Plains $CO_2$ Reduction (PCOR) Partnership

# RED RIVER 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 Red River 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

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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 $CO_2$.

## FORMATION NAME

Red River 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).

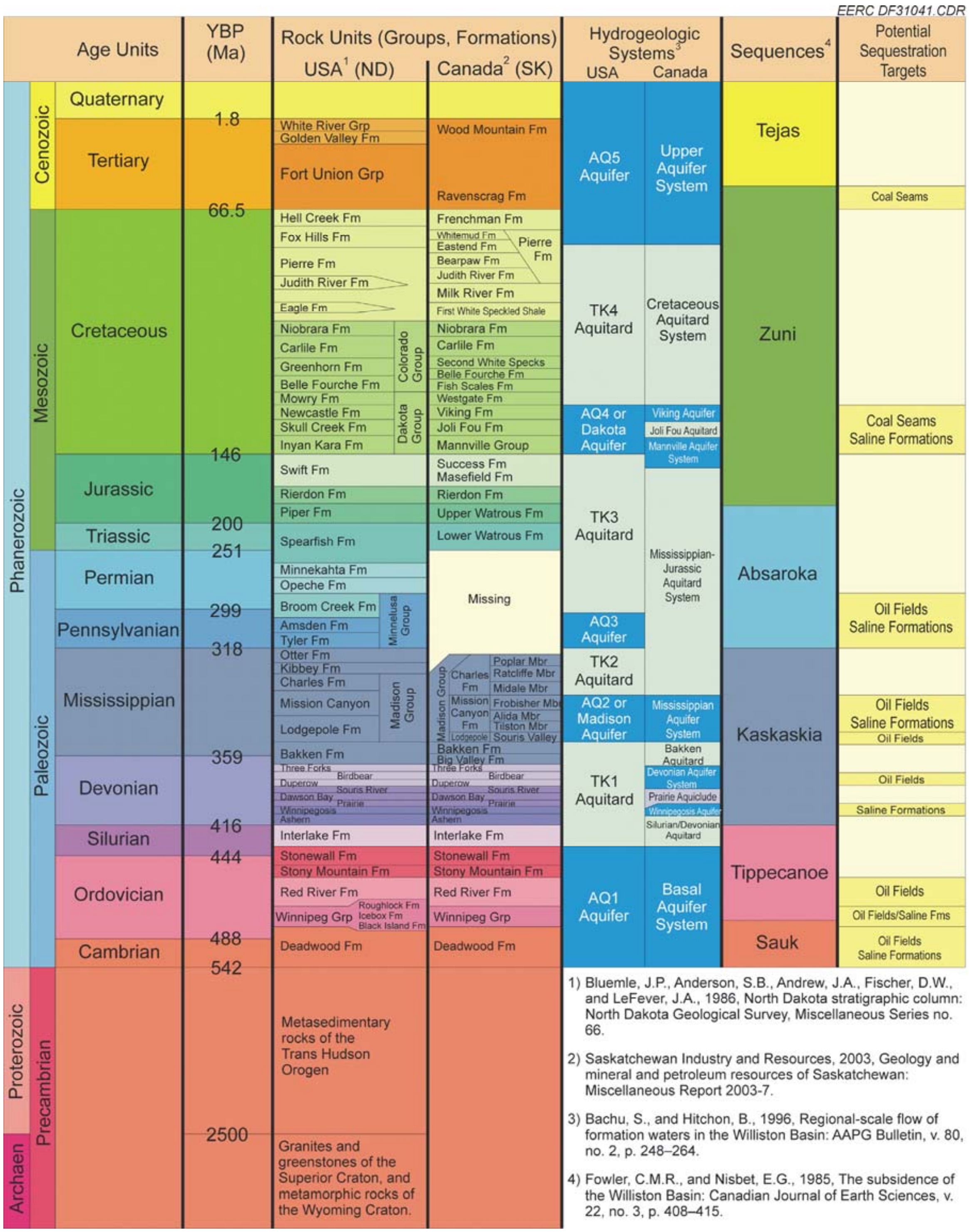


Figure 1. Williston Basin stratigraphic and hydrogeologic column.

## FORMATION AGE (LeRud, 1982)

Upper Ordovician Period (see Figure 1)
Trentonian to Edenian Epoch
Big Horn Group

## GEOLOGICAL SEQUENCE

Tippecanoe

## HYDROSTRATIGRAPHY (FIGURE 1)

AQ1 Aquifer (Downey et al., 1987)
Basal Aquifer System (Bachu and Hitchon, 1996)
Cambrian–Ordovician Aquifer System (Downey, 1986)

## GEOGRAPHIC DISTRIBUTION (modified from LeRud [1982])

Williston Basin; southern Manitoba, eastern Montana, North Dakota, southern Saskatchewan, western South Dakota

## THICKNESS

The Red River Formation reaches a maximum thickness in excess of 700 feet in the basin center, while the oil-productive upper Red River (Figure 2) can be greater than 250 feet in thickness (Carroll, 1978).

## CONTACTS

The upper contact is conformable with the Stony Mountain Formation. The lower contact with the Winnipeg Formation is disconformable (Kohm and Louden, 1988).

## LITHOLOGY

Primary: carbonate
Secondary: evaporate

## SUBDIVISIONS

The Red River Formation, the basal unit of the Big Horn Group, has been subdivided into two informal members (Sinclair, 1959). The lower member is the lower two-thirds of the formation and is comprised of fossiliferous and selectively dolomitized limestones. The upper member has informally been subdivided into four dolomitized porosity zones: the "D," "C," "B," and "A" zones, in ascending order (Ballard, 1963, Friestad, 1969, Carroll, 1978).

## LITHOFACIES

The A, B, and C zones in the upper member consist of a lithologic sequence that is repeated in each member. That sequence (Figure 3) was described by Carroll (1978) in stratigraphic order as "1) impermeable, mottled, slightly dolomitic, bioturbated, fossiliferous wakestone, 2) porous, laminated, fine-grained brown dolomitic mudstone, 3) impermeable nodular anhydrite, 4) a thin argillaceous bed that corresponds to a gamma-ray log character traceable throughout the basin." Although the anhydrites that cap the upper three zones are not present in parts of the basin margin, they are widespread, as they are present across much of the basin (Figure 3). The D zone consists of a selectively dolomitized, burrowed, and fossiliferous mudstone to wakestone (Carroll, 1978).

## DEPOSITIONAL ENVIRONMENT

Marine to shallow marine to sabkha

## DEPOSITIONAL MODEL

Two depositional models have been proposed to explain the origin of the dolomites and capping anhydrites in the upper Red River Formation. In the first

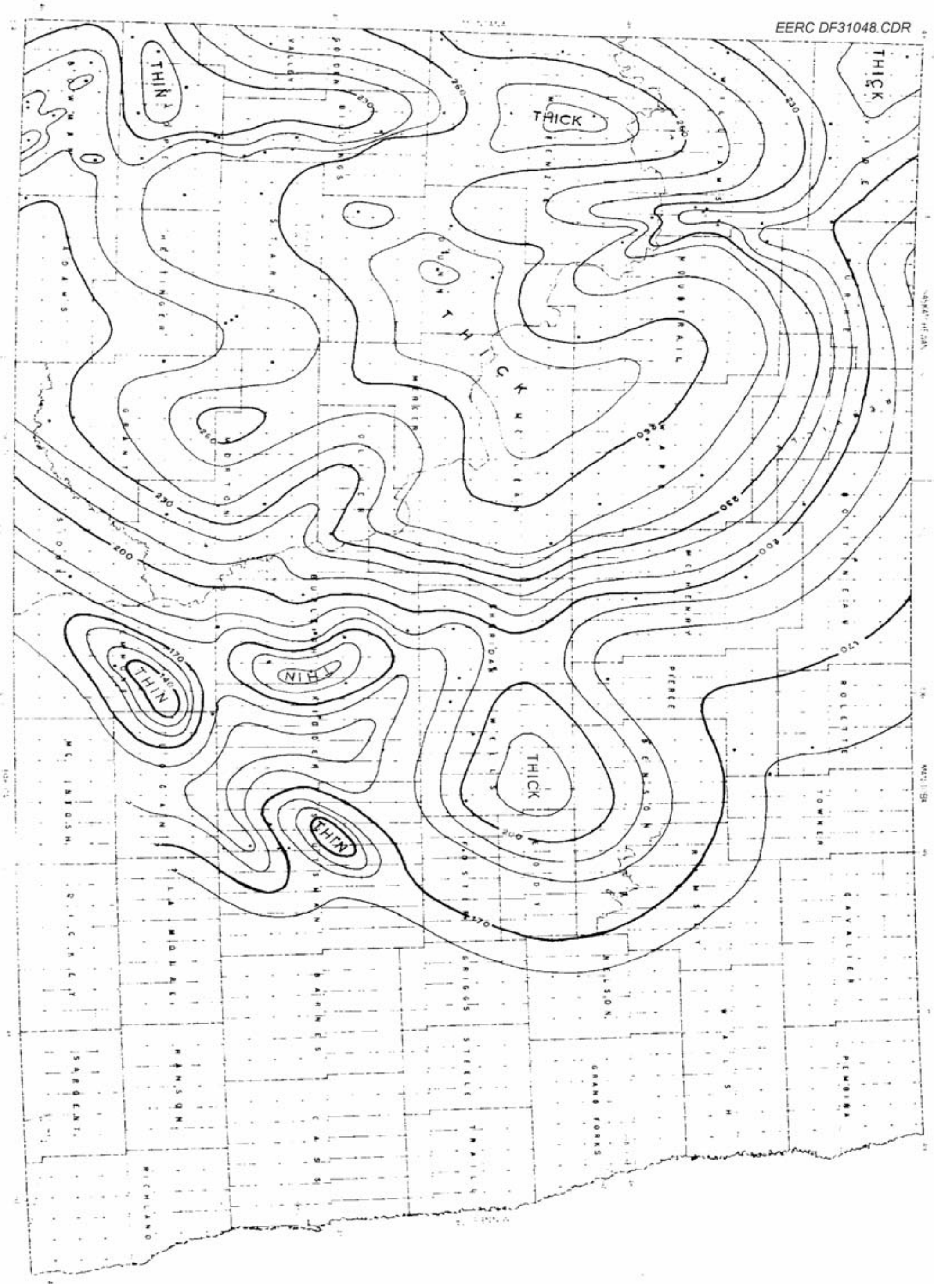


Figure 2. Isopach map of the Upper Red River Formation
in North Dakota (Carroll, 1978).

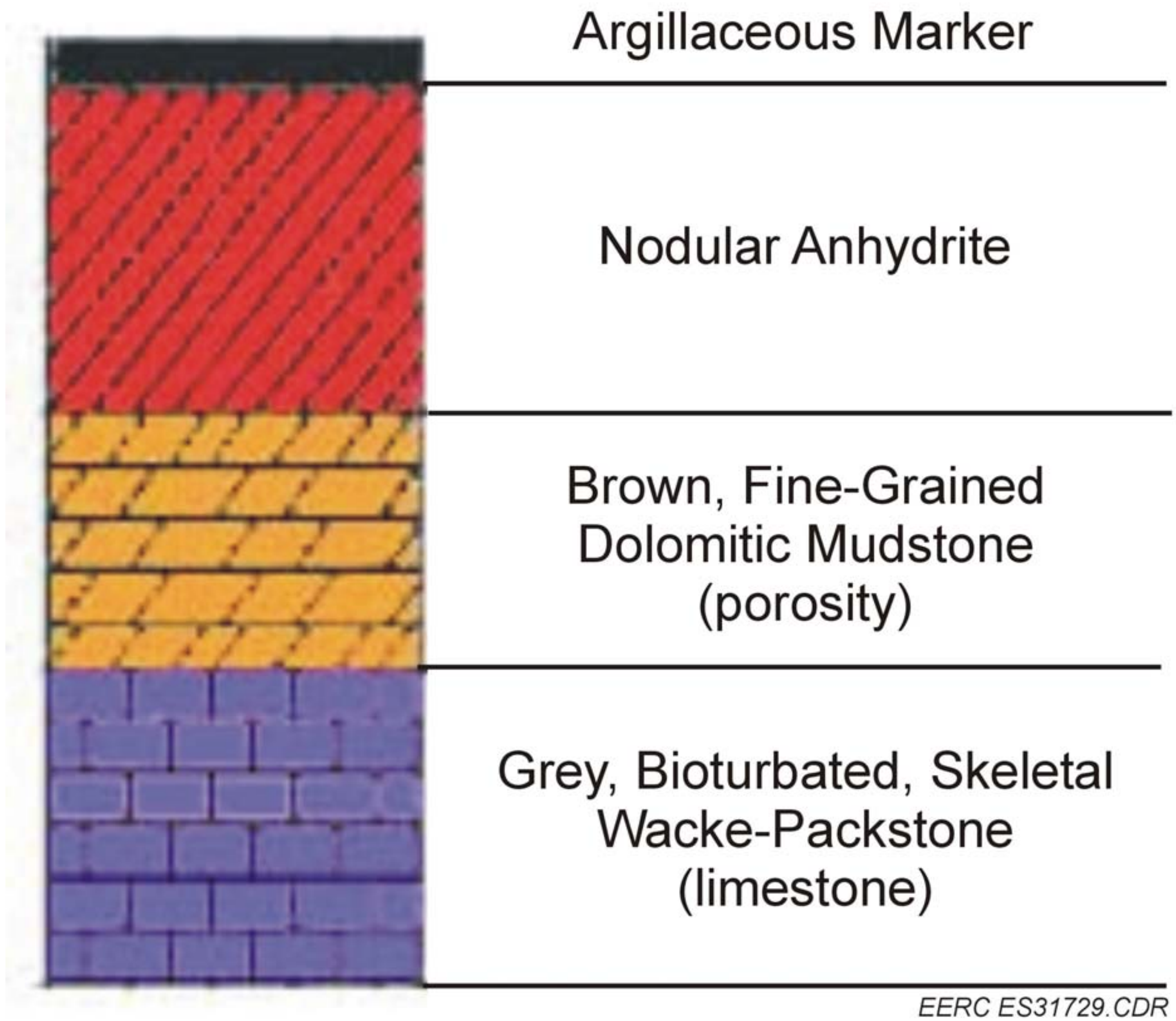


Figure 3. Generalized lithologic sequence in upper Red River (modified from Carroll, 1978).

model, the marine waters in the central Williston Basin evaporated to the point that a sabkha developed there (Carroll, 1978), while in the second model, all deposition occurred in subtidal environments (Kendall, 1976).

**RESERVOIR CHARACTERISTICS**

Data taken from the Medicine Pole Hills Oil Field, Bowman County, North Dakota.

Data from Fischer and others (1990) (Figure 4):

- Average porosity: 15%–16% in B zone, 8%–25% in C zone
- Average permeability: 6.9 mD
- Average pay thickness: 10–20 feet

Reservoir thickness varies from a few feet to approximately 10+ feet in the A and B members to tens of feet in the C and D members. Locally, Horse Creek

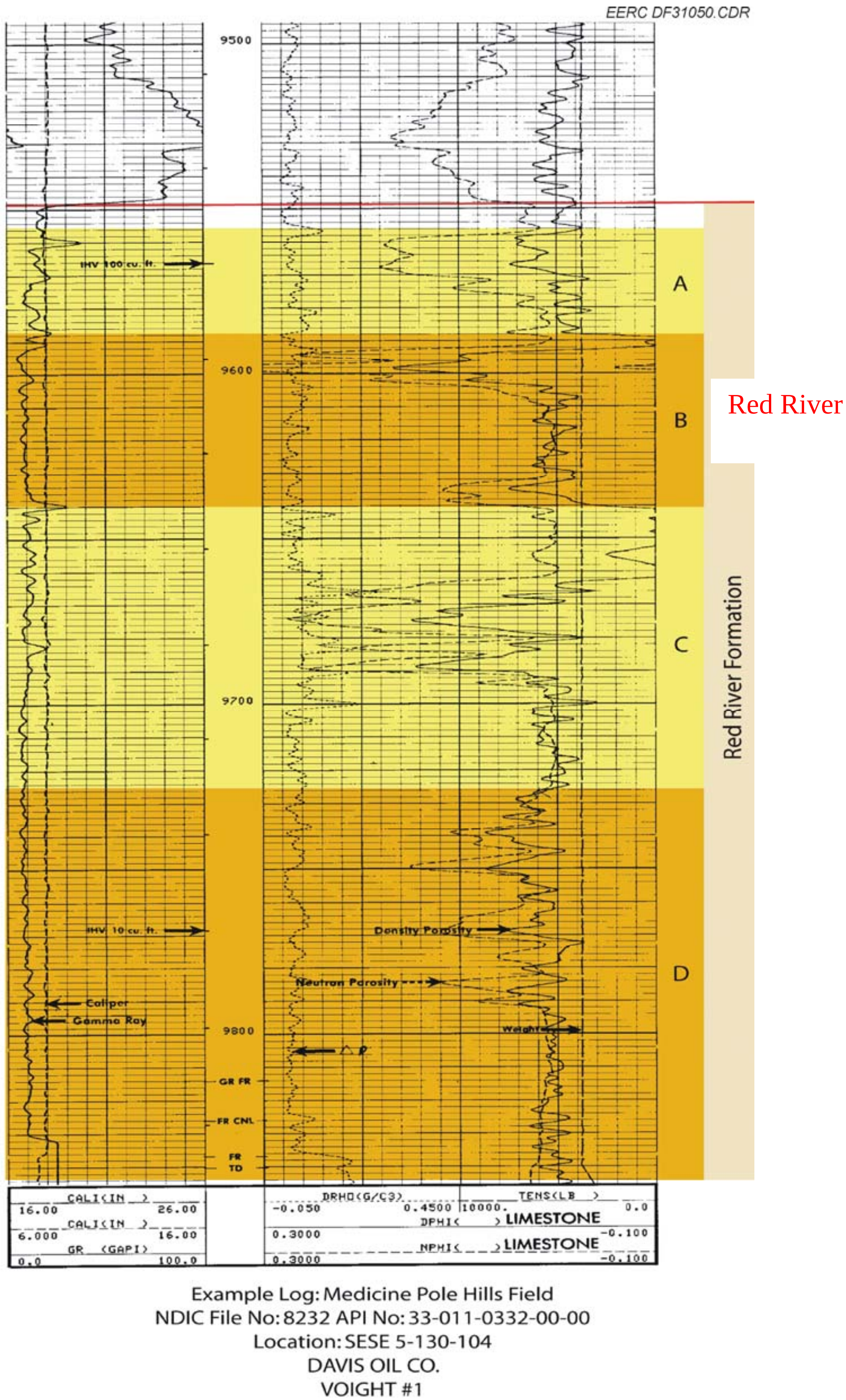


Figure 4. Example log of the Medicine Pole Hills Field.

and Horse Creek South Fields, Bowman County, North Dakota Field Data from Longman and others (1990):

- Average porosity: 17.8%
- Median permeability: 5–11 mD
- Reservoir temperature: 200°F
- Average net pay: 15 feet

## HYDRODYNAMIC CHARACTERISTICS (AQ4)

The potentiometric surface for the Red River rises to the southwest, with flow to the north northeast (LeFever, 1998; Downey, 1986) (Figures 5–8).

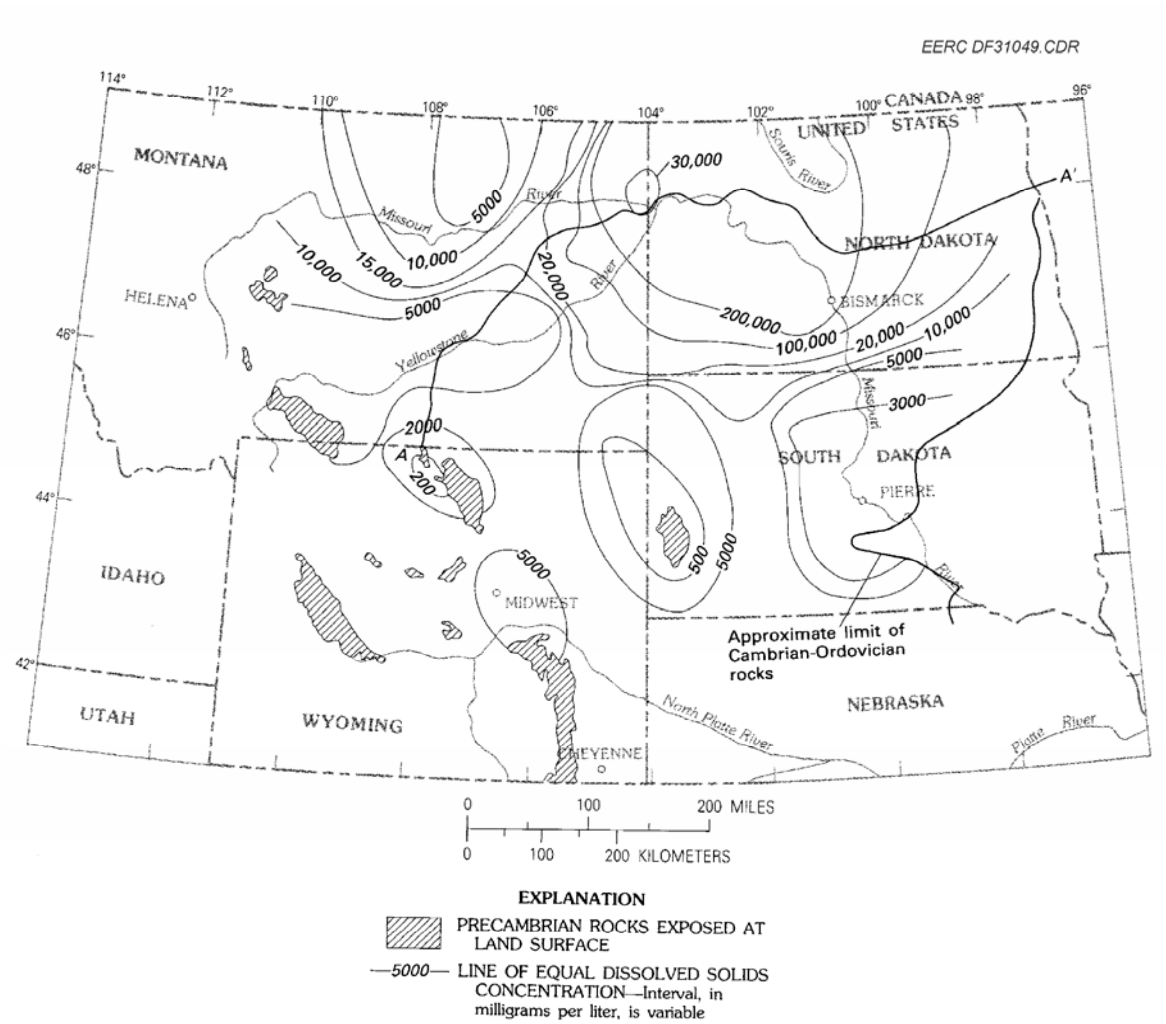


Figure 5. Concentration of dissolved solids in water from the Cambrian–Ordovician Aquifer (from Downey [1986]).

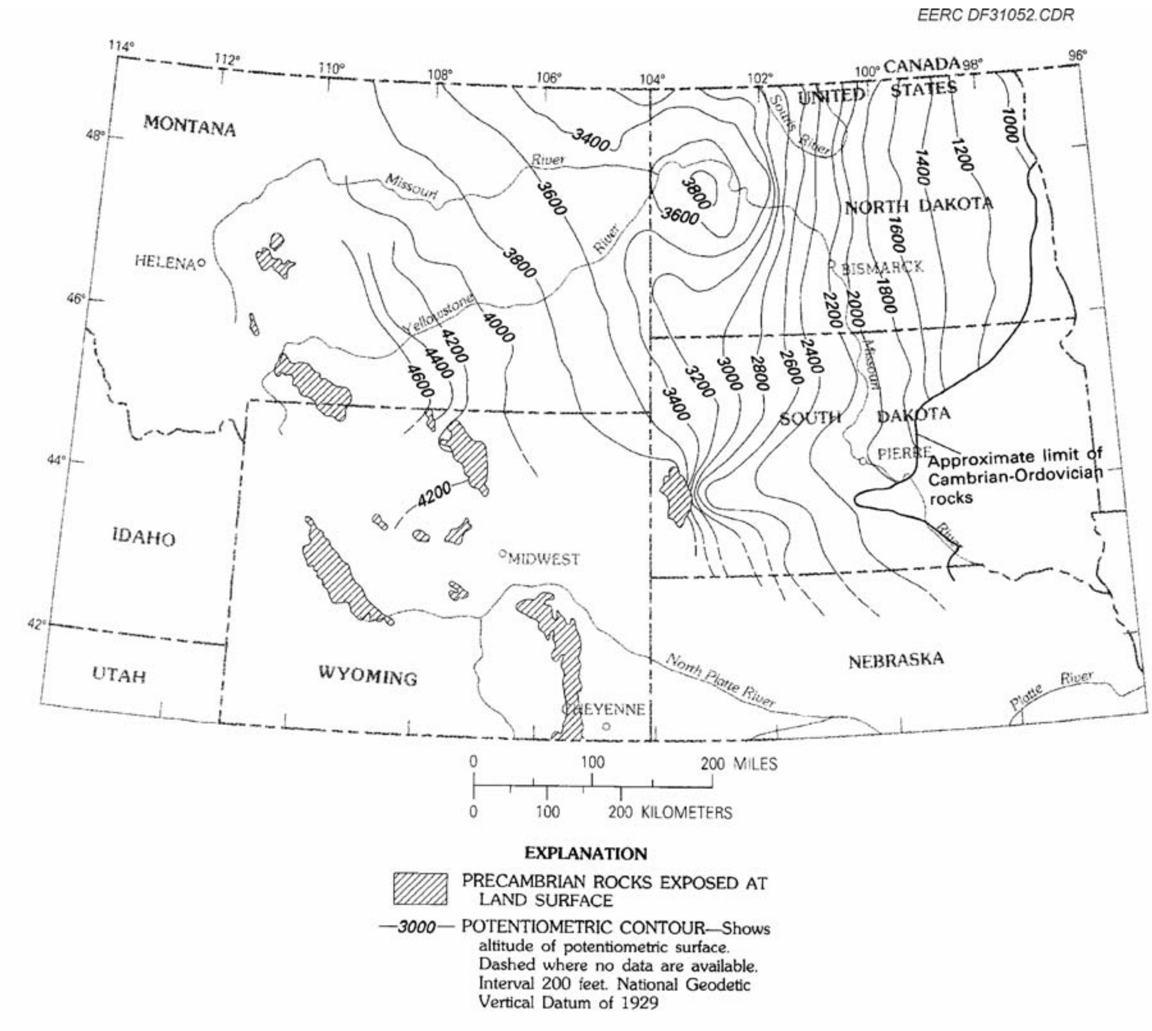


Figure 6. Simulated potentiometric surface of the Cambrian–Ordovician Aquifer (from Downey [1986]).

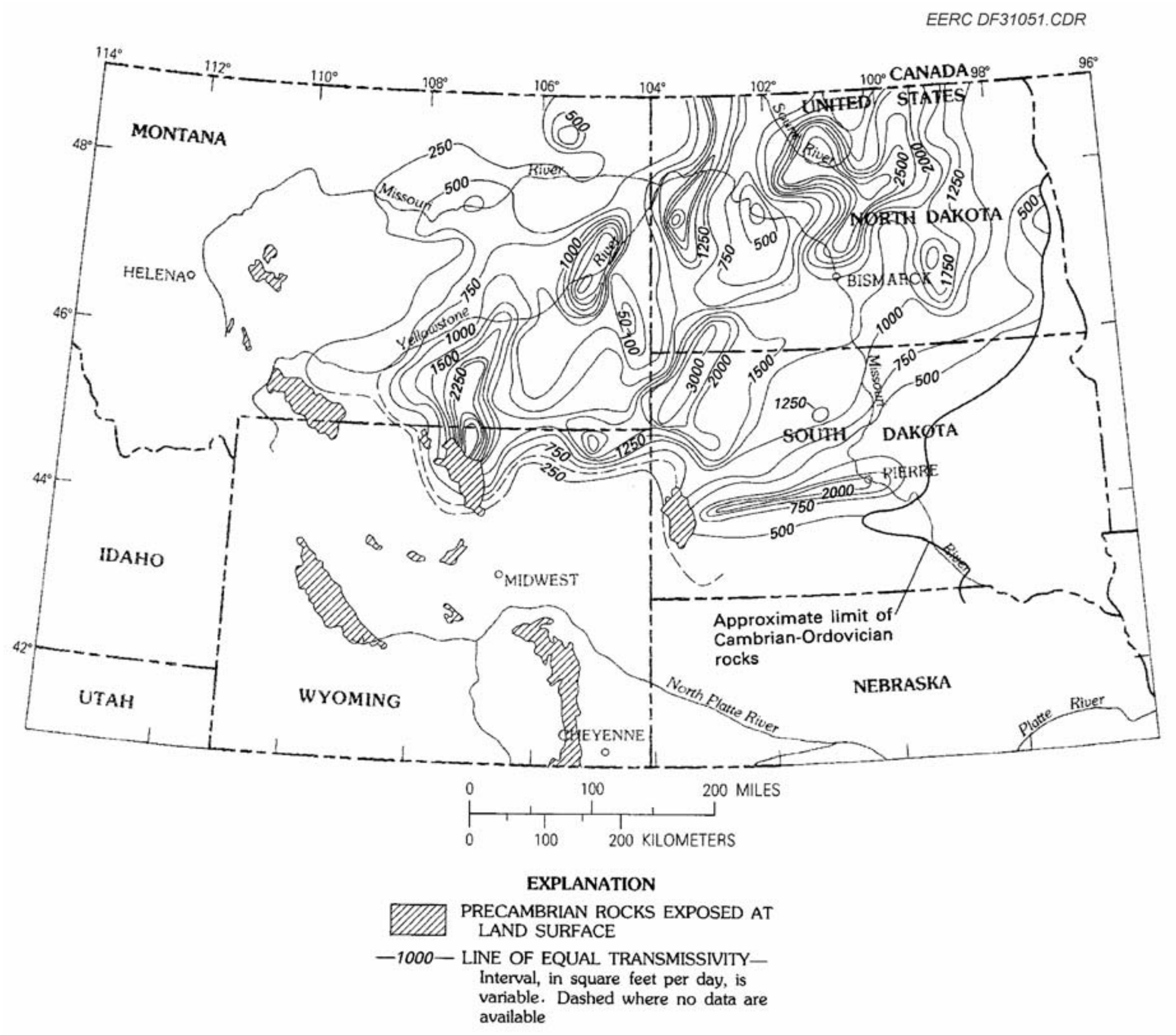


Figure 7. Transmissivity of the Cambrian–Ordovician Aquifer (from Downey [1986]).

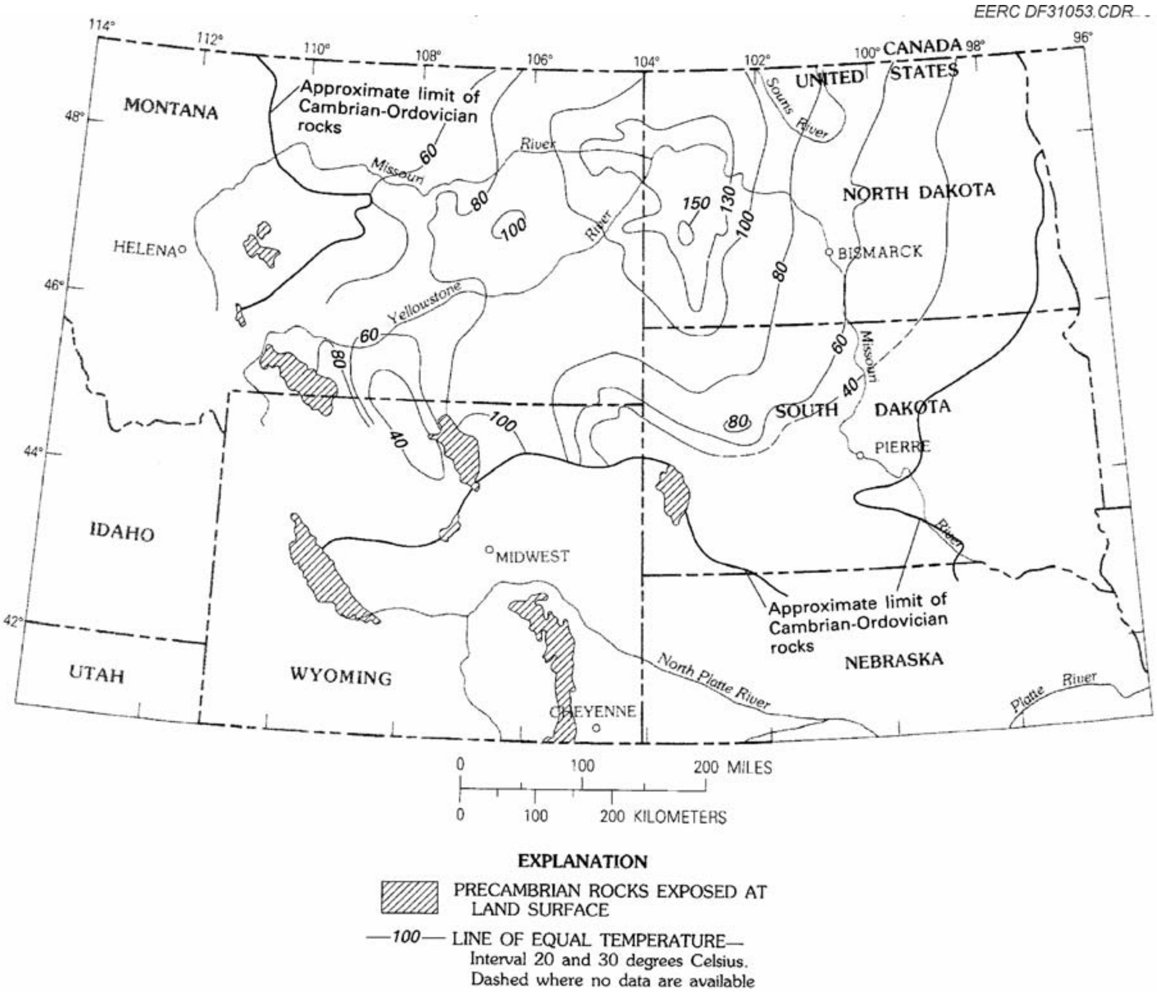


Figure 8. Water temperatures in the Cambrian–Ordovician Aquifer (from Downey [1986]).

## HYDROCARBON PRODUCTION

The Red River Formation is productive across most of western North Dakota, Montana, and southeast Saskatchewan. Most Red River Formation production has been found west of the Nessen Anticline, in the deepest parts of the basin, and is associated with structural closures. However, the best porosity is not always coincident with the structure's crest (Longman and others, 1983; Fischer and others, 1990). The Red River Formation is the second most important hydrocarbon-producing horizon in North Dakota and produces hydrocarbons in many fields.

## SINK POTENTIAL

The Red River Formation is considered to be one of the primary sink candidates in the Williston Basin. Although there is variability in reservoir distribution, there is perhaps more reservoir continuity present than in other overlying carbonate formations Kohm and Louden (1988) presented an interpretation of the Red River that included bands of continuous porosity development in northeastern Richland County (Figure 9). Abandoned oil fields will also offer excellent local sink potential.

Reservoir thickness varies from a few feet to approximately 10+ feet in the A and B members to tens of feet in the C and D members. Regionally, the Stoughton Formation serves as a competent vertical trap, as demonstrated along the Cedar Creek Anticline (Kohm and Louden, 1988). Where present, the anhydrites serve as excellent traps, especially where draped over a structure.

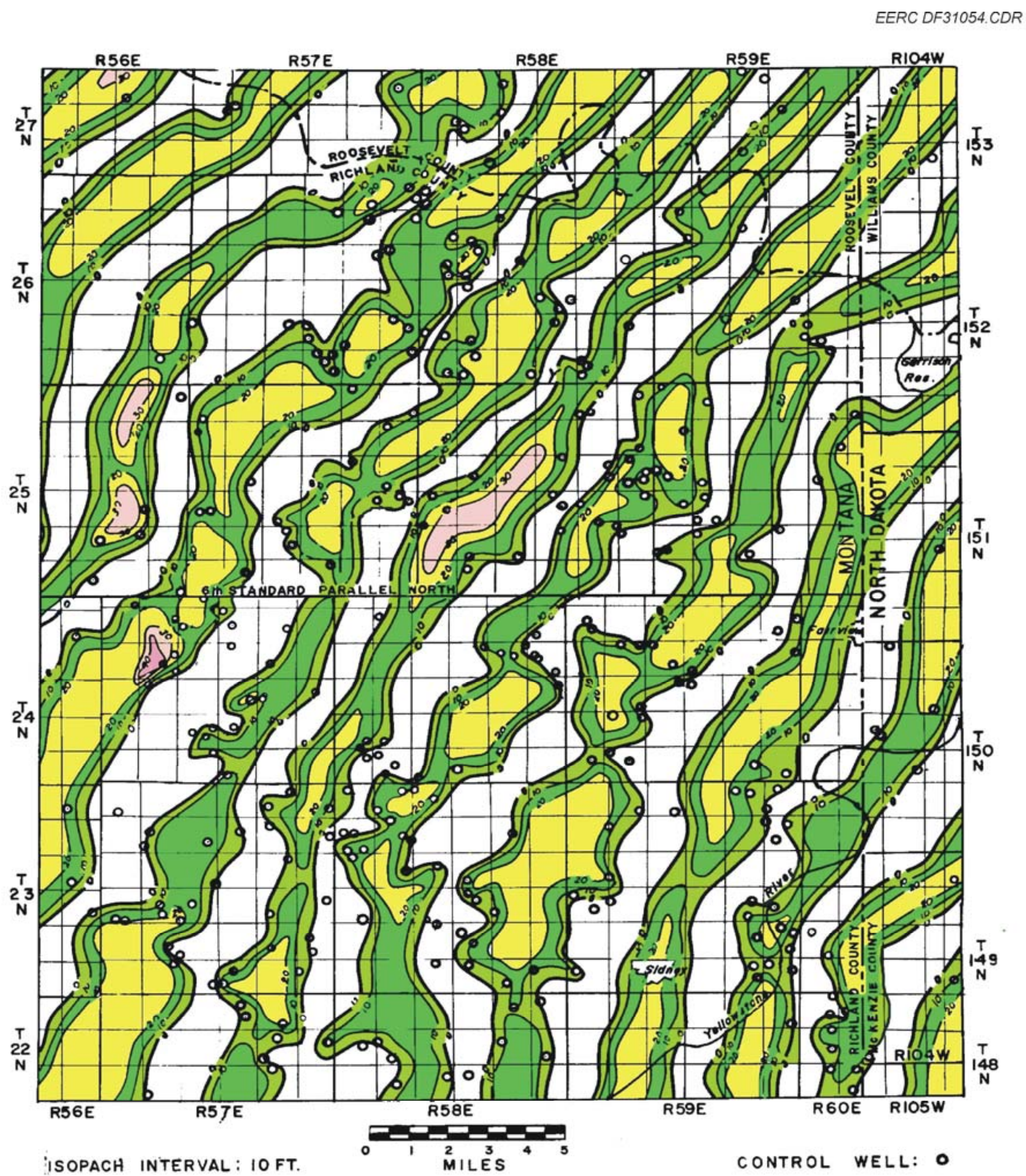


Figure 9. Isopach of net feet of Red River "C laminated" porosity: 6% in northeastern Richland County, Montana (modified from Kohm and Louden, 1988).

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