Overview of the Paleotopography on the Sub-Mesozoic Unconformity and Hydrocarbon Accumulation in the Mississippian Madison Group of Southeastern Saskatchewan

Arden Marsh [1]

Marsh, A. (2017): Overview of the paleotopography on the sub-Mesozoic unconformity and hydrocarbon accumulation in the Mississippian Madison Group of southeastern Saskatchewan; *in* Summary of Investigations 2017, Volume 1, Saskatchewan Geological Survey, Saskatchewan Ministry of the Economy, Miscellaneous Report 2017-4.1, Paper A-4, 10p.

Abstract

The location, shape and orientation of Mississippian oil pools in southeastern Saskatchewan is directly correlated to the paleotopography of the strata in which the oil is found. Accurate knowledge of the paleotopography of Mississippian strata relies on the quality of the data available, and the density and distribution of the wells being used to produce paleotopographic maps and models. Further drilling will enhance the amount of data available and the density of wells, and lead to a better understanding of the distribution and significance of various geological features on the sub-Mesozoic unconformity and their control on hydrocarbon accumulation.

Oil has been produced from Mississippian-age reservoirs in southeastern Saskatchewan since the early 1950s. Over the years, many papers have been written and talks presented regarding various aspects of the Mississippian strata in this part of the province, often focusing on individual beds. There are also regional reports that discuss the entire Mississippian, however, many of these reports were written using sparse well data, a result of the limited number of wells that were drilled at the time the reports were written. With the current abundance of wells drilled through the Mississippian in southeastern Saskatchewan, it was possible to prepare updated regional maps of these strata. This has resulted in the discovery of some interesting—but not surprising—relationships between paleotopography and hydrocarbon accumulation.

Data from over 4000 non-horizontal wells in southeast Saskatchewan were used to prepare updated high-resolution regional maps of the Mississippian strata, showing the known and potential areas of hydrocarbon accumulation. Using maps produced by the analysis of production and core data, this paper will show the relationships between paleotopography and known areas of Mississippian oil production, and highlight the potential for further oil production from these strata.

Keywords: *Mississippian, sub-Mesozoic unconformity, Madison Group, southeastern Saskatchewan, oil, oil cut, paleotopography*

1. Introduction

The purpose of this paper is to show the relationship between the paleotopography on the sub-Mesozoic unconformity structural surface and Mississippian-age accumulations of hydrocarbons in southeastern Saskatchewan (Figure 1). Production and core analysis data from wells that have targeted Mississippian reservoirs in the Madison Group have been used to map the oil cut for the Mississippian. The maps produced using these data can also be used to infer potential traps for Mississippian reservoirs, as well as potential oil-water contacts.

[1] Saskatchewan Ministry of the Economy, Saskatchewan Geological Survey, 201 Dewdney Avenue East, Regina, SK S4N 4G3

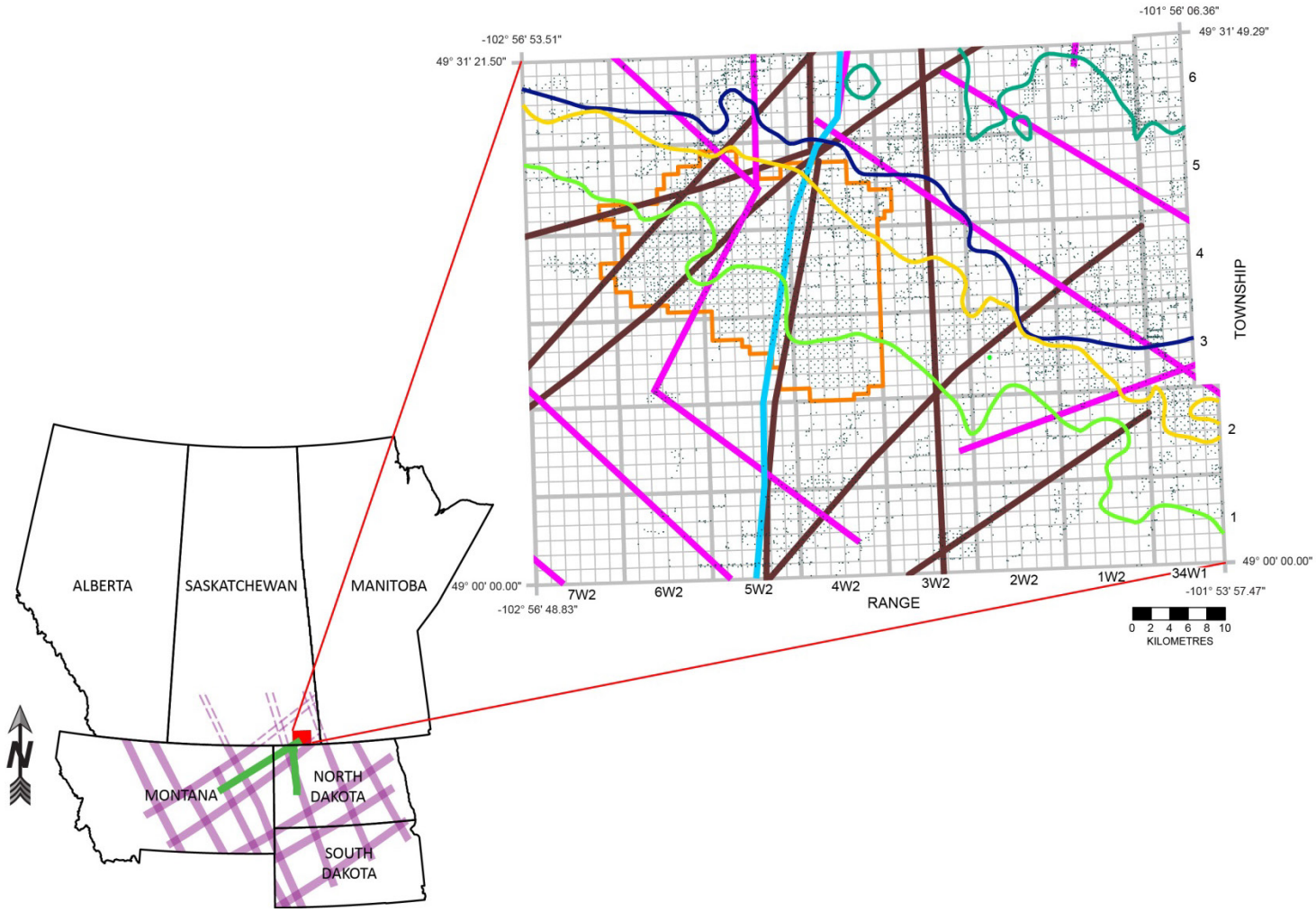

Figure 1 – *Inset map (lower left) showing the location of the study area (red polygon). (Note: the paleotectonic features (thick purple and green lines) that conntrolled both sedimentation and the emplacement of hydrocarbons that are extrapolated into southern Saskatchewan are* modified from *Brown and Brown (1987), and Wright* et al. *(1994)). The map of the study area (upper right) shows the wells used (dark green crosses) to produce the oil cut maps and other figures in this report; the outline of the Steelman pool (orange outline); the subcrop edges for the Frobisher Beds (blue-green lines), Midale Beds (dark blue line), Ratcliffe Beds (yellow line) and Poplar Beds (light green line) (*modified from *Marsh and Love (2014)); as well as paleotectonic lineaments (brown lines* from *Saskatchewan Ministry of Energy and Resources (2006); light blue and magenta lines* from *Li and Morozov (2007)).*

2. Study Area and Data Sources

The study area extends from Township 1, Range 34 west of the First Meridian (34W1), to Township 6, Range 7 west of the Second Meridian (7W2) (Figure 1) and is situated roughly along the northeast flank of the Williston Basin. Stratigraphic data from over 4048 non-horizontal wells was used to produce updated high-resolution regional maps of the Mississippian structural surface that is referred to as the sub-Mesozoic unconformity (Figure 2).

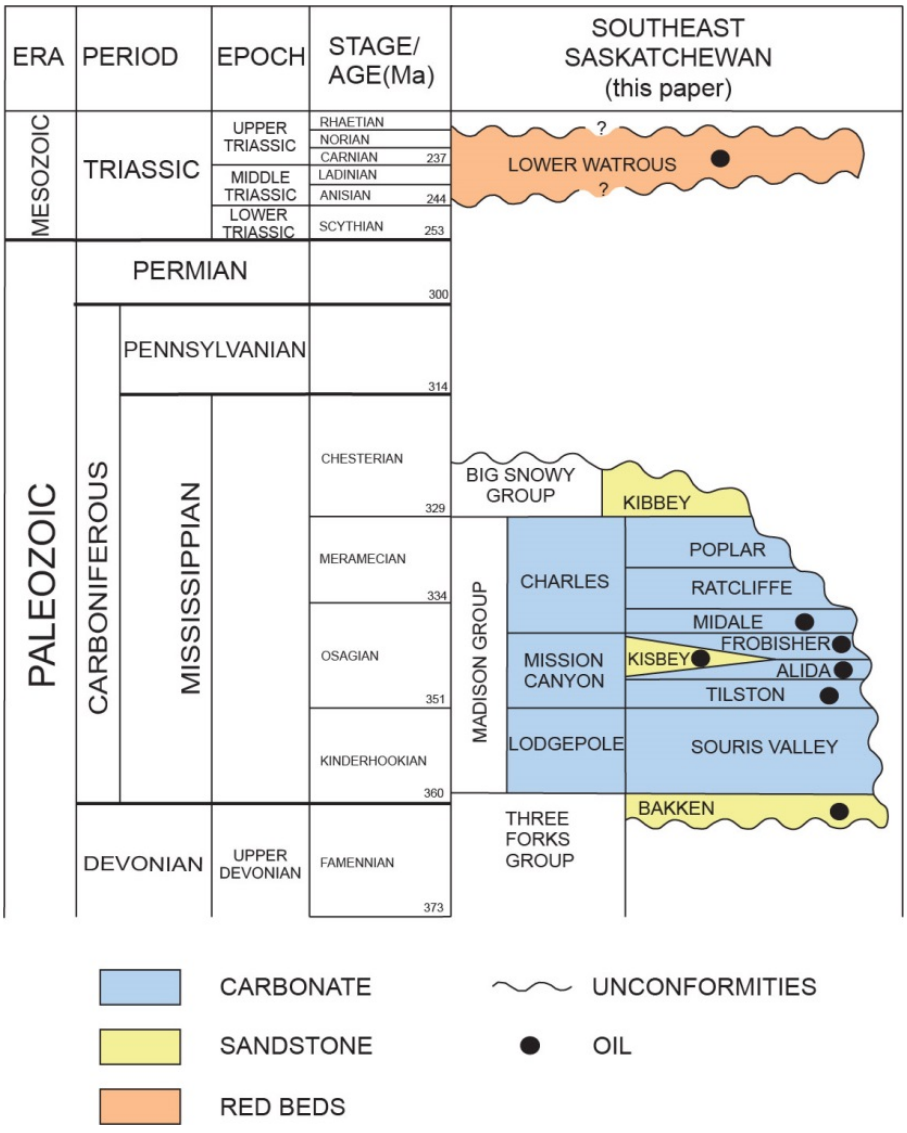

Figure 2 – *Chart showing subdivisions of uppermost Devonian through Triassic strata in southeastern Saskatchewan. The unconformity above the Big Snowy Group that extends down the right edge of the column is referred to as the 'sub-Mesozoic unconformity'. The Mississippian strata that subcrop within the study area are the Alida through Poplar beds. Oil production to the end of 2017 from the Mississippian strata that subcrop within the study area was mostly from the Frobisher (43.7 x 10^6 m^3 from 3232 wells) and Midale (64.1 x 10^6 m^3 from 3032 wells) beds. Minor oil production was attributed to the Alida Beds (4.0 x 10^6 m^3 from 284 wells) and Kisbey Sandstone (6.8 x 10^3 m^3 from 1 well). The Tilston Beds do not subcrop within the study area, but do also have some production (224 x 10^3 m^3 from 9 wells). The stratigraphic chart is* modified from *Saskatchewan Ministry of the Economy (2014).*

Production data from 6449 well completions that have at some time produced oil from Mississippian reservoirs were used to calculate oil cut for the Mississippian strata. Similarly, pore oil and water volumes from core analysis within Mississippian strata from 1824 wells were also used to calculate oil cut.

The formula used to calculate oil cut using production data, adapted from Theloy *et al.* (2013) and Kohlruss (2015), is as follows:

Initial 3 months oil production / (initial 3 months oil production + initial 3 months water production)

The formula below was used to calculate oil cut using core analysis data.

Pore oil volume % / (pore oil volume % + pore water volume %)

The production and core analysis data used in this paper were extracted from geoLOGIC's database using geoSCOUT software. The manipulation of stratigraphic, production and core analysis data was carried out in Microsoft® Excel. A structure contour map of the sub-Mesozoic unconformity, contour maps of Mississippian oil cut, and a 3-D composite map were created in Golden Software Inc.'s Surfer® version 12, using the software's kriging algorithm. The geographic base for the maps is in NAD83 with a 0.005 degree (approximately 555 m) grid spacing (22 260 grid nodes).

3. Discussion

Detailed mapping of the paleogeography of the sub-Mesozoic unconformity in southeastern Saskatchewan revealed a highly irregular surface that dips, in a regional sense, to the south-southwest (Figure 3). Irregularities on the sub-Mesozoic unconformity surface are caused by several somewhat parallel to curvilinear, northeast-to-southwest–trending, topographic highs that are related to deep-seated regional lineaments (thick purple and green lines in lower left of Figure 1) within this area of the Williston Basin. Past authors (Holter, 1969; Thomas, 1974; Brown and Brown, 1987; Kent, 1987; Gerhard *et al*., 1991; Wright *et al*., 1994; Kreis and Kent, 2000) have defined these linear features as part of the Weldon-Brockton-Froid-Fromberg Lineament Zone and proposed that they extend into the study area (Figure 1). This zone of lineaments was created by regional stresses that deformed and faulted Precambrian basement rocks underlying the Phanerozoic strata in this area (Holter, 1969; Thomas, 1974; Bell and Babcock, 1986; Brown and Brown, 1987; Kent, 1987; Gerhard *et al*., 1991; Bell *et al*., 1994; Wright *et al*., 1994; Kreis and Kent, 2000).

The distribution of hydrocarbon reservoirs within the Mississippian strata in the study area has been attributed to a variety of mechanisms: subcrop pinch-out traps created by an angular unconformity overlain by low permeability Lower Watrous Member strata (Fuzesy, 1960; Nimegeers and Nickel, 2005); stratigraphic traps in larger pools (*i.e.*, Steelman pool, Figure 1) in which hydrocarbons are trapped within reservoirs that are facies controlled (Fuzesy, 1960; Nimegeers and Nickel, 2005; Marsh, 2006); and/or structural traps created by northeast-to-southwest– and northwest-to-southeast–trending linear to curvilinear, fault-controlled, deep-seated structures (Holter, 1969; Thomas, 1974; Bell and Babcock, 1986; Brown and Brown, 1987; Kent, 1987; Gerhard *et al*., 1991; Bell *et al*., 1994; Wright *et al*., 1994; Kreis and Kent, 2000). Mississippian subcrop plays are generally considered to be located parallel and to the southwest of subcrop edges of the Mississippian strata (Figure 1; Marsh and Love, 2014) in which they're found (Nimegeers and Nickel, 2005). Stratigraphic plays within the Mississippian, as with other Phanerozoic strata, are dependent upon lithology and facies distribution (Fuzesy, 1960; Nimegeers and Nickel, 2005). Mississippian structural plays are typically found along flanks and up-dip of linear to curvilinear features that can be seen on the paleotopographic surface of the sub-Mesozoic unconformity (Fuzesy, 1960; Nimegeers and Nickel, 2005).

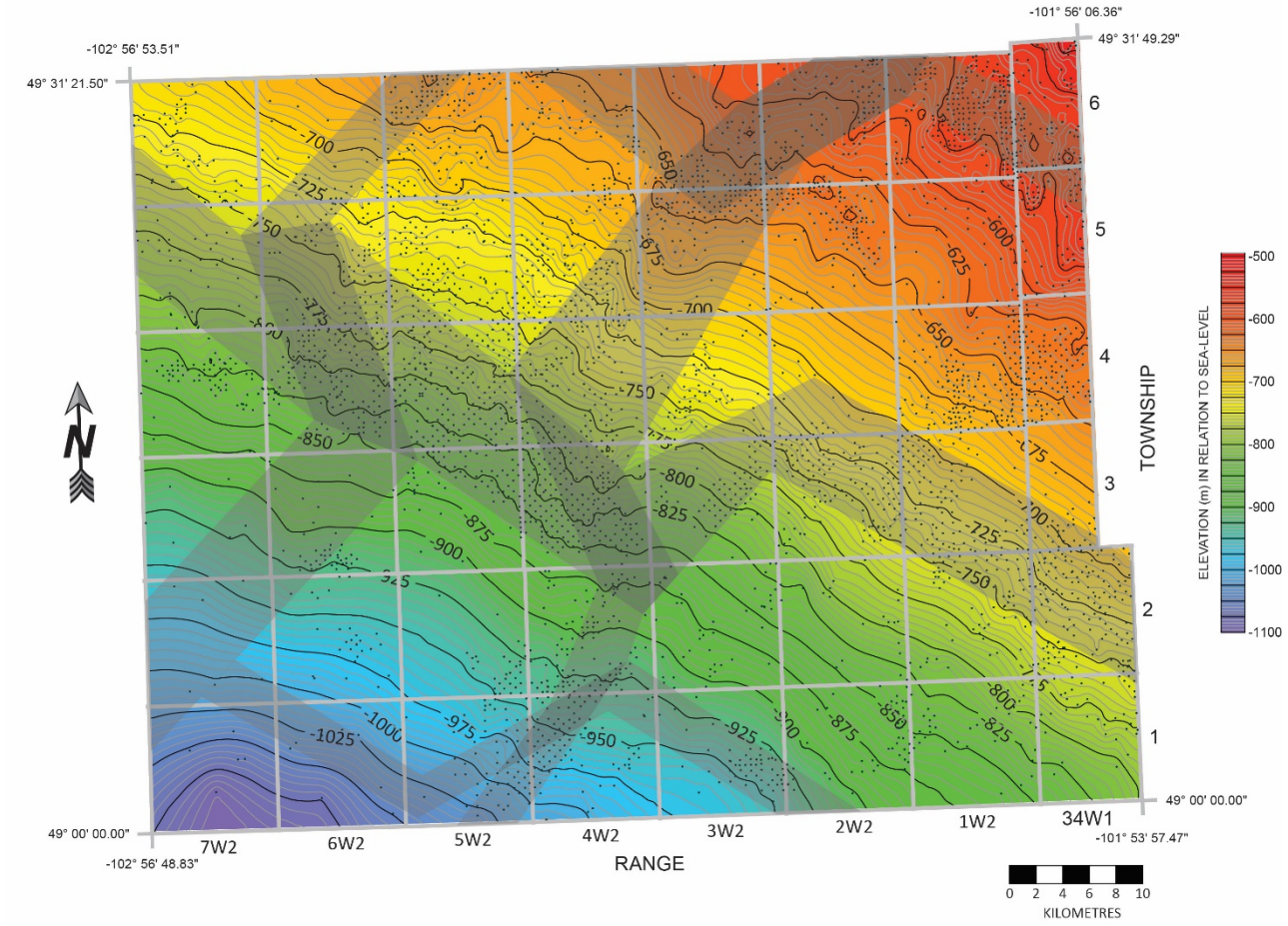

Figure 3 – *Structure map of the sub-Mesozoic unconformity. Major contours are every 25 m (labelled); minor contours are every 5 m (unlabelled). The wells used to produce this map are shown as dark green dots. Inferred lineaments within the study area are shown as grey polygons. The general regional dip shown by the contours is toward the south-southwest, which tends to mask the regional northwest-southeast paleotectonic lineaments. Northeast-southwest–oriented lineaments, however, are easily recognizable as northeast and southwest deflections of the structure contour lines. It should also be noted that the general regional distribution of the wells in the study area is partially related to the regional paleotectonics.*

Initial oil cut (>40%) maps for all Mississippian Madison Group strata within the study area (Figures 4 and 5) illustrate that accumulations of oil are concentrated within certain locations due to what appears to be either their relationship to subcrops or to paleotopographic structural highs.

The map of oil cut derived from production data is shown in Figure 4. This oil cut map gives an almost complete picture of the locations of the oil-producing areas, which is supplemented by the oil cut map derived from core analysis data (Figure 5). When the two oil cut maps are combined (Figure 6), a complete overview of the oil cut for the entire Mississippian Madison Group strata is derived. This combination of oil cut maps highlights the 'sweet spots' in the study area—that is, the areas with the highest oil cut—which also generally coincide with regional inferred lineaments within the study area.

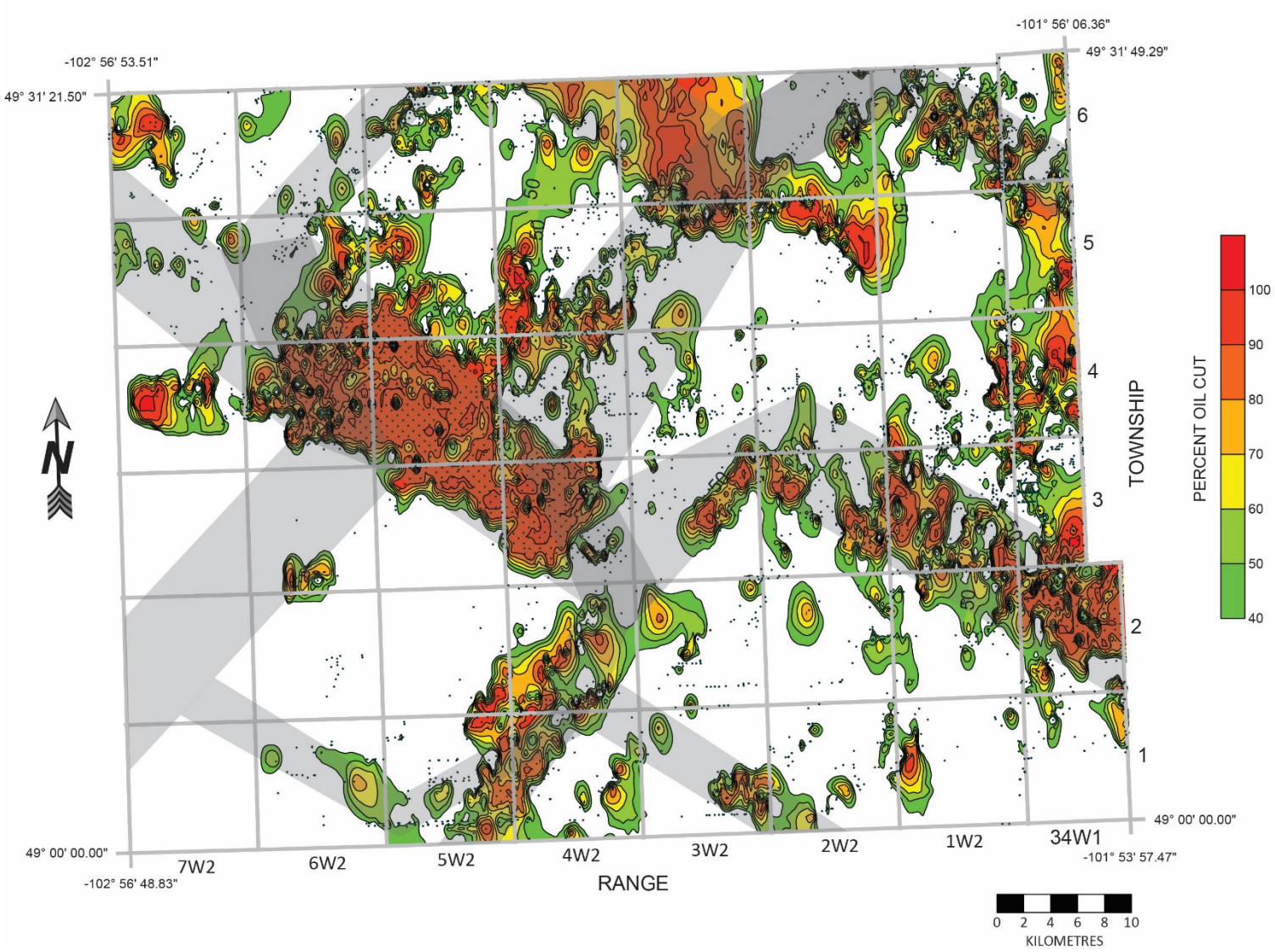

Figure 4 – *Map showing oil cut (>40%) from Mississippian oil-producing wells. The wells that were used to create this map are shown as dark green dots. Inferred lineaments within the study area are shown as wide grey bands. Contour intervals are in 0.10 intervals (10%).*

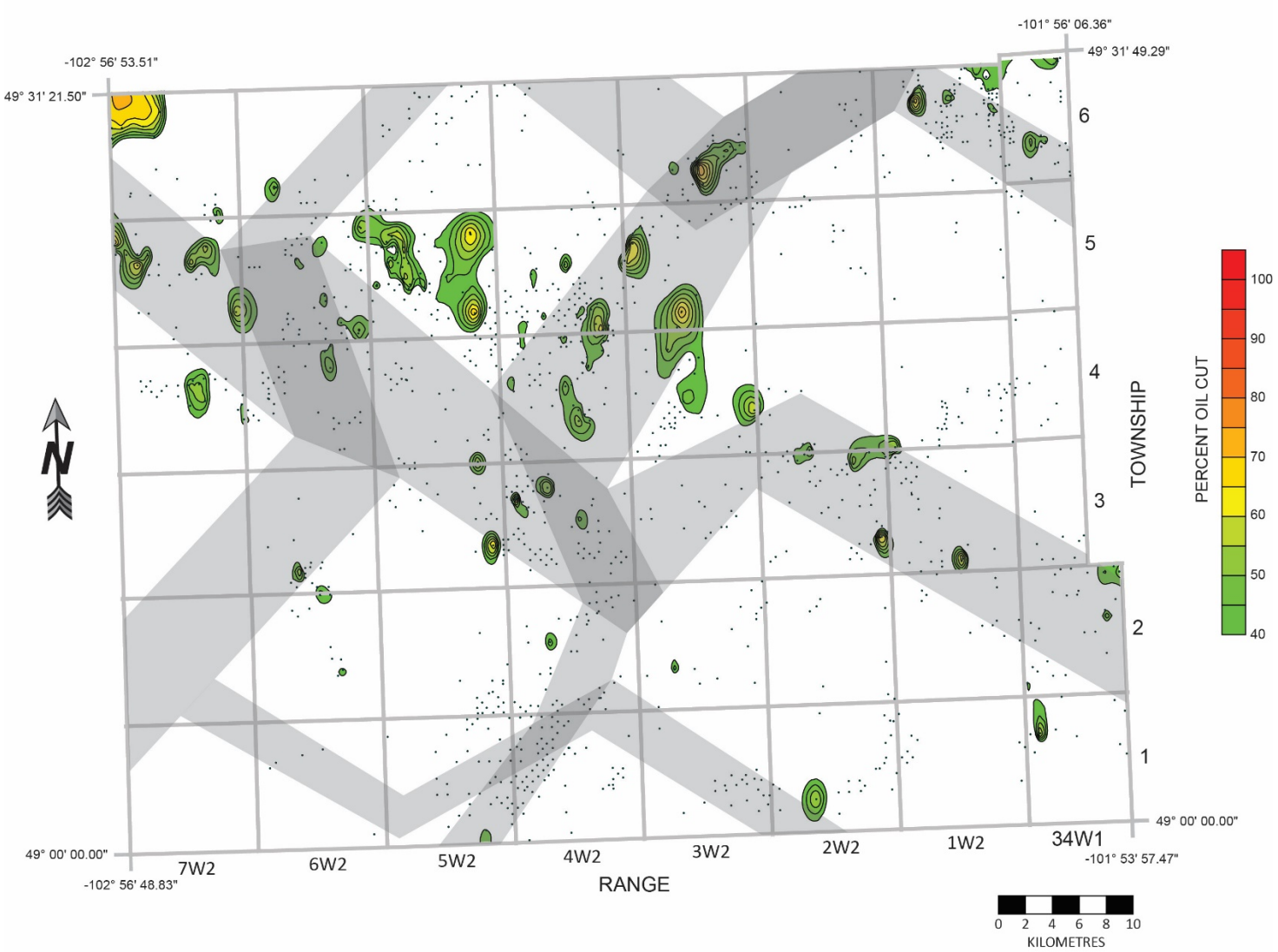

Figure 5 – *Map showing oil cut (>40%) from wells with Mississippian core that have pore volume oil% and pore volume water% as part of the results reported from core analysis. The wells that were used to create this map are shown as dark green dots. Inferred lineaments within the study area are shown as wide grey bands. Contour intervals are in 0.05 intervals (5%).*

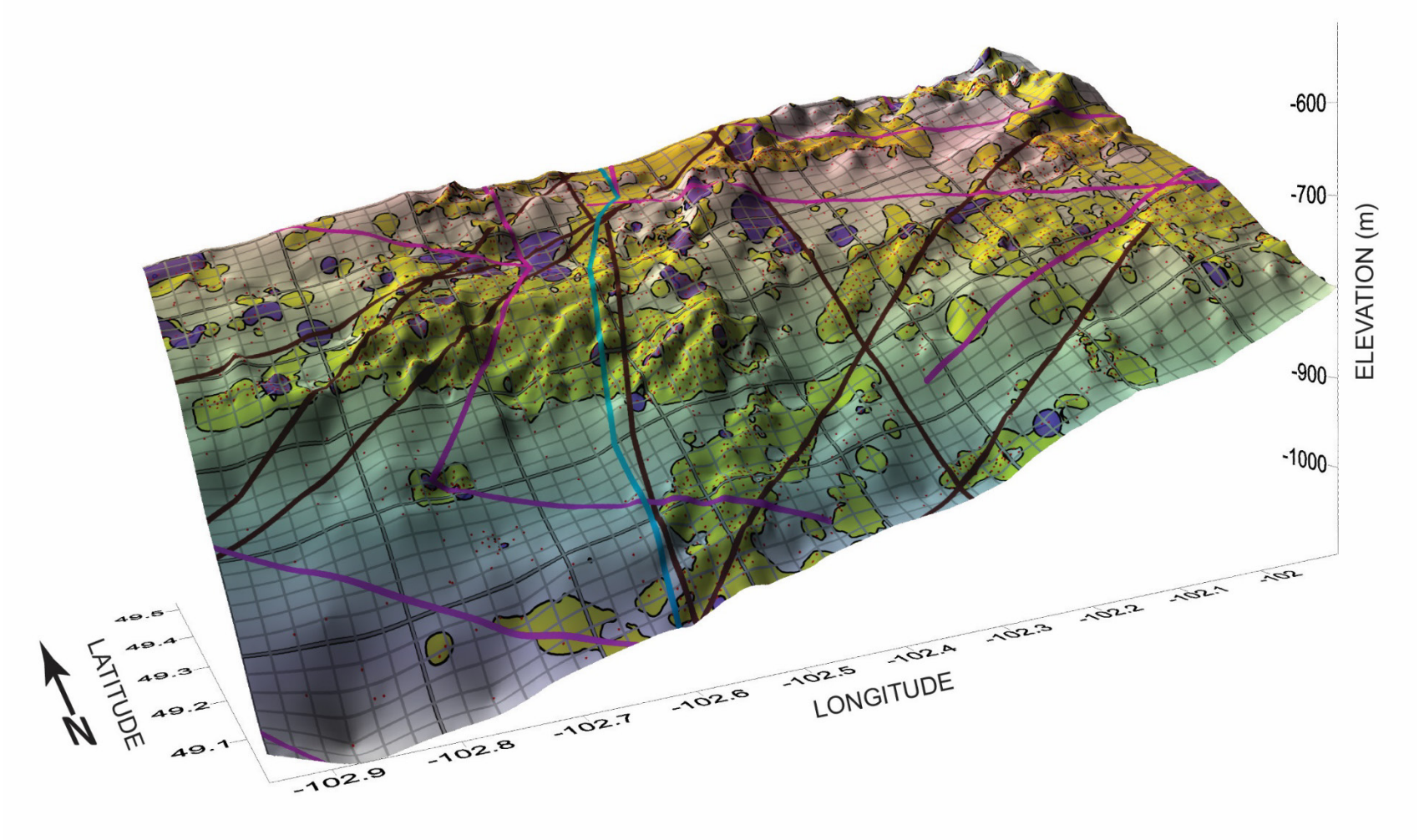

Figure 6 – *Composite 3-D map showing oil cut derived from production data from Mississippian oil-producing wells (yellow-green shaded areas outlined in black) and oil cut derived from wells with core analysis within Mississippian strata (purple shaded areas outlined in black) overlain on the sub-Mesozoic unconformity structural surface. The regional paleotectonic lineaments* from *Saskatchewan Ministry of Energy and Resources (2006) are shown as brown lines, and those* from *Li and Morozov (2007) are shown as blue and magenta lines. The wells that were used to create the sub-Mesozoic unconformity structural surface are shown as red dots.*

4. Summary

This paper presents the results of the first part of a project that will eventually characterize all of the reservoirs within the Mississippian strata in southeastern Saskatchewan. To date, stratigraphic data from 4048 non-horizontal wells has been used to produce a detailed map of the paleotopographic surface of the sub-Mesozoic unconformity. Oil cut maps have been produced using data from 6449 well completions and 1824 wells with core analyses. A 3-D composite map combining all of the oil cut data overlain on the structural surface of the sub-Mesozoic unconformity has been produced to show the relationship between paleotopography and oil cut. The relationships shown in these maps may also be used to interpret the general location of potential oil-water contacts within Mississippian strata in the study area.

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