Plains CO_2 Reduction (PCOR) Partnership

DEADWOOD 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 the Deadwood Formation 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, and hydrodynamic characteristics. The Deadwood Formation in the Williston Basin is considered to be a potential sink for long-term sequestration of CO_2.

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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 experience to support the PCOR Partnership:

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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 are beyond the scope of the formation outline.

FORMATION NAME

Deadwood 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)

Late Cambrian to early Ordovician Periods (Figure 1)
Albertan to Canadian Epochs
No group status

GEOLOGICAL SEQUENCE

Sauk

HYDROSTRATIGRAPHY (Figure 1)

Cambrian–Ordovician Aquifer System (Downey, 1986; Downey et al., 1987)

GEOGRAPHIC DISTRIBUTION (modified LeRud, 1982)

Williston Basin; southeast Montana, North Dakota, southern Saskatchewan, northeast Wyoming, western South Dakota

THICKNESS

The Deadwood Formation reaches a thickness in excess of 250 ft in west-central North Dakota (Figure 2).

CONTACTS

The upper contact is unconformable with the Black Island Formation of the Winnipeg Group. The lower contact is unconformable with the Precambrian.

LITHOLOGY

Initial deposition was clastic: shales, siltstones, and sandstones.

Later, carbonates were deposited in the basin center: limestones and dolomites.

SUBDIVISIONS

The Deadwood Formation has been informally subdivided into six members (Figure 3). In ascending order, they are the A, B, C, D, E, and F members (LeFever et al., 1987). Members A and B represent the transgressive maximum, while Member F represents the minimum (Figure 4).

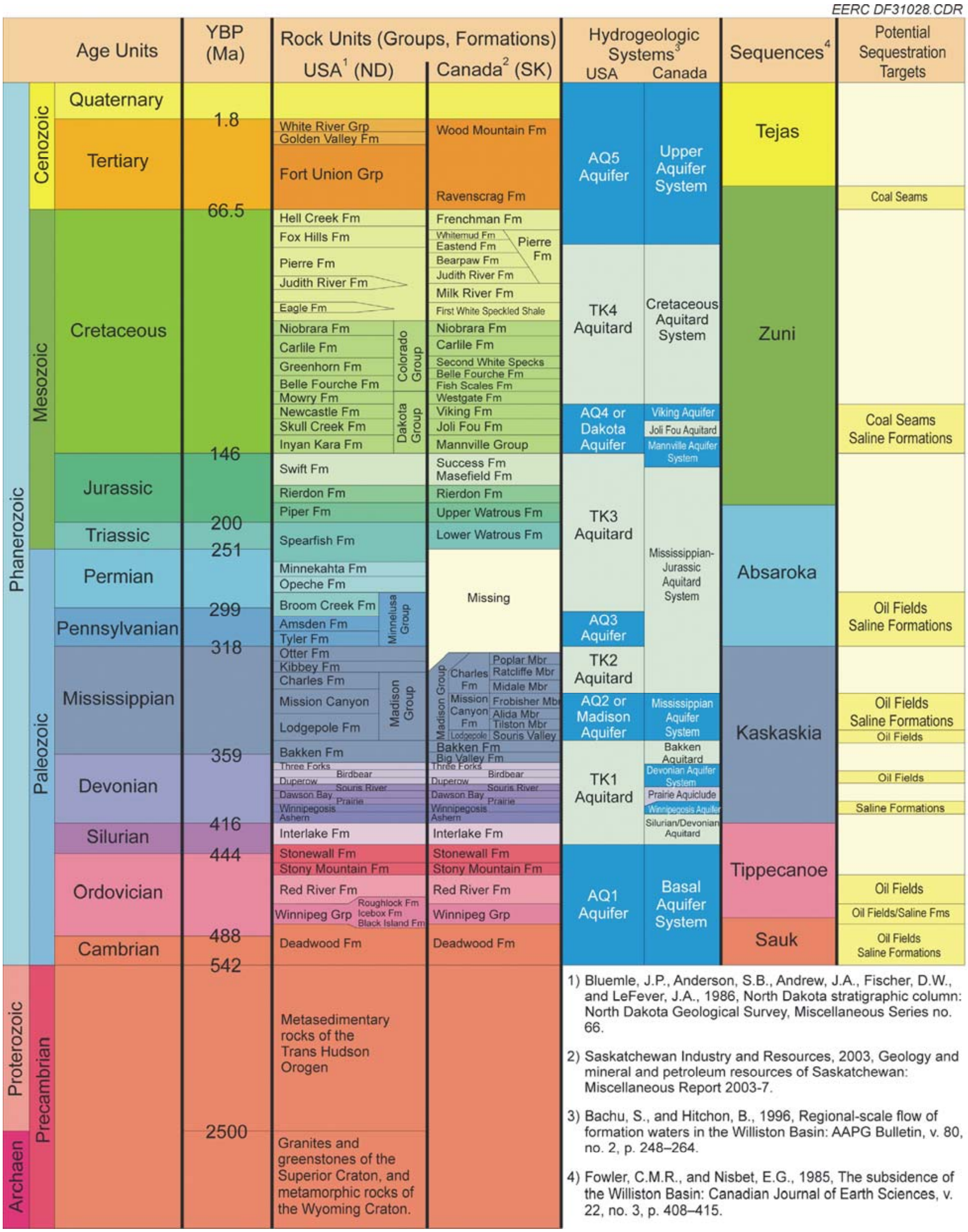

Figure 1. Williston Basin stratigraphic and hydrogeologic column.

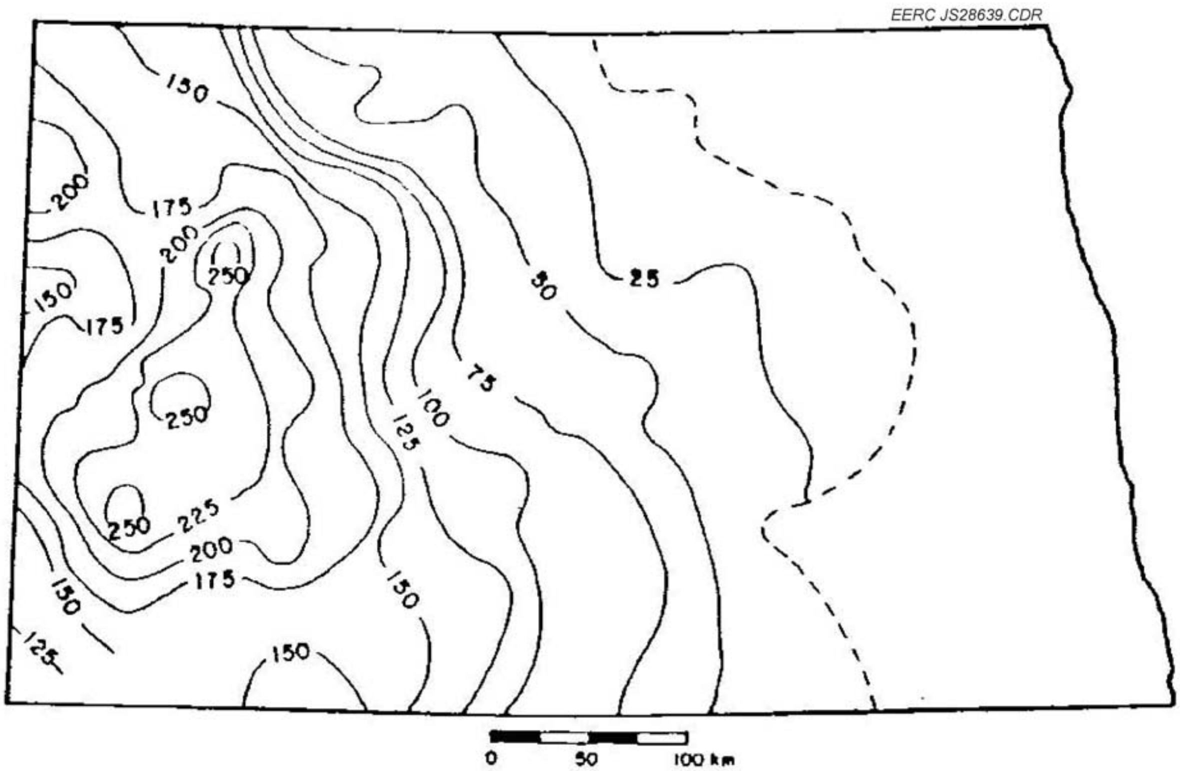

Figure 2. Deadwood isopach in North Dakota (LeFever et al., 1987).

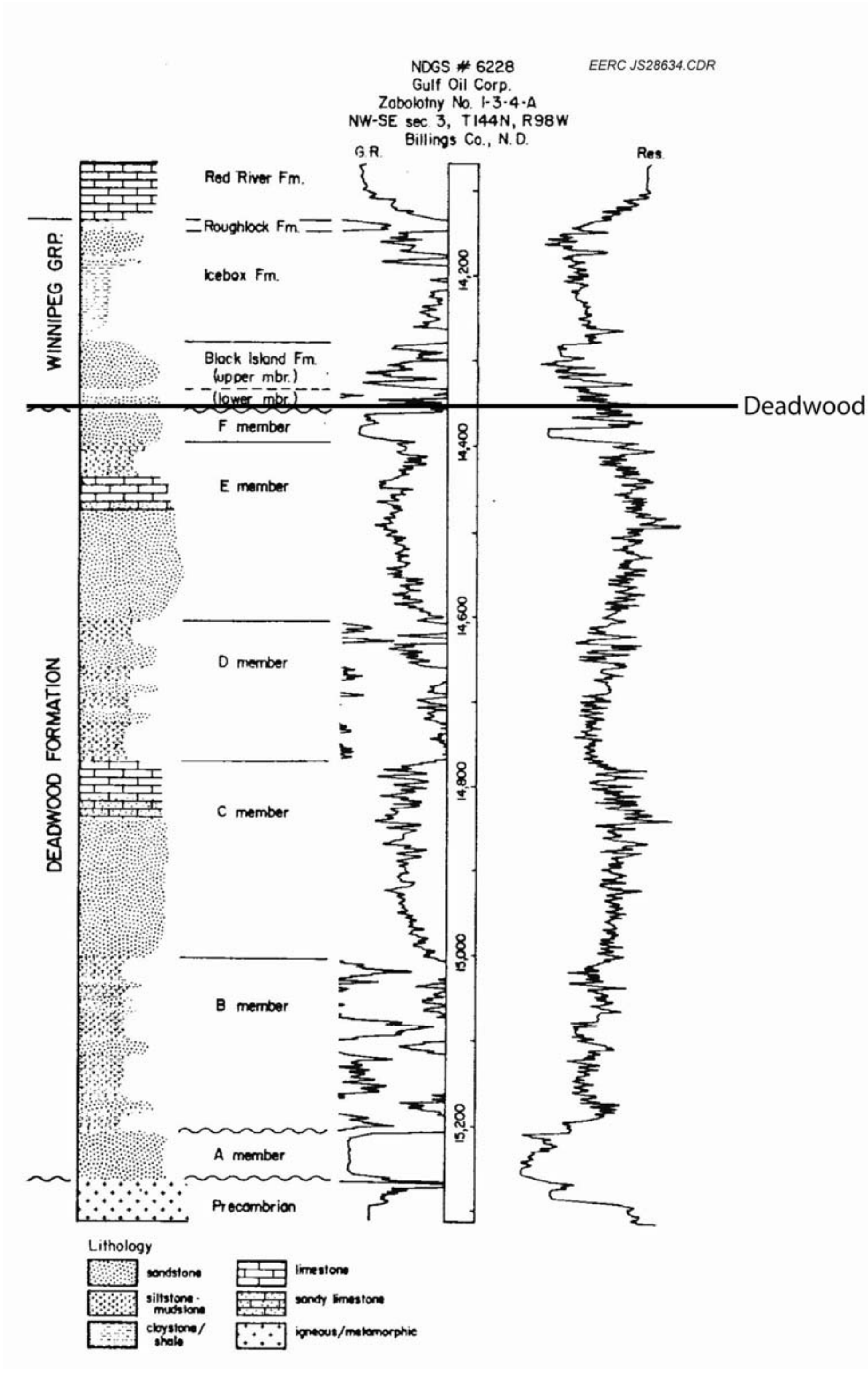

Figure 3. Subdivision of the Deadwood Formation (LeFever et al., 1987).

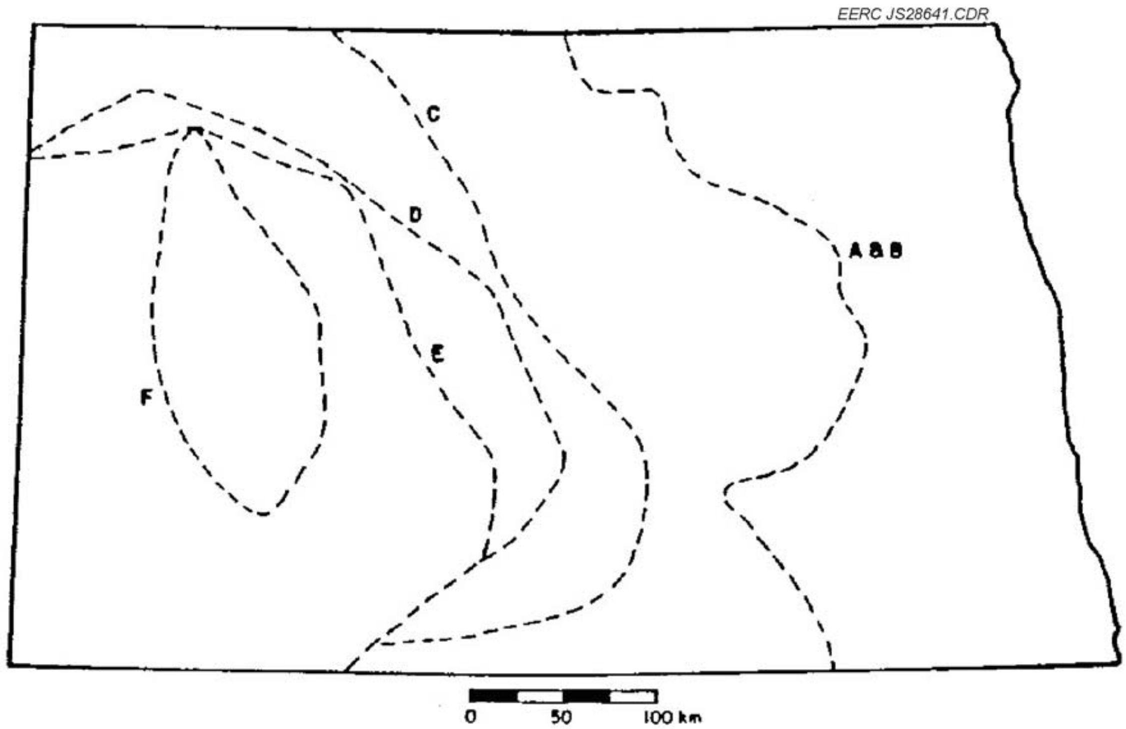

Figure 4. Approximate aerial extent of Deadwood subdivisions (LeFever et al., 1987).

LITHOFACIES (LeFever et al., 1987)

Member A is a basal quartz arenite to glauconitic quartz arenite with minor conglomerate and granite wash. Member B is a glauconitic to quartzose siltstone, very fine sandstone, and minor claystone. Member C is a fine- to medium-grained sandstone with lesser amounts of mudstone and carbonate. Member D is an interbedded siltstone, mudstone, and sandstone, with minor amounts of carbonate. Member E consists of a very fine to coarse-grained sandstone overlain by a thin sandstone–limestone unit and a mottled sandstone–shale unit. Member F is predominantly a very fine to coarse-grained sandstone with minor siltstone, mudstone, and carbonate.

DEPOSITIONAL ENVIRONMENT

Marine to shallow marine

DEPOSITIONAL MODEL

The upper Cambrian Deadwood Formation records both the earliest Phanerozoic sedimentation and the beginning of the Sauk Sequence in the Williston Basin. The Cambrian Sea gradually transgressed eastward into an embayment on the edge of the stable Cordilleran shelf (Carlson, 1960; Lochman-Balk and Wilson, 1967; LeFever et al., 1987). This event was dynamic and included a series of minor regressive and recurrent transgressive events before a major sea-level drop occurred at the end of the Early Ordovician.

Initially, siliciclastic sediments, sands, and shales were deposited as the dominant sediment type in the Williston Basin. During the Lower Ordovician, carbonate sediments began to be deposited in the center of the basin, which had by then formed and begun to subside (LeFever et al., 1987).

RESERVOIR CHARACTERISTICS

The reservoir quality of the Deadwood Formation varies greatly throughout the basin.

There are limited core data available for the A member of the Deadwood Formation.

From data collected, measured porosity can be in excess of 10% and permeabilities can exceed 100 mD (core analysis: NESW 9-163-87; NDIC File No: 6296; API No. 33-075-00718-00-00).

EXAMPLE CORE DATA

Beaver Lodge Field
Core analysis: LT7 1-152-95; NDIC File No.13405; API No. 33-053-02397-00-00.

- Average porosity: 2.6% (maximum porosity: 7.9%).
- Average permeability: 3.26 mD (maximum permeability: 72.3 mD).

HYDRODYNAMIC CHARACTERISTICS (AQ4) (Downey, 1986; Downey et al., 1987)

If hydrodynamic flow exists, it should be from outcrop positions in the Black Hills northeastward into the basin.

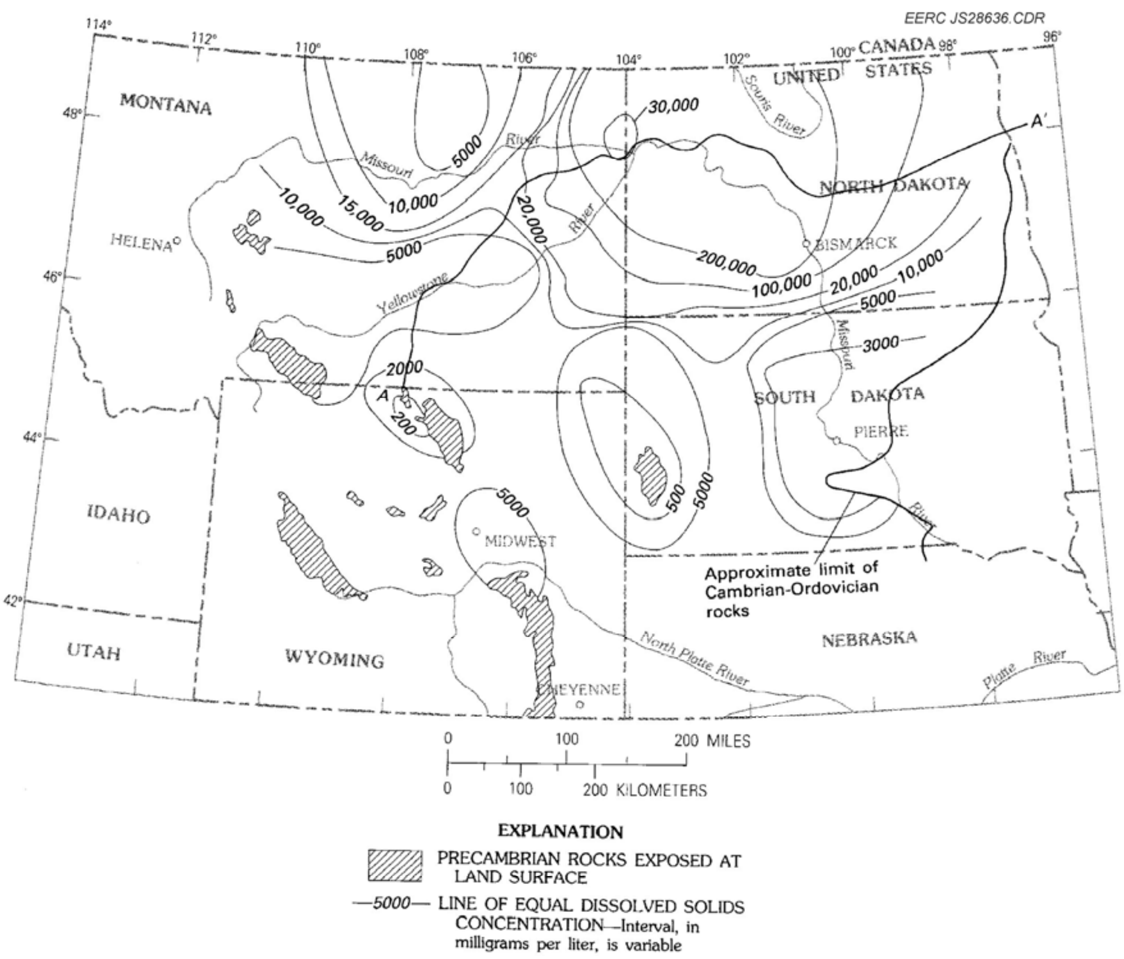

Figure 5. Concentration of dissolved solids in water from the Cambrian–Ordovician Aquifer (Downey, 1986; Downey et al., 1987).

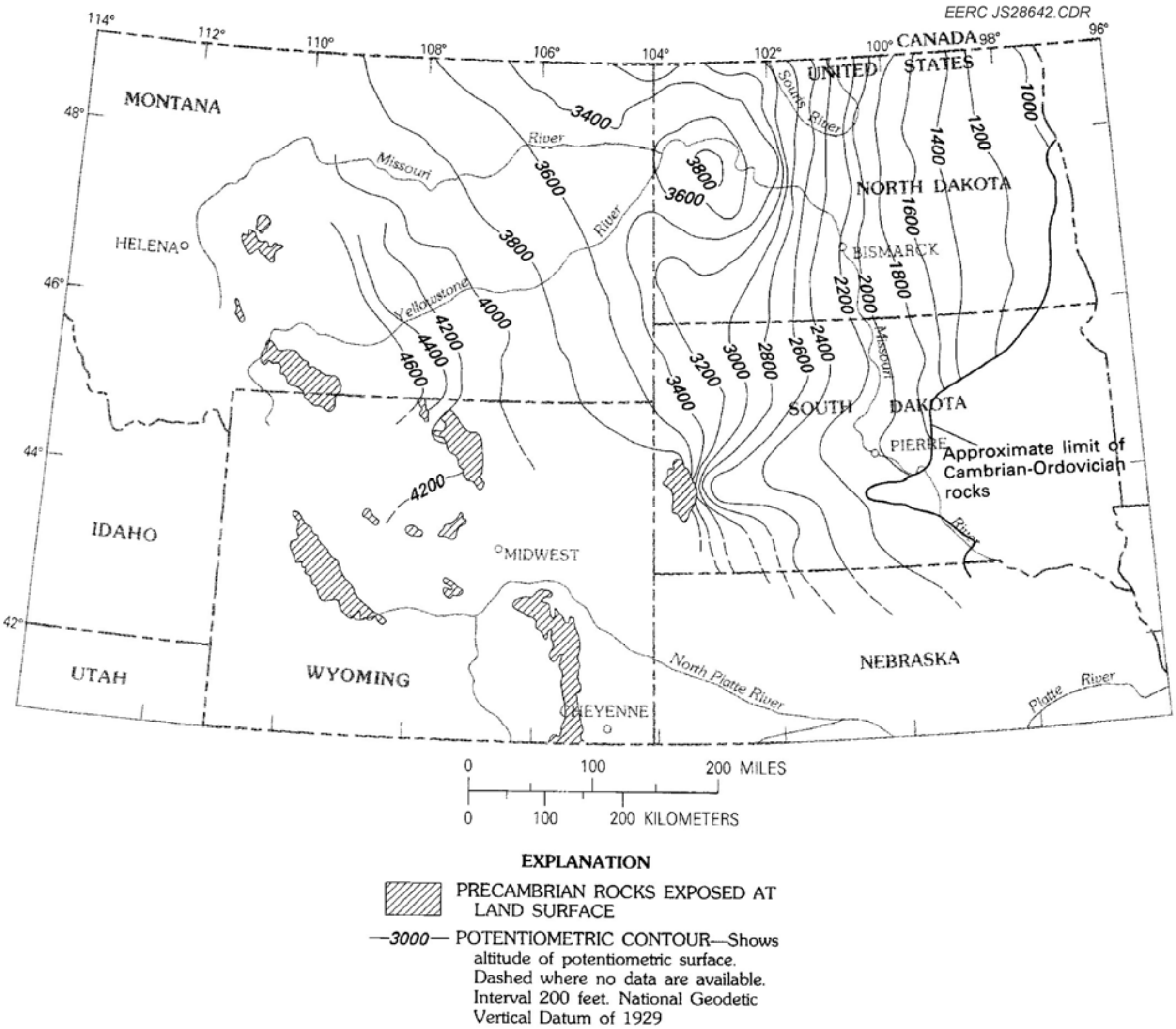

Figure 6. Simulated potentiometric surface of the Cambrian–Ordovician Aquifer (Downey, 1986; Downey et al., 1987).

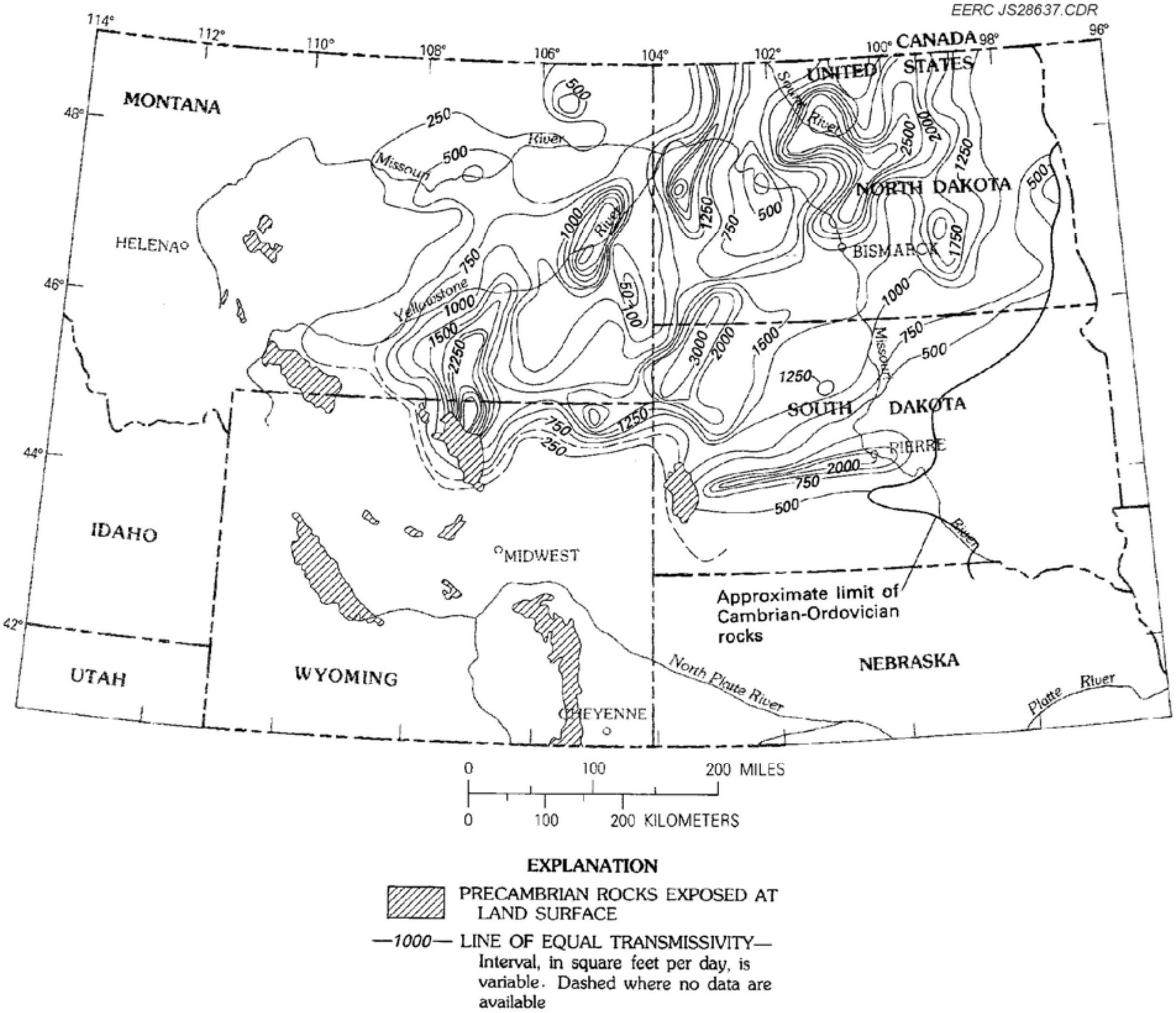

Figure 7. Transmissivity of the Cambrian–Ordovician Aquifer (Downey, 1986; Downey et al., 1987).

HYDROCARBON PRODUCTION

In North Dakota, the Deadwood Formation is productive on the Nesson Anticline in central North Dakota, at Richardton and Taylor Fields on the Heart River Anticline in eastern Stark County, and in Newporte Field in Renville County. Newporte Field is considered by some workers to be an astrobleme.

SINK POTENTIAL

The Deadwood Formation represents potentially important sinks for sequestration of CO_2 in the Williston Basin. The complex stratigraphy, varying from clean quartz sandstones to dirty siltstones and sandstones to carbonates and a relatively closed basin, seems to offer an ideal sequestration target. The single greatest problem in utilizing the Deadwood Formation may be a relative lack of porosity and permeability in the conventional reservoir types and a limited knowledge of porosity distribution.

Presently, Member A represents the obvious and primary interval for CO_2 sequestration within the Deadwood Formation. It also represents the basal unit and maximum extent of the initial trangressive event of the Sauk Sequence and varies in thickness from a few feet to over 150 ft in thickness. An isopach of Member A in North Dakota shows an erratic thickness distribution, resulting from deposition across an eroded and "hummocky" basement. Considering the paucity of Member A penetrations, there appears to be numerous instances of Member A pinching out locally or along major structure (Anderson, 1988).

LeFever and coworkers (1987) identified three major lithologies within Member A: 1) a poorly sorted conglomerate that locally overlies the basement, 2) a very fine to coarse-grained quartz arenite that is well sorted but may contain some thin stringers of clay, and 3) a very fine to coarse-grained glauconitic quartz arenite that is well sorted and may occasionally be interbedded with thin shale laminae.

One potential concern with respect to long-term storage of large volumes of CO_2 is the fact that Member A is believed to be correlative to the basal unit of the Deadwood that outcrops in the Black Hills of South Dakota (LeFever et al., 1987). What is not presently clear is whether the outcrop is continuous with the deeper basin of Member A or isolated because of the rapid stratigraphic variations previously noted. If Member A and the outcrop are connected, there may be sufficient hydrodynamics to effectively isolate the horizon.

A series of vertical traps can be demonstrated within Deadwood Formation Member A. Locally, individual clay lithofacies add a component of trapping. Such clay lithofacies can be identified from well logs.

Regionally, the Icebox Formation of the Winnipeg Group (commonly referred to as the Winnipeg Shale) acts as a trap. The Icebox, primarily a shale, is present throughout most of the Williston Basin.

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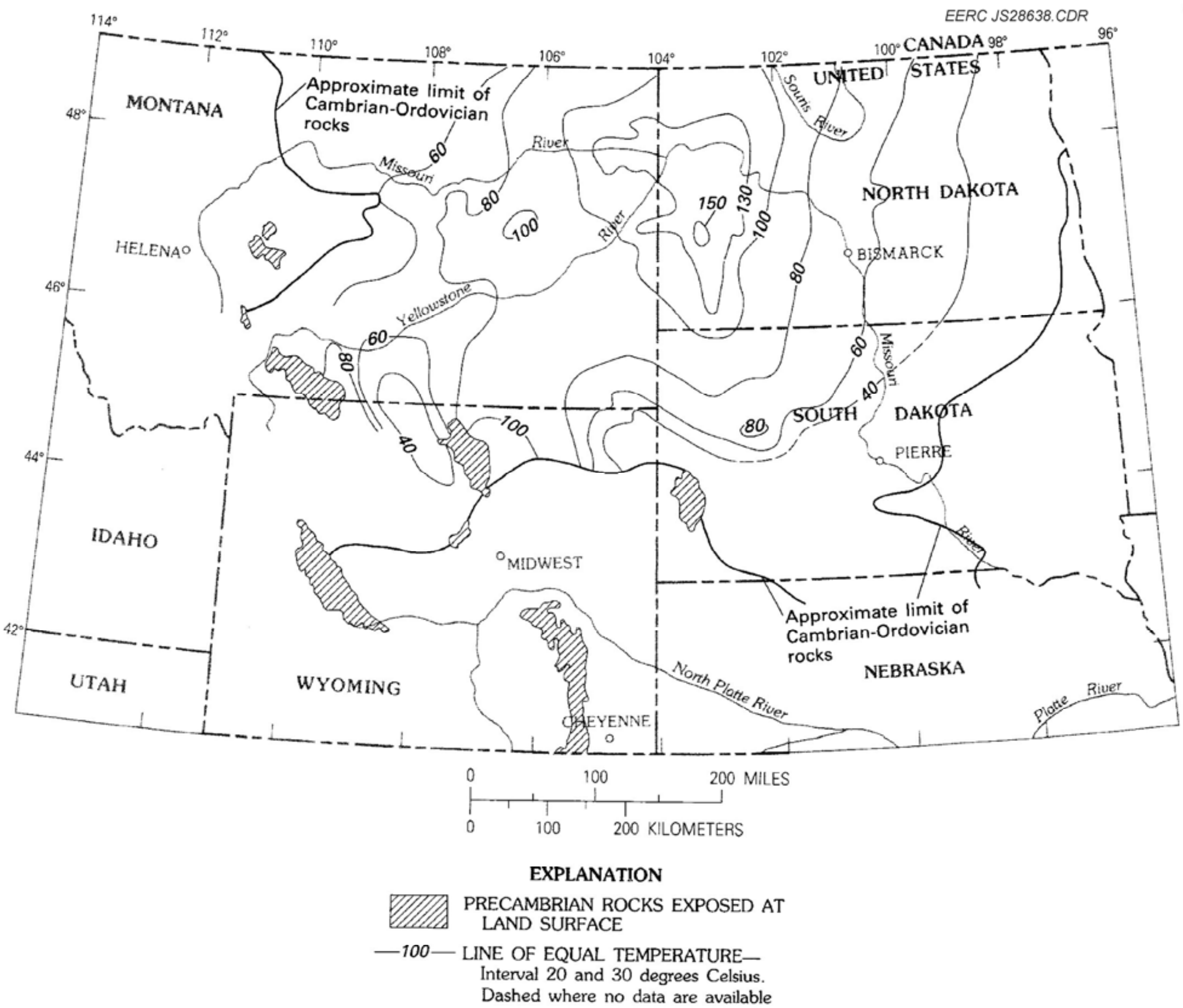

Figure 8. Water temperatures in the Cambrian–Ordovician Aquifer (Downey, 1986).

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