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Subsurface distribution and reservoir properties of the Winnipeg Formation, Southeastern Saskatchewan

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Summary

The Late Ordovician Winnipeg Formation is a siliciclastic stratigraphic unit which occurs in the subsurface of the Province of Saskatchewan, nearby Manitoba and North Dakota. In southeastern Saskatchewan, the formation accumulated in the northeastern edge of the intracratonic Williston Basin and consists of two members: lower sandstone-dominated Black Island and upper shale-dominated Icebox members. This work conveys preliminary results of sedimentological attributes, subsurface distribution and the reservoir properties of the lower member of the formation. Member thickness and overall lithofacies properties of two members are based on core and wireline logs analysis from over 350 wells. The lower member of the formation consists of well- to moderately-sorted, fine- to coarse-grained, bioturbated, locally cross bedded quartz arenite with subordinate shale laminae and rare ferruginous, pisoids (oolitic) sandstone. The sandstone is poorly to moderately porous and constituent the pay zone for oil and gas in southeastern Saskatchewan. The upper Icebox Member consists of grey to greenish, fissile shale which is considered as a cap rock of the underlying sandstone reservoir. This work as well as previous studies envisage a high energy shoreface depositional setting for the lower member and offshore depositional environment for the upper member.

Subsurface isopach, upper surface of the formation and porosity distribution have been generated and interpreted. The isopach map shows that mapping is applied to investigate the member's depositional setting, thickness variations and subsurface distribution of the porous sandstone. Subsurface mapping of the total thickness of the formation shows variations in three zones. Zone 1, which constitutes most of the mapped area, shows that the formation thickens towards southeast of the province. Zone 2 occurs west of the zone 1 and shows a relatively thin distribution of the formation reaching less 8 meters. This zone shows northeast-southwest trend possibly controlled by paleotopographic feature. Farther west of zone 2, the formation get thicker westward.

2D and 3D depth mapping of the upper surface of the formation also confirms the occurrence of an elevated zone which matches that of zone 2. The map also shows that the basin is shallower towards north, northeast and northwest and deep towards south, thus conforming that the depocenter of the Williston Basin was located farther south of the international border. For the reservoir characterization, porosity interval map of the Black Island Member shows that the thickness of the porous intervals is also split in three zones that match the same zones of the thickness distribution. The eastern large area, the thickness of the porous interval has an overall southeastward increase. In zone 2 area, the porous zone is the thinnest and then increases westward. The thickness distribution maps suggest existence of a paleohigh in zone 2 and, possibly pre-Yeoman Formation erosion caused the thickness reduction in zone 2.

Introduction

The Winnipeg Formation is a Late Ordovician siliciclastic unit that occurs subsurface SE Saskatchewan. The formation was deposited in the Williston Basin which covers SW Manitoba and extends farther south into the neighboring states of USA (Fig.1a). The formation is exposed along the west shore of Lake Winnipeg, but none of these outcrops show a complete stratigraphic section of this formation (Oberg, 1966). The formation represents marine sedimentation during the initial period of the northward expansion of the Late Ordovician transgression in the Williston Basin (Paterson, 1971; McCabe, 1978; Norford et al., 1994). Middle Cambrian Deadwood Formation occurs disconformably on the Precambrian basement rocks and is unconformably overlain by the Winnipeg Fm. (Fig.1b) (LeFever 1996). Upper Ordovician Yeoman Formation succeeds unconformably the Winnipeg Formation in southeast Saskatchewan. In SE Saskatchewan, the Winnipeg Formation was deposited in the northeastern edge of the intracratonic Williston Basin and consists of two members: lower sandstone-dominated Black Island Member (bioturbated quartz arenite) and upper shale-dominated Icebox member (greenish grey bioturbated shale and mudstone) (Kreis 2004). The lower member is economically important and produces a fair amount of oil in North Dakota, but less in Saskatchewan and not in Manitoba. Sedimentologic, stratigraphic, diagenetic, subsurface distribution and reservoir quality of the lower sandstone-dominated member of the formation is deemed to be essential for better understanding of the hydrocarbon potential of this unit. We present here preliminary results of an on-going research work.

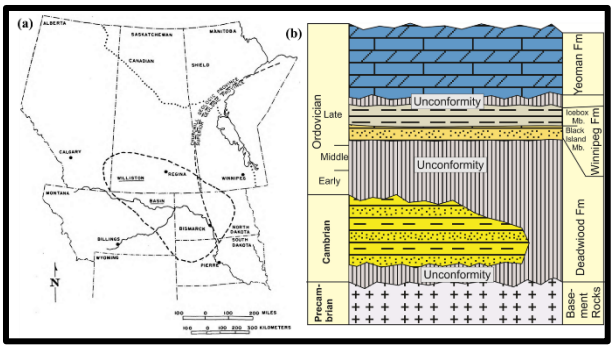

Figure.1. (a) Distribution of Williston basin in the United States and Canada (Worsley and Fuzesy, 1978), and (b) Precambrian to Ordovician stratigraphy in southeast Saskatchewan province (modified from Dorador et al., 2019).

The methodology includes collection, analysis and integration of data: (1) core logging and cutting analysis, (2) wireline log analysis/ thin section (3) well summary sheets/published papers. Subsurface mapping, core stratigraphic log, and correlation are used to understand the sedimentatologic depositional style of the Winnipeg Formation within the Saskatchewan province. Study area includes over 350 well information to generate the subsurface maps (Fig. 2.a). The objective of this short paper is to understand the sedimentological attributes, subsurface distribution and the reservoir properties of the lower member of the formation.

Results and observations

Subsurface mapping:- Isopach map of upper surface of the formation and porosity distribution have been generated and interpreted. The isopach map shows that mapping is applied to investigate the member's depositional setting, thickness variations and subsurface distribution of the porous sandstone. Subsurface mapping of the total thickness of the formation shows variations in three zones (Fig.2.b). Zone 1, which constitutes most of the mapped area, shows that the formation thickens towards southeast of the province. Zone 2 occurs west of the zone 1

and shows a relatively thin distribution of the formation reaching less 8 meters. This zone shows northeast-southwest trend possibly controlled by paleotopographic feature. Farther west of zone 2, the formation get thicker westward. Depth structure map and 3D mapping (Fig.2.c & d) of the upper surface of the formation also confirms the occurrence an elevated zone which matches that of zone 2. The map also shows that the basin was shallower towards north, northeast and northwest and deep towards south, thus conforming that the depocenter of the Williston Basin was located farther south of the international border.

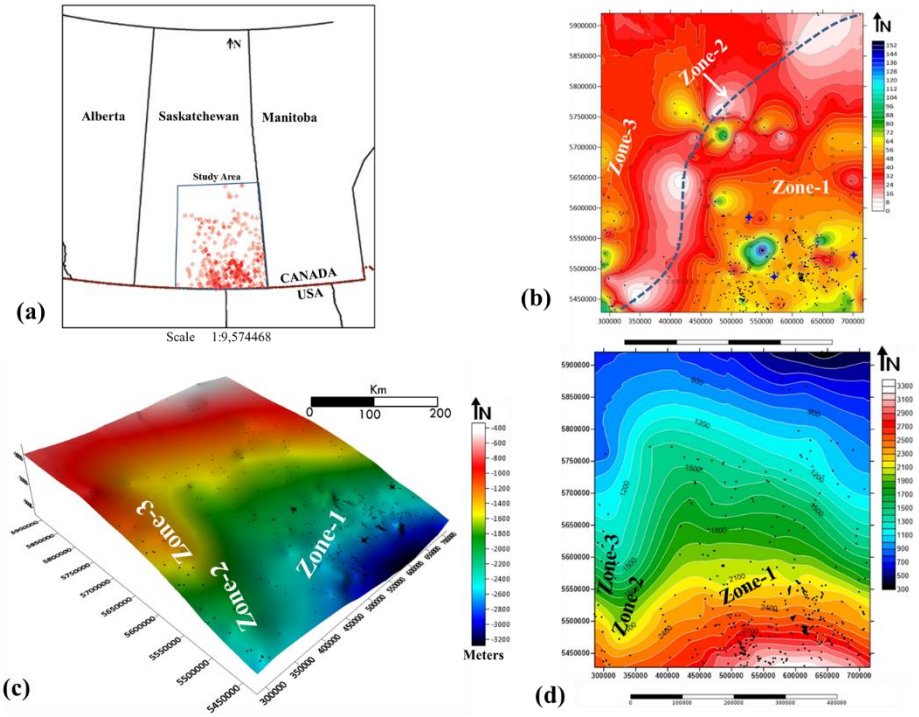

Figure.2. Subsurface distribution of the Winnipeg Formation (a) Study area (b) Isopach map showing SE-ward thickening of the formation. (c) 3D depth map from the upper surface of the formation. The formation deepens SE –ward. (d) 2D map of the upper surface of the formation showing subsurface distribution comparable to that of the 3D map. See text for discussion of the three zones (1, 2 & 3)

Reservoir properties:- For the reservoir characterization, porosity interval map of the Black Island Member shows that the thickness of the porous intervals is also split in three zones that match the same zones of the thickness distribution (Fig.3.a). The eastern large area, the thickness of the porous interval has an overall southeastward increase. In zone 2 area, the porous zone is the thinnest and then increases westward. The thickness distribution maps suggest existence of a paleohigh in zone 2 and, possibly pre-Yeoman Formation erosion caused the thickness reduction in zone 2.

Three wells core (131/03-08-017-19w2/00, 21/08-06-007-15w2/0, and 01/05-15-010-02w2/0) are also interpreted on the basis of facies analysis, sedimentary structures and trace fossils. Black Island Member (sandstone) mostly consist of white to light and dark grey, very fine to coarse grained containing pyrite, glauconite and quartz grains, very porous, moderate to poor

consolidation, and fair porosity are observed. Grey to brownish sandstones color is due to organic matter associated with the bioturbation and calcite cementation and early to late diagenesis is also very dominant with quartz arenite (Fig.3.b & c). Correlation is also done between three wells that indicates that Black Island Member is dominant with coarsening upward sequence indicates low sea level settings. Icebox Member is finning upward sequence with high sea level conditions. The Black Island Member thickness indicates that it is more widespread than the Icebox Member in the province

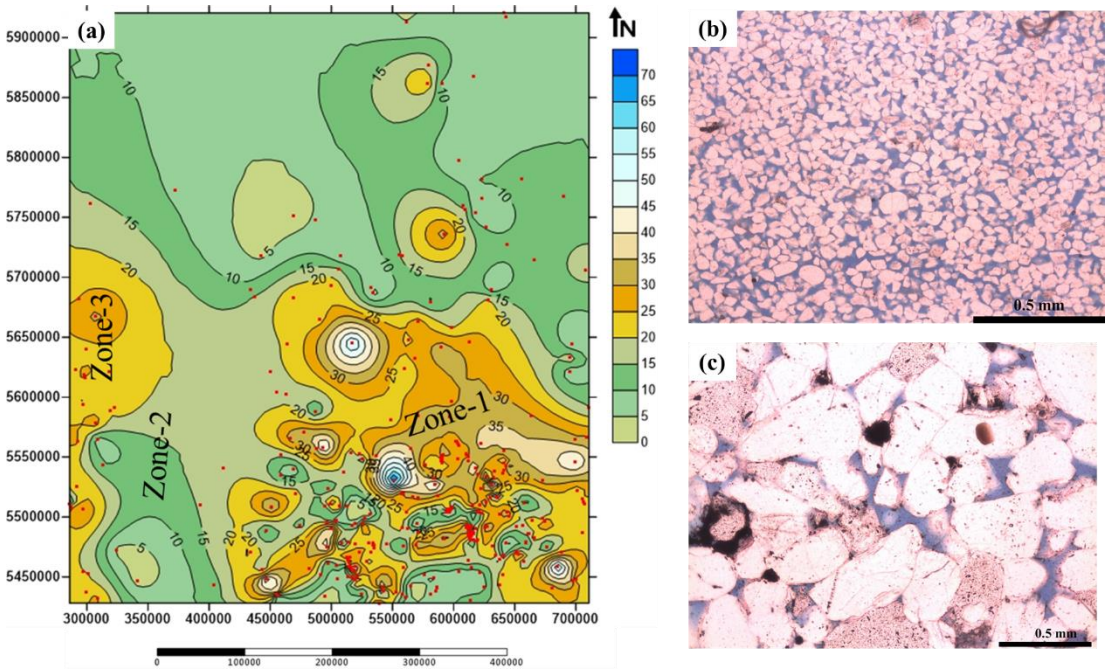

Figure.3. Porous zones estimation of Winnipeg Formation (a) Porosity interval map of Black Island Member indicates more porous zone is toward southern and western site (b) Quartz arenite with pores and interbedded grains at depth 2066.5m of 131/03-08-010-19w2/00 well, and (c) Quartz arenite with pores and interbedded grains at depth 2292.9m of 101/05-15-010-2w2/00 well.

Conclusions

The Winnipeg Formation consists of a lower quartz arenite member (Black Island Mb.) and upper shale-dominated member (Icebox Mb.) The lower member was deposited in a medium to high energy shoreface and constitutes the reservoir unit of the formation in SE Saskatchewan. 2D and 3D isopach map of the formation, structure of its upper surface map and thickness variation of the porous zone of the lower member furnish the subsurface distribution of these properties. The maps show three zones that can be summarized as follows. Zone 1: this zone occurs about 3/4th of the study area and is characterized by thick section of the formation that gets deeper SE-ward. It also preserves the thickest pay zone which also gets deeper SE-ward. Zone 2 is a relatively narrow, NE-SE-oriented corridor of apparently uplifted appearance. This

corridor constitutes the shallowest zone and thinnest porous zone. Zone 3 occurs west of zone 2 and gets thicker and deeper away from the uplifted corridor.

Acknowledgements

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