Plains CO_2 Reduction (PCOR) Partnership

Practical, Environmentally Sound CO_2 Sequestration

NEWCASTLE FORMATION OUTLINE

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EXECUTIVE SUMMARY

The Williston Basin is a relatively large, intracratonic basin with a thick sedimentary cover in excess of 16,000 ft. It is considered by many to be tectonically stable, with only a subtle structural character. The stratigraphy of the area is well studied, especially in those intervals that produce oil.

The basin has significant potential as a geological sink for sequestering carbon dioxide (CO_2). This topical report focuses on the general geological characteristics of formations in the Williston Basin that are relevant to potential sequestration in petroleum reservoirs and deep saline formations.

This report includes general information and maps on formation stratigraphy, lithology, depositional environment, hydrodynamic characteristics, and hydrocarbon occurrence. The Newcastle Formation in the Williston Basin has the potential to be a CO_2 sink through either enhanced oil recovery or saline formation storage.

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BACKGROUND/INTRODUCTION

Formation outlines have been prepared as a supplement to the “Overview of Williston Basin Geology As It Relates to CO_2 Sequestration (Fischer et al., 2004). Although the stratigraphic discussion presented in the “Overview” is in a convenient format for discussing the general characteristics of the basin, it does not provide insight into the specific characteristics of every formation. A formation outline summarizes, in outline form, the current knowledge of the basic geology for each formation. If not specifically noted, the formation boundaries and names reflect terminology that is recognized in the North Dakota portion of the Williston Basin. The intended purpose of the formation outlines will provide a convenient basis and source of reference from which to build a knowledge base for more detailed future characterization. The development of sequestration volume estimates and rankings are beyond the scope of the formation outlines prepared as part of the Phase I activities.

The Plains CO_2 Reduction (PCOR) Partnership believes these outlines are a necessary component in characterizing the sequestration potential of the basin. Although the stratigraphic discussion presented in the “Overview of Williston Basin Geology As It Relates to CO_2 Sequestration” is in a convenient format for discussing the general characteristics of the basin, it does not provide insight into the specific characteristics of every formation. In fact, each lithostratigraphic or geohydrologic unit discussed in that report can be further subdivided into individual formations. Formations may, in turn, be subdivided. Each subdivision may represent a sink, hereafter referred to as a “geological sequestration unit” (GSU) or a confining unit (aquitard). Some of the subdivisions may already be considered part of a large regional GSU or confining unit, while others may be localized and isolated. Many will represent a potential GSU within a regionally defined confining unit or a confining unit within a regionally defined sink.

Presently, the PCOR Partnership refers to CO_2 sequestration reservoirs as “sequestration units,” based on accepted legal terminology or protocol currently in use in the petroleum industry. CO_2 injection requires joint operating agreements that will necessitate the establishment of unitized lands for CO_2 sequestration, whether they are in petroleum reservoirs, coal beds, or subsurface formations or intervals containing brine.

Two main categories of GSUs are recognized in the formation outlines: conventional and unconventional. Conventional GSUs are considered to be nonargillaceous, or “clean,” lithologies that have preserved porosity and permeability; unconventional GSUs are those that may be porous but lack permeability, or are “dirty.” Loss of permeability in a porous reservoir may be due to the presence of organic detritus in the rock matrix. The distinction between conventional and unconventional reservoirs is made for a number of reasons:

- Injection into conventional GSUs may not require significant borehole stimulation because of inherent porosity and permeability; however, injection into unconventional GSUs may require significant stimulation, including fracture stimulation prior to injection, because of the lack of inherent permeability.

- For conventional reservoirs or GSUs, the presence of bounding or confining units will have to be well demonstrated and understood; these units will be the trapping mechanism for injected fluids. Unconventional GSUs, because of the inherent lack of permeability, may be self-trapping.

- Conventional GSUs may not need expensive stimulation procedures and, therefore, would be less sensitive to economic constraints.

- Unconventional GSUs that have a component of organic-rich matrix materials need to be investigated as to the capacity, if any, to play a role in fixation of CO_2.

A distinction is also made between primary and secondary GSUs. A primary GSU is a regional GSU with lateral continuity and would likely be capable of sequestering a significant amount of CO_2. A primary GSU would be the main target in a regional sequestration unit. A secondary GSU is less continuous and perhaps isolated and capable of sequestering a relatively minor amount of CO_2. For instance, a secondary GSU would not necessarily be a “stand-alone” sequestration target, but it might be utilized for sequestration if a borehole were already in place.

The potential importance of thin or nonregional sinks cannot be overlooked once CO_2 has been captured. The major expenses involved in the postcapture phase of geologic sequestration are transportation and well costs. Smaller sinks that are stratigraphically proximal to a larger sink target represent a means to maximize the economic potential of injection programs by utilizing all available storage encountered in an individual borehole. In order for nonregional sinks to be utilized, detailed characterization and mapping of those units are necessary.

FORMATION NAME

Newcastle Formation Outline

The stratigraphy and nomenclature of the lower Cretaceous varies greatly throughout the PCOR Partnership region. In this document, Williston Basin stratigraphic nomenclature follows that recognized by the North Dakota Geological Survey as summarized in the North Dakota Stratigraphic Column (Bluemle et al., 1986) and the Williston Basin Stratigraphic Nomenclature Chart (Bluemle et al., 1981).

Equivalents to the Newcastle include the Muddy Formation of northeast Montana (Bluemle et al., 1982) and the Viking Formation of southern Saskatchewan (Saskatchewan Industry and Resources, 2004; Reinson et al., 1994).

FORMATION AGE (LeRud, 1982)

Early Cretaceous
Albian
Dakota Group

GEOLOGIC SEQUENCE

Zuni

HYDROSTATIGRAPHY

Downey et al., 1987: AQ 4 Aquifer
Bachu and Hitchon, 1996: Viking Aquifer (Figure 1)

GEOGRAPHIC DISTRIBUTION (modified from LeRud, 1982)

Eastern Montana, North Dakota, South Dakota, southwestern Manitoba, southern Saskatchewan

THICKNESS

The Newcastle thickness (Figures 2 and 3) can be as much as 250 ft in the eastern Dakotas, ranges from 100 to160 ft in the western Dakotas, and averages from 40 to 80 ft thick in eastern Montana (LeFever and McCloskey, 1995). In southwestern Saskatchewan, the Newcastle Formation can be in excess of 100 m thick (Reinson et al., 1994). The Newcastle Formation is absent in part of central North Dakota.

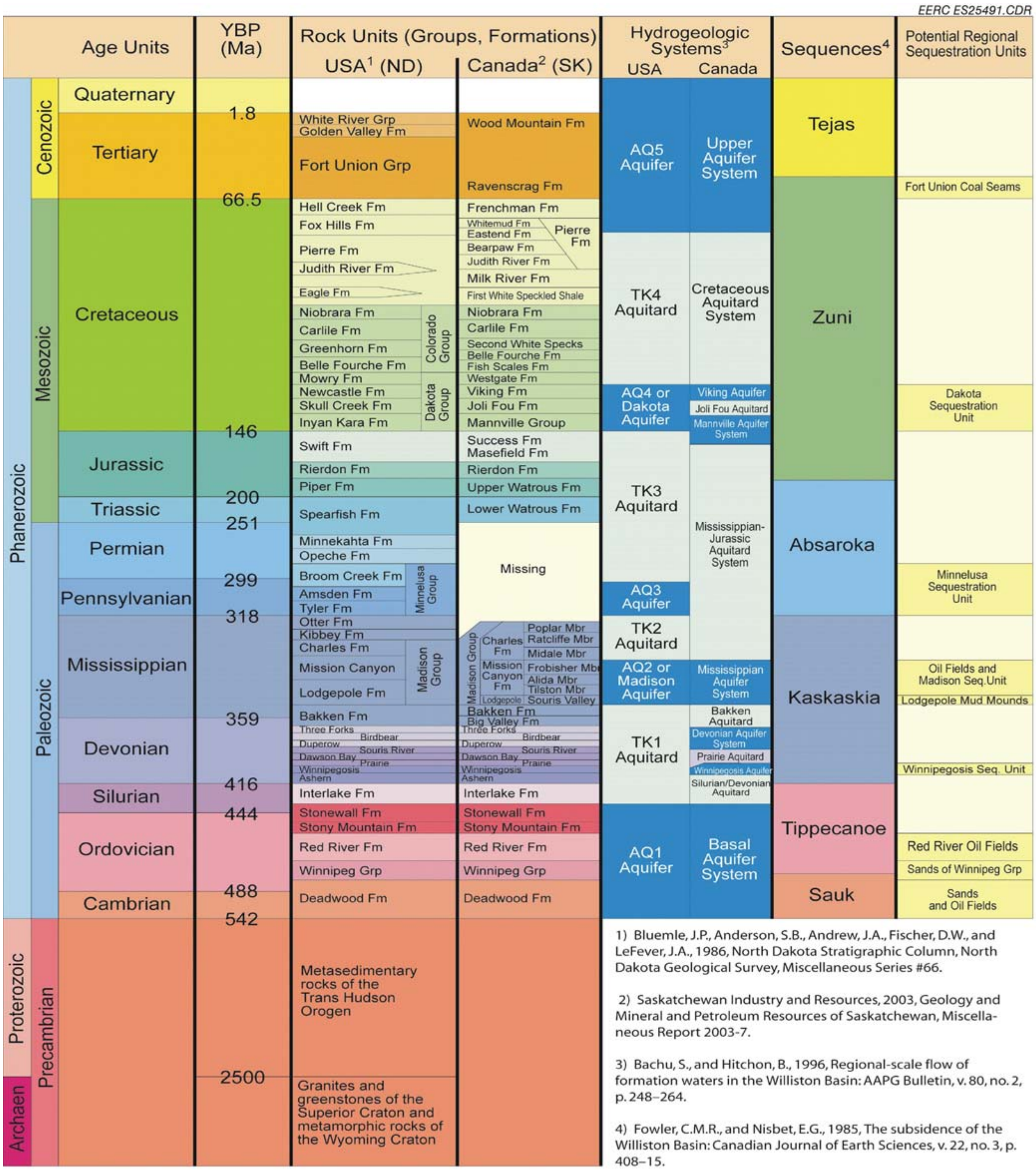

Figure 1. Williston Basin stratigraphic and hydrogeologic column.

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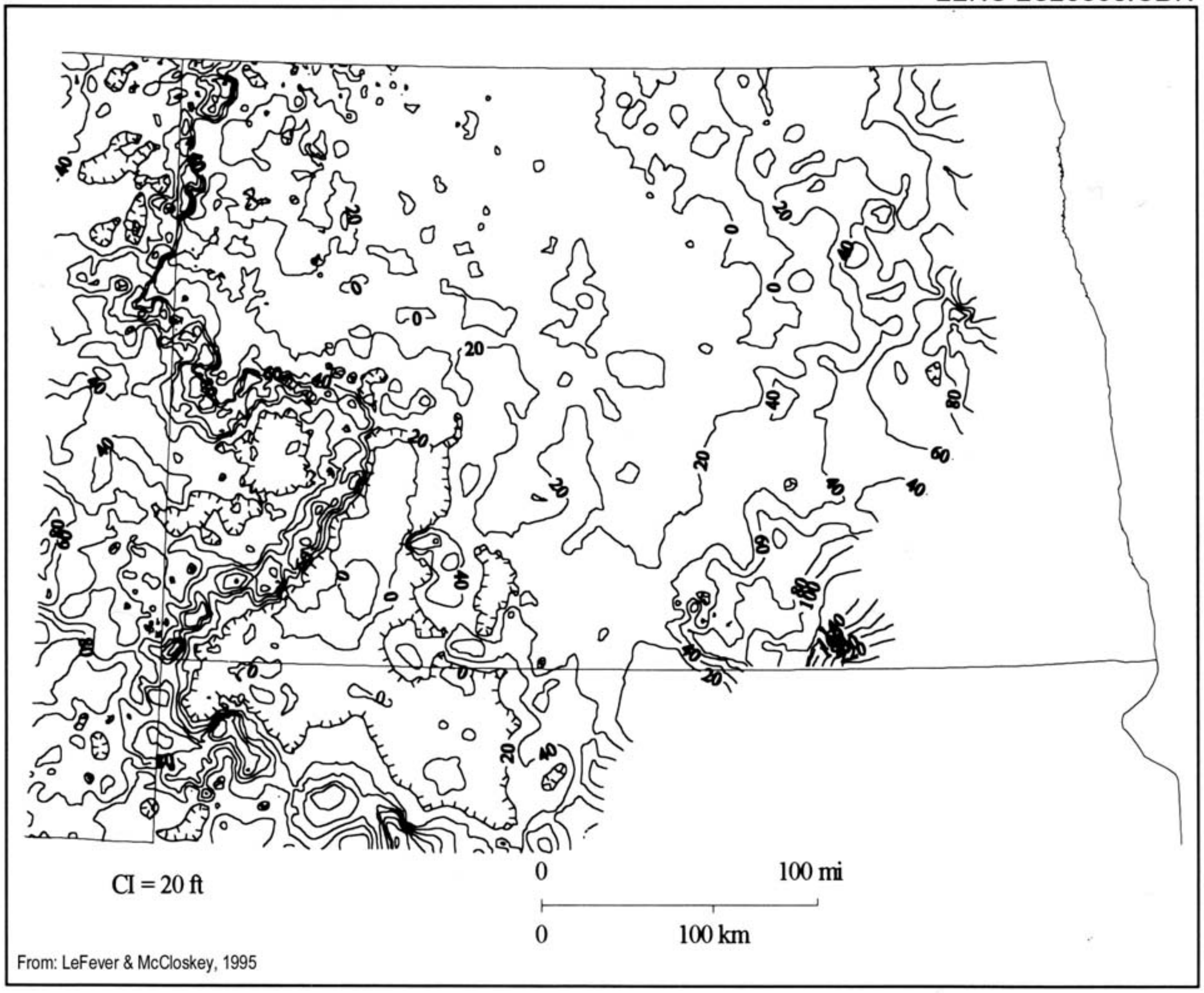

Figure 2. Newcastle Formation isopach for the U.S. portion of the Williston Basin.

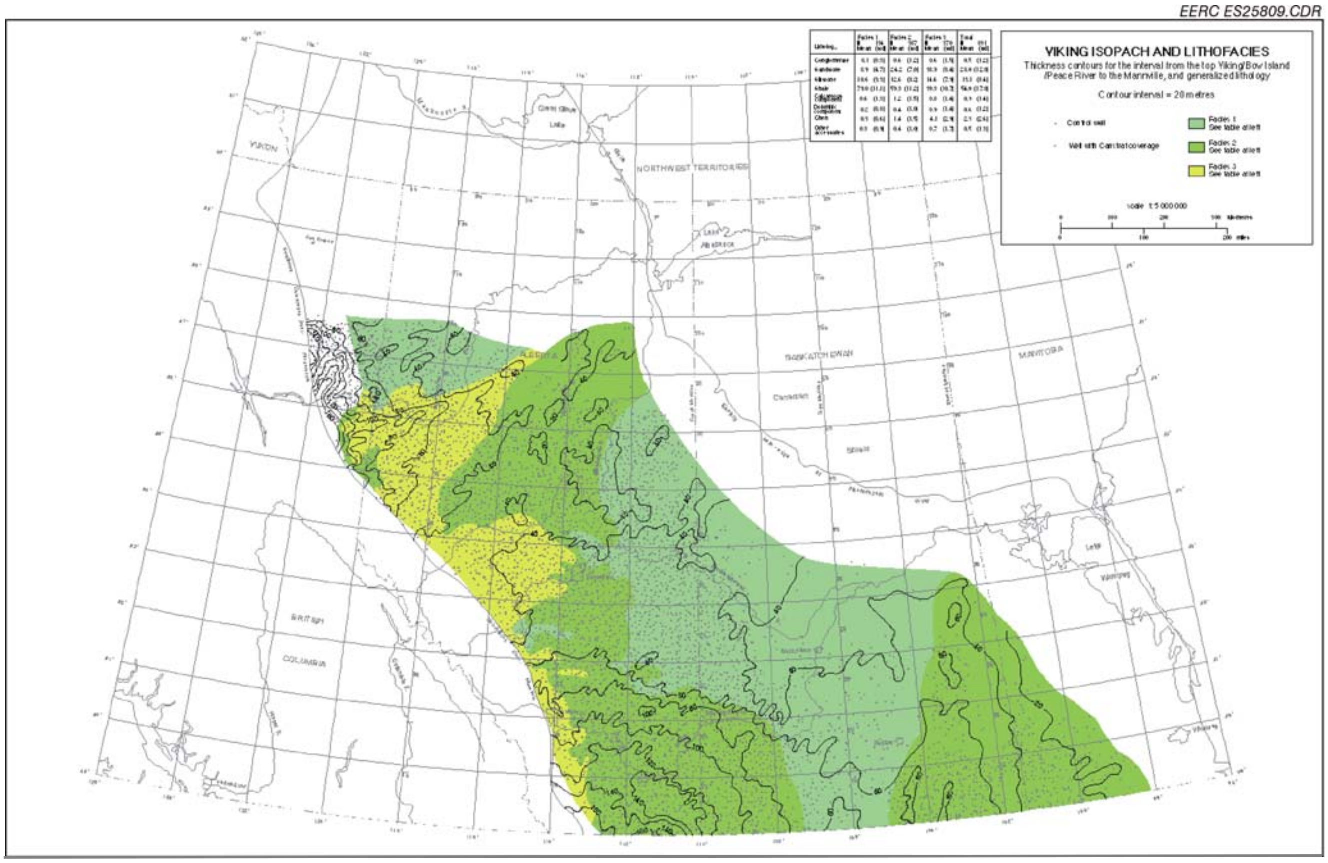

Figure 3. Newcastle (Viking) isopach for the Canadian portion of the Williston Basin.

CONTACTS

The upper contact with the Mowry is conformable (McCloskey, 1995).

The lower contact with the Skull Creek is unconformable (LeFever and McCloskey, 1995; McCloskey, 1995).

LITHOLOGY

Clastic

SUBDIVISIONS

None

LITHOFACIES

The primary Newcastle lithology is mudstone (Reinson et al., 1994; LeFever and McCloskey, 1995; McCloskey, 1995). More than 75 percent of the interval is considered not to be very porous or permeable in Canada because of the presence of silt and shale (Reinson et al., 1994). The second most common lithology is sandstone, fine to coarse grained, thinly to massively bedded. Other lithologies include siltstone and coal (Condon, 2000; LeFever and McCloskey, 1995; McCloskey, 1995; Reinson et al., 1994).

DEPOSITIONAL ENVIRONMENTS

Shallow to marginal marine to nearshore (Reinson et al., 1994; McCloskey, 1995; LeFever and McCloskey, 1995).

DEPOSITIONAL MODEL

During a major regressive phase, shales of the underlying Skull Creek Formation were exposed, and a fluvial channel system was incised. Channel cuts were subsequently filled during a progradational event. A series of transgressions and regressions followed, depositing a thick clastic sequence of nearshore and deltaic sediments.

RESERVOIR CHARACTERISTICS

Porosity in the Newcastle is variable. Anna (1986) has observed a direct relationship to porosity and sand thickness, with better porosities following thickness trends. Where developed, porosity can be significant, in excess of 20 percent (Anna, 1986). In south-central North Dakota, neutron density well log porosity is in the 20 percent range (Figure 4) while sonic well log porosity can be in excess of 35 percent (SWNE Sec. 17 T132 N R74 W).

Although no permeability measurements for the Newcastle core were found in the project area, fluid recoveries from drill stem tests suggest reasonable permeability. Some drill stem tests of a sand in south-central North Dakota commonly encountered fluid within a few hundred feet of the surface. Permeabilities for Muddy (Newcastle equivalent) sands with similar porosities in the Powder River Basin range from 0.1 to 13,000 md, with a geometric mean of 915 md (Szpakiewicz et al., 1989).

HYDRODYNAMIC CHARACTERISTICS

Potentiometric map: Figure 5
Total dissolved solids: Figure 6
Transmissivity: Figure 7
Hydraulic conductivity and storage: Table 1

HYDROCARBON PRODUCTION

The earliest-produced hydrocarbons in North Dakota and South Dakota were from the Newcastle sandstone. Natural gas was discovered in the late 1800s in south-central North Dakota and north-central South Dakota. Natural gas was produced from the Newcastle or Muddy sandstones along with artesian water flow. Natural gas supplied individual farms and at least one municipality, but by the early 1900s, the artesian head was depleted, and most natural gas production ceased. Newcastle produces natural gas and oil in Saskatchewan (Reinson et al., 1994).

SINK POTENTIAL

Newcastle has both conventional and unconventional sink potential. The fluvial sandstone channels are a strong candidate for conventional waste storage sites. The channels consist of relatively “clean” quartz arenite and are often porous and permeable. Siltstone lithofacies represent potential unconventional storage sites for CO_2 storage. Although porous, “dirtier” sandstone lithofacies lack permeability, likely necessitating fracture stimulation prior to injection.

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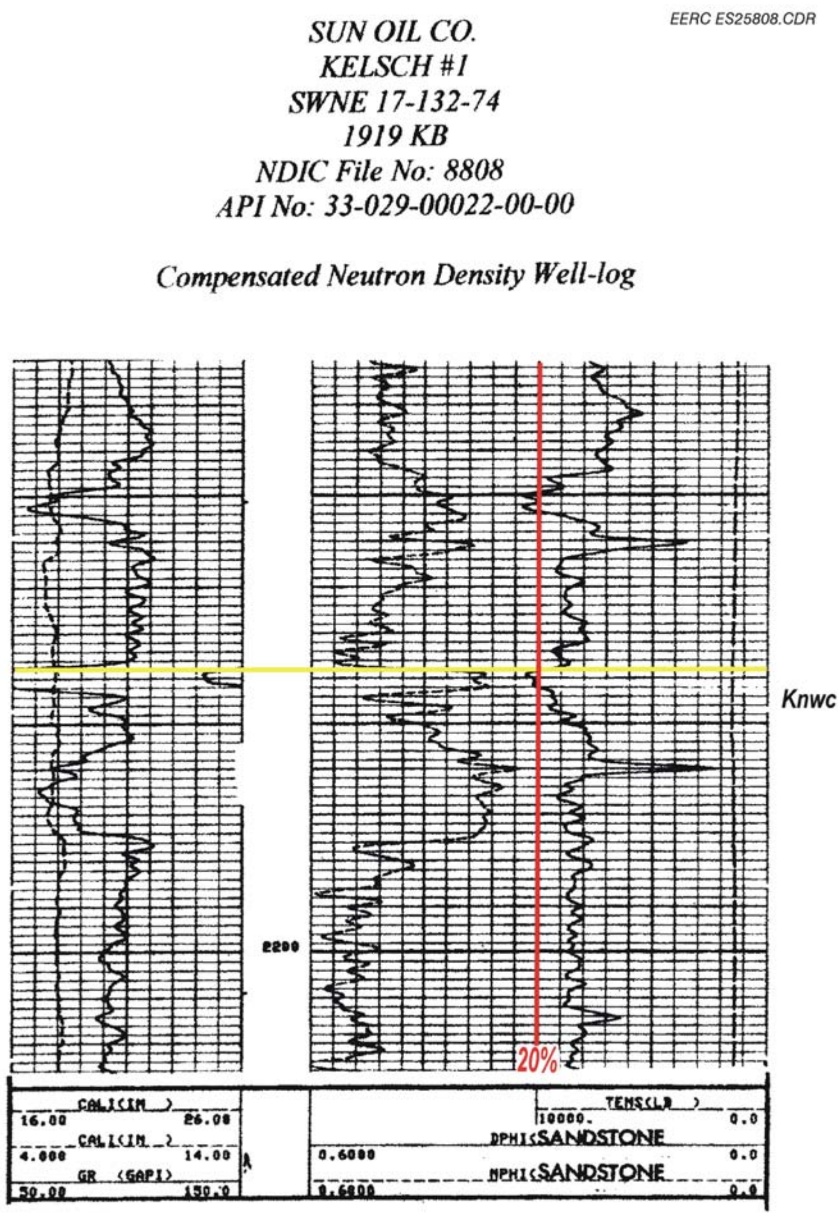


Figure 4. Newcastle Formation example log.

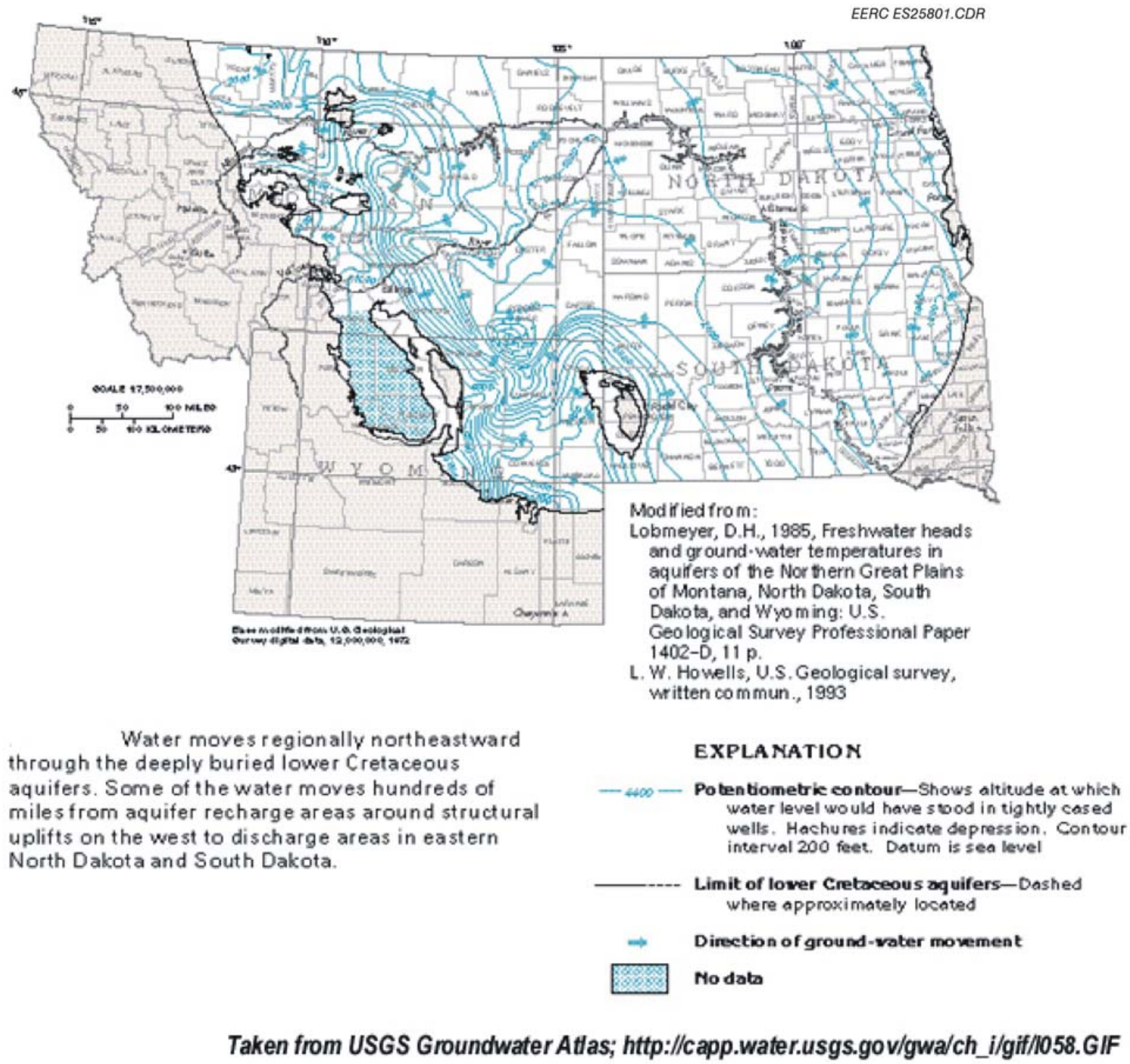
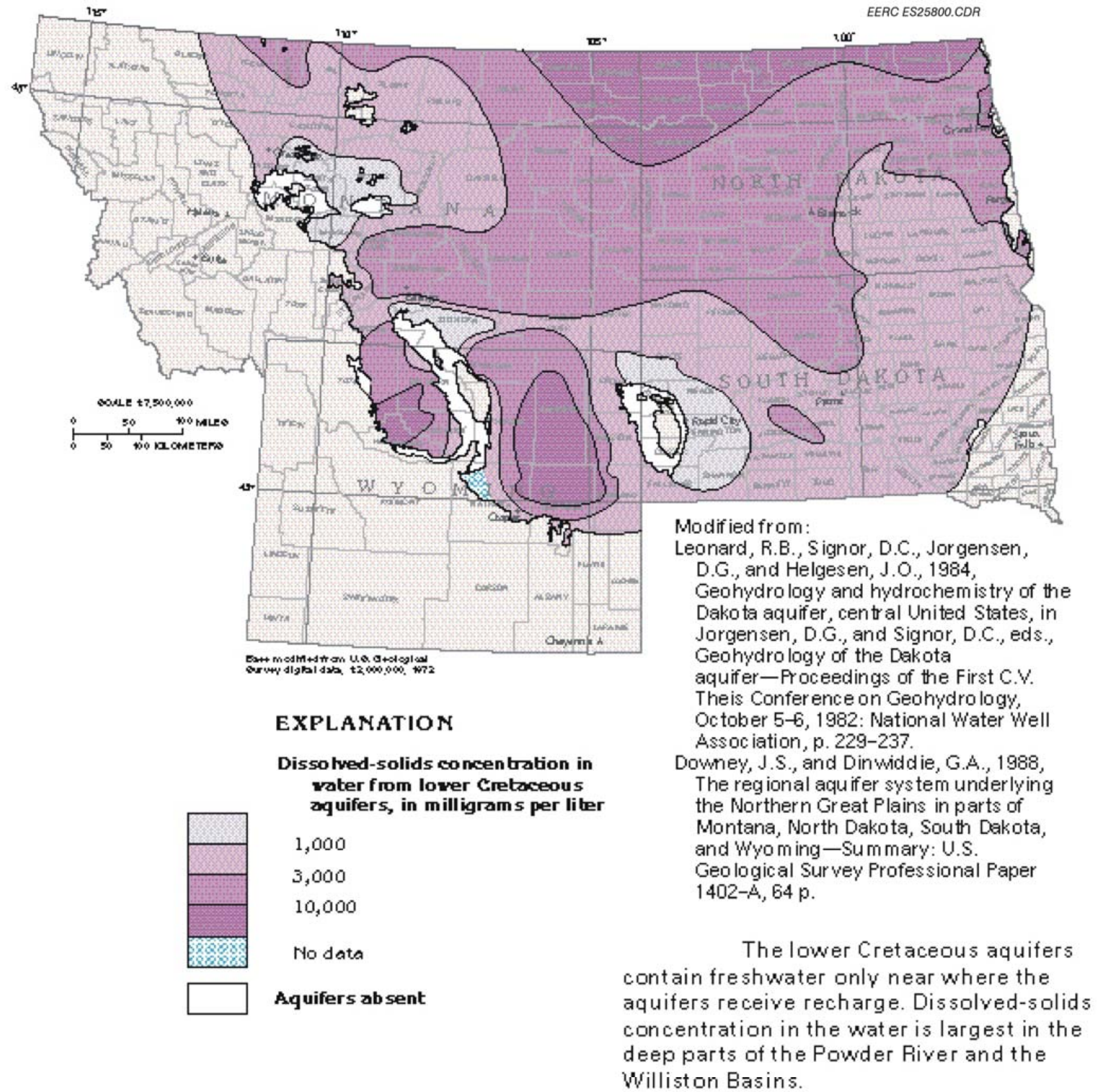
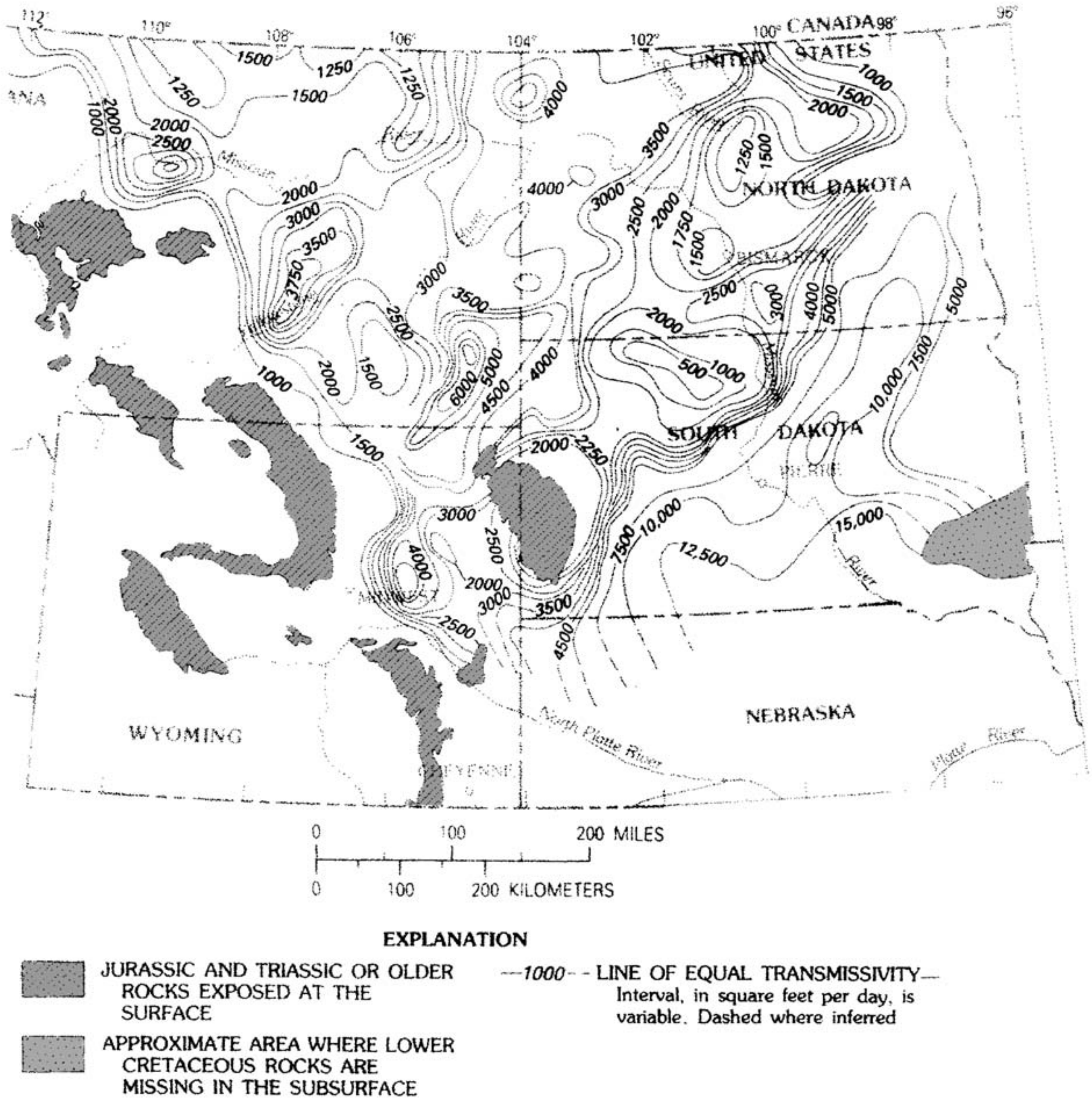


Figure 5. Potentiometric map of the lower Cretaceous formation including the Newcastle Formation.



Taken from the USGS Groundwater Atlas; http://capp.water.usgs.gov/gwa/ch_i/gif/I059.GIF

Figure 6. Map of the total dissolved solids concentrations from lower Cretaceous formations including the Newcastle Formation.



Transmissivity distribution used in the Lower Cretaceous aquifer simulations.

From: USGS PP 1402E

Figure 7. Transmissivity distribution in the lower Cretaceous formations including the Newcastle Formation.

Table 1. Hydraulic Conductivity and Storage Coefficient Values for the Dakota-Newcastle Aquifer (references found in Butler [1984])

Source	Hydraulic Conductivity, feet per second	Storage Coefficient
D.G. Jorgensen (U.S. Geological Survey, written communication, 1982)	6.4×10^{-5}	1×10^{-3}
DeWild, Grand, Reckert and Associates (1980)	6.9×10^{-5}	3.9×10^{-5} to 1.6×10^{-3}
Meinzer (1928)	1.07×10^{-4}	–
Milly (1978)	6.4×10^{-5}	1×10^{-5}
Neuzil (1980)	6.4×10^{-5}	1×10^{-5}
Digital model (author, unpublished data, 1982)	6.4×10^{-5}	–
Specific capacity method (Meyer, 1963)	7.6×10^{-5}	–

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