DUPEROW 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 Duperow Formation in the Williston Basin is considered to have potential storage capacity as a deep brine formation.

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- Apache Canada Ltd.
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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

Duperow 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)

Upper Devonian Period (see Figure 1)
Senecan Epoch
Jefferson Group

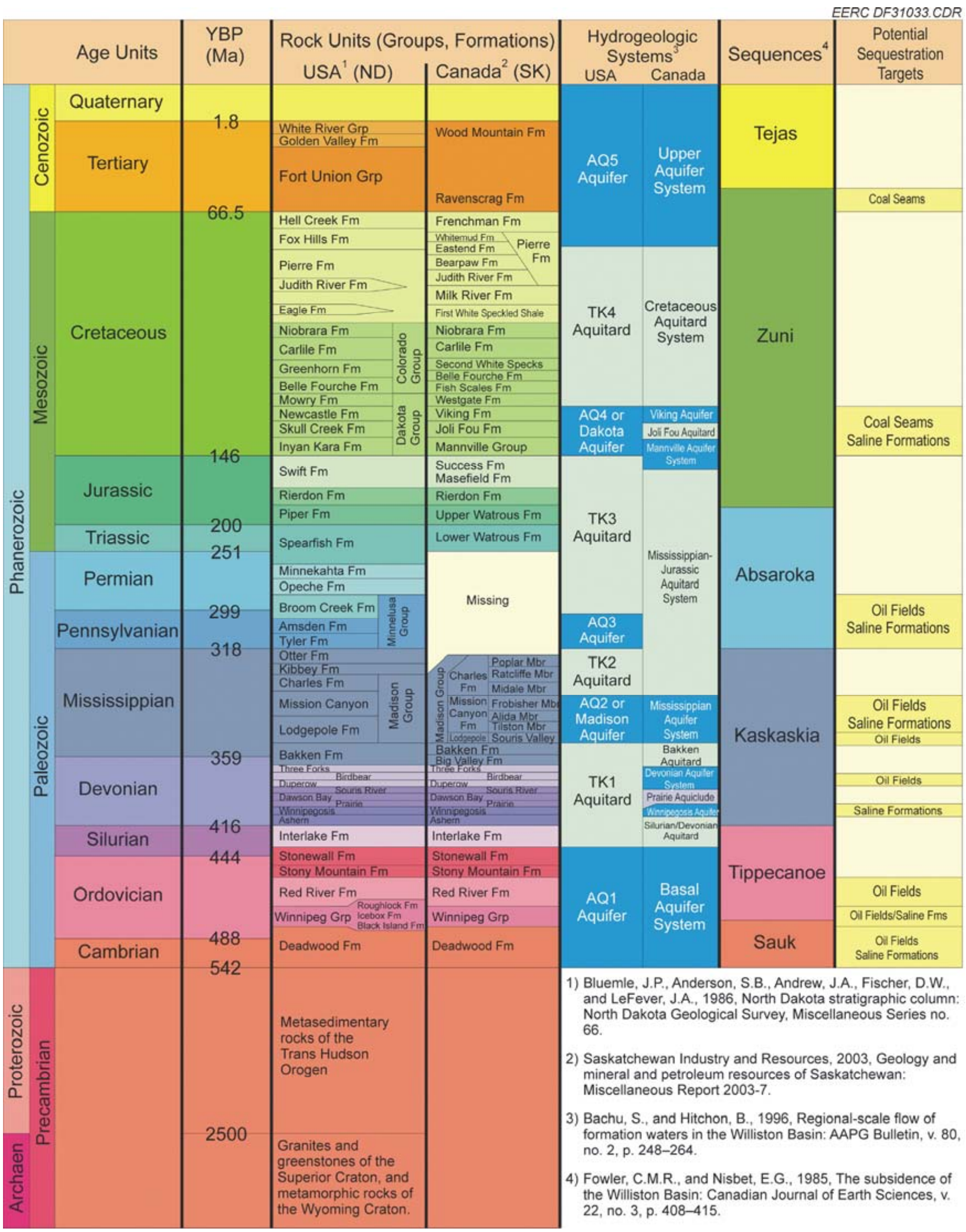

Figure 1. Williston Basin stratigraphic and hydrogeologic column.

GEOLOGICAL SEQUENCE

Kaskaskia

HYDROSTRATIGRAPHY (Figure 1)

Classified as part of the TK1 Aquitard (Downey et al., 1987) in the United States and as the Devonian Aquifer system (Bachu and Hitchon, 1996) in Canada.

GEOGRAPHIC DISTRIBUTION (modified from LeRud [1982])

Williston Basin: Manitoba, eastern Montana, North Dakota, Saskatchewan, and western South Dakota

THICKNESS

The Duperow Formation (Figure 2) can reach a thickness greater than 700 ft in Saskatchewan and attains a thickness greater than 500 ft in northwestern North Dakota (Hoganson, 1978).

CONTACTS

The upper contact with the Birdbear Formation is conformable. The lower contact with the Souris River Formation is comformable. Both the Bird Bear and Souris River Formations are dominated by carbonate rocks.

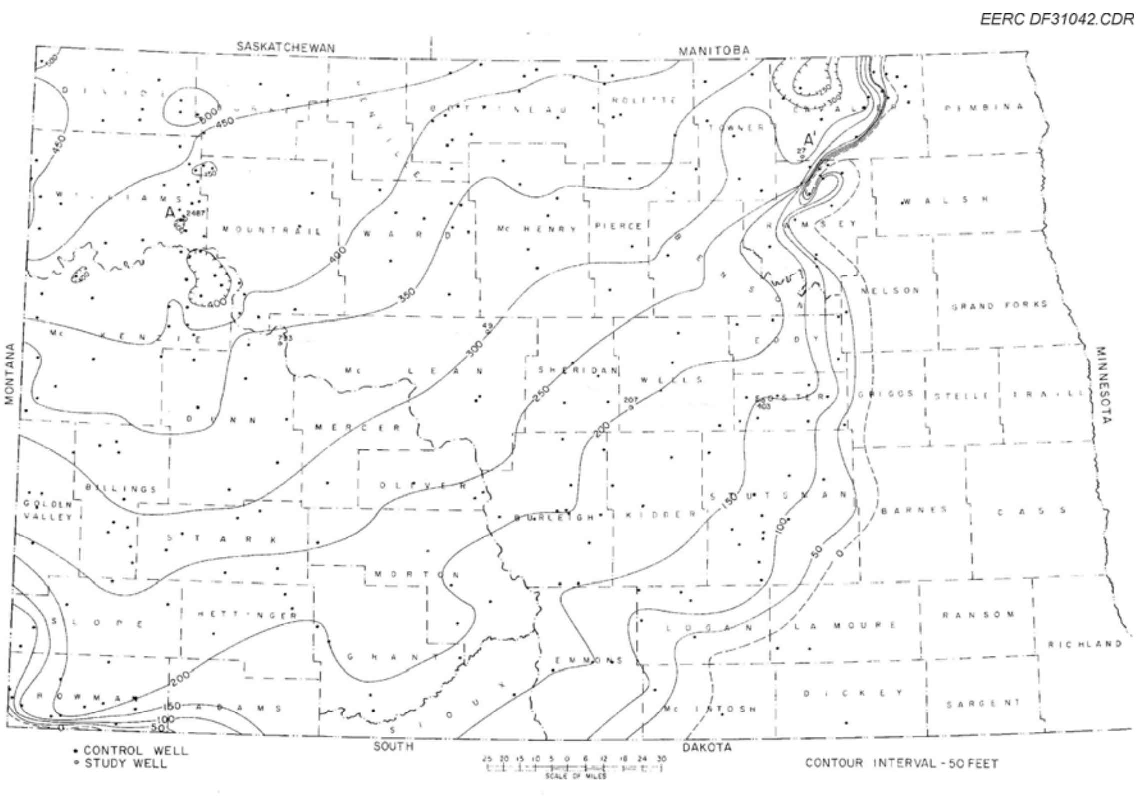

Figure 2. North Dakota Duperow isopach (Hoganson, 1978).

LITHOLOGY

Carbonate with interbedded evaporites

SUBDIVISIONS

The Duperow is usually divided into an upper and lower unit (Wilson, 1967, 1987). The upper unit is characterized by thinner bedded depositional cycles than the lower unit, with intertidal and supratidal sediments dominating. The lower unit exhibits a much thicker subtidal section (type log Figure 3).

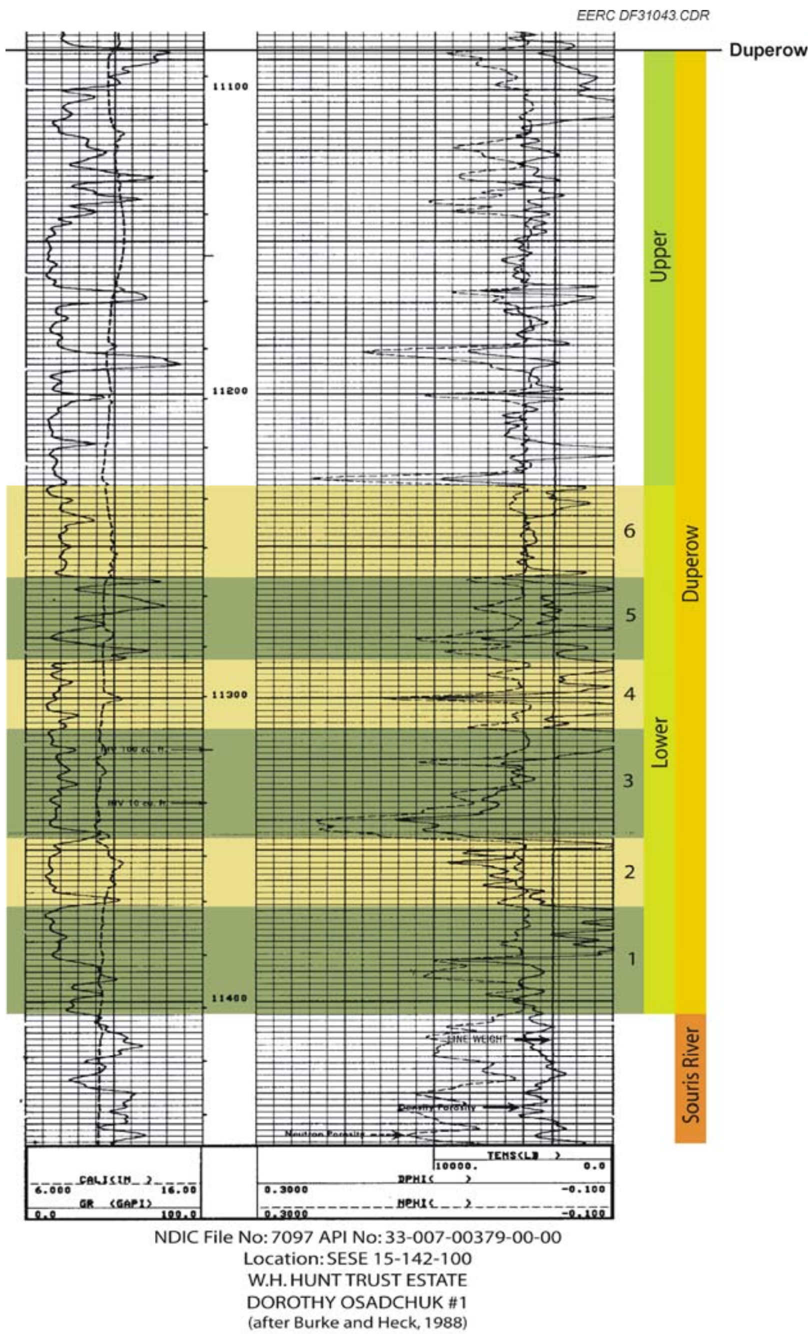

Figure 3. Example log for the Duperow upper and lower units.

LITHOFACIES

"A typical cycle consists of 1) a lower subtidal member which is either a dark brown brachiopod-crinoid wackestone with a mud matrix or a stromatoporoid boundstone, 2) a middle intertidal member which is either a laminated mudstone or a brown lime mudstone characterized by a faunal assemblage of ostracods and calcispheres interbedded with nanofossils to slightly fossiliferous pelletoid beds or laminated lime muds, and 3) an upper supratidal member of bedded anhydrite and grey-green very fine grained dolomite" (after Wilson, 1967; Wilson and Pilatzke, 1987; Hoganson, 1978; taken from Pilatzke et al., 1987).

DEPOSITIONAL ENVIRONMENT

Marine; subtidal to supratidal

DEPOSITIONAL MODEL

Two hypotheses have been proposed to explain the changes in lithology in individual cycles within the Duperow Formation.

The first model is a series of shallowing upward sequences where the depositional environment changed from a lower subtidal environment to a middle, restricted environment and, ultimately, to an upper intertidal to supratidal environment (Wilson, 1967; Wilson and Pilatzke, 1987; Pilatzke et al., 1987). Lithologies similarly changed from burrowed bioclastic limestones containing stromatoporoid banks, to lime mudstones containing ostracods and calcispheres, to bedded anhydrites and silty dolomites.

The second model invokes a series of marine restrictions during which salinity increased. Each restriction began in normal to near-normal marine environments and culminated in a hypersaline environment in which bedded anhydrites and dolomites were deposited (Ehrets and Kissling, 1985). This model has sometimes been called a brining upward sequence.

RESERVOIR CHARACTERISTICS

Based on data from the Tree Top Field, Billings, County, North Dakota. Reservoir data (Burke and Heck, 1988).

- Porosity 6%–21% (core)
- Permeability ranges from 1 to 123 mD with local vertical fractures

Reservoir data (Pilatzke et al., 1987).

- Porosity up to 30+%

Permeability usually ranges from 5 to 30 mD, with some areas showing permeability exceeding 100 to 100+ mD (K range usually 5–30 mD).

HYDRODYNAMIC CHARACTERISTICS

The Duperow potentiometric surface (Figure 4) is somewhat elevated to the southwest and northeast but is not well developed and may not represent water influx (LeFever, 1998).

Concentration of total dissolved (Figure 5) solids in the Duperow can be in excess of 300,000 mg/L (LeFever, 1998).

HYDROCARBON PRODUCTION

The Duperow Formation produces From stratigraphic traps in the central Williston Basin, from structural traps along the Nesson Anticline, and from combination traps on the Billings Anticline. The Duperow Formation also produces on the eastern flank of the Cedar Creek Anticline, where truncated

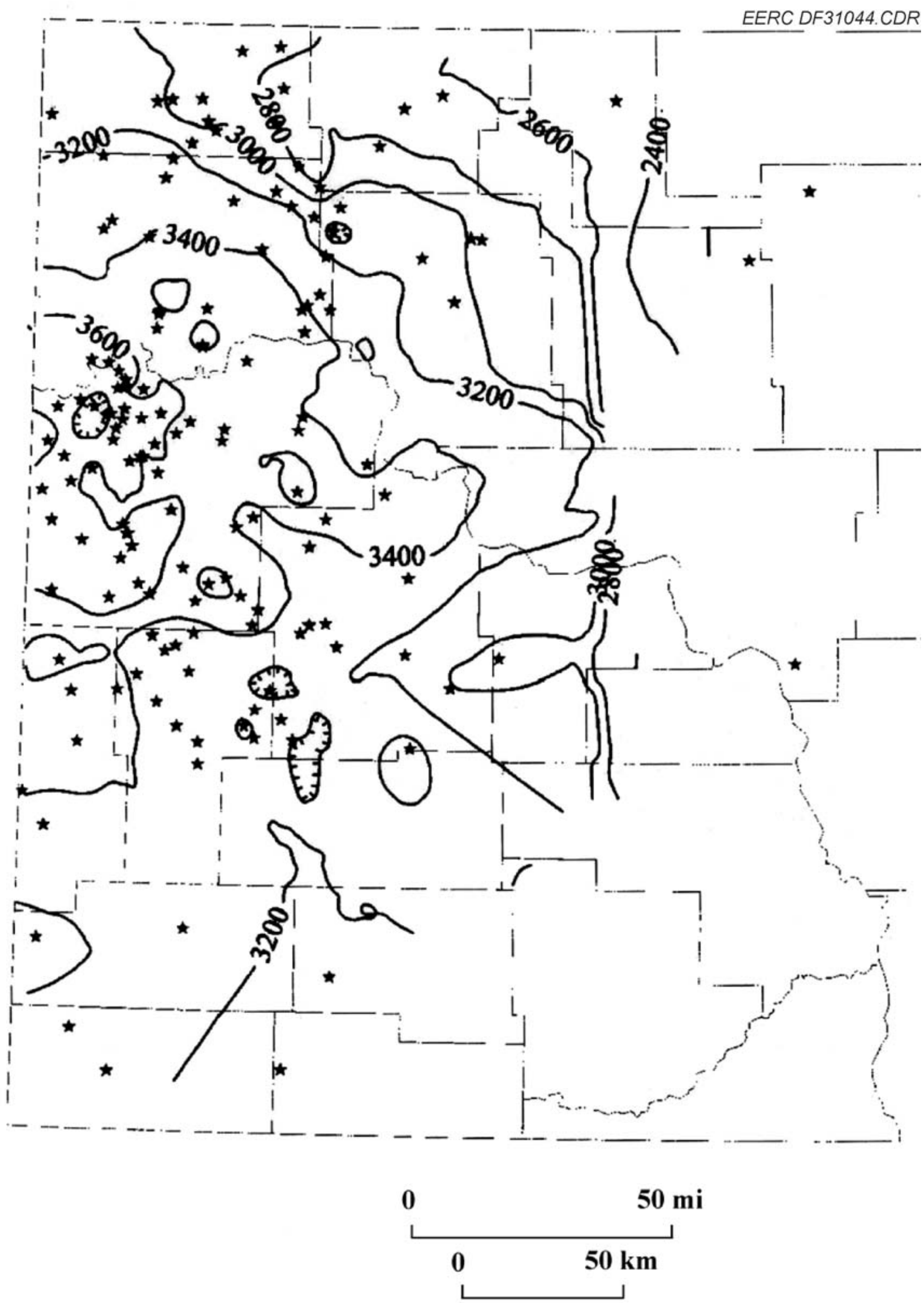

Figure 4. Duperow potentiometric surface based on formation pressures and freshwater hydraulic heads (LeFever, 1998).

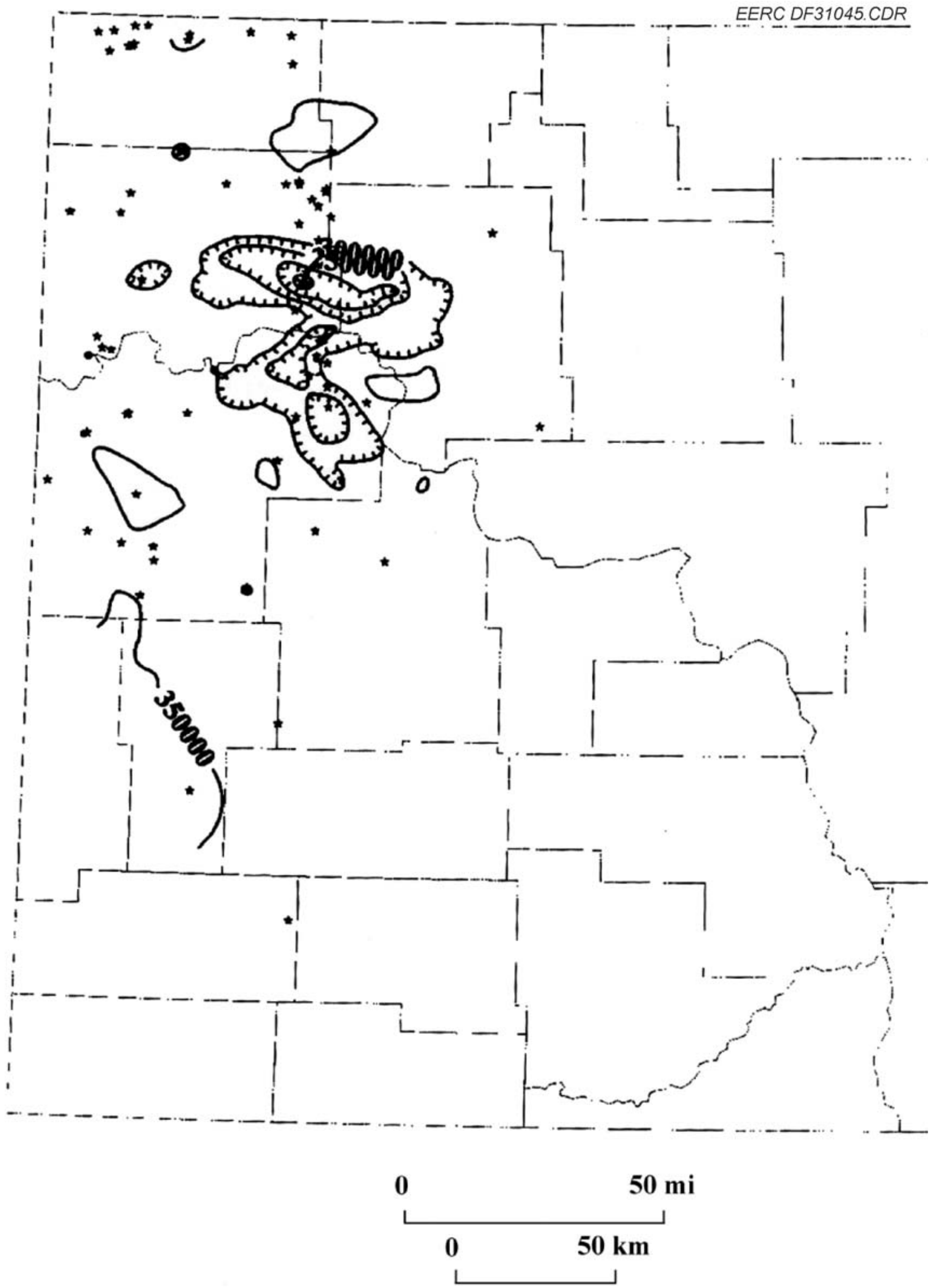

Figure 5. Concentration of total dissolved solids in the Duperow Formation (LeFever, 1998).

porous carbonates are capped by Upper Devonian/Lower Mississippian rocks.

Duperow production is most commonly from fine-grained sucrosic dolomites replacing what most workers interpret to be stromatoporoid banks. Pilatzke et al. (1987) suggest that these banks are limited in aerial extent, 1–1.5 miles in lateral size, and are primarily found in the subtidal portion of any given cycle. Multiple cycles can produce on larger structures; as many as five cycles produce on the Nesson Anticline with 200+ ft of section productive. Production is usually from 2 to 4 ft of porosity in an individual cycle, but in rare occasions, the thickness of the productive zone can be as great as 25 ft.

SINK POTENTIAL

Any of the numerous and thin zones of porosity found in the Duperow Formation is a potential sink. Evaporitic intervals may act as seals for these zones of porosity. Most of the CO_2 storage capacity within the Duperow will likely be within established oil fields.

A unique potential sink exists in northwestern North Dakota. A relatively thick (20+ ft) porosity informally referred to as the G3 (Weinzapfel and Neese, 1986) pinches out into a regionally developed halite (Flat Lake salt).

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