RESERVOIR CHARACTERIZATION AND PETROLOGY OF THE BAKKEN FORMATION, ELM COULEE FIELD, RICHLAND COUNTY, MT

by

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ABSTRACT

Elm Coulee Field, discovered in 2000 in Richland County, Montana, is the largest oil field in the Williston Basin. This field produces from the middle member of the Devonian-Mississippian Bakken Formation and has an estimated ultimate recovery of 200-250 MMBO. The Bakken's diagenetic history in combination with horizontal drilling and hydrofracturing practices make it possible to get large recoveries from this low permeability and porosity field.

The Bakken Formation in Elm Coulee Field is composed of three main members with an average total thickness of 40 feet. The lower Bakken member consists of dark, laminated, organic-rich marine shale. This member pinches out toward the western and southern limits of the field. The middle Bakken member contains six shallow marine silty-dolostone facies. From bottom to top these include: a brachiopod-rich facies, a burrowed and bioturbated facies, two laminated facies, a laminated and burrowed facies, and finally a massive to brachiopod-rich facies. These were deposited in offshore marine and mid to distal shelf environments below normal wave base. Like the lower member, the upper Bakken member is laminated, dark, organic-rich marine shale, but it is continuous across the field. The upper Bakken member is the main source bed for the oil found within the middle Bakken reservoir at Elm Coulee.

The main types of porosity within the middle Bakken are secondary pores and intergranular pores. Secondary porosity is the result of dolomitization and subsequent dissolution. Within portions of the middle Bakken member containing the highest dolomite percentages (up to 60%) and lowest clay percentages,

some of the rhombohedral dolomites have 10 micron gaps along the edges of the crystals. These gaps form due to both the formation of the dolomite rhombs adjacent to the detrital grains and the later dissolution of the edges of those rhombs. If many of these “slot” pores exist, they can connect, thus acting like microfractures, and lead to preferential pathways that contribute to increased permeability and production.

Production at Elm Coulee would not be possible if the Bakken Formation had not undergone a variety of diagenetic stages that have resulted in a dolomite-rich reservoir rock with enhanced secondary porosity. The diagenetic sequence of the Bakken begins with mechanical compaction, early dolomitization related to shelfal seepage reflux, and pyrite formation. Next is a period of dedolomitization, deeper burial related dolomitization, the formation of sphalerite, anhydrite cement, quartz replacement, and quartz overgrowths. There are also two stages of fracturing at Elm Coulee. The first, mineralized vertical to subvertical fractures, is probably related to either Devonian salt dissolution, the reactivation of basement faults, or pressure release from dewatering of the sediments, and the second, open horizontal fractures, is related to pressure release from the hydrocarbon expulsion process. The beginnings of hydrocarbon generation in the shales also expelled acids into the middle Bakken which dissolved parts of the dolomite rhombs, thus increasing porosity and enhancing storage space for the following expelled oil.

The results of this study in conjunction with previous analyses of Elm Coulee Field indicate that the Bakken petroleum system within the Williston

Basin has huge potential for future discoveries. Understanding the distribution of facies, the types of porosity, and the diagenetic stages that have occurred within the middle Bakken reservoir member is the key to determining new drilling targets within Elm Coulee and also to the search for similar locations in this basin that may be good targets for future production.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

Elm Coulee Field, discovered in 2000 and located in Richland County, Montana, is the largest oil field in the Williston Basin (Figure 1.1). This field produces from the Bakken Formation, which includes a lower shale member, a middle silty dolostone member, and an upper shale member. The reservoir for this field is within the middle Bakken member. Cumulative production from Elm Coulee Field as of August 2011 totals 107,446,717 BBL oil, 86,038,476 MCF gas, and 14,752,219 BBL water.

1.1 **Objectives and Purpose**

The goal of this thesis is to better characterize the Elm Coulee reservoir and to understand the distribution of the producing units and facies within the middle Bakken silty dolostone, as well as the diagenetic stages the Bakken has undergone since deposition.

The four cores used in this study are located in Richland County, Montana, USA, within the Elm Coulee Field in the Williston Basin (Figure 1.2). The wells are: 1) Jackson-Rowdy, 2) Brutus East-Lewis, 3) Foghorn-Ervin, and 4) RR Lonetree-Edna.

Since Elm Coulee is located near the western depositional edge of the Bakken formation, there are a few differences in the facies present here when compared to those found in central Williston Basin Bakken fields. For example,

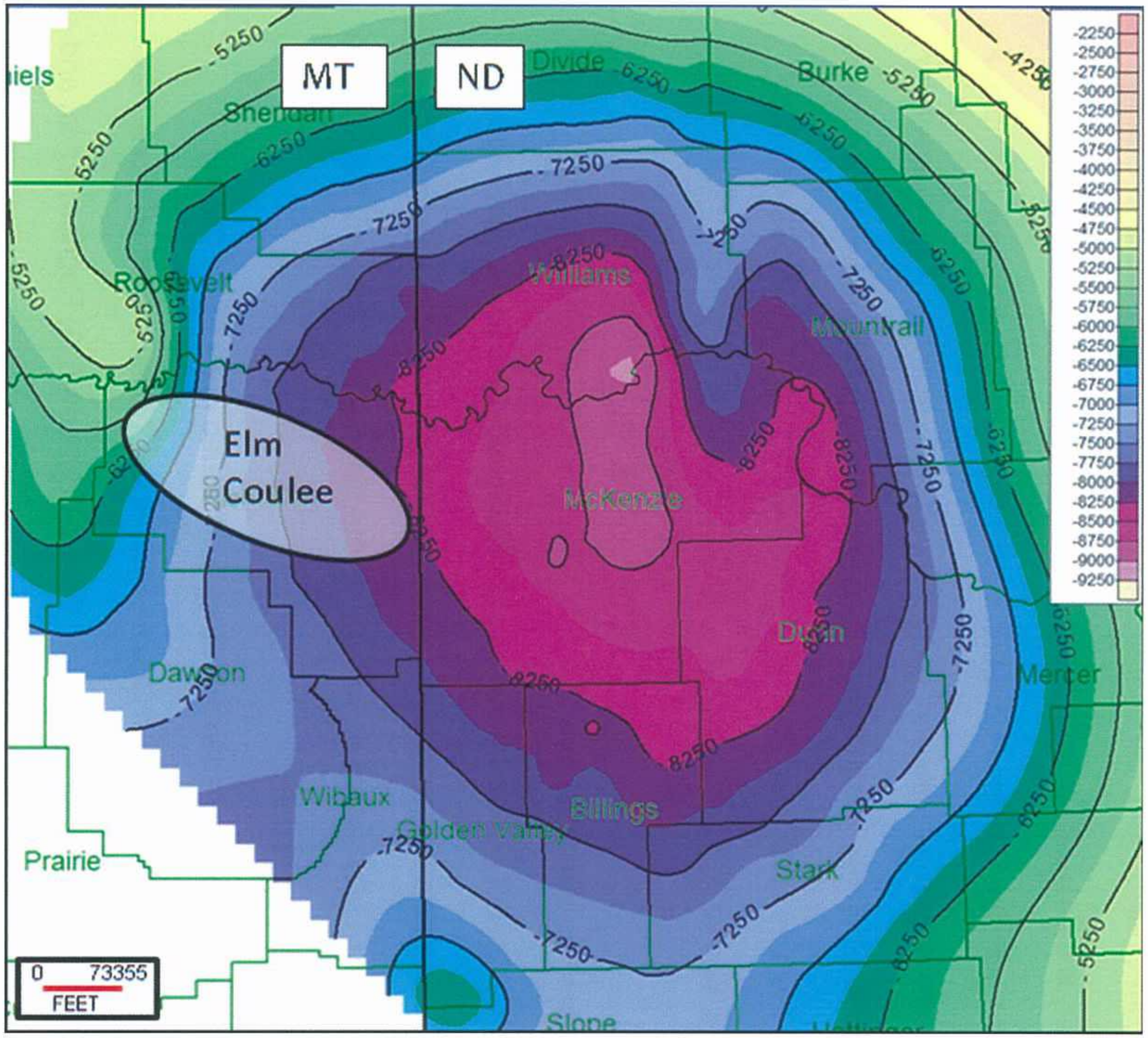

Figure 1.1 Structure map of the Williston Basin showing the location and size of Elm Coulee Field in Richland County, MT. Map modified from original created by CSM student Adrian Almanza (2011).

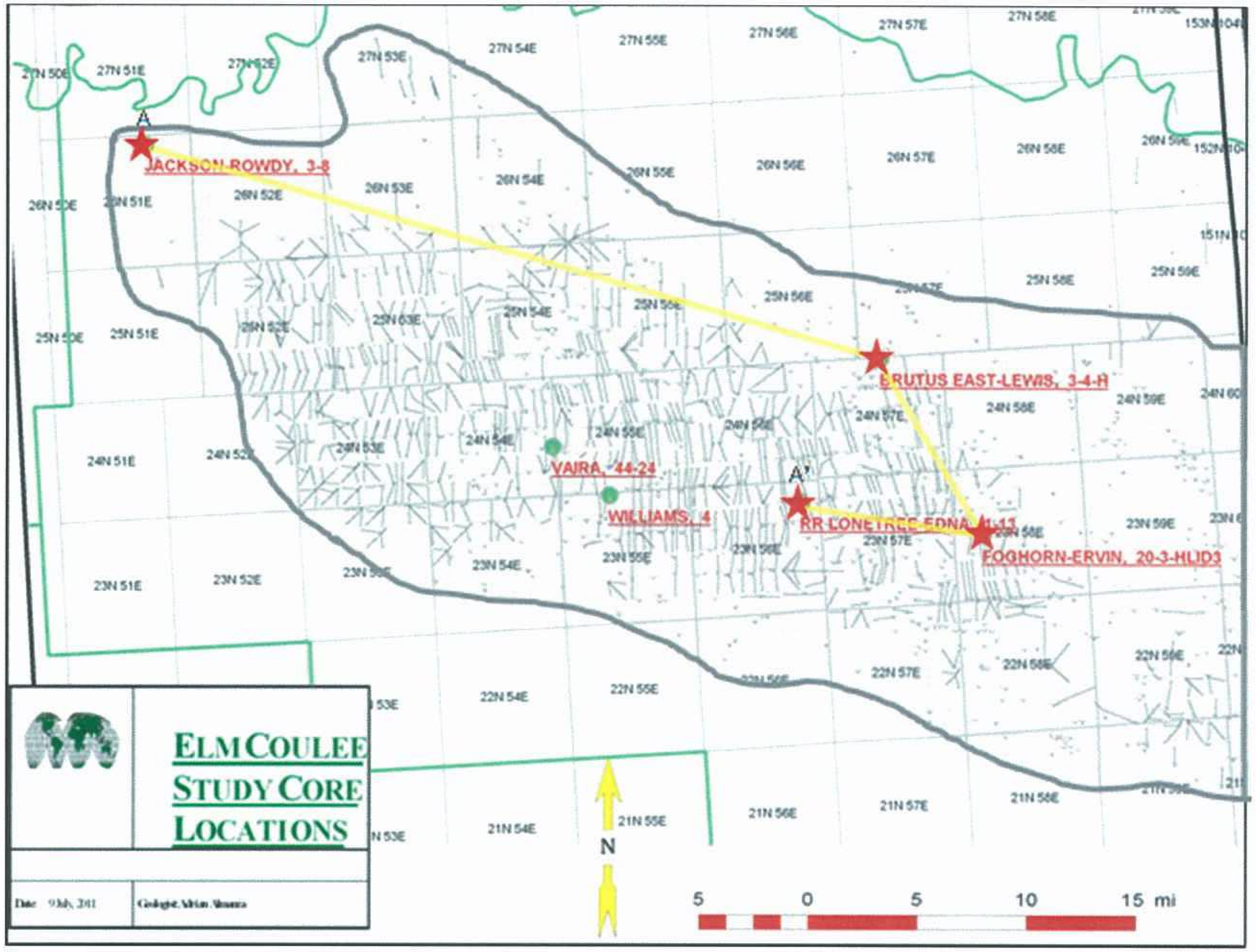

Figure 1.2 Close up of Elm Coulee field (in grey) in Richland County, MT. The four main wells in this study are Jackson-Rowdy, Brutus East-Lewis, Foghorn-Ervin, and RR Lonetree-Edna (marked with red stars). The yellow A-A' cross-section line corresponds to the cross-section in Figure 4.10. Petrographic thin sections from the Vaira and Williams wells (marked with green dots) were also used in this study. Map modified from original created by CSM student Adrian Almanza (2011).

the lower Bakken member is siltier in this portion of the Williston Basin, and it pinches out to the south and west at the depositional limit of the lower member (Figure 1.3). Also, some of the middle Bakken member facies have a different character at Elm Coulee and some are not present locally. Finally, there tends to be relatively little original limestone in this field because most of the limestone has been dolomitized.

The presence of fractures, pore types and their distribution, and permeability networks are other important reservoir factors that will be analyzed and discussed. Analysis of these things combined with detailed petrographic descriptions lead to a better overall understanding of the reservoir at Elm Coulee Field.

Finally, the creation of a diagenetic chart for the field helps summarize the processes the Bakken rocks have undergone since deposition and gives an understanding of the events under which this reservoir came to be.

1.2 **Geologic Overview**

Having knowledge of the geologic history, structure, and stratigraphy within and surrounding the Bakken Formation is vital before studying the formation in depth. Aside from being a first step in any proper geological study, having a general overview of these subjects can lend insight in how to properly analyze and explore for production targets within a seemingly simple formation.

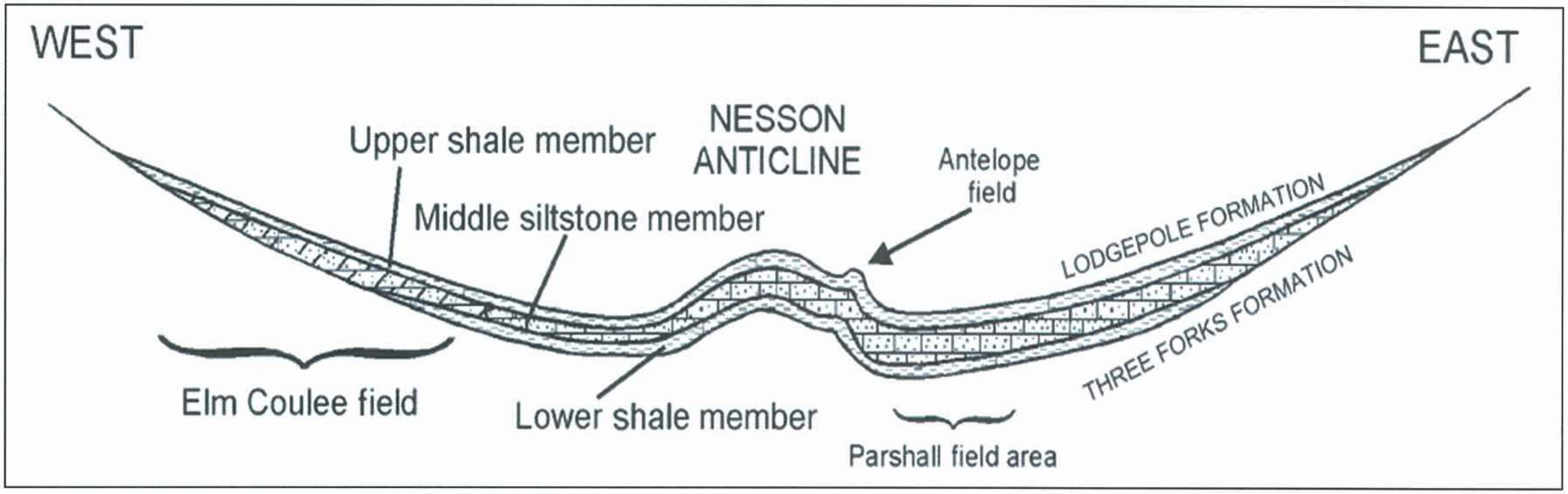

Figure 1.3 Cross-section of the Williston Basin showing the location of Elm Coulee in relation to the three Bakken members. The field is located along the depositional edge of the lower member, and the middle member is more dolomitic in this part of the basin (from Sonnenberg and Pramudito, 2009, modified from Meissner, 1978).

1.2.1 **Structure**

Elm Coulee Field is located on the western side of the Williston Basin in Richland County, MT. The Williston Basin is a large, semicircular, intracratonic basin on the southwest edge of the Canadian Shield (Flannery, 2006). This approximately 133,000 mi^2 basin covers portions of Montana, North Dakota, South Dakota, Manitoba, and Saskatchewan, and overlies the Wyoming Craton, the Superior Craton, and the Trans-Hudson orogenic belt (Gerhard et al., 1990; Pitman et al., 2001). The deepest basement in the Williston Basin is located near Williston, North Dakota (Webster, 1984; Carlson and Anderson, 1965).

Major structural features within the basin include the Nesson and Billings anticlines in North Dakota and the Cedar Creek anticline located in South Dakota and Montana (Figure 1.4). The Cedar Creek and Nesson are both fault bounded anticlines, and the Nesson has a major fault system along its western side that has been active since the Precambrian. All of these faults and folds are thought to have formed in relation to a Proterozoic wrench-fault system (Gerhard et al., 1990).

The Nesson fault system, in conjunction with a fault zone between the Superior Craton and the Trans-Hudson orogenic belt, has allowed fluid movement that apparently helped with the dissolution of the Devonian Prairie Formation salts (LeFever et al., 1991). Dissolution and collapse of the Prairie salts led to local thickness variations in the overlying Bakken Formation (Martinuik, 1991).

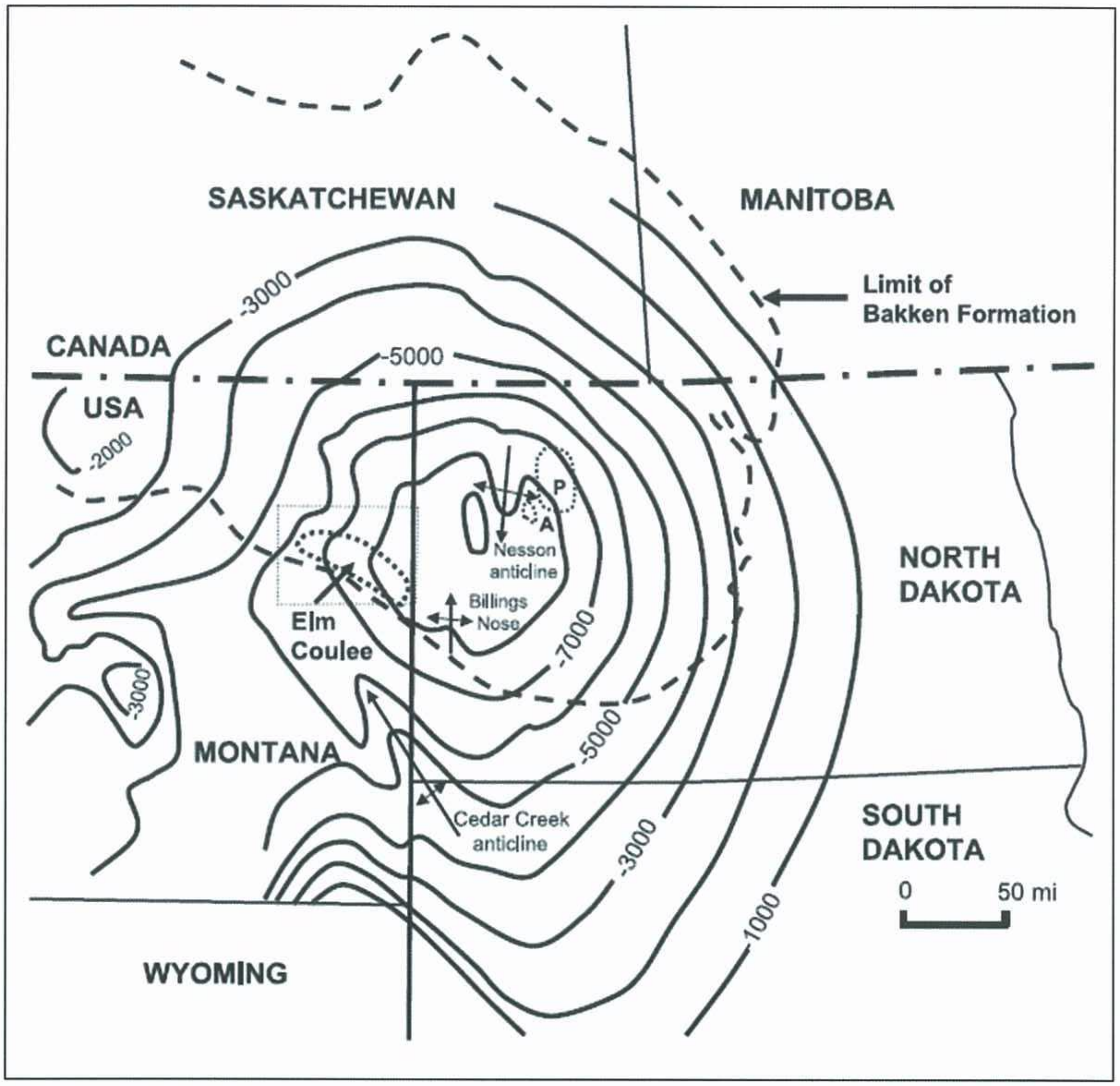

Figure 1.4 Contour map of the Williston Basin on the base of the Mississippian. P = Parshall Field, A = Antelope Field (from Sonnenberg and Pramudito, 2009, modified from Webster, 1984).

During Bakken depositional times, the proto-Williston Basin was an extension of the Devonian Elk Point Basin of Canada. At this time, the basin was located in tropical regions near the equator along the western margin of pre-North America (Figure 1.5) (Nordeng, 2009; Sonnenberg and Pramudito, 2009; Blakey, 2011).

1.2.2 **Stratigraphy**

From Cambrian to Tertiary time, around 16,000 feet of sedimentary rocks were nearly continuously deposited in the Williston Basin with initial sedimentation occurring over an irregular Precambrian surface (Figure 1.6) (Pitman et al., 2001). The Cambrian to middle Mississippian rocks are mostly carbonates, while the majority of rocks deposited after the middle Mississippian are clastics (Flannery, 2006). A major unconformity separates the Paleozoic from Mesozoic strata (McCabe, 1959; LeFever et al., 1991). The depocenter of the basin is east of the Nesson Anticline and east of the deepest part of the present-day Williston Basin (Carlisle et al., 1992).

1.2.2.1 **The Bakken Petroleum System**

The Bakken Petroleum System, also known as the Bakken Pool, consists of the three members of the Devonian-Mississippian Bakken Formation, the upper 50 feet of the underlying Devonian Three Forks Formation, and the lower 50 feet of the overlying Mississippian Lodgepole Formation (Figure 1.7) (Nordeng, 2009; Murphy, 2010).

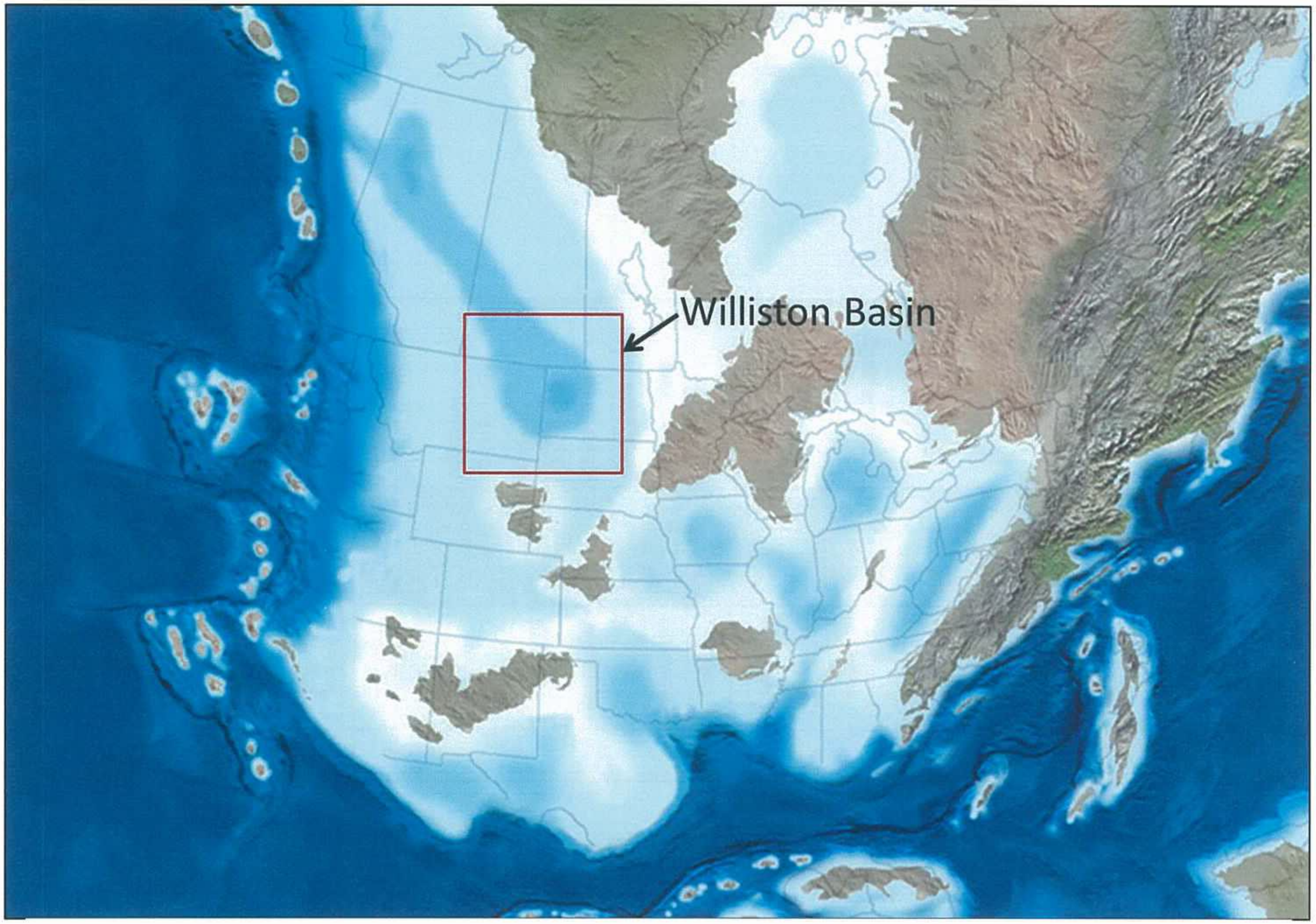

Figure 1.5 Paleogeographic map showing the location of the Williston Basin during the late Devonian while the first half of the Bakken was deposited. At this time, the basin was located in the tropics near the equator (Nordeng, 2009; image modified from Blakey, 2011).