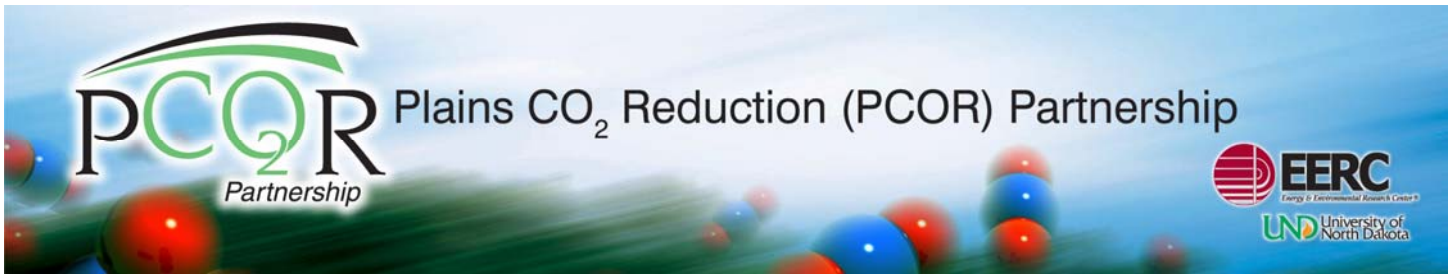

BROOM CREEK FORMATION OUTLINE

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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. This topical report is part of a series that focuses on the general geological characteristics of formations in the Williston Basin that are relevant to potential sequestration in petroleum reservoirs and deep brine formations.

This report includes general information and maps on formation stratigraphy, lithology, depositional environment, hydrodynamic characteristics, and hydrocarbon occurrence. The Broom Creek Formation in the Williston Basin is considered to have potential storage capacity as a deep brine formation.

ACKNOWLEDGMENTS

The Plains CO_2 Reduction (PCOR) Partnership is a diverse group of public and private sector stakeholders working toward a better understanding of the technical and economic feasibility of capturing and storing (sequestering) CO_2 emissions from stationary sources in the central interior of North America. It is one of seven regional partnerships funded by the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory Regional Carbon Sequestration Partnership Initiative, which represents more than 350 organizations in 41 states, three Indian nations, and four Canadian provinces. DOE is focused on understanding the opportunities and issues associated with CO_2 sequestration.

The PCOR Partnership represents public agencies, utilities, oil and gas companies, engineering firms, associations and nonprofit organizations, and universities (see PCOR Partnership list below). The Energy & Environmental Research Center (EERC) would like to thank the following partners who have provided funding, data, guidance, and/or

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- Alberta Geological Survey
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- Ameren Corporation
- American Lignite Energy (ALE)
- Apache Canada Ltd.
- Basin Electric Power Cooperative
- Bechtel Corporation
- Blue Source, LLC
- BNI Coal, Ltd.
- British Columbia Ministry of Energy, Mines and Petroleum Resources
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- Ducks Unlimited Canada
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- Missouri Department of Natural Resources
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- Murex Petroleum Corporation
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- Nexant, Inc.
- North American Coal Corporation
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- Shell Canada Energy
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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 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 outline 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 outline.

Two main categories of potential geological sequestration formation target zones are recognized in the formation outlines: conventional and unconventional. Conventional formation target zones are considered to be nonargillaceous, or "clean," lithologies that have preserved porosity and permeability; unconventional formation target zones are those that may be porous but lack permeability or are "dirty." Loss of permeability in a porous reservoir may be as a result of the presence of organic detritus in the rock matrix. These terms are derived from the lexicon for oil and gas exploration, where the same attributes of "conventional" and "unconventional" are applied to the description of reservoirs. The distinction between conventional and unconventional formation target zones or reservoirs is made for a number of reasons:

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

- For conventional formation target zones, 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 zones, because of the inherent lack of permeability, may be self-trapping.

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

- Unconventional zones 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.

FORMATION NAME

Broom Creek Formation

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) (Figure 1). Equivalents to the Broom Creek Formation include the Minnelusa Formation of Montana. The Broom Creek Formation is absent in Canada.

FORMATION AGE (Lerud, 1982)

Permian Period (Figure 1)
Wolfcampian Epoch
Minnelusa Group

GEOLOGICAL SEQUENCE

Absaroka

HYDROSTRATIGRAPHY (Figure 1)

AQ3 Aquifer System (Downey et al., 1987)

GEOGRAPHIC DISTRIBUTION (modified from Lerud [1982])

Southwestern portion of Williston Basin (southwestern North Dakota, southeastern Montana, northwestern South Dakota), extending into Wyoming

THICKNESS

In the Williston Basin (Figure 2), the Broom Creek Formation is more than 375 ft thick in northwestern North Dakota (Rygh, 1990).

CONTACTS

The Broom Creek unconformably overlies the Pennsylvanian Amsden Formation and is unconformably overlain by the Permian Opeche Formation (Ziebarth, 1972; Hoda, 1977; Rygh, 1990).

LITHOLOGY

Primarily clastic

SUBDIVISIONS

None

LITHOFACIES

Rygh (1990) recognizes three separate lithofacies in the Broom Creek: 1) eolian sandstone, 2) nearshore marine sandstone, and 3) shallow marine carbonate.

The Broom Creek Formation is "composed of interbedded pinkish-gray to pale red and pale reddish-brown fine- to medium-grained, subangular to well-rounded, locally dolomitic sandstone with poor to good porosity and pinkish-gray to pale red and grayish-red, microcrystalline, locally anhydritic dolomite that is generally nonporous but locally may have fair, vuggy porosity. Locally, interbeds of grayish-tan to moderate red shale and earthy, textured dolomite are present." (Taken from Ziebarth, 1972.)

DEPOSITIONAL ENVIRONMENT

Marine

DEPOSITIONAL MODEL

A four-phase depositional model has been proposed for the Broom Creek Formation of the Williston Basin: 1) eolian dunes migrated over an erosional surface, 2) a marine transgression occurred with a reworking of eolian dune sediments, 3) carbonate mud was deposited, and 4) marine regression and exposure occurred in the final phase (Rygh, 1990).

Most of the sand in the Broom Creek Formation represents deposition in a beach or offshore bar environment or as coastal eolian deposits (Ziebarth, 1972; Rygh, 1990). Marine deposition probably occurred in shallow waters of relatively

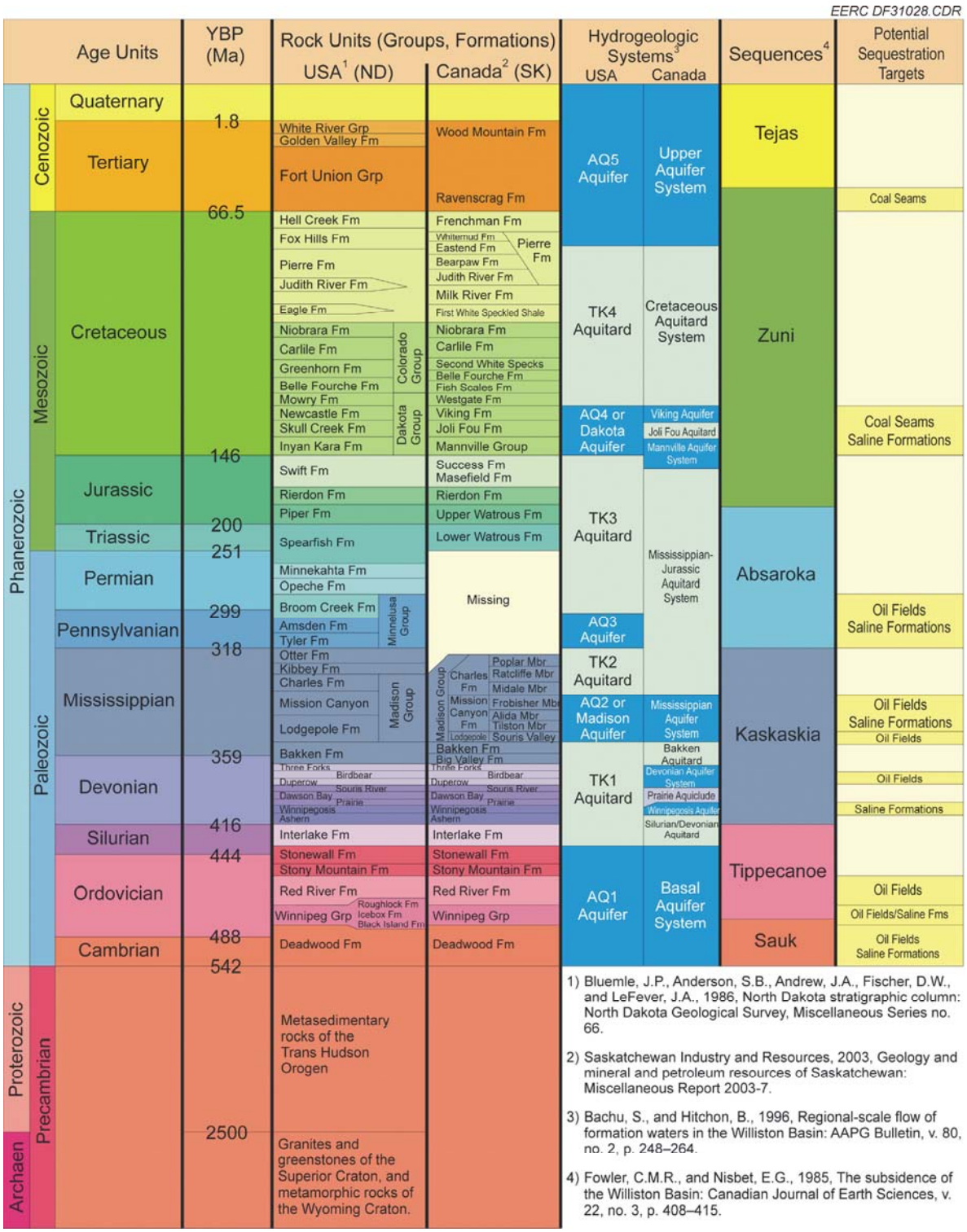

Figure 1. Williston Basin stratigraphic and hydrogeologic column.

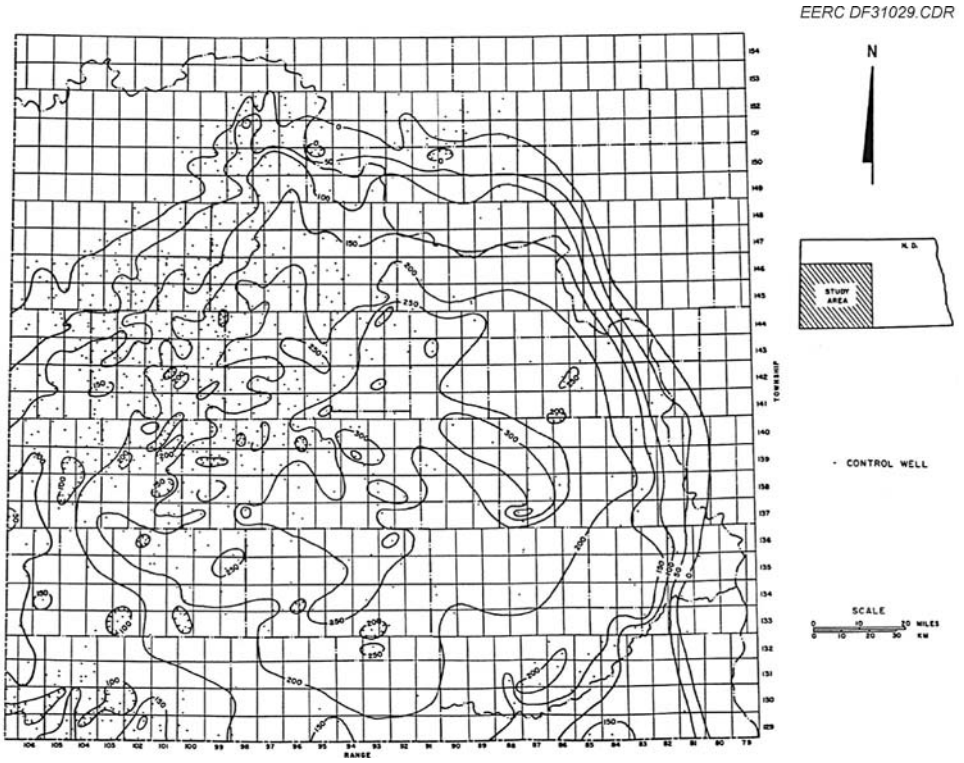

Figure 2. Broom Creek isopach (Rygh, 1990).

high energy, as demonstrated by the lack of shales in the formation. Because of extensive recrystallization, an interpretation of the exact depositional environments for the dolomites present in the formation is difficult but probably represents deposition in shallow shelf environments.

RESERVOIR CHARACTERISTICS

Typical log response for the Broom Creek section (Figure 3).

From North Dakota State Department of Health ANG (American Natural Gas) Coal Gasification Injection well testimony (Mercer County, North Dakota):

- Relative Porosity: 18% (reduced to account for overburden)
- Relative Permeability: 100–200mD (calculated from injection test data)

From the unpublished Energy & Environmental Research Center FutureGen proposal (Bowman County, North Dakota):

- Effective Log Porosity: 14%

HYDRODYNAMIC CHARACTERISTICS

Hydrodynamic flow (Figure 4) in the Broom Creek is to the northeast (Hoda, 1977). Recharge occurs in the Black Hills (Schoon, 1971). The Broom Creek is a closed system with no outcrop discharge area (Hoda, 1977).

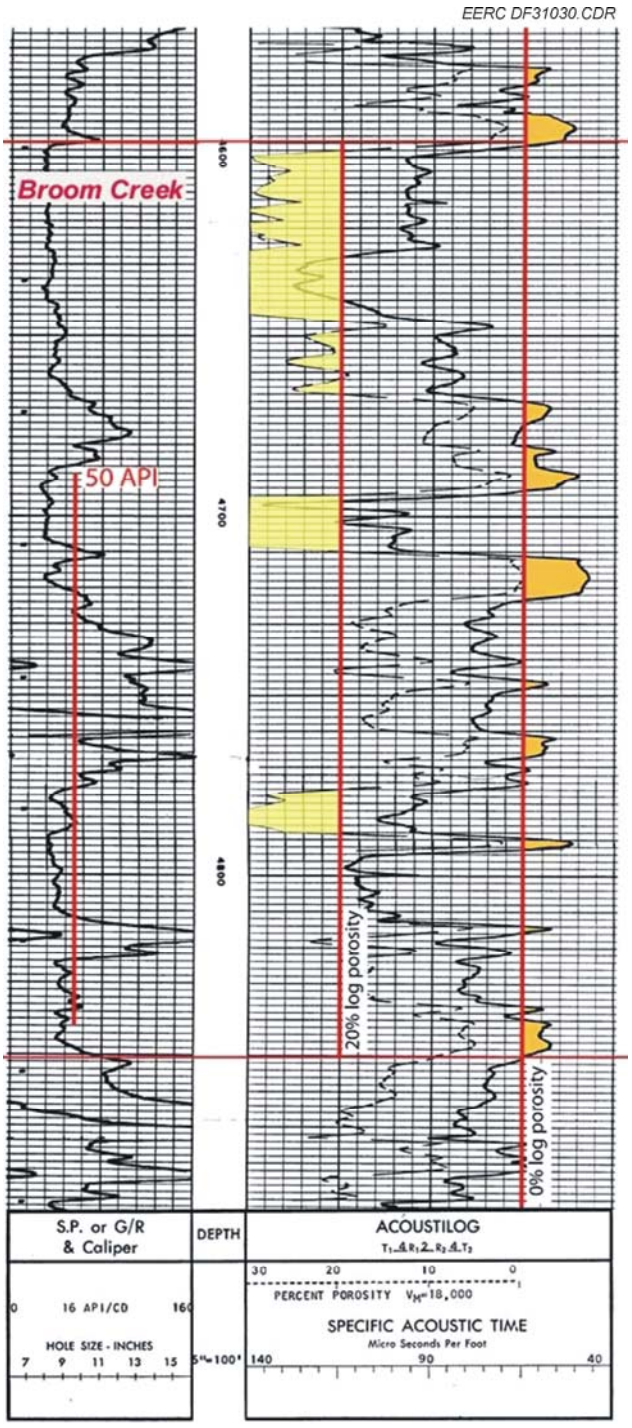

Figure 3. Typical Broom Creek log response.
General American Oil Company of Texas
Rockenbach 1-10
SWNW 10-143-83

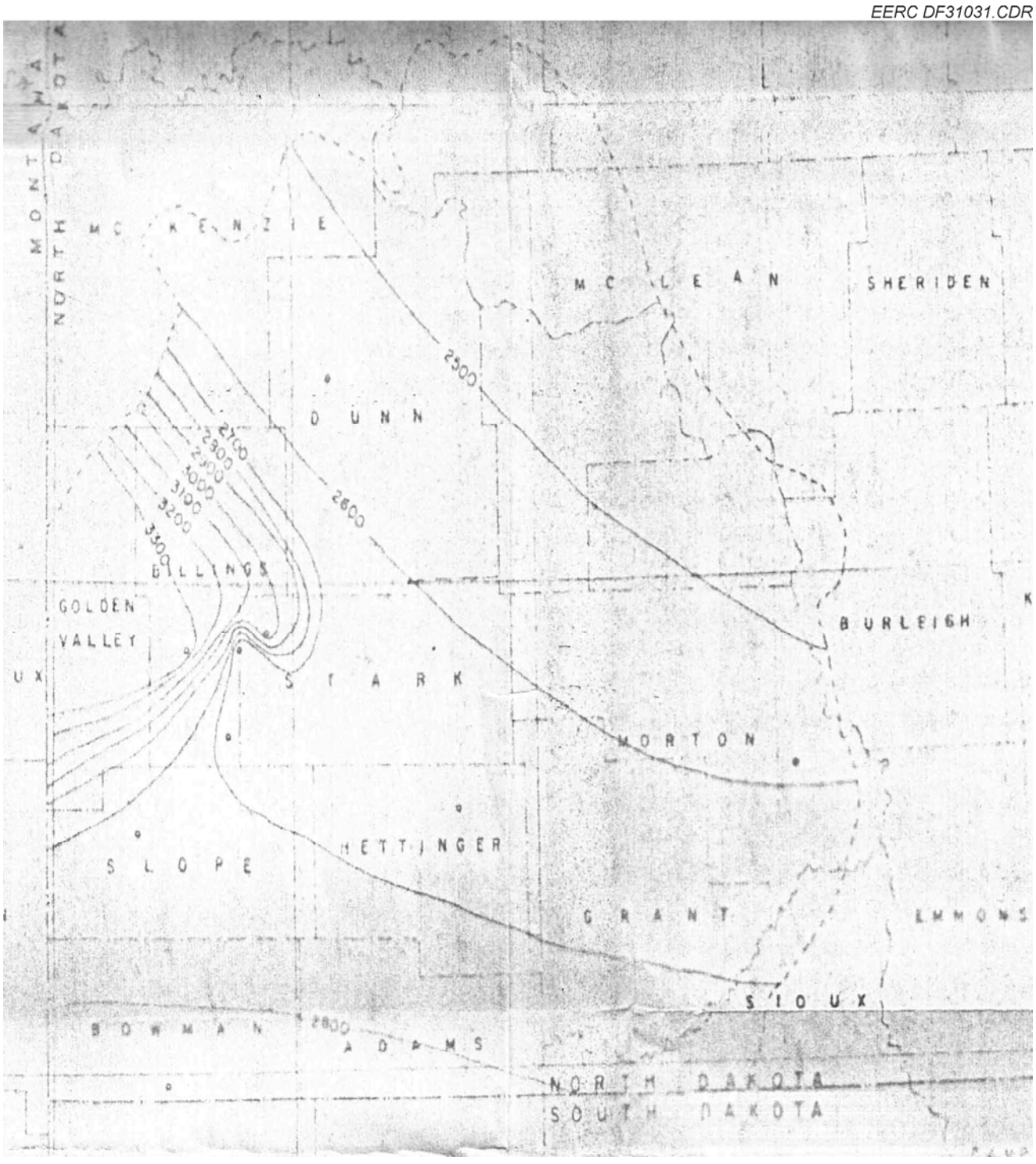

Figure 4. Broom Creek hydraulic head (Hoda, 1977).

Salinity in the Broom Creek has been documented to range from approximately 10,000 ppm total dissolved solids (TDS) to in excess of 325,000 ppm TDS (Hoda, 1977) (Figure 5).

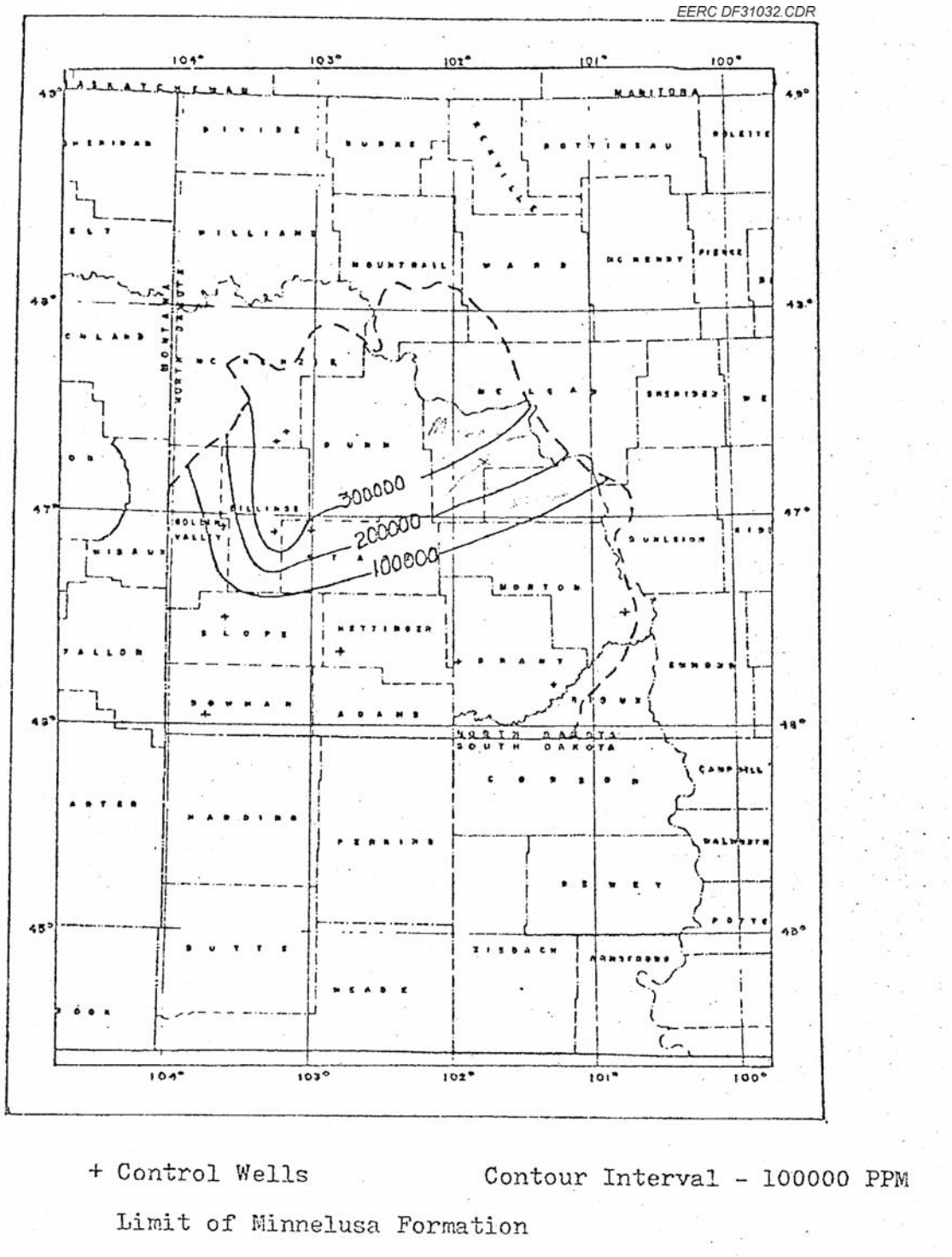

Figure 5. Broom Creek salinity (Hoda, 1977).

HYDROCARBON PRODUCTION

No production to date. The presence of nitrogen gas in the Broom Creek is well documented (Marchant, 1966; Rygh 1990). The gas is not present everywhere but can be locally overpressured. Several "blowouts" associated with overpressured nitrogen in the Broom Creek Formation have been reported during the drilling of oil and gas wells in North Dakota.

SINK POTENTIAL

Conventional

The Broom Creek is considered to be an excellent candidate for CO_2 sequestration. The lithology of the reservoir is clastic, and it is porous and permeable. The formation pinches out into impermeable rocks, in central North Dakota, preventing sequestered carbon from moving updip. The competency of Broom Creek traps has been locally demonstrated by the occurrence of nitrogen gas accumulation. The formation is currently used for injection of wastewater in two wells in Mercer County, North Dakota.

A 1-MMt/year CO_2 injectivity rate has been calculated for the Broom Creek for a single well in Bowman County, North Dakota (Redetzke SWD #1; Sec. 23-T133N-R97W).

Parameters for the Broom Creek reservoir at this location include the following:

Depth: 6500 ft
Formation Thickness; 148 ft
Effective Porosity: 14%
Dissolved NaCl: 0.22 molal
Formation Pressure: 2814.2 psi

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