# MISSION CANYON FORMATION OUTLINE

David W. Fischer, Fischer Oil & Gas, Inc.
Julie A. LeFever, North Dakota Geological Survey
Richard D. LeFever, University of North Dakota – Geology/Geological Engineering
Lynn D. Helms, North Dakota Industrial Commission
James A. Sorensen, Energy & Environmental Research Center
Steven A. Smith, Energy & Environmental Research Center
Edward N. Steadman, Energy & Environmental Research Center
John A. Harju, Energy & Environmental Research Center

**May 2005**

## EXECUTIVE SUMMARY

The Williston Basin is a relatively large, intracratonic basin with a thick sedimentary cover in excess of 16,000 ft. The Williston Basin 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 are oil productive.

The Williston 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 outline includes general information and maps on formation stratigraphy, lithology, depositional environment, hydrodynamic characteristics, and hydrocarbon occurrence. The Mission Canyon Formation has potential to be a $CO_2$ sink through either enhanced oil recovery or saline aquifer storage.

## ACKNOWLEDGMENTS

The PCOR Partnership is a collaborative effort of public and private sector stakeholders working toward a better understanding of the technical and economic feasibility of capturing and storing (sequestering) anthropogenic 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 (NETL) Regional Carbon Sequestration Partnership (RCSP) Program. The Energy & Environmental Research Center (EERC) would like to thank the following partners who provided funding, data, guidance, and/or experience to support the PCOR Partnership:

- Alberta Department of Environment
- Alberta Energy and Utilities Board
- Alberta Energy Research Institute
- Amerada Hess Corporation
- Basin Electric Power Cooperative
- Bechtel Corporation
- Center for Energy and Economic Development (CEED)
- Chicago Climate Exchange
- Dakota Gasification Company
- Ducks Unlimited Canada
- Eagle Operating, Inc.
- Encore Acquisition Company
- Environment Canada
- Excelsior Energy Inc.

- Fischer Oil and Gas, Inc.
- Great Northern Power Development, LP
- Great River Energy
- Interstate Oil and Gas Compact Commission
- Kiewit Mining Group Inc.
- Lignite Energy Council
- Manitoba Hydro
- Minnesota Pollution Control Agency
- Minnesota Power
- Minnkota Power Cooperative, Inc.
- Montana–Dakota Utilities Co.
- Montana Department of Environmental Quality
- Montana Public Service Commission
- Murex Petroleum Corporation
- Nexant, Inc.
- North Dakota Department of Health
- North Dakota Geological Survey
- North Dakota Industrial Commission Lignite Research, Development and Marketing Program
- North Dakota Industrial Commission Oil and Gas Division
- North Dakota Natural Resources Trust
- North Dakota Petroleum Council
- North Dakota State University
- Otter Tail Power Company
- Petroleum Technology Research Centre
- Petroleum Technology Transfer Council
- Prairie Public Television
- Saskatchewan Industry and Resources
- SaskPower
- Tesoro Refinery (Mandan)
- University of Regina
- U.S. Department of Energy
- U.S. Geological Survey Northern Prairie Wildlife Research Center
- Western Governors' Association
- Xcel Energy

The EERC also acknowledges the following people who assisted in the review of this document:

Erin M. O'Leary, EERC
Tom Heck, Consulting Geologist, Denver
Kim M. Dickman, EERC
Steph L. Wolfe, EERC

## 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). They provide a summary, in outline form, of the current knowledge of the basic geology for each formation. If not specifically noted, the formation boundaries and name reflect terminology that is recognized in the North Dakota portion of the Williston Basin.

The 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 paper 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 to be part of a large regional GSU or confining unit, while others will 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 we are referring to $CO_2$ sequestration reservoirs as "sequestration units," based on accepted legal terminology or protocol currently in use in the petroleum industry. Injection of $CO_2$ will require joint operating agreements which will necessitate the establishment of unitized lands for $CO_2$ sequestration, whether they are in petroleum reservoirs, saline aquifers, or coalbeds.

Two main categories of GSU 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; nonconventional 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 (Figures 1 and 2). The distinction between conventional and nonconventional 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 **will** 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; they will be the trapping mechanism for injected fluids. Unconventional GSUs, because of the inherent lack of permeability, may be self-trapping.

- Conventional GSUs will not need expensive stimulation procedures and, therefore, will 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 would be a regional GSU with lateral continuity. It would 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 would be less continuous, and perhaps isolated and capable of sequestering a 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 will be transportation and well costs. Smaller sinks that are stacked above 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 mapping of those units will be necessary.

## FORMATION NAME

Mission Canyon
Madison Group

## FORMATION AGE (Lerud, 1982)

Mississippian
Osagian to Meramerican

## GEOLOGICAL SEQUENCE

Kaskaskia

## GEOSTRATIGRAPY

Downey, 1984: AQ2 Aquifer
Bachu and Hitchon, 1996: Mississippian Aquifer system

## GEOGRAPHIC DISTRIBUTION (modified from Lerud, 1982)

Montana, South Dakota, North Dakota, southwestern Manitoba, southern Saskatchewan Williston Basin (Figure 1)

## THICKNESS

In the Williston Basin, the Mission Canyon reaches a maximum thickness in excess of 700 ft (213.4 m) (Carlson and LeFever, 1987).

## CONTACTS (after Heck, 1979)

The upper contact with the Charles Formation is conformable, except along the eastern basin margin.

The lower contact with the Lodgepole Formation is conformable, except along the eastern basin margin.

## SUBDIVISIONS

The Mission Canyon has been subdivided into two intervals: the Frobisher–Alida and the Tilston (Figure 2; Example wireline log). The Frobisher–Alida interval overlies the Tilston and has been further subdivided into a number of informal, wireline log-defined intervals (Harris et al., 1965; Voldseth, 1987). In ascending order, they are the Landa, Wayne, Glenburn, Mohall, Sherwood, Bluell, Coteau, Dale, and Rival (Figure 3).

## LITHOLOGY

Primary: carbonate
Secondary: evaporite

## LITHOFACIES

Numerous lithofacies are present in the Mission Canyon Formation. Among those lithofacies similar ones have been recognized by various workers (Lindsay, 1988; Shanley, 1983; Petty, 1988; Potter, 1995; and Hendricks et al., 1987). Petty (1988) describes six major facies in his study of the formation:

- Facies I: anhydrite, stromatolitic mudstone

- Facies II: burrowed mudstone-wackestone, stromatolitic mudstone
- Facies III: peloidal-pisolitic-intraclastic grainstone/packstone or peloidal-oolitic-skeletal grainstone
- Facies IV: burrowed mudstone
- Facies V: burrowed skeletal wackestone or packstone
- Facies VI: skeletal grainstone

Facies distribution is difficult to predict because it represents a continuum of sediments deposited in a depositional system that changes rapidly.

Porosity and permeability in the Mission Canyon is determined in part by depositional facies (Lindsay, 1988; Petty, 1988). It is, therefore, difficult to predict and varies greatly between individual wells (Figure 4; Mission Canyon porosity and permeability crossplots).

## DEPOSITIONAL ENVIRONMENT

Marine

## DEPOSITIONAL MODEL

Deposition occurred in environments that ranged from open marine to coastal sabkha or salina and recorded a major regressive sequence (Lindsay, 1988; Kent et al., 1988). Within that regressive event, repetitive carbonate shoaling-upward cycles are recognized. A simplified and idealized cross section basinward from the shoreline (Figure 5) would include sabkha evaporites, lagoonal mudstones and wackestones, shoreline and island barrier grainstones to packstones, flanked by intra-island wackestones to packstones, and wackestones to mudstones of the basin center (modified from Lindsay, 1988; Petty, 1988).

## RESERVOIR CHARACTERISTICS

From Lindsay (1988)
Northcentral North Dakota (Nesson anticline trend)
Average field porosity: 8%
Average field permeability: 7 md
Northeast producing North Dakota (basin margin trend)
Average field porosity: 13%
Average field permeability: 32 md

From Petty (1988)
Southwestern North Dakota (Billings Nose trend)
Average field porosity: 13.3%–19.8%
Average permeability: 3.7–27 md

From Kent et al. (1988)
Southeast Saskatchewan (basin margin trend)
Average field porosity: 9%–13%
Average permeability: 5–100 md

## HYDRODYNAMIC CHARACTERISTICS

- Flow direction in the Madison Group is assumed to reflect the Mission Canyon flow. Madison Group flow is generally to the east–northeast (Downey, 1984; Downey et al., 1987, Downey and Dinwiddle, 1988; LeFever, 1998; Bachu and Hitchon, 1996).
- Figure 6; potentiometric map (Downey, 1984).
- Figure 7; flow direction map (Downey, 1984).
- Transmissivity from 3500 $ft^2$ (325 $m^2$)/day to less than 250 $ft^2$ (23.2 $m^2$)/day (Downey, 1984).
- Figure 8; transmissivity (Downey, 1984).
- Total dissolved solids (TDS) can be in excess of 300,000 mg/L (2.5 lb/gal) (Downey, 1984).
- Figure 9; TDS concentrations (Downey, 1984).
- Water temperature in the Madison Group can be in excess of 130°C (266°F).
- Figure 10; water temperature map (Downey, 1984).
- Flow rates are generally low, ranging from less than 2 to 70 ft (0.6—21 m)/yr.

- Figure 11; rates of groundwater flow (Downey, 1984).

## HYDROCARBON PRODUCTION

Approximately 60% of the oil produced in North Dakota according to the North Dakota Geological Survey (NDGS; www.oilgas.nd.gov) has come from the Charles and Mission Canyon Formations. (Figure 12; Location of Mission Canyon production).

Lindsay (1988) and Hendricks and others (1987) identified four main types of Mission Canyon traps: 1) combination structural and stratigraphic traps, 2) porous carbonate (usually an island or shoal) pinching out updip into impermeable (intertidal or interisland) carbonate, 3) porous carbonate facies changing updip into impermeable anhydrite, and 4) truncated porous carbonate capped by impermeable Triassic rocks.

## SEQUESTRATION POTENTIAL

Primary
Conventional

## SINK CHARACTERIZATION

There is potential to use $CO_2$ in tertiary oil recovery projects in many of the Mission Canyon oil fields in the Williston Basin.

Although there is great variability in reservoir development and distribution, the Mission Canyon is potentially a significant sink for the sequestration of $CO_2$. Regional work in the Madison Group by Downey (1984) shows a significant part of the total Madison interval to be porous (Figure 13; Porosity distribution in the Madison Aquifer). Continuity of porosity is either present or enhanced by fractures.

## TRAP CHARACTERIZATION

A competent top seal is present over the Mission Canyon throughout much of the Williston Basin. Downey (1984), Downey et al. (1987), and Bachu and Hitchon (1996) have interpreted and categorized the overlying rocks (primarily evaporites, halites, and nonporous carbonates) of the Mississippian Charles Formation as part of a regional trap (aquitard) system (Figure 14). On the eastern portion of the eastern edge of the Williston Basin, the overlying trap is weak or absent (Figure 14), and leakage will occur. Vertical leakage may also occur along inherent structural zones of weakness or lineaments (Figure 15).

A competent bottom seal is also present throughout much of the basin. Downey (1984), Downey et al. (1987), and Bachu and Hitchon (1996) have interpreted and categorized much of the Paleozoic section immediately underlying the Mission Canyon as part of an aquitard system that includes the tight and impermeable shales of the Bakken Formation.

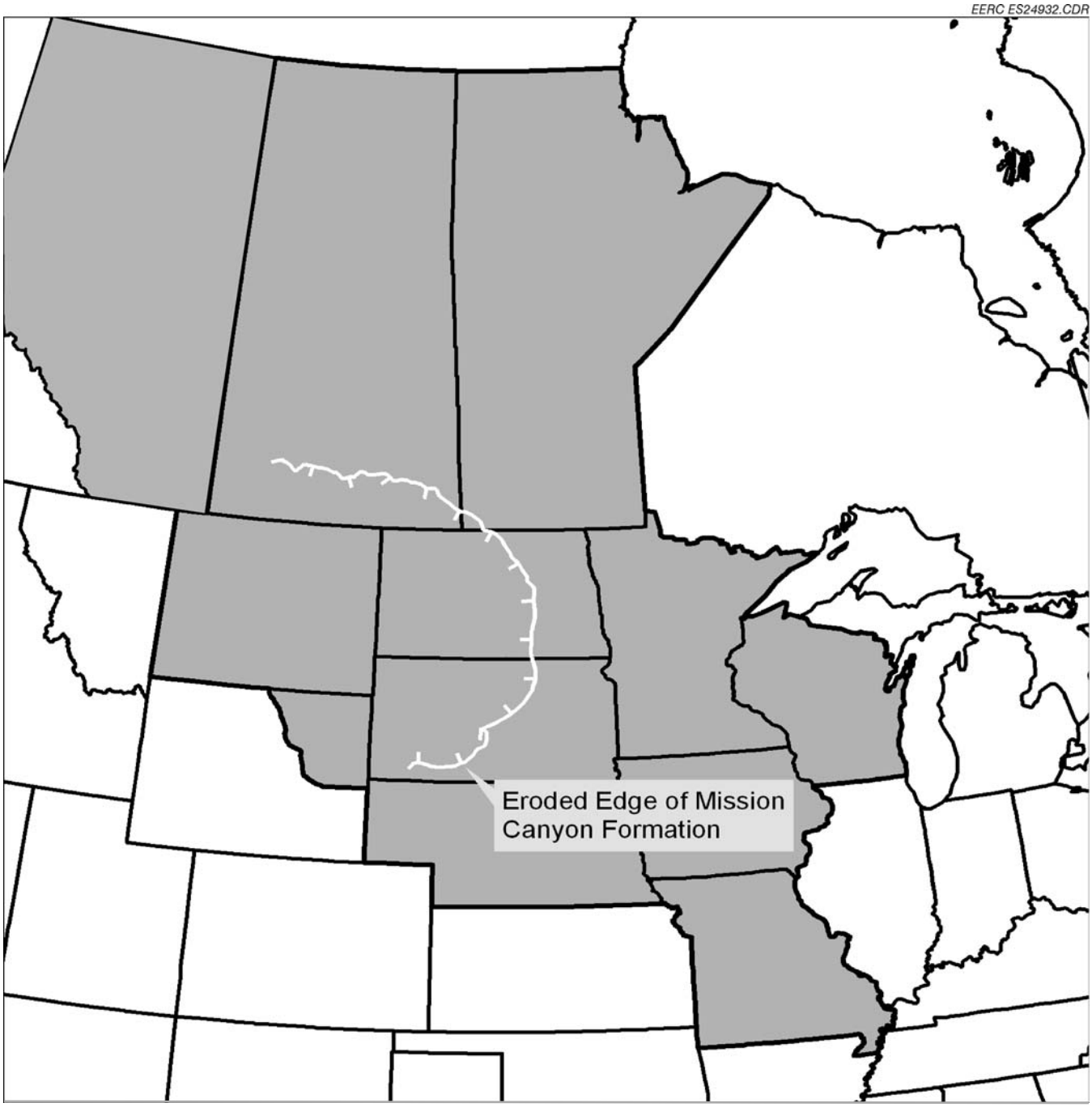


Figure 1. Geographic distribution of the Mission Canyon (modified from Lindsay, 1988).

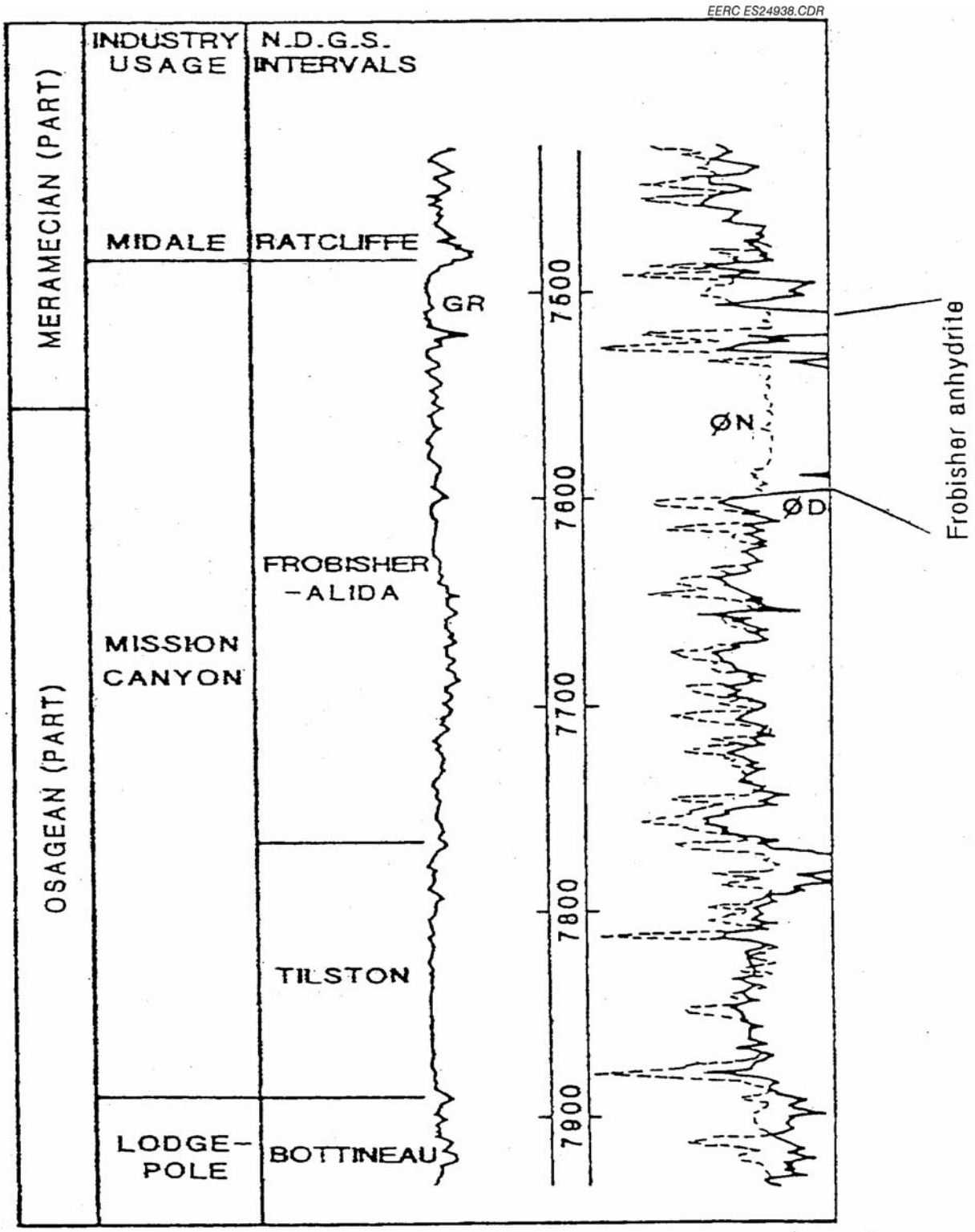


Figure 2. Example wireline log (compensated neutron formation density) for the Mission Canyon (modified from Petty, 1988); NDIC Well No. 7930; Section 32, Township 131, North Range 98 West; Ray (GR) scale 0–100 API; porosity scale 0–30%.

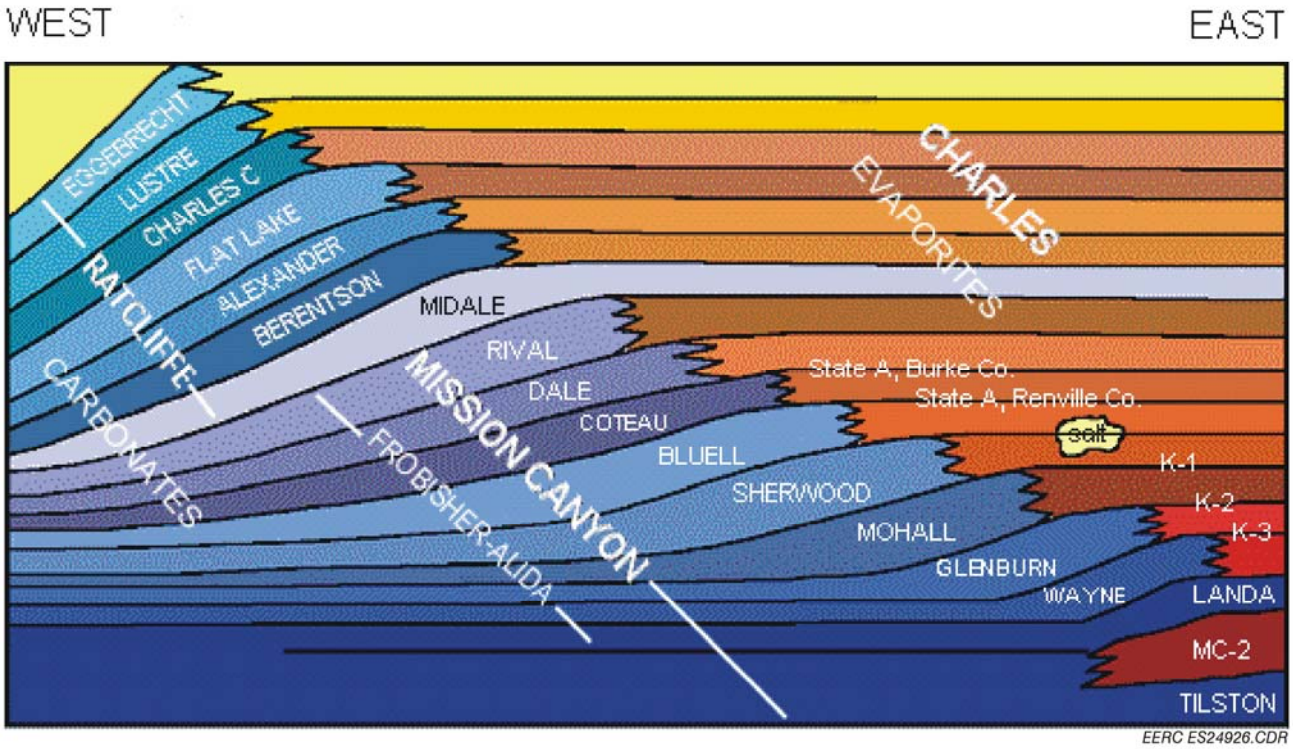


Figure 3. Facies relationships and nomenclature of the Mission Canyon and Charles Formations in the Williston Basin (modified from Hendricks et al., 1988; Voldseth, 1986; Harris et al., 1966). The blue colors represent carbonate rocks, and the reds and yellows represent evaporites (modified from "Overview of the Petroleum Geology of the Williston Basin," NDGS Web site).

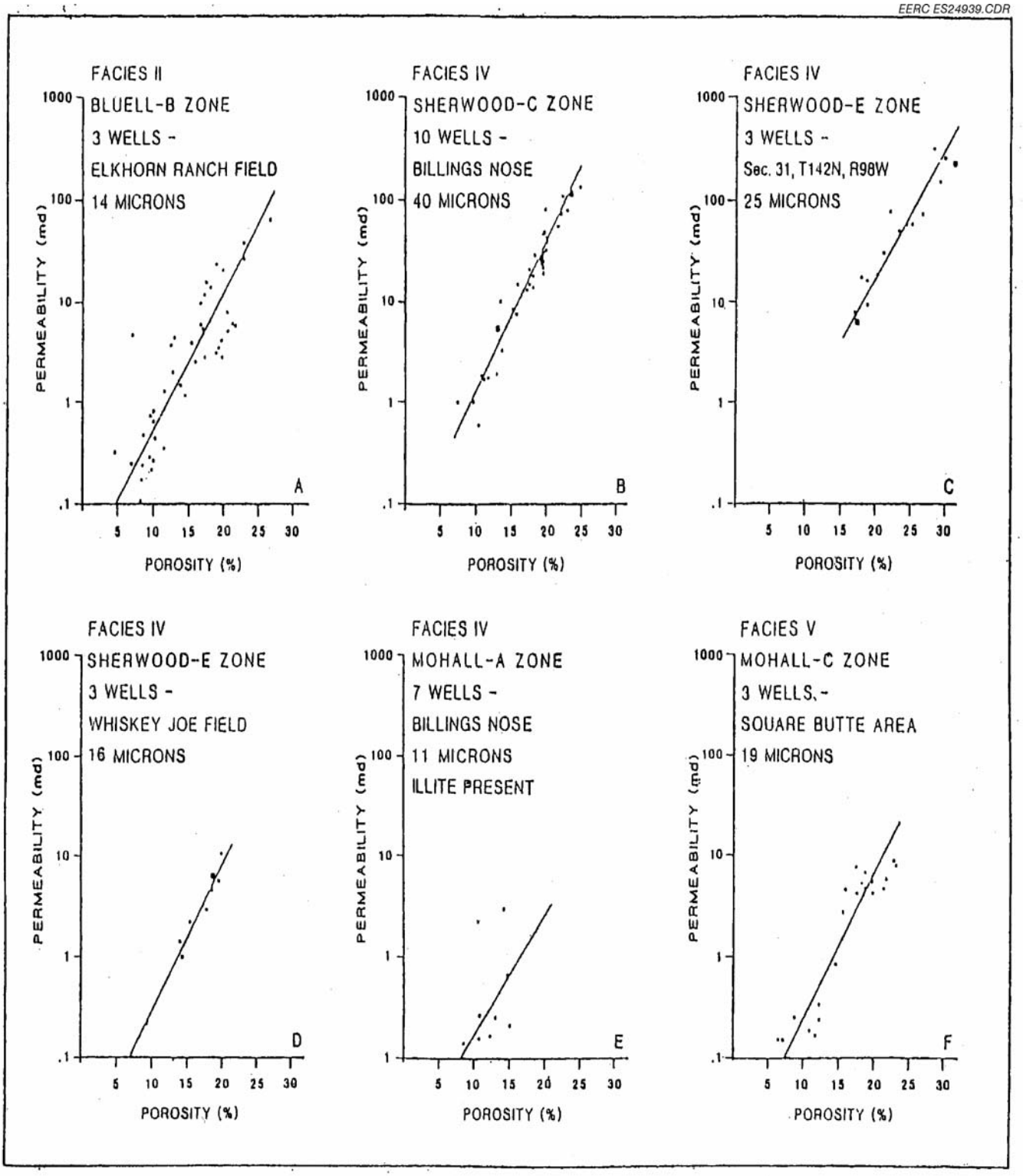


Figure 4. Mission Canyon porosity and permeability crossplots (Petty, 1988).

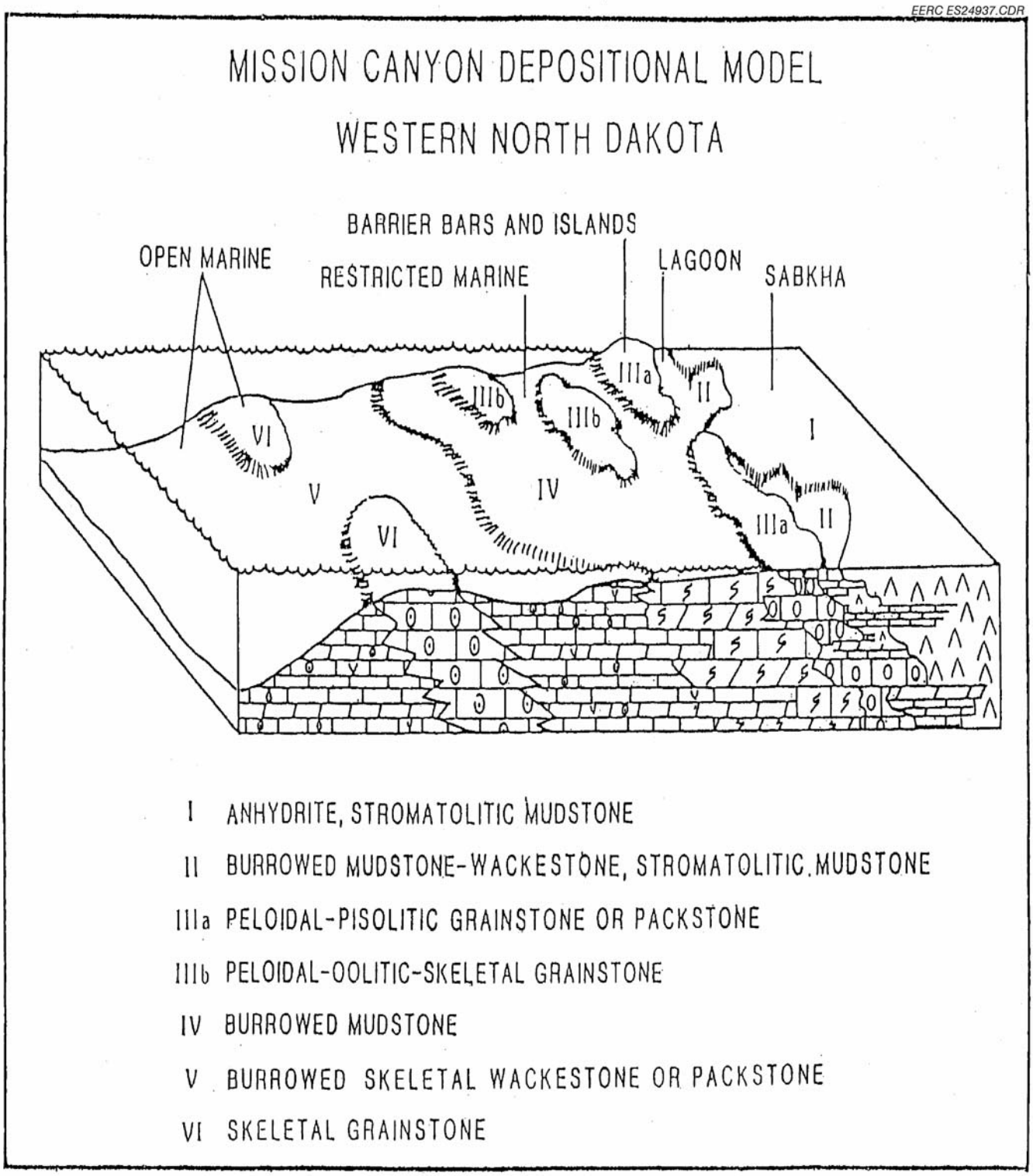


Figure 5. Mission Canyon depositional model (taken from Petty, 1988).

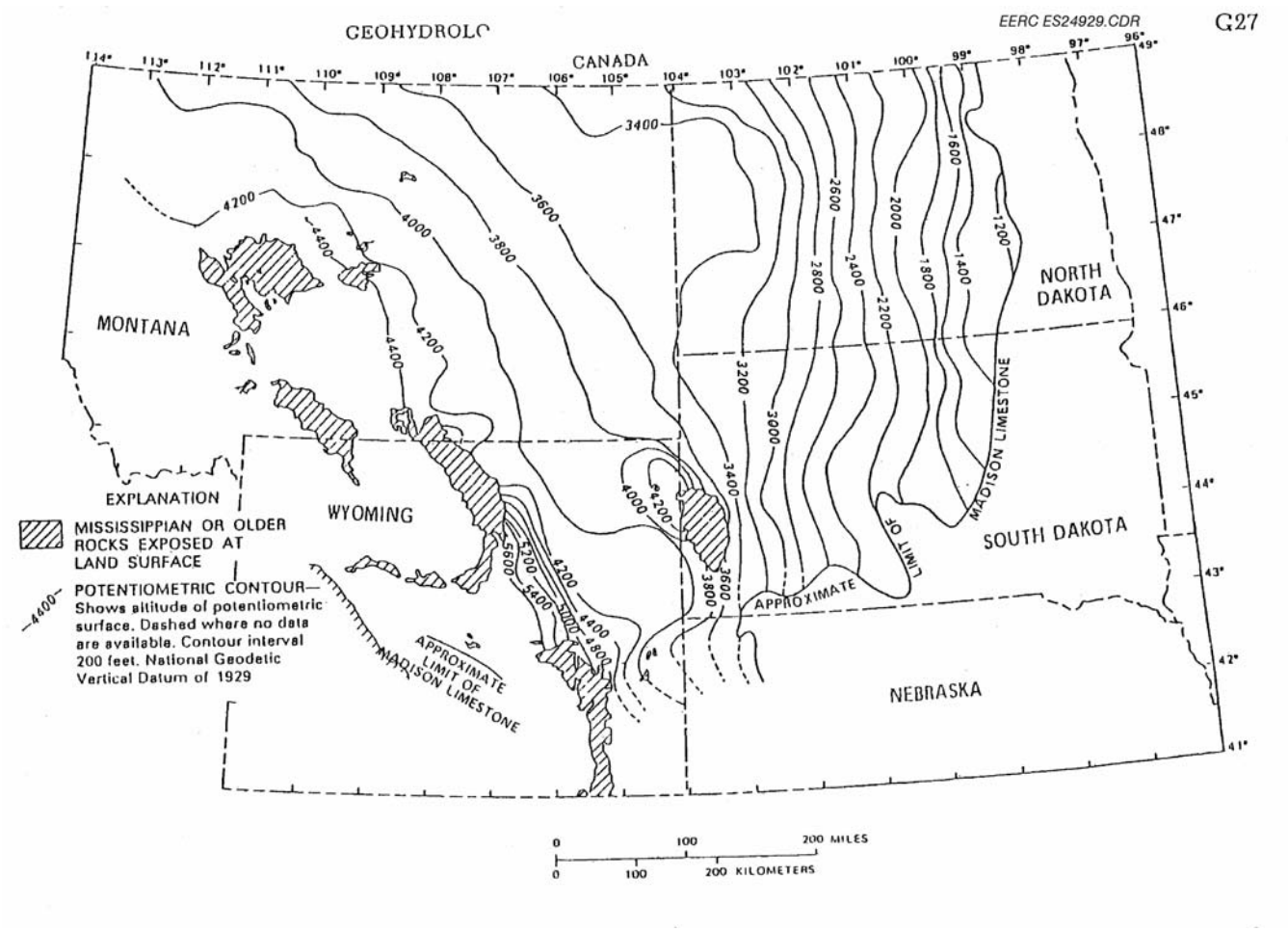


Figure 6. Madison Aquifer (Mission Canyon and Lodgepole Formations) potentiometric surface (Downey, 1984).

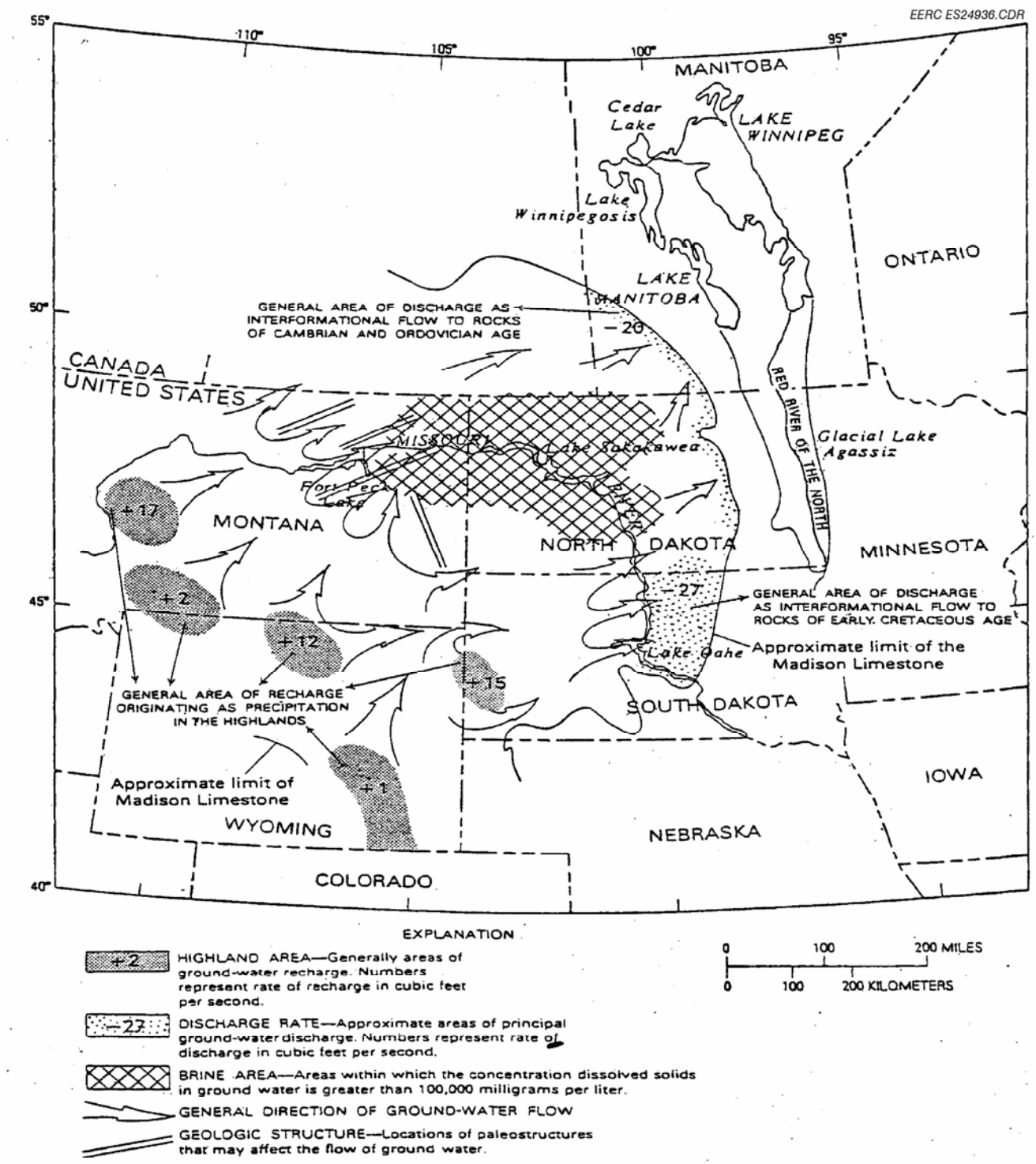


FIGURE 39.—Predevelopment flow directions, recharge areas, and discharge areas in the Madison aquifer (AQ2) as determined through simulation.

Figure 7. Madison Aquifer (Mission Canyon and Lodgepole Formations) flow direction (Downey, 1984).

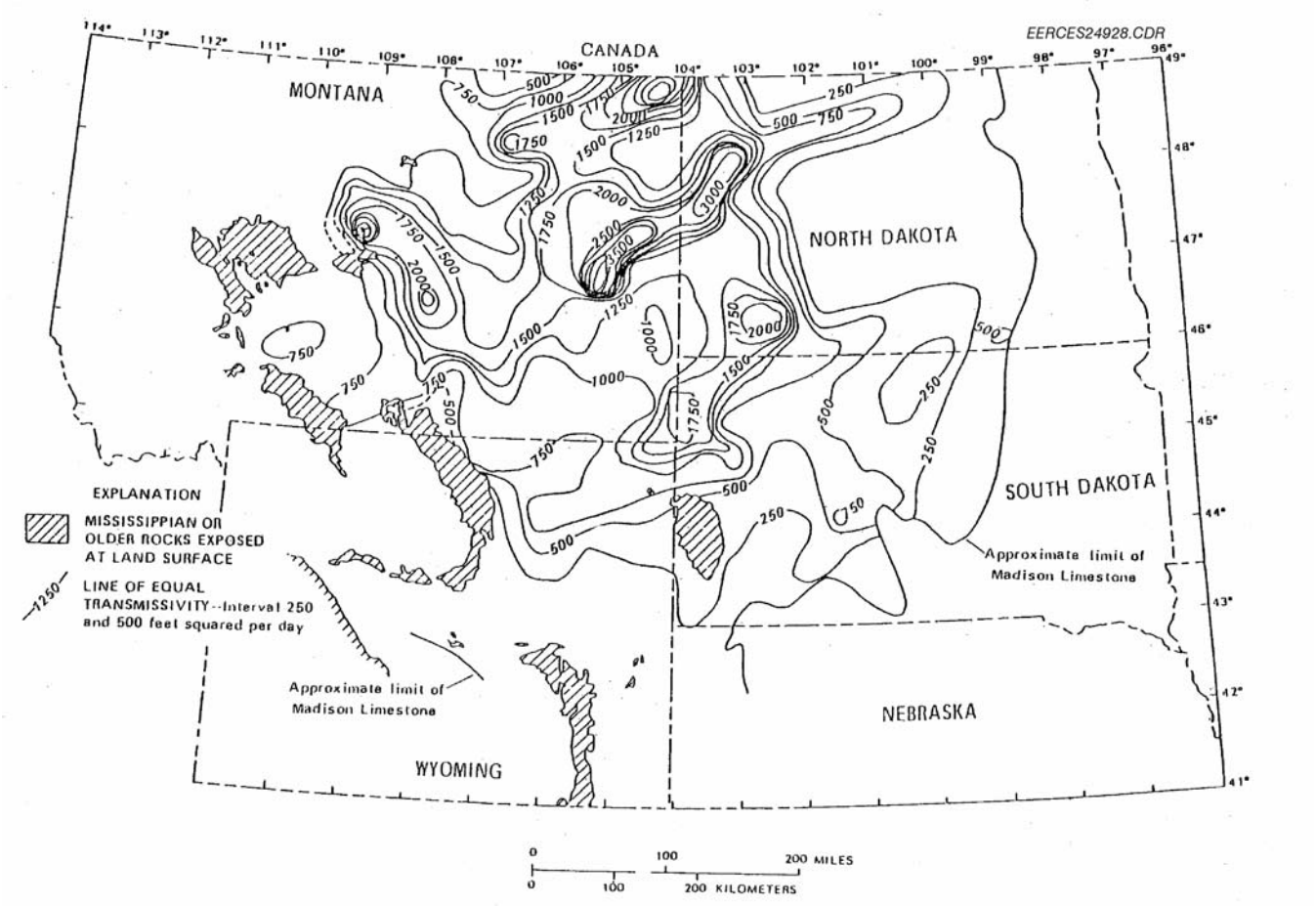


Figure 8. Madison Aquifer (Mission Canyon and Lodgepole Formations) transmissivity (Downey, 1984).

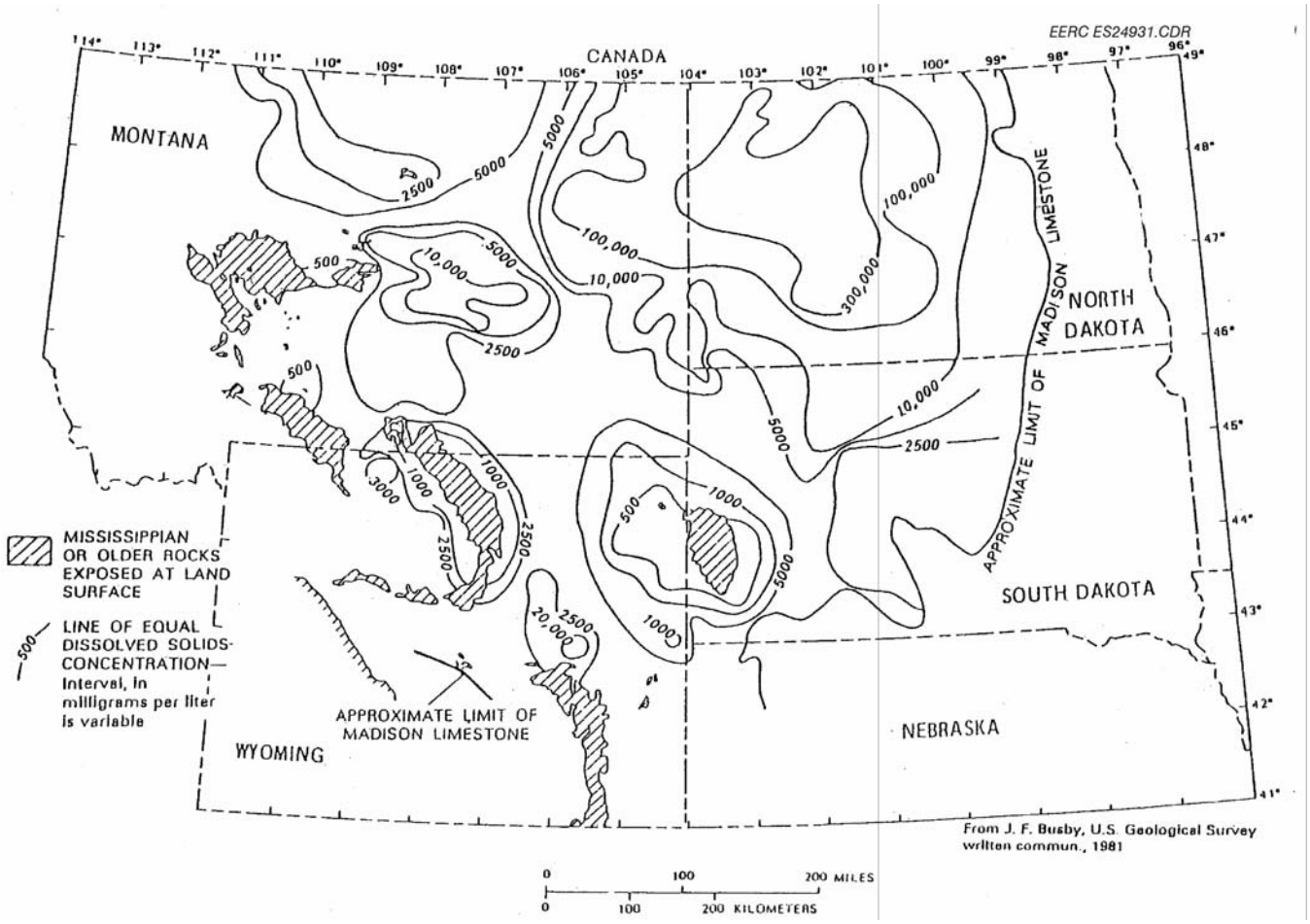


Figure 9. Madison Aquifer (Mission Canyon and Lodgepole Formations) TDS (Downey, 1984).

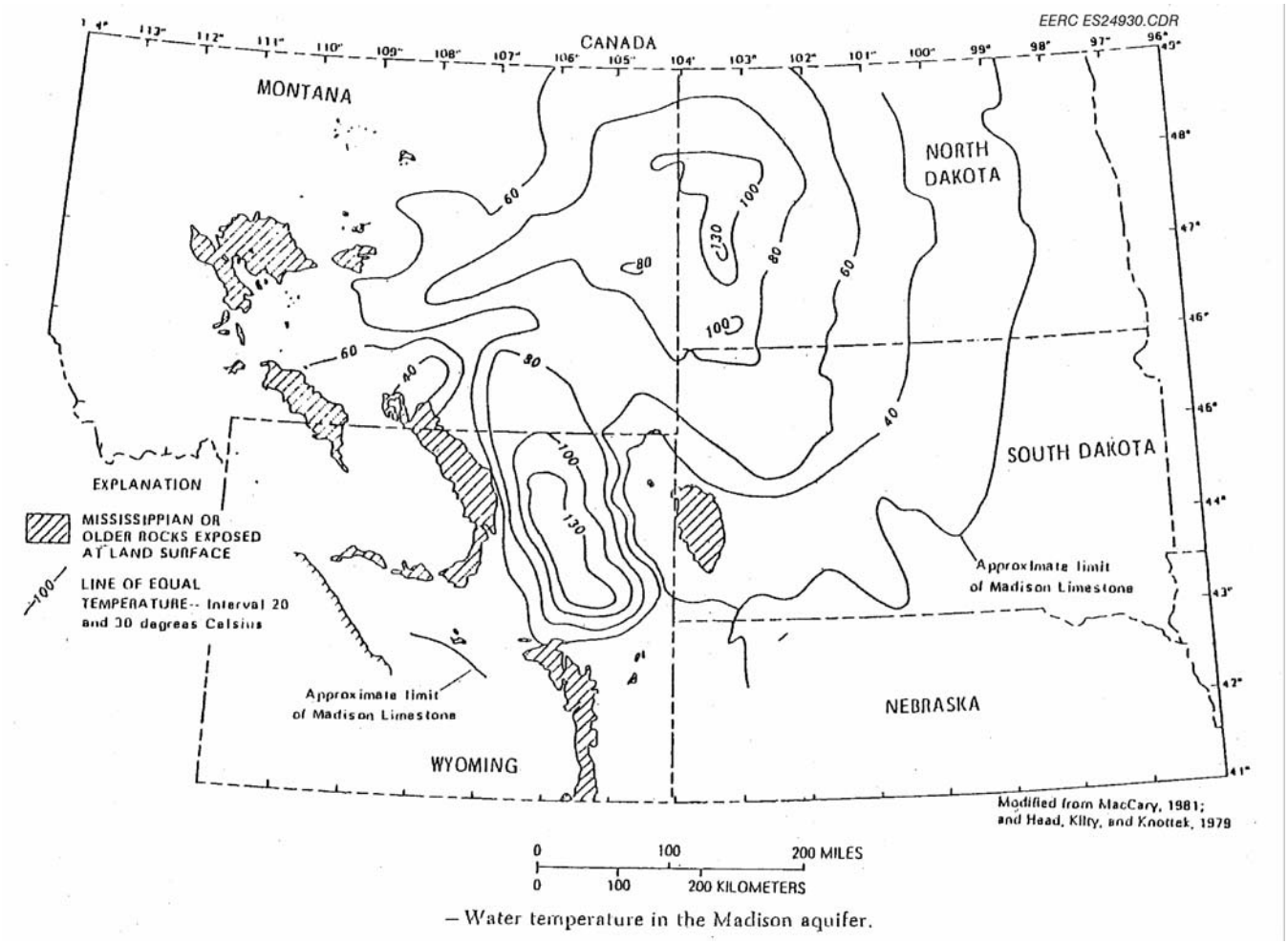


Figure 10. Madison Aquifer (Mission Canyon and Lodgepole Formations) water temperature (Downey, 1984).

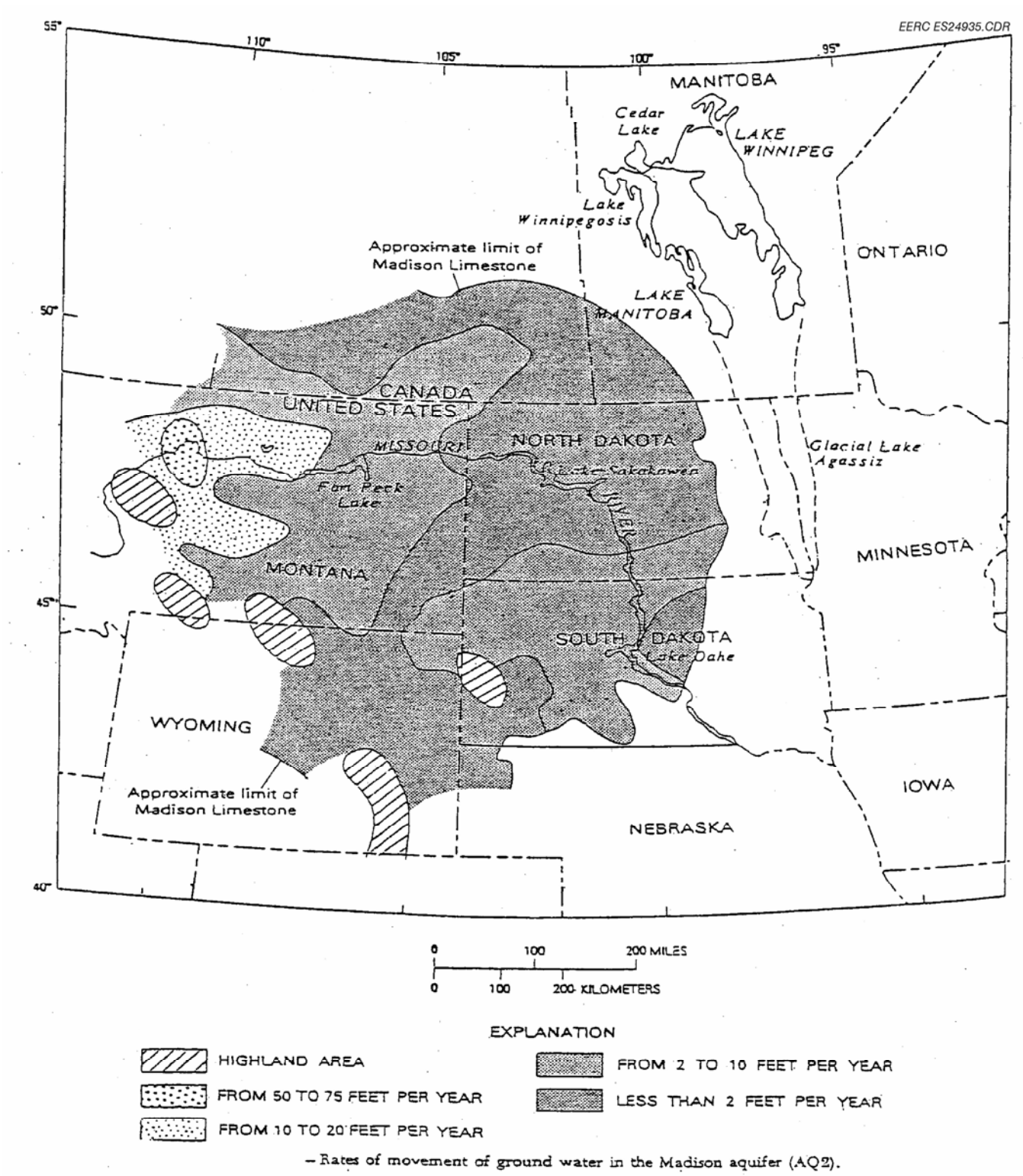


Figure 11. Madison Aquifer (Mission Canyon and Lodgepole Formations) rate of groundwater movement (Downey, 1984).

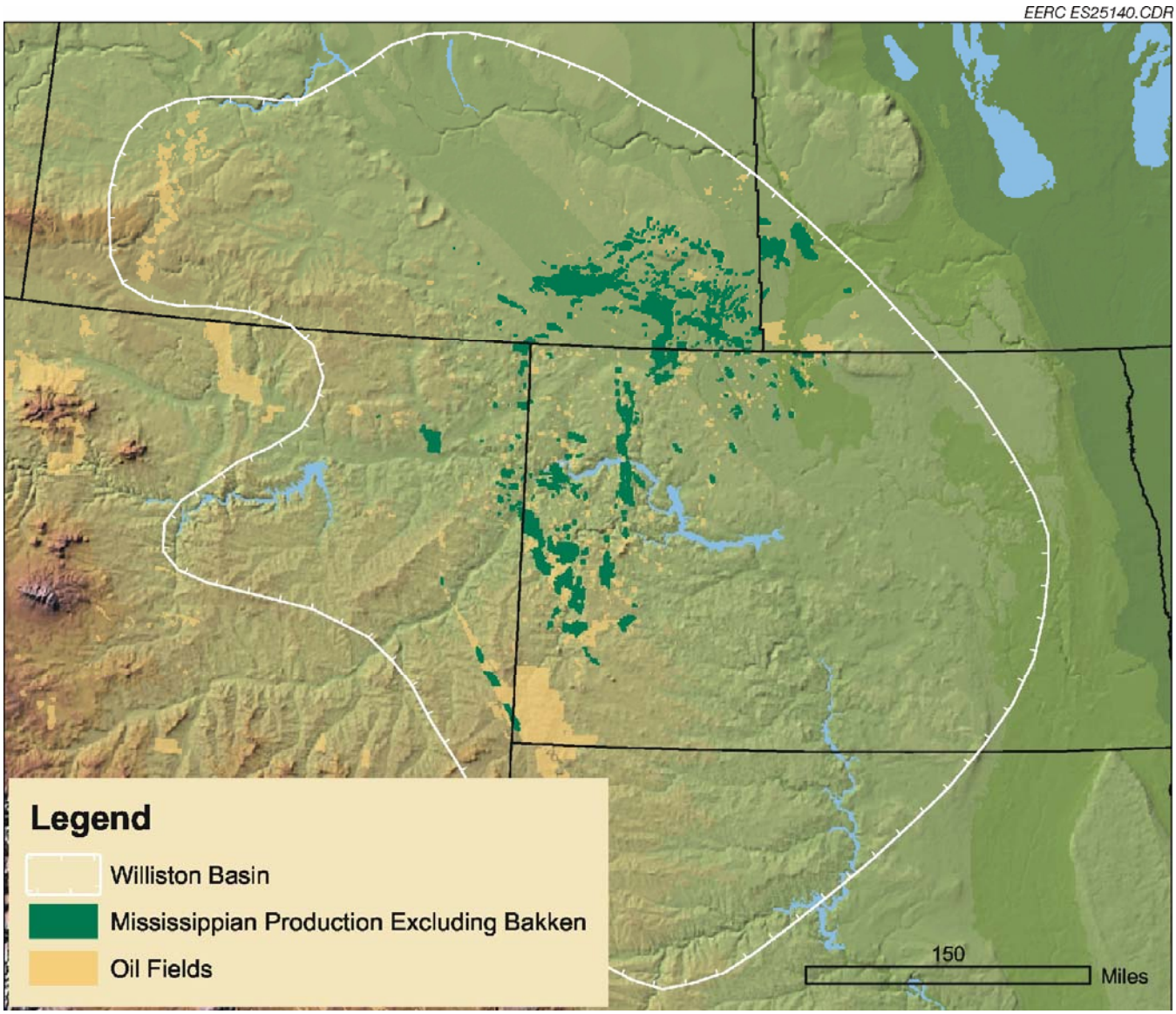


Figure 12. Location of Mississippian production (excluding Bakken Formation). The Mission Canyon is Mississippian in age.

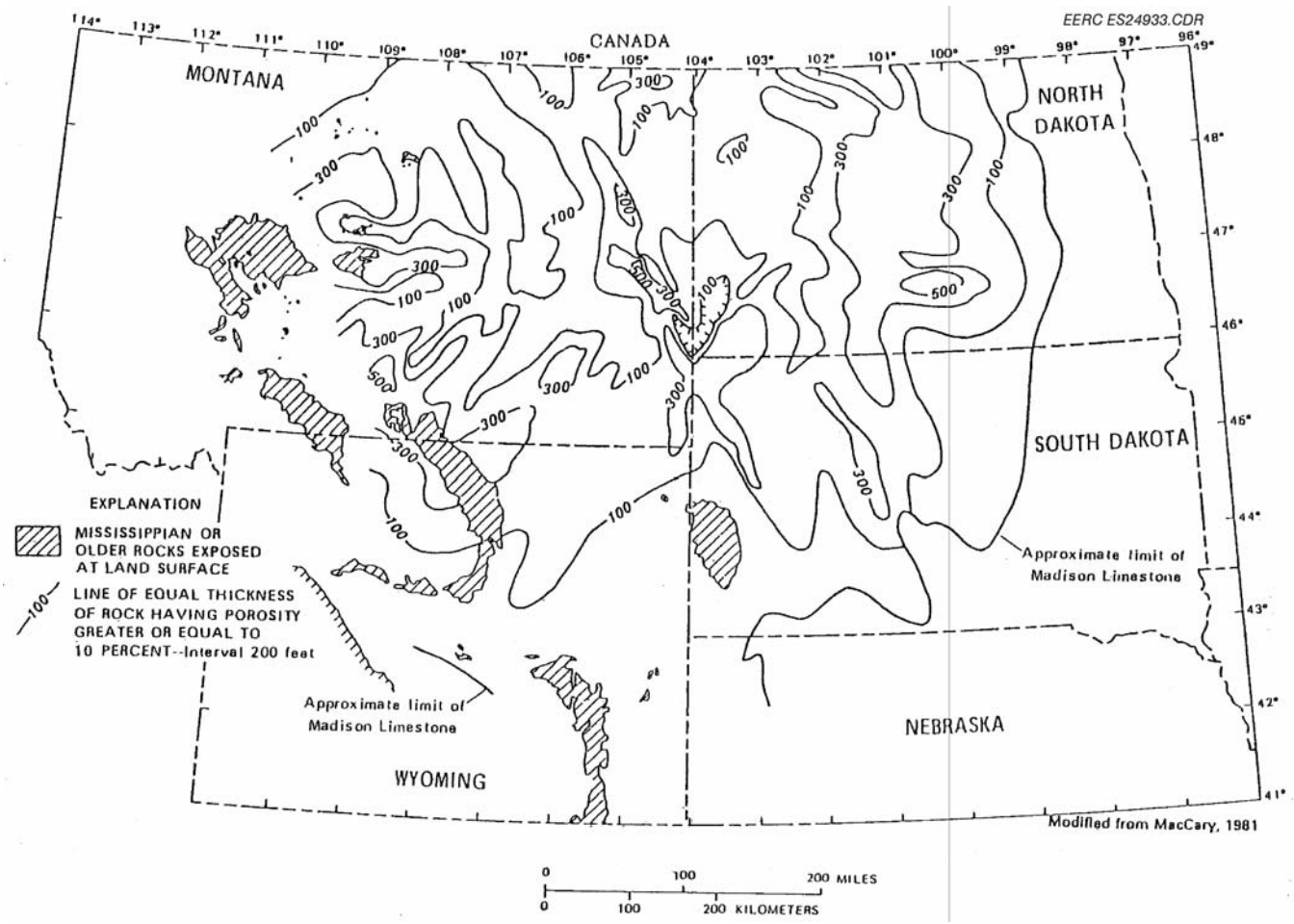


Figure 13. Porosity distribution in the Madison Aquifer (Mission Canyon and Lodgepole Formations) (Downey, 1984).

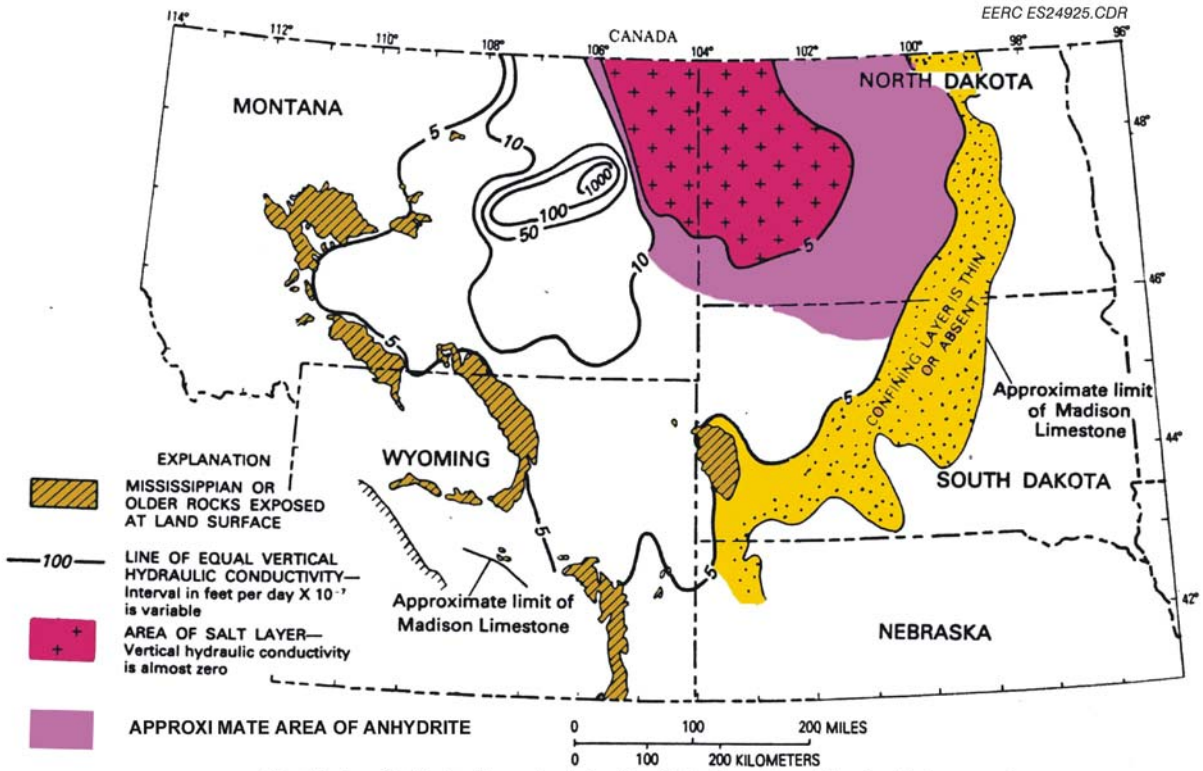


Figure 14. Simulated vertical hydraulic conductivity of layers overlying the Madison Aquifer (Mission Canyon and Lodgepole Formations) (Downey, 1984) with areas of evaporites (salt and anhydrite) noted.

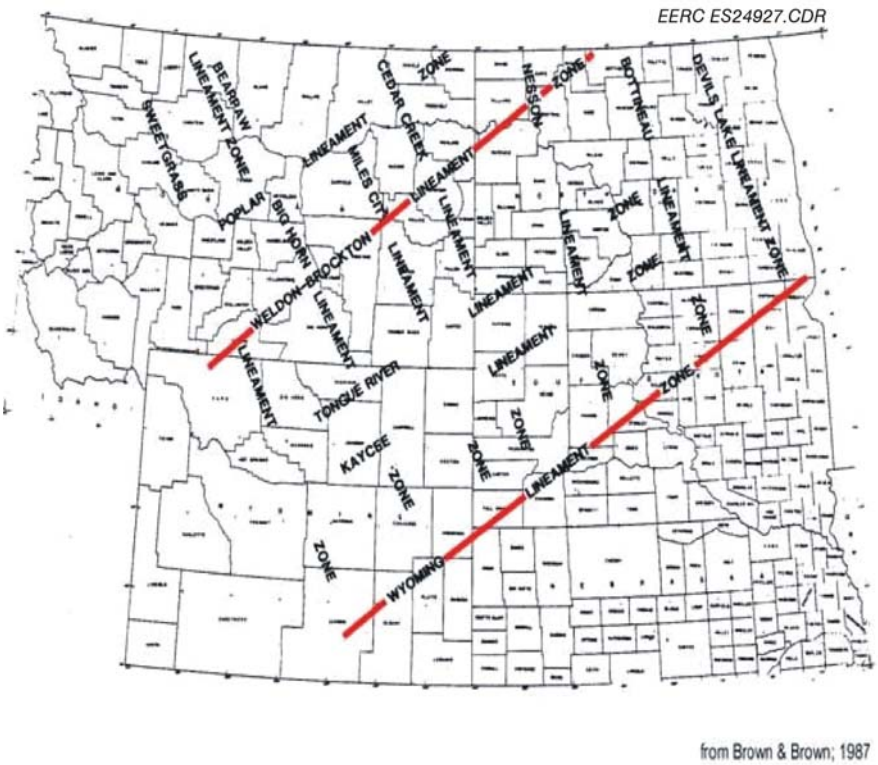


Figure 15. Major tectonic lineaments (Brown and Brown, 1987).

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**For more information on this topic, contact:**

**David Fischer, Fischer Oil and Gas, Inc.**
**(701) 746-8509; fischerd@gfwireless.com**

**Jim Sorensen, EERC Senior Research Manager**
**(701) 777-5287; jsorensen@undeerc.org**

**Edward Steadman, EERC Senior Research Advisor**
**(701) 777-5279; esteadman@undeerc.org**

**John A. Harju, EERC Associate Director for Research**
**(701) 777-5157; jharju@undeerc.org**

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