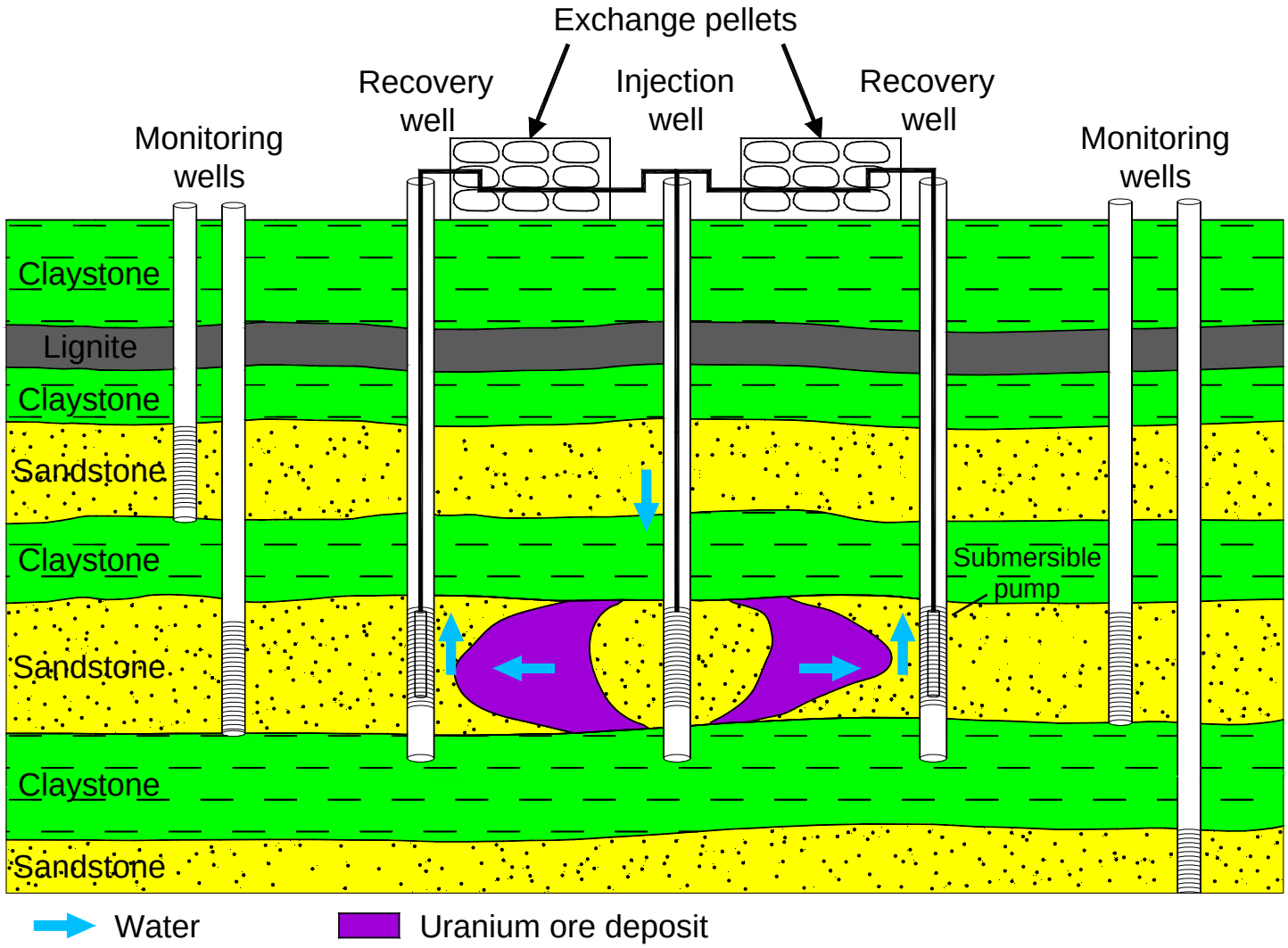
1948	Uranium exploration begins in North Dakota.
1950s – 1960s	Uranium exploration continues, uranium test pits dug.
1962 - 1967	Uranium mining takes place in western North Dakota.
1968	Rules for Subsurface Minerals Program adopted (this program would have required uranium mine reclamation had mining not halted in 1967).
1976 - 1981	Companies drill 1,400 uranium exploration holes in North Dakota.
1980s	U.S. Dept of Energy evaluates Griffin and Belfield uraniferous lignite rotary kiln sites.
1980 -- 2004	North Dakota Public Service Commission Abandoned Mine Lands Fund pays for the reclamation of eight abandoned uranium mine sites involving 454 acres and costing approximately $3.2 million.
2008	DMR-Geological Survey creates 58 pages of in situ leach uranium mining rules.
2008	Formation Resources, Inc. (PacMag Metals) drills 400 exploration holes in Slope and Billings counties looking for uranium, molybdenum, and germanium.

IN SITU LEACH URANIUM MINING



IN SITU LEACH URANIUM MINING

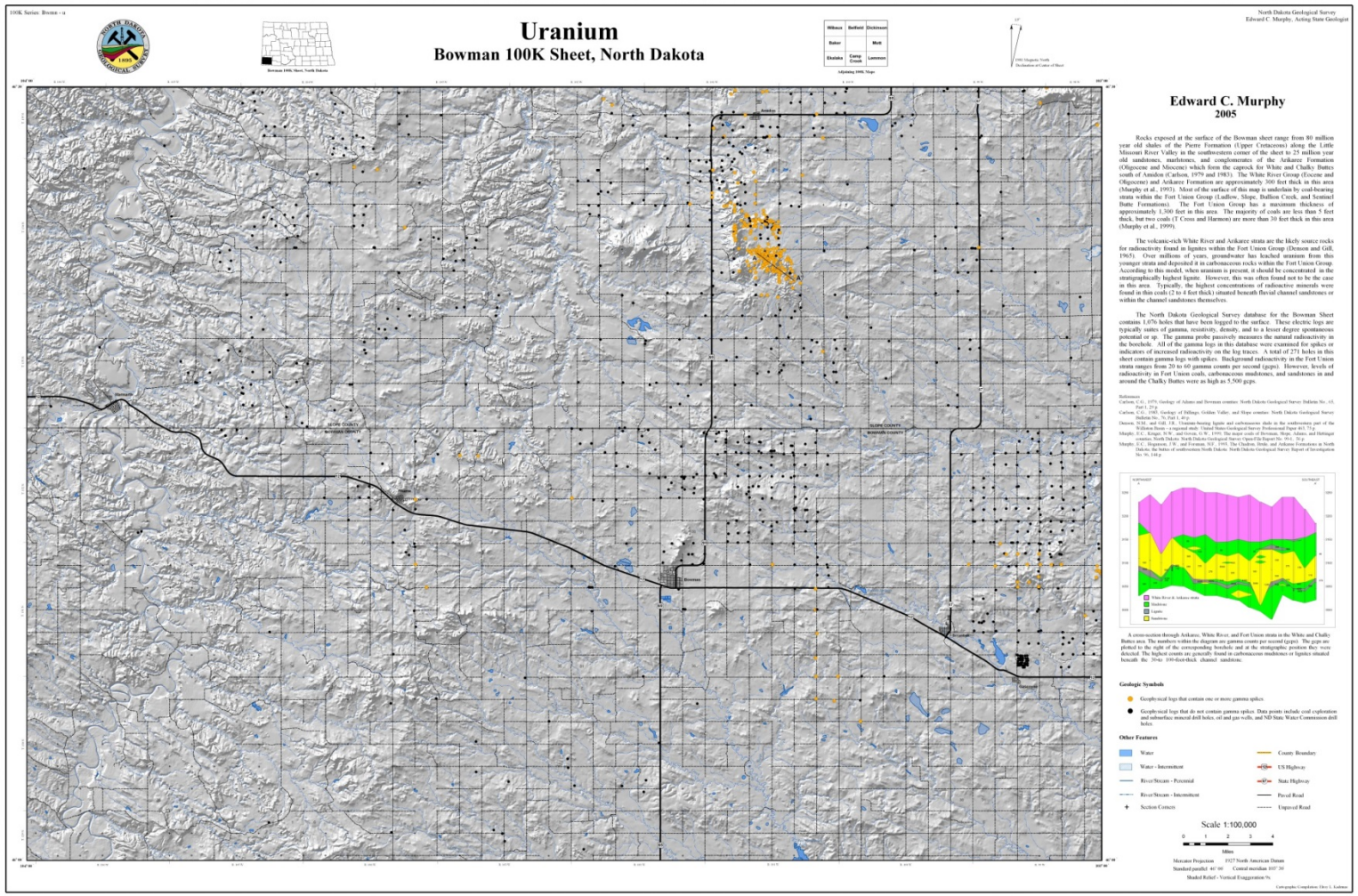
Oxygen, hydrogen peroxide, or potassium permanganate, etc are added to the injected water to encourage uranium to go into solution.

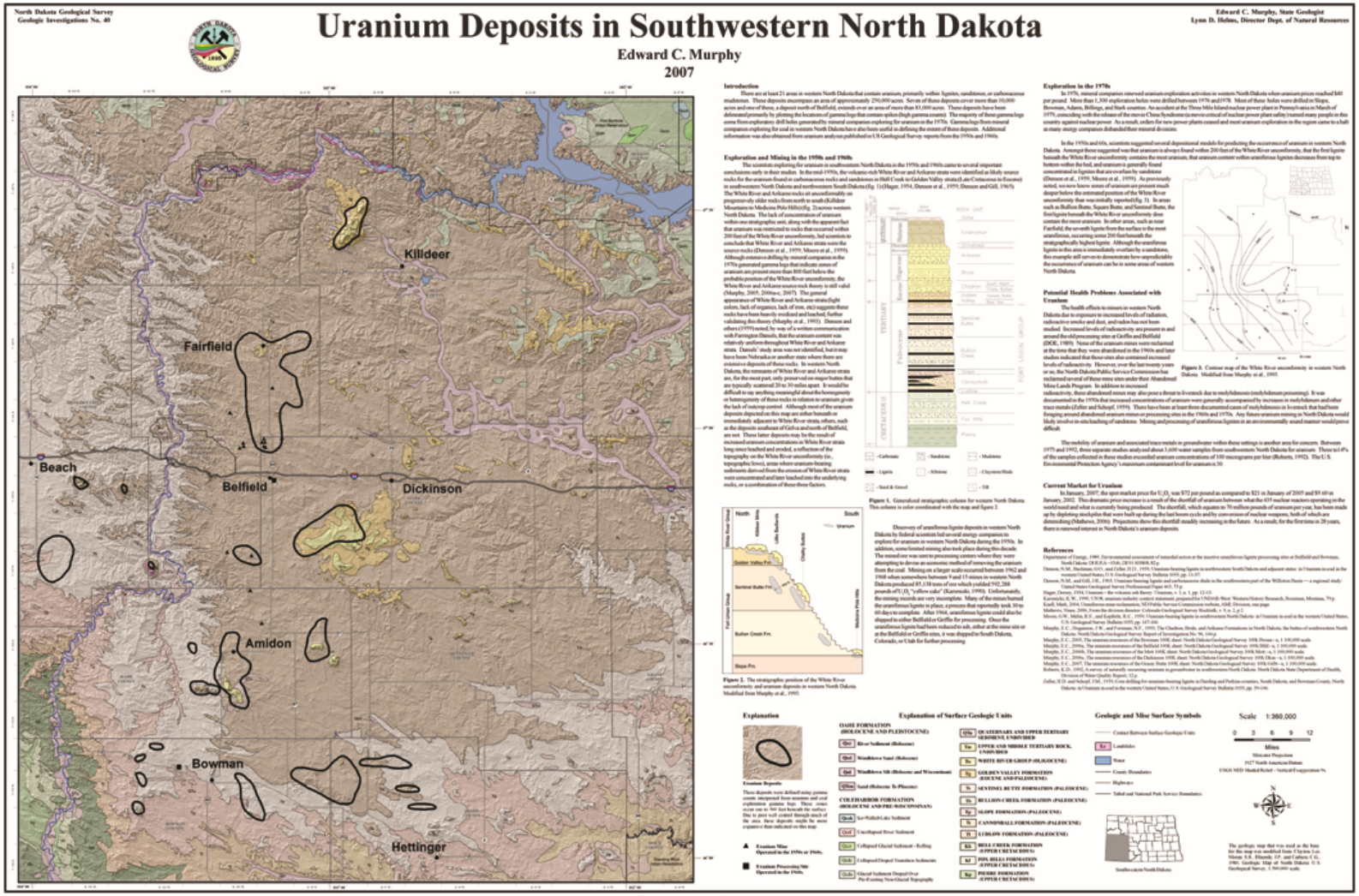


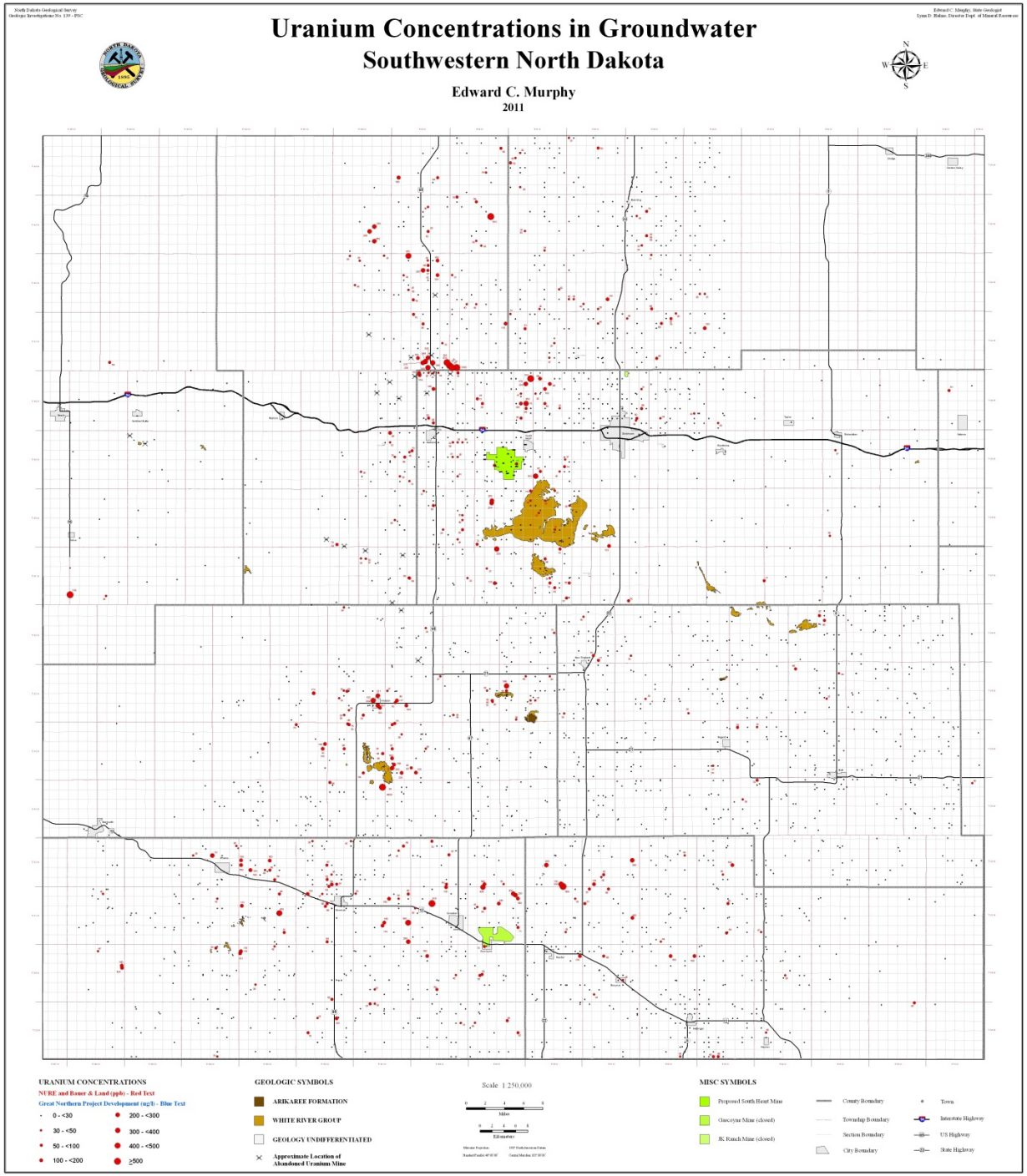
An in situ leach uranium well field at Cameco Corporation's Crow Butte operation near Crawford, Nebraska. Scientists from three North Dakota agencies (Dept of Mineral Resources, Public Service Commission, and Health Department) toured this site in 2007 so they would be better prepared to regulate ISL uranium mining if it were to come to North Dakota.

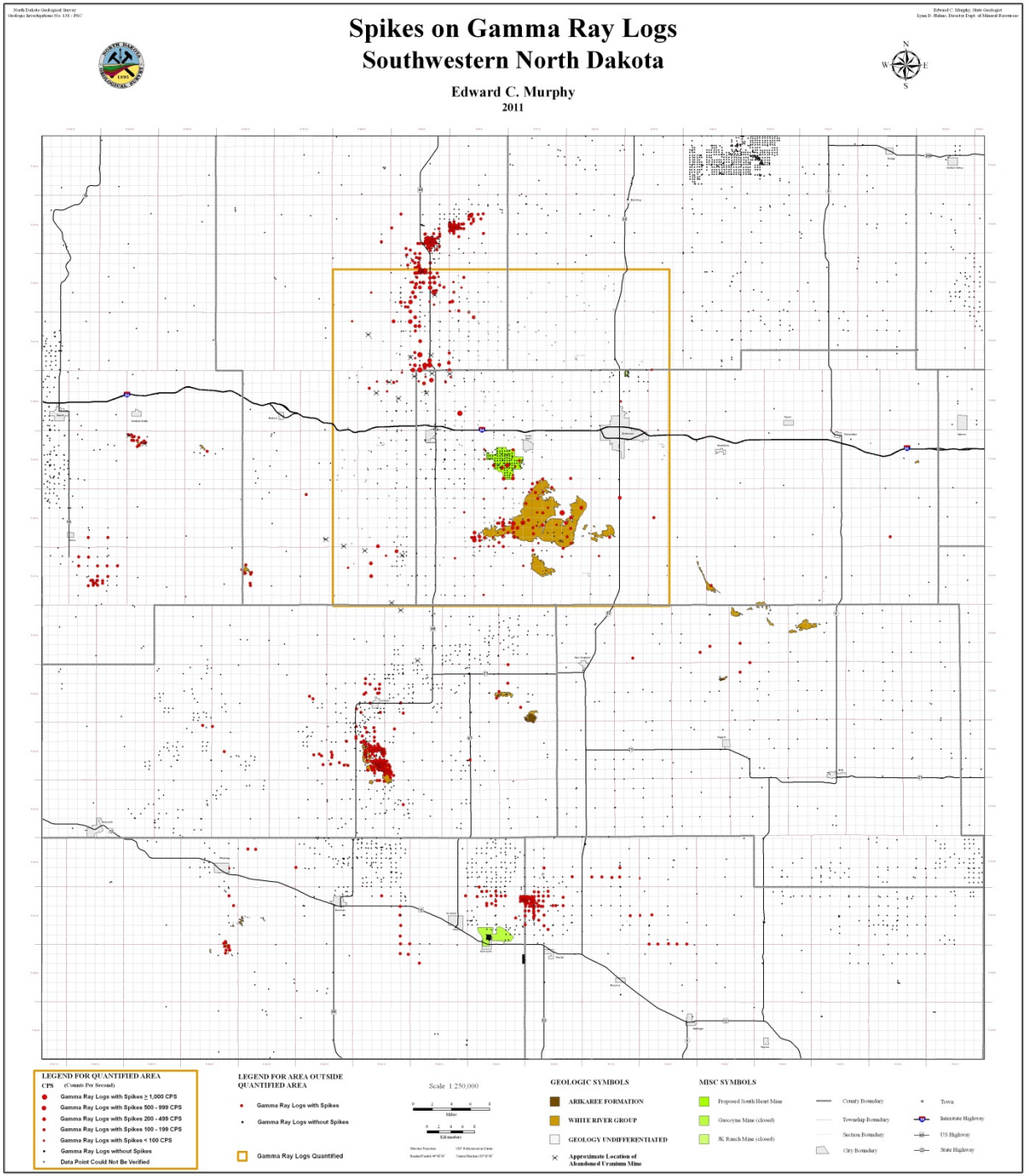
URANIUM RESOURCES IN NORTH DAKOTA

The North Dakota Geological Survey has published a number of uranium maps that can be downloaded for free from https://www.dmr.nd.gov/ndgs/
Slides 44 - 47 are examples of these publications.




North Dakota Geological Survey
Geologic Investigations No. 40
Uranium Deposits in Southwestern North Dakota
Edward C. Murphy
2007
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Natural Resources
Killdeer
Fairfield
Beach
Belfield
Dickinson
Amidon
Bowman
Hettinger
Introduction
Exploration and Mining in the 1950s and 1960s
Exploration in the 1970s
Potential Health Problems Associated with Uranium
Current Market for Uranium
References
Explanation
Explanation of Surface Geologic Units
Geologic and Misc Surface Symbols
Scale 1:380,000


Uranium Concentrations in Groundwater
Southwestern North Dakota
Edward C. Murphy
2011
N
W
E
S
URANIUM CONCENTRATIONS
NURE and Bauer & Land (ppb) - Red Text
Great Northern Project Development (ug/l) - Blue Text
0 - <30
30 - <50
50 - <100
100 - <200
200 - <300
300 - <400
400 - <500
≥500
GEOLOGIC SYMBOLS
ARIKAREE FORMATION
WHITE RIVER GROUP
GEOLOGY UNDIFFERENTIATED
Approximate Location of Abandoned Uranium Mine
Scale 1:250,000
Miles
Kilometers
MISC SYMBOLS
Proposed South Heart Mine
Gascoyne Mine (closed)
JK Ranch Mine (closed)
County Boundary
Township Boundary
Section Boundary
City Boundary
Town
Interstate Highway
US Highway
State Highway


Spikes on Gamma Ray Logs
Southwestern North Dakota
Edward C. Murphy
2011
N
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E
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LEGEND FOR QUANTIFIED AREA
CPS (Counts Per Second)
Gamma Ray Logs with Spikes ≥ 1,000 CPS
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Gamma Ray Logs with Spikes 100 - 199 CPS
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Gamma Ray Logs without Spikes
Data Point Could Not Be Verified
LEGEND FOR AREA OUTSIDE QUANTIFIED AREA
Gamma Ray Logs with Spikes
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North Dakota Geological Survey
Geologic Investigations No. 40

Uranium Deposits in Southwestern North Dakota

Edward C. Murphy
2007

Edward C. Murphy, State Geologist
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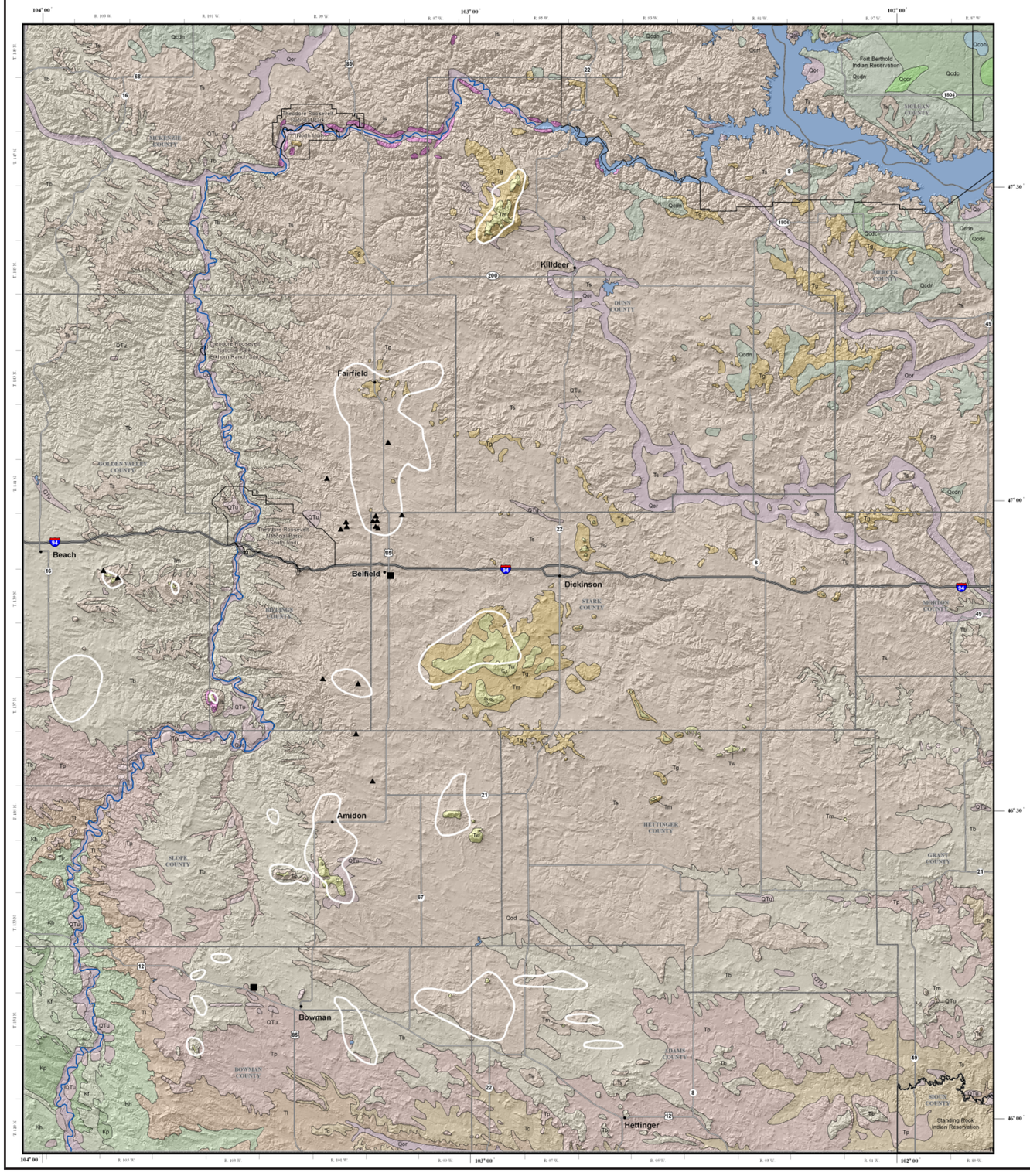

Introduction

There are at least 21 areas in western North Dakota that contain uranium, primarily within lignites, sandstones, or carbonaceous mudstones. These deposits encompass an area of approximately 250,000 acres. Seven of these deposits cover more than 10,000 acres and one of these, a deposit north of Belfield, extends over an area of more than 83,000 acres. These deposits have been delineated primarily by plotting the locations of gamma logs that contain spikes (high gamma counts). The majority of these gamma logs come from exploratory drill holes generated by mineral companies exploring for uranium in the 1970s. Gamma logs from mineral companies exploring for coal in western North Dakota have also been useful in defining the extent of these deposits. Additional information was also obtained from uranium analyses published in US Geological Survey reports from the 1950s and 1960s.

Exploration and Mining in the 1950s and 1960s

The scientists exploring for uranium in southwestern North Dakota in the 1950s and 1960s came to several important conclusions early in their studies. In the mid-1950s, the volcanic-rich White River and Arikaree strata were identified as likely source rocks for the uranium found in carbonaceous rocks and sandstones in Hell Creek to Golden Valley strata (Late Cretaceous to Eocene) in southwestern North Dakota and northwestern South Dakota (fig. 1) (Hager, 1954; Denson et al., 1959; Denson and Gill, 1965). The White River and Arikaree rocks sit unconformably on progressively older rocks from north to south (Killdeer Mountains to Medicine Pole Hills) (fig. 2) across western North Dakota. The lack of concentration of uranium within one stratigraphic unit, along with the apparent fact that uranium was restricted to rocks that occurred within 200 feet of the White River unconformity, led scientists to conclude that White River and Arikaree strata were the source rocks (Denson et al., 1959; Moore et al., 1959). Although extensive drilling by mineral companies in the 1970s generated gamma logs that indicate zones of uranium are present more than 800 feet below the probable position of the White River unconformity, the White River and Arikaree source rock theory is still valid (Murphy, 2005; 2006a-c; 2007). The general appearance of White River and Arikaree strata (light colors, lack of organics, lack of iron, etc) suggests these rocks have been heavily oxidized and leached, further validating this theory (Murphy et al., 1993). Denson and others (1959) noted, by way of a written communication with Farrington Daniels, that the uranium content was relatively uniform throughout White River and Arikaree strata. Daniels' study area was not identified, but it may have been Nebraska or another state where there are extensive deposits of these rocks. In western North Dakota, the remnants of White River and Arikaree strata are, for the most part, only preserved on major buttes that are typically scattered 20 to 30 miles apart. It would be difficult to say anything meaningful about the homogeneity or heterogeneity of these rocks in relation to uranium given the lack of outcrop control. Although most of the uranium deposits depicted on this map are either beneath or immediately adjacent to White River strata, others, such as the deposits southeast of Golva and north of Belfield, are not. These latter deposits may be the result of increased uranium concentrations in White River strata long since leached and eroded, a reflection of the topography on the White River unconformity (ie., topographic lows), areas where uranium-bearing sediments derived from the erosion of White River strata were concentrated and later leached into the underlying rocks, or a combination of these three factors.

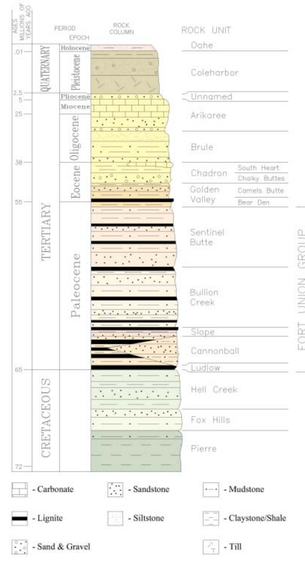

Figure 1. Generalized stratigraphic column for western North Dakota. This column is color coordinated with the map and figure 2.

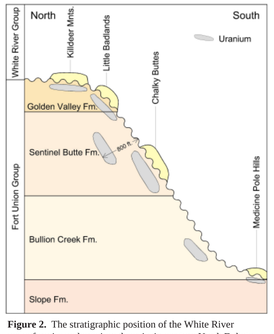

Figure 2. The stratigraphic position of the White River unconformity and uranium deposits in western North Dakota. Modified from Murphy et al., 1993.

Discovery of uraniferous lignite deposits in western North Dakota by federal scientists led several energy companies to explore for uranium in western North Dakota during the 1950s. In addition, some limited mining also took place during this decade. The mined ore was sent to processing centers where they were attempting to devise an economic method of removing the uranium from the coal. Mining on a larger scale occurred between 1962 and 1968 when somewhere between 9 and 15 mines in western North Dakota produced 85,138 tons of ore which yielded 592,288 pounds of U_3O_8 "yellow cake" (Karsmizki, 1990). Unfortunately, the mining records are very incomplete. Many of the mines burned the uraniferous lignite in place, a process that reportedly took 30 to 60 days to complete. After 1964, uraniferous lignite could also be shipped to either Belfield or Griffin for processing. Once the uraniferous lignite had been reduced to ash, either at the mine site or at the Belfield or Griffin sites, it was shipped to South Dakota, Colorado, or Utah for further processing.

Exploration in the 1970s

In 1976, mineral companies renewed uranium exploration activities in western North Dakota when uranium prices reached $40 per pound. More than 1,300 exploration holes were drilled between 1976 and1978. Most of these holes were drilled in Slope, Bowman, Adams, Billings, and Stark counties. An accident at the Three Mile Island nuclear power plant in Pennsylvania in March of 1979, coinciding with the release of the movie China Syndrome (a movie critical of nuclear power plant safety) turned many people in this country against nuclear power. As a result, orders for new power plants ceased and most uranium exploration in the region came to a halt as many energy companies disbanded their mineral divisions.

In the 1950s and 60s, scientists suggested several depositional models for predicting the occurrence of uranium in western North Dakota. Amongst those suggested was that uranium is always found within 200 feet of the White River unconformity, that the first lignite beneath the White River unconformity contains the most uranium, that uranium content within uraniferous lignites decreases from top to bottom within the bed, and uranium is generally found concentrated in lignites that are overlain by sandstone (Denson et al., 1959; Moore et al., 1959). As previously noted, we now know zones of uranium are present much deeper below the estimated position of the White River unconformity than was initially reported (fig. 3). In areas such as Bullion Butte, Square Butte, and Sentinel Butte, the first lignite beneath the White River unconformity does contain the most uranium. In other areas, such as near Fairfield, the seventh lignite from the surface is the most uraniferous, occurring some 200 feet beneath the stratigraphically highest lignite. Although the uraniferous lignite in this area is immediately overlain by a sandstone, this example still serves to demonstrate how unpredictable the occurrence of uranium can be in some areas of western North Dakota.

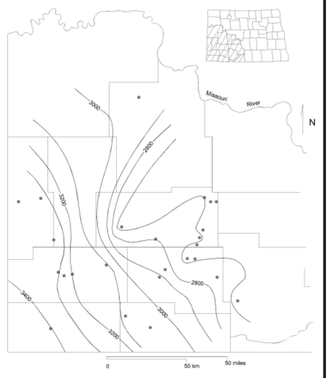

Figure 3. Contour map of the White River unconformity in western North Dakota. Modified from Murphy et al., 1993.

Potential Health Problems Associated with Uranium

The health effects to miners in western North Dakota due to exposure to increased levels of radiation, radioactive smoke and dust, and radon has not been studied. Increased levels of radioactivity are present in and around the old processing sites at Griffin and Belfield (DOE, 1989). None of the uranium mines were reclaimed at the time that they were abandoned in the 1960s and later studies indicated that those sites also contained increased levels of radioactivity. However, over the last twenty years or so, the North Dakota Public Service Commission has reclaimed several of these mine sites under their Abandoned Mine Lands Program. In addition to increased radioactivity, these abandoned mines may also pose a threat to livestock due to molybdenosis (molybdenum poisoning). It was documented in the 1950s that increased concentrations of uranium were generally accompanied by increases in molybdenum and other trace metals (Zeller and Schopf, 1959). There have been at least three documented cases of molybdenosis in livestock that had been foraging around abandoned uranium mines or processing sites in the 1960s and 1970s. Any future uranium mining in North Dakota would likely involve in-situ leaching of sandstone. Mining and processing of uraniferous lignites in an environmentally sound manner would prove difficult.

The mobility of uranium and associated trace metals in groundwater within these settings is another area for concern. Between 1975 and 1992, three separate studies analyzed about 3,600 water samples from southwestern North Dakota for uranium. Three to14% of the samples collected in these studies exceeded uranium concentrations of 100 micrograms per liter (Roberts, 1992). The U.S. Environmental Protection Agency's maximum contaminant level for uranium is 30.

Current Market for Uranium

In January, 2007, the spot market price for U_3O_8 was $72 per pound as compared to $21 in January of 2005 and $9.60 in January, 2002. This dramatic price increase is a result of the shortfall of uranium between what the 435 nuclear reactors operating in the world need and what is currently being produced. The shortfall, which equates to 70 million pounds of uranium per year, has been made up by depleting stockpiles that were built up during the last boom cycle and by conversion of nuclear weapons, both of which are diminishing (Mathews, 2006). Projections show this shortfall steadily increasing in the future. As a result, for the first time in 28 years, there is renewed interest in North Dakota's uranium deposits.

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Explanation

Uranium Deposits

These deposits were defined using gamma counts interpreted from uranium and coal exploration gamma logs. These zones occur one to 500 feet beneath the surface. Due to poor well control through much of the area, these deposits might be more expansive than indicated on this map.

▲ **Uranium Mine Operated in the 1950s or 1960s.**

■ **Uranium Processing Site Operated in the 1960s.**

Explanation of Surface Geologic Units

OAHE FORMATION (HOLOCENE AND PLEISTOCENE)

- Qor — River Sediment (Holocene)
- Qod — Windblown Sand (Holocene)
- Qol — Windblown Silt (Holocene and Wisconsinan)
- QTou — Sand (Holocene To Pliocene)

COLEHARBOR FORMATION (HOLOCENE AND PRE-WISCONSINAN)

- Qcoh — Ice-Walled-Lake Sediment
- Qocr — Uncollapsed River Sediment
- Qccr — Collapsed Glacial Sediment - Rolling
- Qcdc — Collapsed/Draped Transition Sediments
- Qcdn — Glacial Sediment Draped Over Pre-Existing Non-Glacial Topography

- QTu — QUATERNARY AND UPPER TERTIARY SEDIMENT, UNDIVIDED
- Tm — UPPER AND MIDDLE TERTIARY ROCK, UNDIVIDED
- Tw — WHITE RIVER GROUP (OLIGOCENE)
- Tg — GOLDEN VALLEY FORMATION (EOCENE AND PALEOCENE)
- Ts — SENTINEL BUTTE FORMATION (PALEOCENE)
- Tb — BULLION CREEK FORMATION (PALEOCENE)
- Tp — SLOPE FORMATION (PALEOCENE)
- Tc — CANNONBALL FORMATION (PALEOCENE)
- Tl — LUDLOW FORMATION (PALEOCENE)
- Kh — HELL CREEK FORMATION (UPPER CRETACEOUS)
- Kf — FOX HILLS FORMATION (UPPER CRETACEOUS)
- Kp — PIERRE FORMATION (UPPER CRETACEOUS)

Geologic and Misc Surface Symbols

- Contact Between Surface Geologic Units
- Ls — Landslides
- Water
- County Boundaries
- Highways
- Tribal and National Park Service Boundaries

Southwestern North Dakota

Scale 1:360,000

0 3 6 9 12

Miles

Mercator Projection
1927 North American Datum
USGS NED Shaded Relief - Vertical Exaggeration 9x

N W E S

The geologic map that was used as the base for this map was modified from: Clayton, Lee, Moran, S.R., Bluemle, J.P., and Carlson, C.G., 1980, Geologic Map of North Dakota: U.S. Geological Survey, 1:500,000 scale.

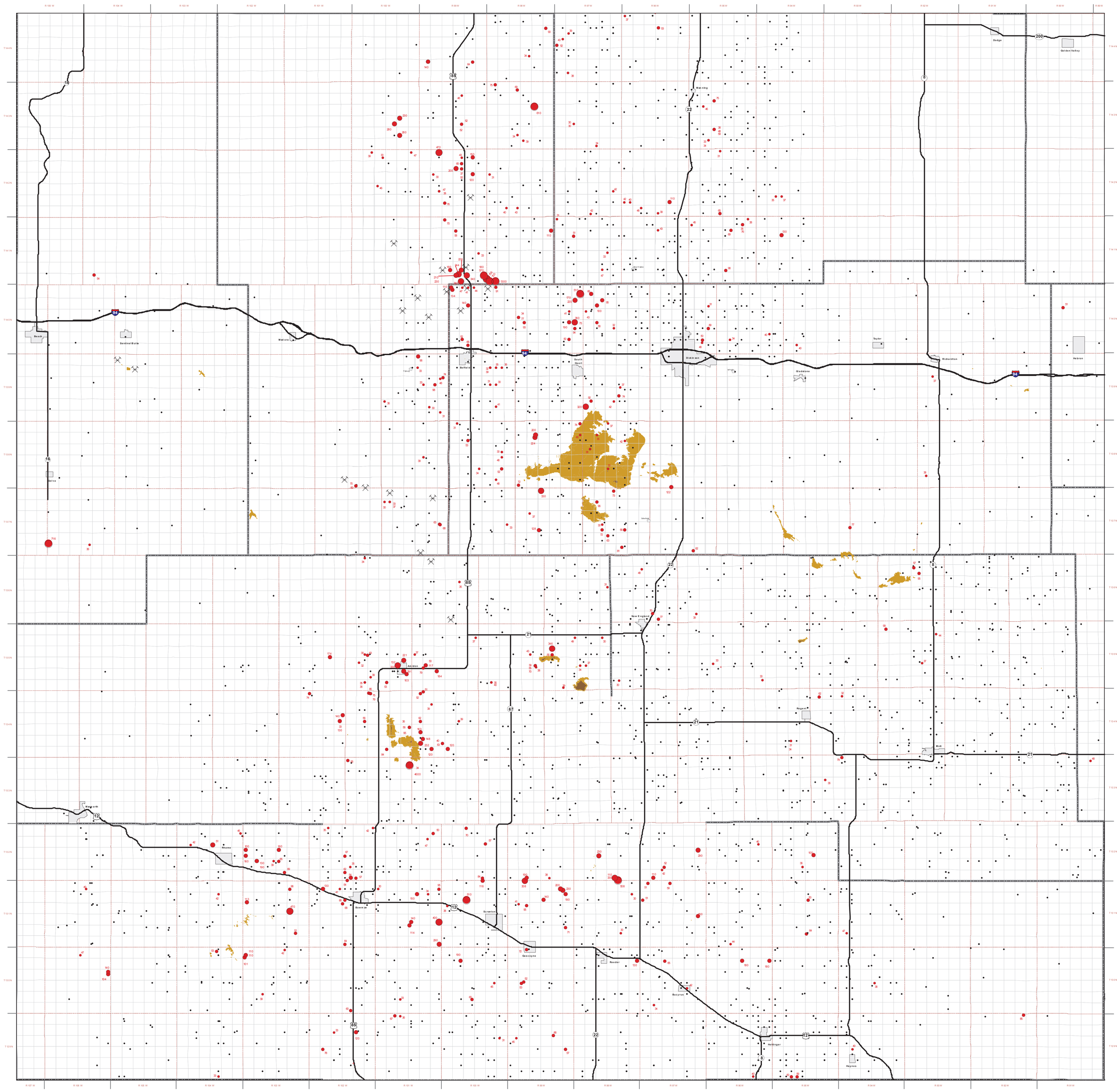
North Dakota Geological Survey
Geologic Investigations No. 139

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

Uranium Concentrations in Groundwater
Southwestern North Dakota

Edward C. Murphy

2011



URANIUM CONCENTRATIONS

NURE and Bauer & Land (ppb) - Red Text

- 0 - <30
- 30 - <50
- 50 - <100
- 100 - <200
- 200 - <300
- 300 - <400
- 400 - <500
- ≥500

SURFACE GEOLOGY

- ARIKAREE FORMATION
- WHITE RIVER GROUP
- GEOLOGY UNDIFFERENTIATED
- Approximate Location of Abandoned Uranium Mine

Scale 1:250,000

0 2 4 6 8 Miles

0 2 4 6 8 Kilometers

Mercator Projection — 1927 North American Datum
Standard Parallel 46°00'00" — Central Meridian 103°00'00"

The Bauer and Land Company collected groundwater samples for uranium analysis from almost 3,500 private domestic wells and stock wells in southwestern North Dakota between October 1975 and June 1978. The uranium detection limit was 2 ppb. The National Uranium Resource Evaluation program (NURE) collected 545 groundwater samples from southwestern North Dakota during the summer of 1979, sampling several of the same wells that Bauer and Land had sampled. The uranium detection limit for the NURE program was <1 ppb.

MISC SYMBOLS

- County Boundary
- Township Boundary
- Section Boundary
- City Boundary
- Town
- Interstate Highway
- US Highway
- State Highway

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Edward C. Murphy, State Geologist
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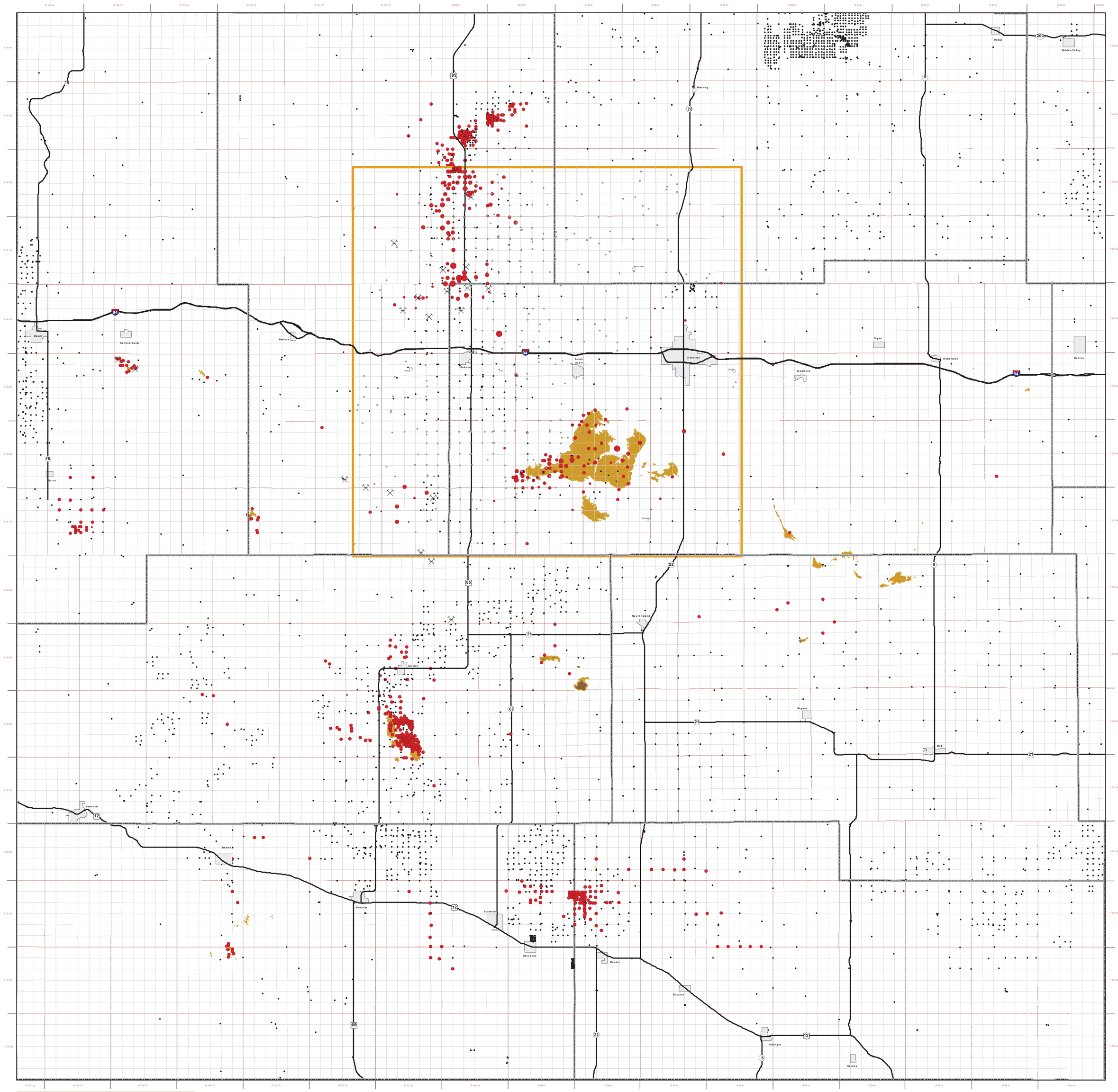
Spikes on Gamma Ray Logs
Southwestern North Dakota

Edward C. Murphy

2011



LEGEND FOR QUANTIFIED AREA

CPS (Counts Per Second)

- Gamma Ray Logs with Spikes ≥ 1,000 CPS
- Gamma Ray Logs with Spikes 500 - 999 CPS
- Gamma Ray Logs with Spikes 200 - 499 CPS
- Gamma Ray Logs with Spikes 100 - 199 CPS
- Gamma Ray Logs with Spikes < 100 CPS
- Gamma Ray Logs without Spikes
- Data Point Could Not Be Verified

LEGEND FOR AREA OUTSIDE QUANTIFIED AREA

- Gamma Ray Logs with Spikes
- Gamma Ray Logs without Spikes

Gamma Ray Logs Quantified

Scale 1:250,000

0 2 4 6 8 Miles

0 2 4 6 8 Kilometers

Mercator Projection — 1927 North American Datum
Standard Parallel 46° 00' 00" — Central Meridian 103° 00' 00"

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