The Dakota Group of the Williston Basin

An Important Geologic Unit for Produced Water from Oil and Gas Development in North Dakota

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Introduction

Significant volumes of co-produced water are generated daily during production operations for oil and gas in North Dakota. Produced water is an oil and gas industry term that describes the formation water that is generated as a by-product of oil and gas production. Formation water, also referred to as connate water, exists naturally within the formation along with the hydrocarbons which, because of lower density, float on the water. Formation water initially reflects the water quality of the depositional environment of the petroleum reservoir: marine, brackish, or fresh water. Approximately 7 to 10 barrels, equivalent to 280-400 gallons of water, are generated for every barrel of oil produced worldwide (USDI, 2011). Oil reservoirs generally contain significantly greater volumes of water than gas reservoirs; therefore, the amount of produced water in North Dakota is significant with approximately 13,000 producing oil wells currently in the state (NDIC, 2015). In North Dakota, over a million barrels of produced water are generated daily. In addition, the amount of produced water generated usually increases over the life of a well because oil and gas is depleted as hydrocarbons are extracted from the subsurface.

Most produced water is brine (saltwater), with very high concentrations of total dissolved solids. Major components include hydrocarbons, salts, metals, radionuclides, and production chemicals (Sumi, 2005). Of these, salts are the most significant contaminant. Salts are primarily chlorides and sulfides of calcium, magnesium, and sodium, with chloride salts up to ten times the salinity of seawater. Because these contaminants are present in such high concentrations, produced water is considered industrial waste.

Produced Water Disposal

Produced water is by far the largest volume waste stream associated with the production of oil and gas (USDI, 2011). Subsurface injection is the industry-preferred alternative for produced water disposal. In some cases, re-injection of produced water is not feasible because the subsurface formation does not have the capacity to receive the water. Because produced water is brine, produced water disposal wells are referred to as saltwater disposal wells (SWD wells).

Produced Water Regulation

Produced water is regulated through the Underground Injection Control (UIC) program under the Safe Drinking Water Act (SDWA of 1974 (EPA, 2015). The UIC program is responsible for regulating operations related to injection wells that are used to place fluids into the subsurface for storage or disposal. An injection well is used to place fluids deep underground into rock units with significant pore space, such as sandstone or limestone. These fluids include water, wastewater, and brine. Injection wells are grouped into six classes by the EPA. SWD wells are considered Class II UIC wells.

In the U.S., major use of injection wells started in the 1930s to dispose of produced water generated during oil and gas production. Effective disposal of unwanted brine, preservation of surface waters, and enhanced recovery of oil in certain formations were achieved through injection in the oil fields.

Injection of Produced Water into Favorable Geologic Units

Geology of the area is the major factor in determining if injection is a viable option for produced water disposal. North Dakota's Williston Basin has an ideal sequence of geologic units (Dakota Group) present at an optimal depth for produced water disposal. The Lower Cretaceous (~100-113 million years) Dakota Group of North Dakota consists of four formations (fig. 1). In descending order they are:

- Mowry Formation-marine shale
- Newcastle Formation-marginal marine sandstone
- Skull Creek Formation-marine shale
- Inyan Kara Formation-marginal marine and non-marine sandstone and shale

Overlying the Dakota Group are several thousand feet of Cretaceous marine deposits including the 2300-foot-thick Pierre Formation. The Jurassic (~150-200 million years) Swift Formation unconformably underlies the Dakota Group and consists of up to 725 ft. (221 m) of marginal marine shale with interbedded limestone. The Dakota Group is present at approximately 5,000-6,200 ft. (1524-1890 m) in the heart of the Williston basin.

These Cretaceous and Jurassic rocks are present throughout the Williston Basin of North Dakota and provide a complete succession of rocks for produced water injection. Of specific importance is the Inyan Kara Formation, which consists of sandstones and shales deposited in incised valleys along the coastline of the Cretaceous Western Interior Seaway (figs. 2 and 3). These valleys were cut by north-northwesterly flowing rivers that drained into the seaway from highlands in southern North Dakota, Minnesota, and Canada. The valleys formed as the Cretaceous seaway

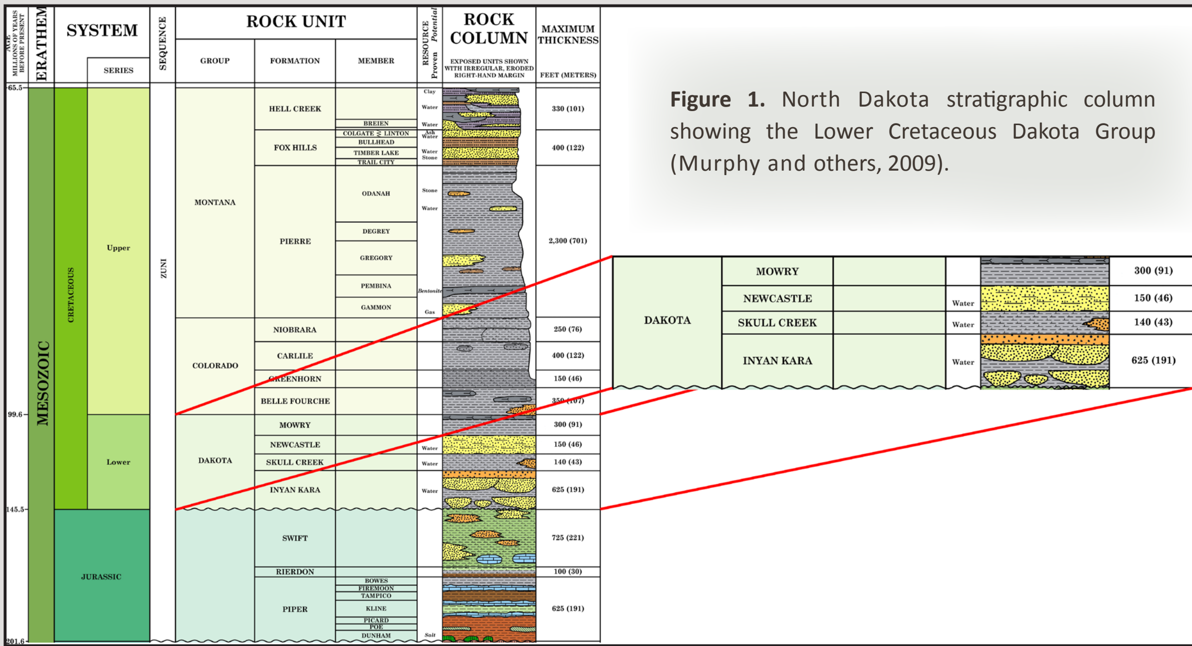

Figure 1. North Dakota stratigraphic column showing the Lower Cretaceous Dakota Group (Murphy and others, 2009).

withdrew (regressed) from North Dakota twice over a period of approximately 10 million years. The seaway transgressed back into the area forming estuaries, and sands were deposited in the valleys as sea-level rose, again in two transgressive events. Eventually the sea completely flooded all of North Dakota and the overlying marine units were deposited (figs. 4 and 5).

Inyan Kara sandstones deposited in these valleys are thick, porous (20-30% porosity), and permeable (Darcy level) enough to accept the injected water and the lateral continuity of the units allows for injected water to easily move into the formation (figs. 6 and 7), especially along valley trends. Figure 7 shows an injectable sandstone thickness map from the Inyan Kara of the Watford City 100K Sheet where several distinct north-northwest-trending valleys can be identified. Between these valleys, in the interfluve area, sandstones are thinner, much less continuous, and have porosity/permeability an order of magnitude lower than incised valley sandstones. Therefore interfluve sandstones are not optimal for injection of produced water.

Although some lateral continuity is important, these units must have good seals above to protect shallow aquifers. The thick shales of the Pierre Formation provide such a seal and it, along with the underlying Swift Formation, allow for excellent confining layers that will vertically contain injected brines within the Inyan Kara Formation.

Figure 8 shows a typical Class II injection well and the units penetrated in northwestern North Dakota. Wells must extend the upper casing at least 50 ft. (15 m) into the Pierre Formation. The hypothetical well extends into the Swift Formation and is screened for injection into the Inyan Kara.

Other important factors besides geology include the locations of producing wells and fields, and road access so that the produced water can be transported minimal distances, if necessary (fig. 7).

Saltwater Disposal Wells in North Dakota
The first commercial oil well in North Dakota was drilled by Amerada Petroleum in 1951 (AOGHS, 2015). The first saltwater disposal well in North Dakota began operating in 1953. Although North Dakota has been producing oil since 1951, only since 2005 has the Bakken oil boom made North Dakota the fourth largest oil-producing state in the U.S., and one of the largest onshore plays in the country. With these significant increases in oil production came similar increases in produced water production. Presently, North Dakota produces over a million barrels per day of produced water, requiring innovative methods and strategies to dispose of these prodigious amounts of waste fluids.

Prior to the development of hydraulic fracturing and refined horizontal drilling techniques, oil production in North Dakota was much less than it is today. During the years 1995-2005, North Dakota produced more than 320 million barrels of oil and over 670 million barrels of produced water. In 2005, 185 SWD wells were operating in North Dakota (fig. 9).

Oil and gas production over the last decade has increased significantly with the discovery of the Parshall field in Mountrail County in 2004 and the use of horizontal drilling/hydraulic fracturing technology. Most of this production has come from the Bakken-Three Forks petroleum system. North Dakota has produced nearly 1.5 billion barrels of oil over this time period. Produced water over this same time frame is also significant, with over 1.7 billion barrels generated. Approximately 90% of this produced water was disposed of in the Inyan Kara. In August 2015, there were 435 active SWD in North Dakota, 412 of these are Dakota Group/Inyan Kara wells (fig. 10). The amount of produced water generated from 2005 to 2015 was nearly three times the amount generated in the preceding decade.

Future of Produced Water in North Dakota
North Dakota produced its three billionth barrel of oil in January 2015 (NDIC, 2015) and it is estimated that four billion barrels

will be achieved by 2018. That is four billion barrels or more of produced water to deal with since the 1950s; over 220 billion gallons, enough water to supply the 19 million people of the New York metropolitan area for one year. Of course, this water is not drinkable, and because 98% of produced water from onshore wells is injected back into the subsurface (Clark and Veil, 2009), operators in North Dakota will need to have new, innovative, and environmentally sound practices in managing produced water disposal.

In support of this effort, the North Dakota Geological Survey is preparing a series of Inyan Kara maps at a scale of 1:100,000 (fig. 7) and cross-sections to help operators identify ideal locations for SWD wells across the entire state. These publications show Inyan Kara injectable sandstone thicknesses and trends that can be used with supporting data and road maps to identify potential well locations. These maps and cross-sections are extremely useful because Inyan Kara sandstone trends are very unpredictable, going from hundreds of feet of continuous sandstone to virtually nothing over a distance of only a few thousand feet (roughly 600 m). These maps and cross sections will assist in the disposal of produced water in North Dakota for many decades to come.

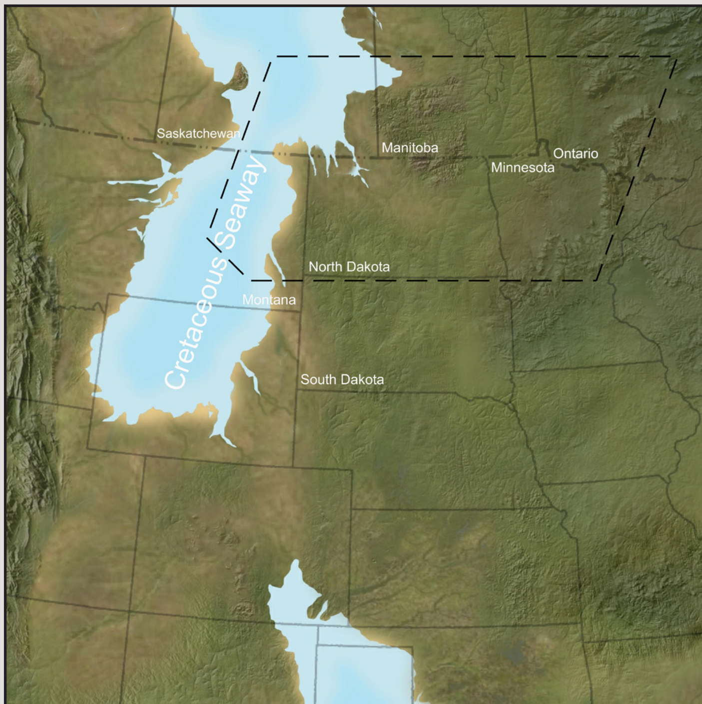

Figure 2. Paleogeographic map of North Dakota area during Inyan Kara time (c.a., 106 Ma). Dashed line shows figure 3 area. Modified from Blakey, 2014.

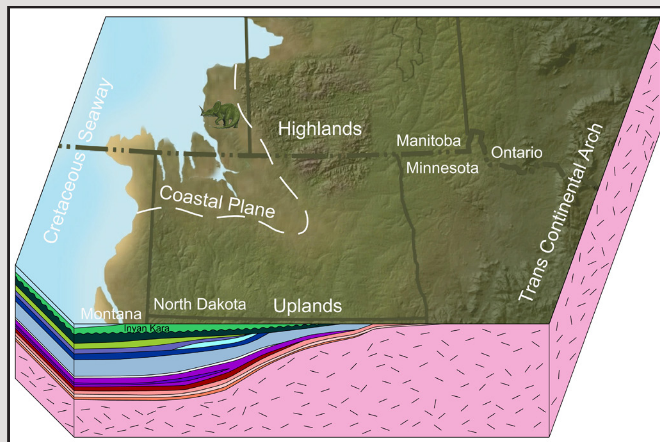

Figure 3. Block diagram of North Dakota area showing paleogeography and geologic setting during Inyan Kara time (c.a., 106 Ma). Modified from Blakey, 2014.

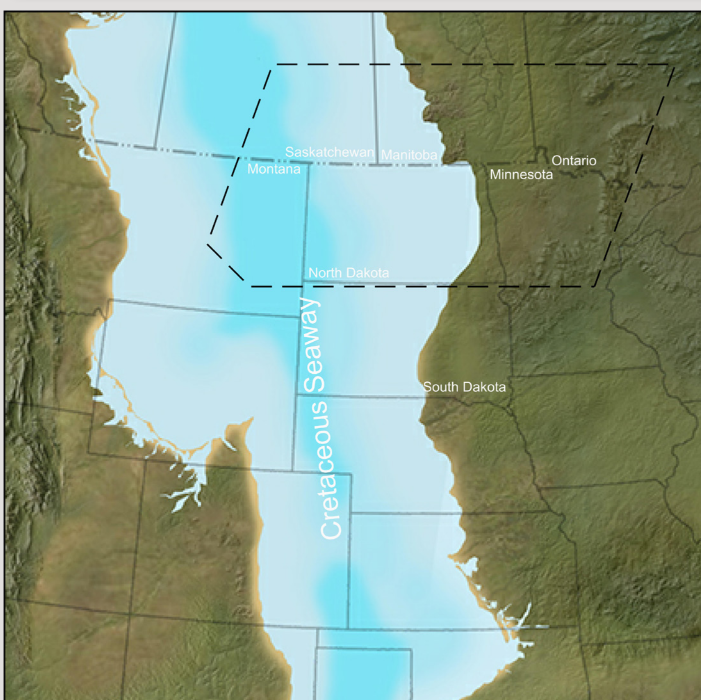

Figure 4. Paleogeographic map of North Dakota area during post Inyan Kara time (c.a., 105-103 Ma). Dashed line shows figure 5 area. Modified from Blakey, 2014.

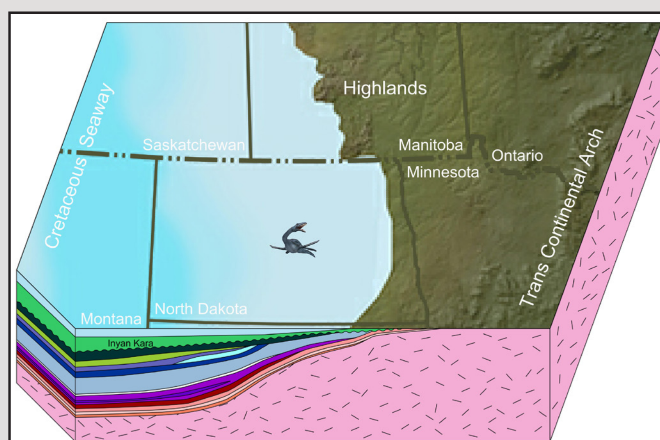

Figure 5. Block diagram of North Dakota area showing paleogeography and geologic setting during post Inyan Kara time (c.a., 105-103 Ma). Modified from Blakey, 2014.

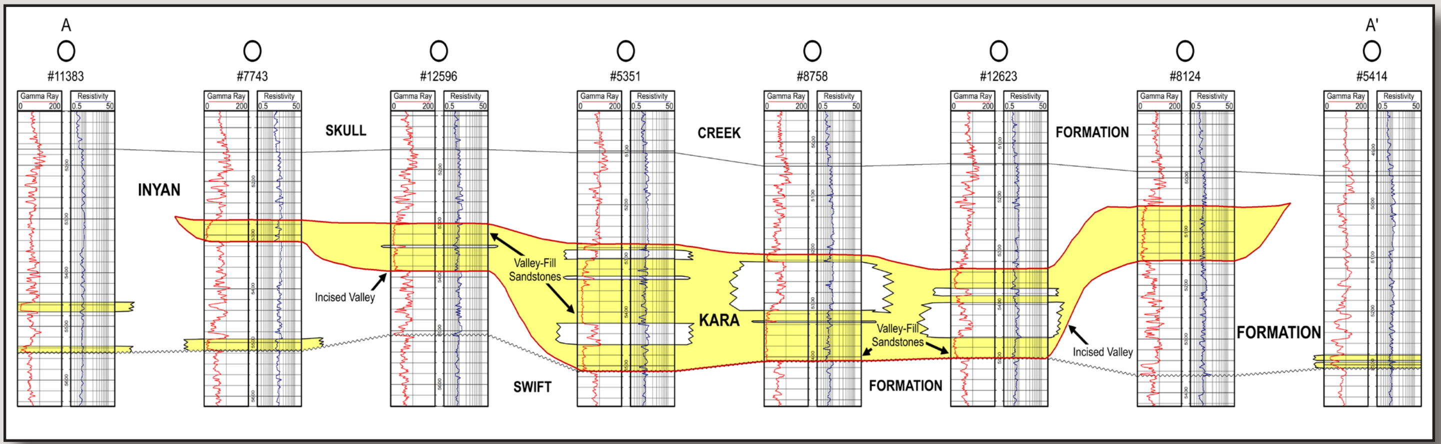

Figure 6. Geologic cross-section from the eastern half of the Watford City 100K Sheet showing incised valley and valley fill deposits of the Inyan Kara Formation.

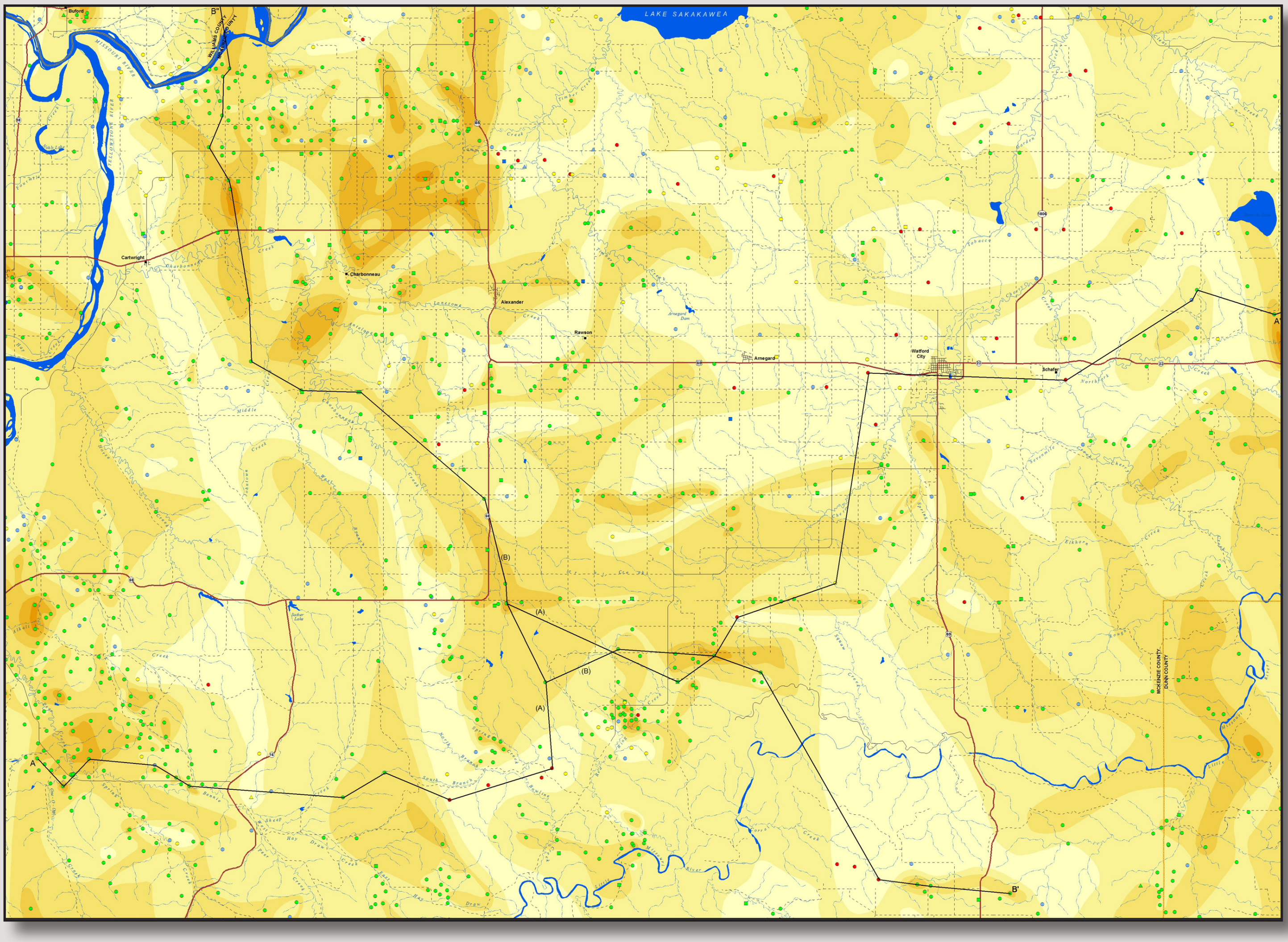

Figure 7. Inyan Kara sandstone isopach map, Watford City 100K Sheet, North Dakota (Bader, 2015). The darker the shade of yellow, the thicker the sandstone. Circles are oil wells, squares are operating disposal wells, and triangles are inactive disposal wells.

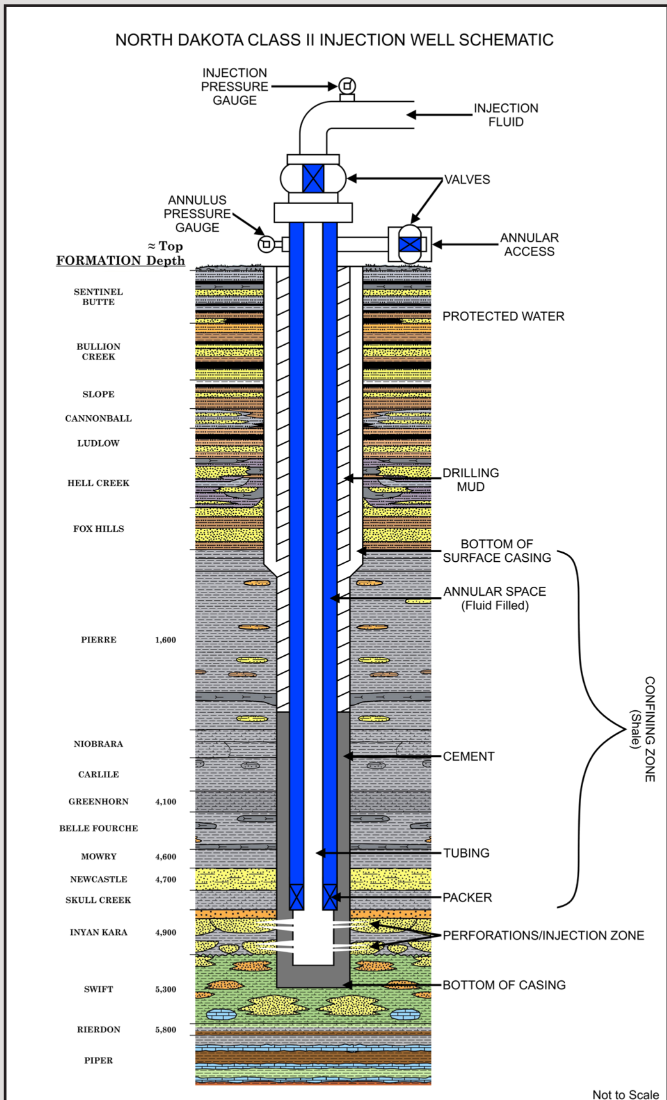

Figure 8. Typical North Dakota Class II injection well schematic and geologic units of northwestern North Dakota.

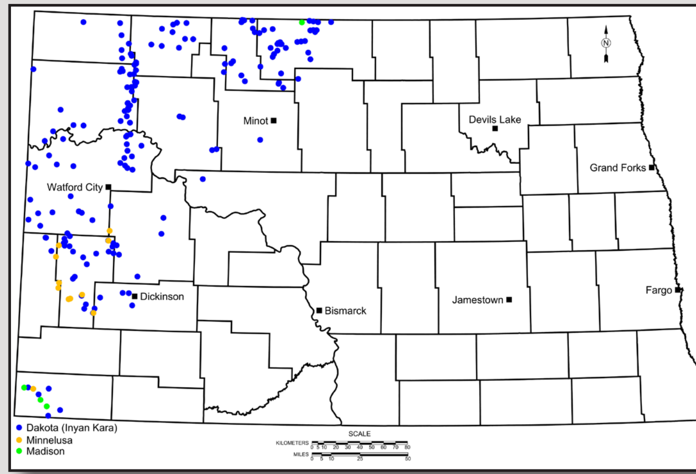

Figure 9. Active saltwater disposal wells in North Dakota, January 2005.

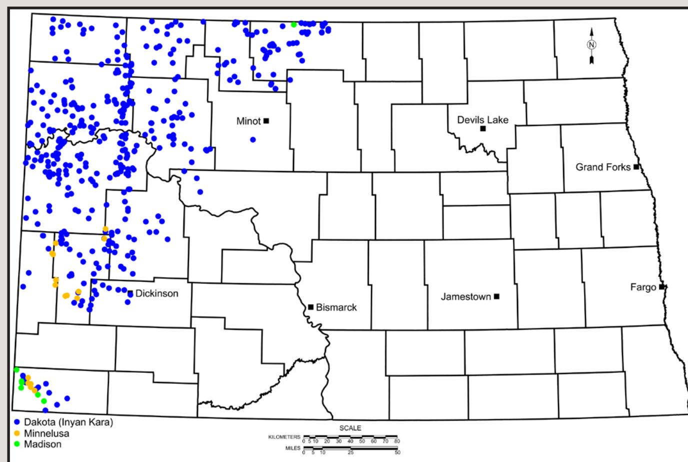

Figure 10. Active saltwater disposal wells in North Dakota, August 2015.

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