Plains CO_2 Reduction (PCOR) Partnership

WINNIPEGOSIS 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 Winnipegosis 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) carbon dioxide (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

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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 is to 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 is beyond the scope of the formation outline.

Two main categories of potential geological sequestration formation target zones are recognized in the formation outline: 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 due to 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 carbon dioxide (CO_2).

FORMATION NAME

Winnipegosis Formation

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).

FORMATION AGE (LeRud, 1982)

Middle Devonian Period
Erian Epoch
Elk Point Group

GEOLOGICAL SEQUENCE

Kaskaskia

HYDROSTRATIGRAPHY (Figure 1)

Winnipegosis Aquifer (Bachu and Hitchon, 1996)

TK1 Confining layer (Downey et al., 1987)

GEOGRAPHIC DISTRIBUTION (modified from LeRud [1982])

Williston and Elk Point Basins:

- Alberta, Manitoba
- Eastern Montana
- North Dakota
- Saskatchewan
- South Dakota

THICKNESS

In North Dakota, the thickness of the Winnipegosis can vary substantially, exceeding 200 ft in places (Perrin, 1987; Ehrets and Kissling, 1987).

CONTACTS

The upper contact with the Prairie Formation is unconformable. The overlying Prairie Formation is composed of salts and anhydrite and is, therefore, an excellent seal for CO_2 in the Winnipegosis Formation. The lower contact with the Ashern Formation is conformable.

LITHOLOGY

Primary: carbonate and limestone with some dolomite

Secondary: evaporate and anhydrite

SUBDIVISIONS

None.

DEPOSITIONAL ENVIRONMENT

Marine basin to shallow marine shelf

LITHOFACIES

Perrin (1982; 1987) (Figure 2) suggests that Winnipegosis deposition in North Dakota occurred in two separate regions: a deeper basin and a basin slope/shelf.

The deeper basin is characterized by pinnacle reefs and an intrareef laminated limestone lithofacies. Deposition on the carbonate slope/shelf includes platform margin reefs, patch reefs, and sediments deposited in lagoonal and tidal flat environments.

The most pronounced and important lithofacies of the Winnipegosis Formation with respect to CO_2 sequestration are the reef lithofacies: pinnacle, platform, and patch. Eherts and Kissling (1987) present detailed facies models for platform margin and pinnacle reefs in the Williston Basin. They interpret the platform margin reef facies to be primarily a boundstone characterized by a diverse assemblage of organisms, including stromatoporoids, corals, and algae that formed on a basin slope facies of diverse character (Figure 3). Reservoir development is noted in both the reef and basin slope facies.

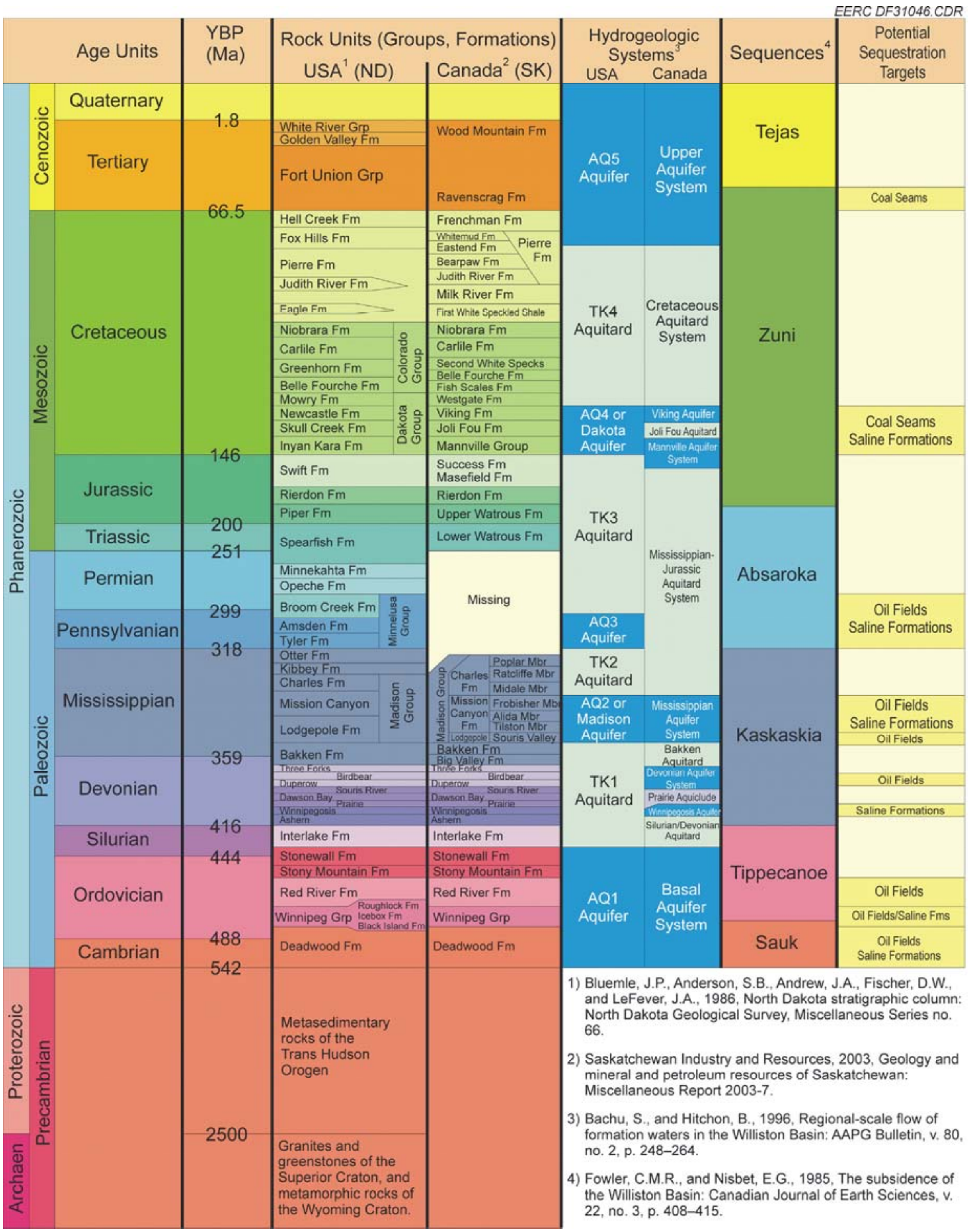

Figure 1. Williston Basin stratigraphic and hydrogeologic column.

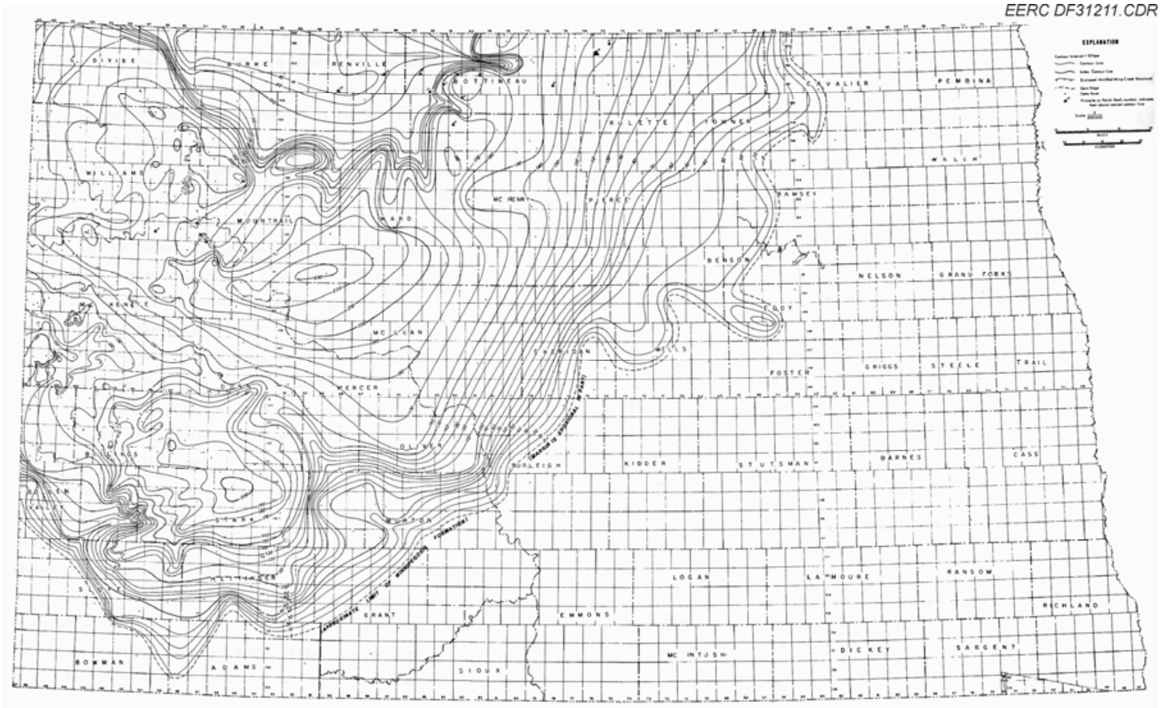

Figure 2. Winnipegosis isopach (Perrin, 1987).

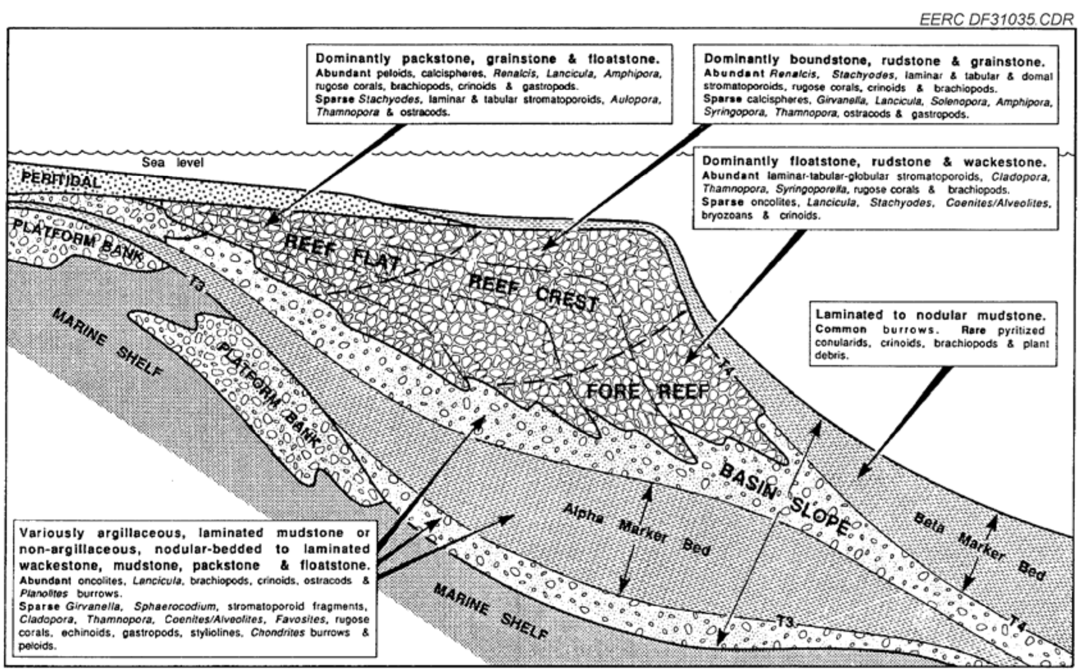

Figure 3. Facies model for platform margin reef (Ehrets and Kissling, 1987).

Pinnacle reefs developed in a marine shelf environment on a relatively mud-rich environment of the basin floor. The reef facies is subdivided into a lower algal–peloidal subfacies overlain by a stromatoporoid coral subfacies (Figure 4).

Perrin (1982) describes the patch reef facies to be a boundstone. The primary constituents in this facies are reported to be stromatoporoids and tabulate coral that are encrusted by blue-green algae.

DEPOSITIONAL MODEL

Initial Winnipegosis deposition occurred in the southeastern extent of the Elk Point Basin and on a broad shelf ramp representing a major transgressive and regressive phase. During the transgressive phase, two distinct depositional environments are recognized: a deep basin surrounded by a platform (Ehrets and Kissling, 1987; Perrin, 1982). Perrin (1987) interprets basinal depositional environments resulting in the formation of pinnacle reefs and interreef laminated mudstones. Shelf depositional environments included shallow marine, patch reef, lagoonal, and tidal flat environments. Ehrets and Kissling (1987) also recognize the development of platform margin reefs. During the regressive phase, progressively shallower subtidal environments are recognized, resulting in intertidal to supratidal carbonates and an upper anhydrite.

RESERVOIR CHARACTERISTICS

Porosity in the Winnipegosis can be seen to have developed almost anywhere in the basin immediately below the upper anhydrite. This zone of porosity can vary greatly in thickness from 1 or 2 feet to over 10 feet. The range of the porosity developed also varies greatly but can be in excess of 20%. On logs, the porosity appears to be dolomitic and, possibly, the result of reflux.

Platform margin facies, based on data from the Temple field in North Dakota, from Eherts and Kissling (1987) are as follows (Figure 5):

- Porosity averages 15% with values frequently over 20%

- Permeability most commonly ranging from 10 to 70 mD

Pinnacle reef facies (Figure 6) are as follows:

- Porosity and permeability varying greatly

- Pinnacle reef facies can be seen in logs (NDIC No. 7976: SWSE 34 T161N R87W)

Core analysis (core depths 8306–8372 ft) revealed:

- Average porosity 10.3%
- Porosity range 3% to 17%
- Average permeability 19 mD
- Permeability range <1 to >200 mD

HYDRODYNAMIC CHARACTERISTICS (TK1)

Although the Winnipegosis formation is included in the TK1 aquitard system by the U.S. Geological Survey, some facies within the formation, for example, reef facies, have adequate porosity and permeability to be considered saline aquifers. This is reflected in nomenclature used by Bachu and Hitchon (1996), where they refer to the formation as the Winnipegosis Aquifer.

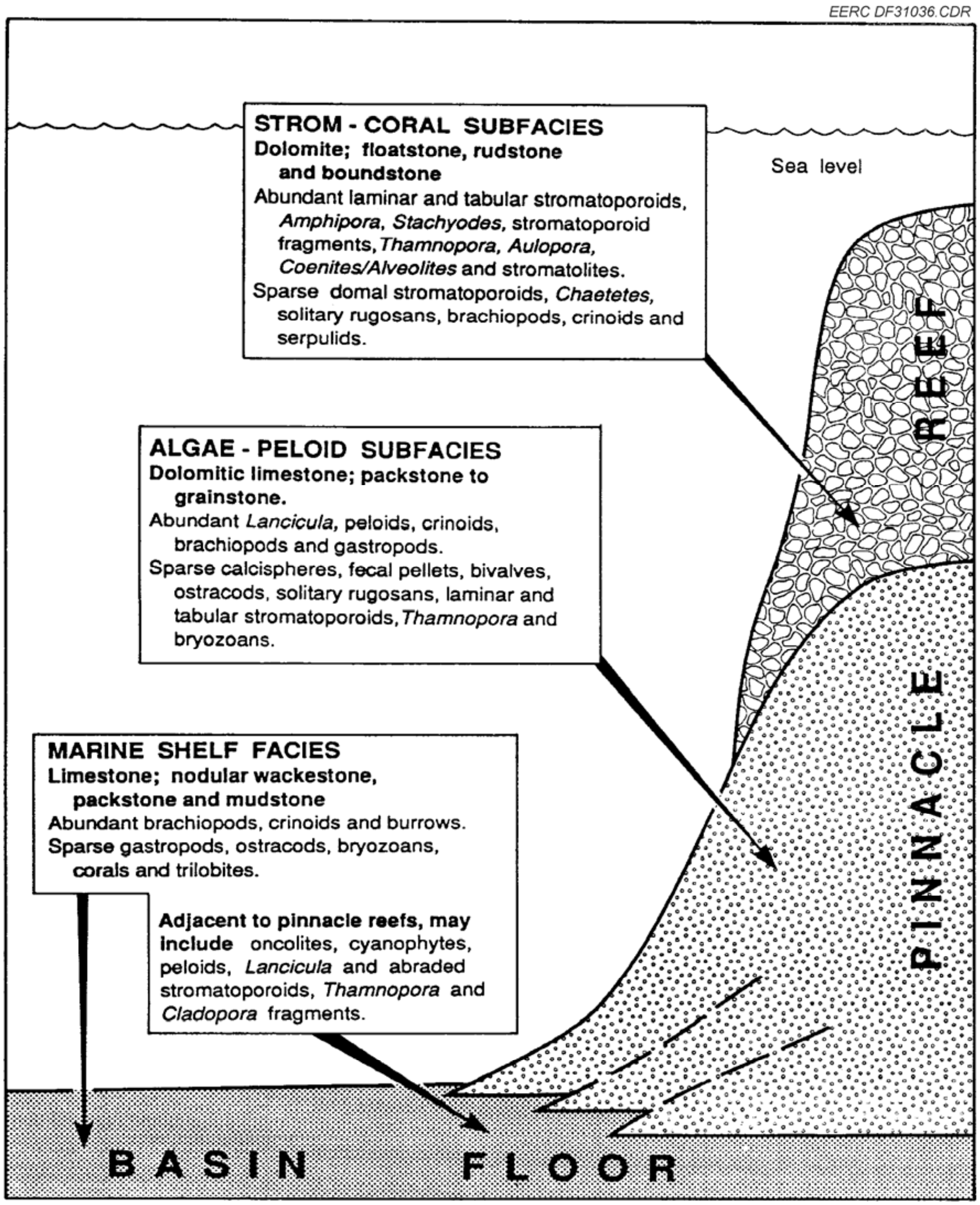

Figure 4. Pinnacle reef facies (Ehrets and Kissling, 1987).

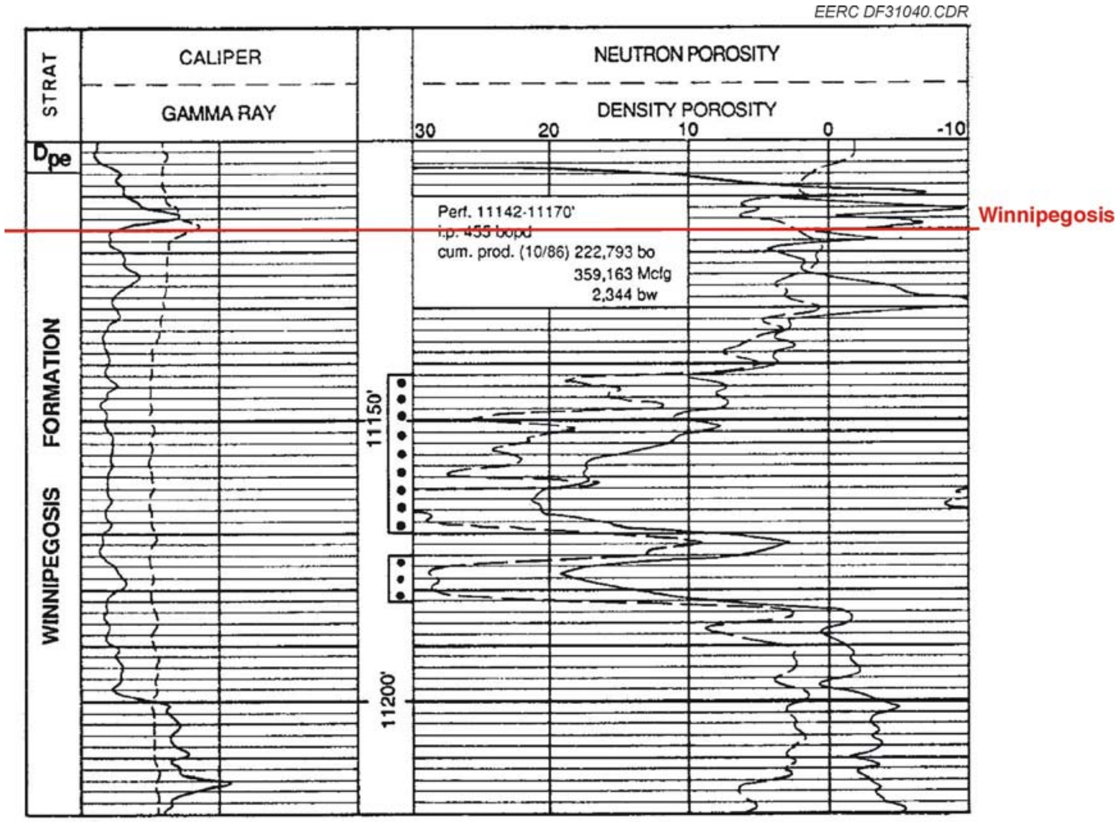

Figure 5. Compensated neutron formation density (CNFD) log characteristics for platform margin reef facies (NDIC No. 10480; Depco No. 22-7 Skarderud; SWNW7-T158N-R95W) (Ehepts and Kissling, 1987).

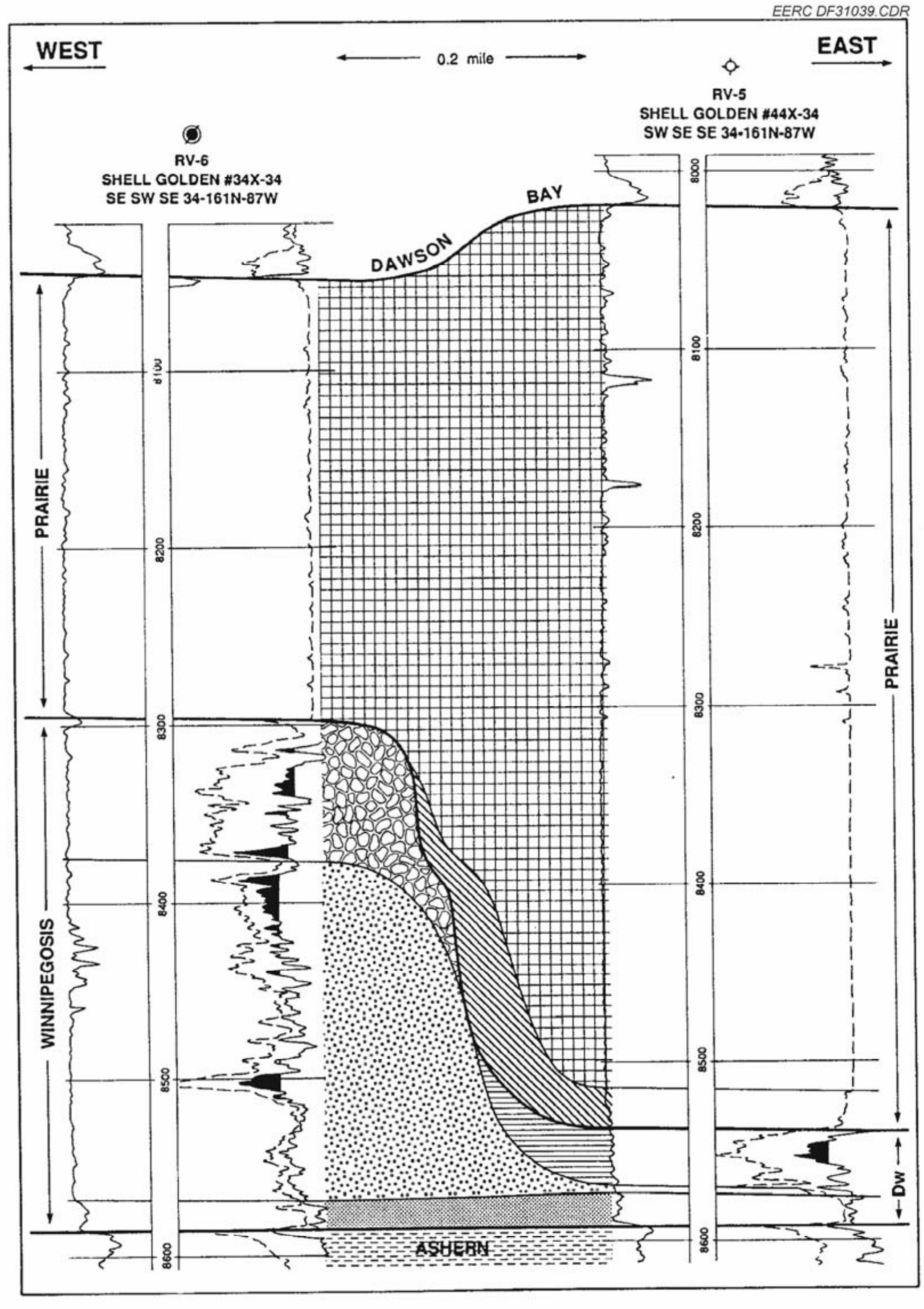

Figure 6. Log characteristic with facies relationship between a pinnacle reef facies (NDIC No. 7976; Shell Oil No. 34x-34 Golden; SESW34-T161N R87W) and off reef (shelf facies of Perrin) facies (NDIC No. 7717; Shell Oil No. 44x-34 Golden; SESE34-T161N-R87W). Darkened log section indicates CNFD log porosity $\geq$ 8% (gamma ray log scale; 1–100 API units; neutron and density porosity scale; −10% to 30%) (Ehrets and Kissling, 1987).

Figure 7 shows the concentration of dissolved solids in water from the Silurian and Devonian rocks (Downey and Dinwiddie, 1988.)

Figure 8 shows the potentiometric surface derived from measurements of head in locally permeable parts of Devonian rocks (Downey and Dinwiddie, 1988).

HYDROCARBON PRODUCTION

Pinnacle reefs produce commercial quantities of oil in the Canadian portion of the Williston Basin but not in North Dakota. Commercial Winnipegosis production has been established in North Dakota along the platform margin at Temple and Hamlet Fields and on the platform in Round Prairie and Moraine Fields.

SINK POTENTIAL

Winnipegosis reefs are excellent local sinks, especially where they are encased by the overlying prairie salt. The reefs are porous and permeable and well encased by impermeable sediments. Estimates of the total number of reefs are not available, but some workers suggest

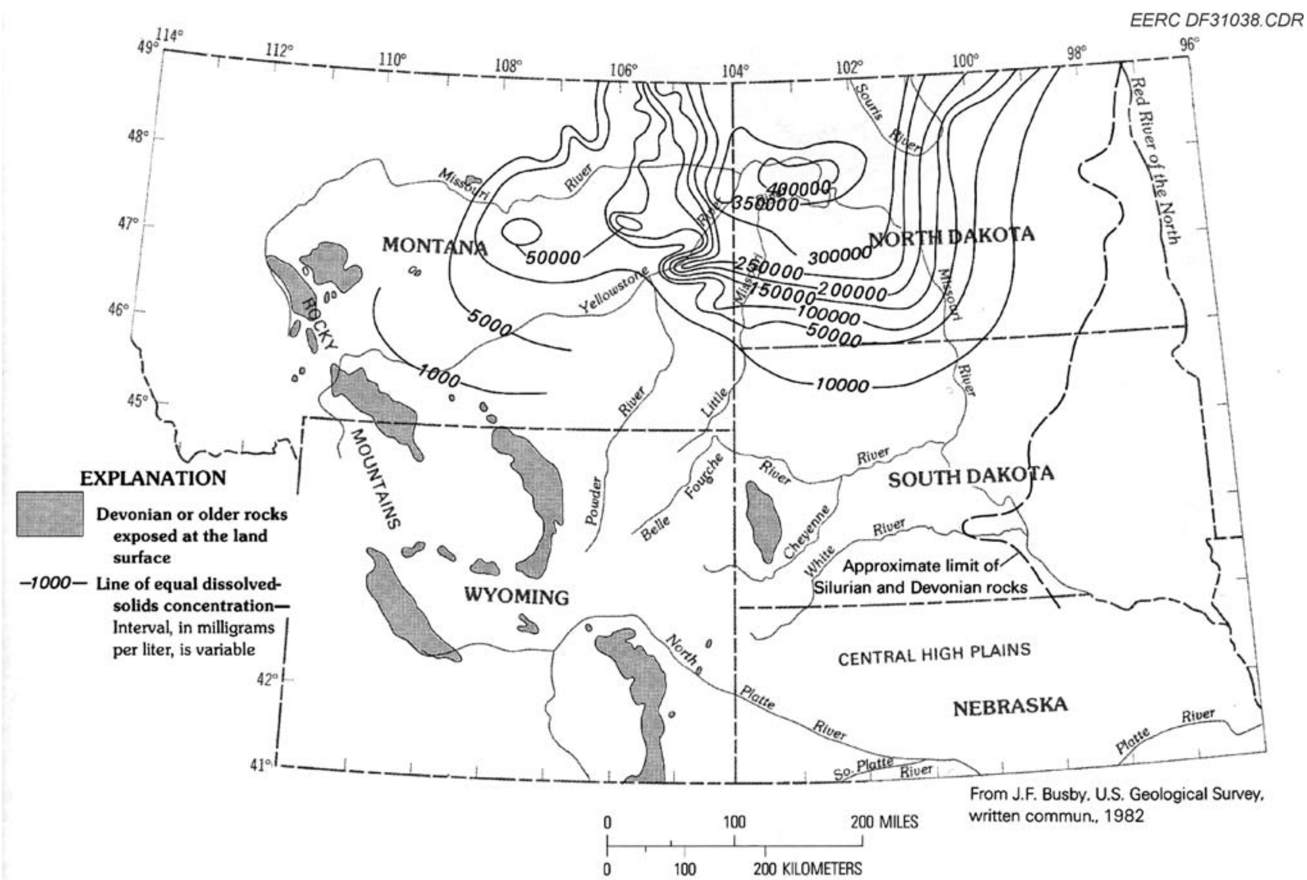

Figure 7. Concentration of dissolved solids in water from the Silurian and Devonian rocks (Downey and Dinwiddie, 1988).

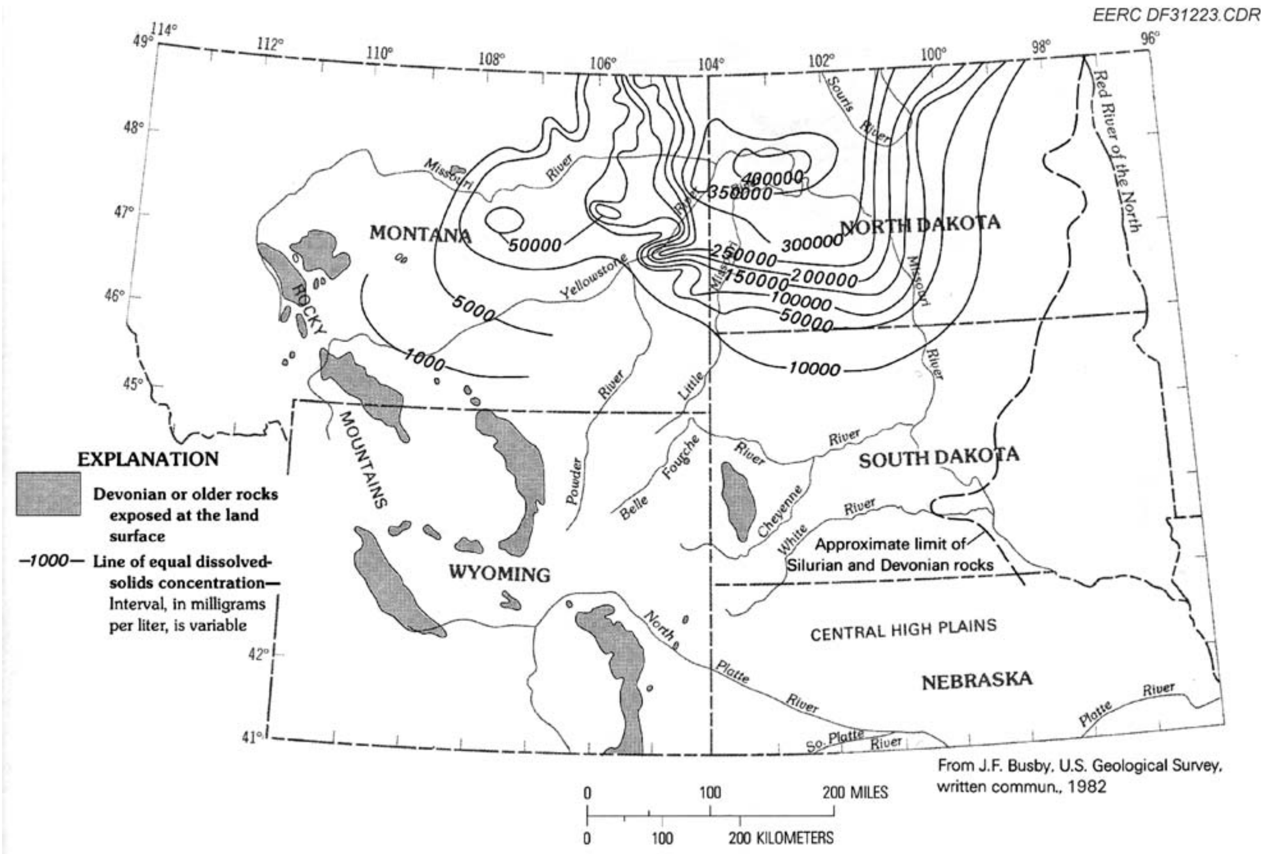

Figure 8. Potentiometric surface derived from measurements of head in locally permeable parts of Devonian rocks (Downey and Dinwiddie, 1988).

they are very numerous and easily identified on seismic. The pinnacle reefs of the Winnipegosis Formation are analogous to those of the Keg River Formation in the Zama oil field of Alberta. A CO_2 sequestration demonstration project in Zama indicates that a single pinnacle reef can have a CO_2 capacity that exceeds 1 million tons (Smith et al., 2007).

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PCOR Partnership

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