Impact of the Dissolution of the Devonian Prairie Salt in North-Central North Dakota

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The seas have transgressed and regressed multiple times throughout the history of the Williston Basin. During regressive times, the reduced water evaporated resulting in hypersaline brines and ultimately the precipitation of halite (salt). Therefore, several salt layers are present in the subsurface of the Williston Basin (fig. 1). The deepest salt present in the basin is the Devonian Prairie salt. During Devonian time the basin was located near the equator at the southeastern end of the Elk Point Basin (fig. 2). Arid climates and restricted conditions allowed for the deposition of a thick sequence of salt and potash. The Prairie reaches a maximum thickness of 638 feet.

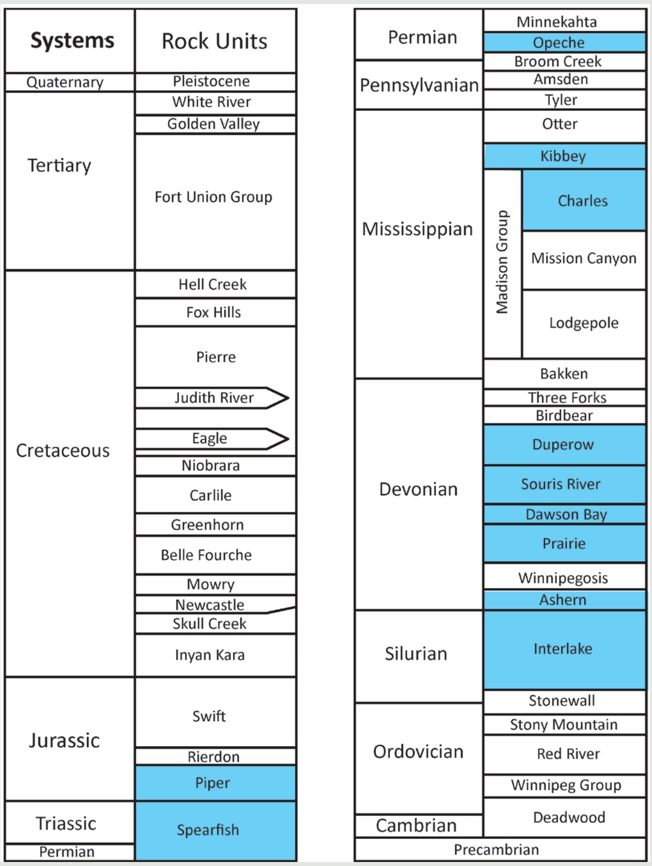

Figure 1. Stratigraphic column of the Williston Basin with the salt bearing formation indicated in blue (LeFever and LeFever, 2005).

Subsequent ground water movement has locally dissolved various salts through time. This dissolution results in the development of a cavern that ultimately collapses bending and fracturing the overlying rock (Burke, 2001). Because this dissolution is episodic it results in rapid changes in thickness, changes in the depositional patterns in the overlying sediments, and has great potential for trapping hydrocarbons and inducing fractures and enhancing porosity in overlying rocks (i.e. Elm Coulee Field in Richland County, Montana; Sonnenberg and Pramudito, 2009).

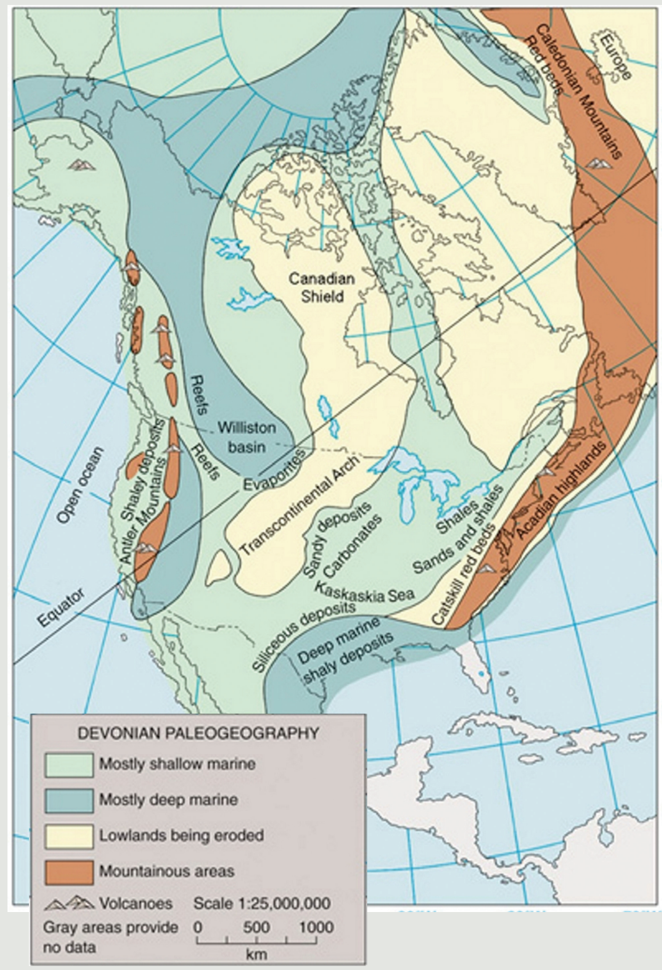

Figure 2. Paleogeographic map of the Devonian (Levin, 1996). Note the position of the equator with respect to the Williston Basin. The Williston Basin is at the end of the Elk Point Basin that continues northwest into Alberta, Canada.

Dissolution

The main salt that underlies the north-central portion of the Williston Basin is the Devonian Prairie salt (fig. 3). Dissolution of this salt can be related to two different mechanisms. The first is the movement of fresher water from the perimeter of the basin. This water travels into and through porous beds dissolving salt along its way. The second occurs when water moves upward along fault zones or faults associated with tectonic boundaries allowing for the further dissolution of the salt.

Figure 3. Core photograph of the Prairie salt from the Prairie Formation from the Pan American Petroleum Corp. - #1 Clifford Marmon (API #33-105-00667-0000; Depth – 11452 ft.; SWSW Sec. 2, T154N, R95W). Note the silt and clay stringers throughout the halite beds. White scale bar = 1 inch.

The north-central area has all of the necessary elements to support the dissolution of salt. Evidence for dissolution of the Prairie salt can be characterized by a cross-section drawn from the Cardinal Drilling Co. - #1 Beatrice Keeler to the Phillips Petroleum Co - #1 Glenn Brandt (fig. 4) and has been recognized by Reed (1961), Parker (1967), Anderson and Hunt (1964). This structural section highlights the removal of the salt and its effect on the overlying sediment. Observations from the section are further supported by core data from the #1 Blanche Thompson, the well without salt. When the Prairie salt was removed in this well it left behind the impurities and interbeds consisting of clays and silts. Also associated with these lithologies are collapse breccias resulting from collapse of the overlying rocks (fig. 5).

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Anderson and Hunt (1964) showed the presence of a series of gravity anomalies along the edge of the Devonian Prairie salt in

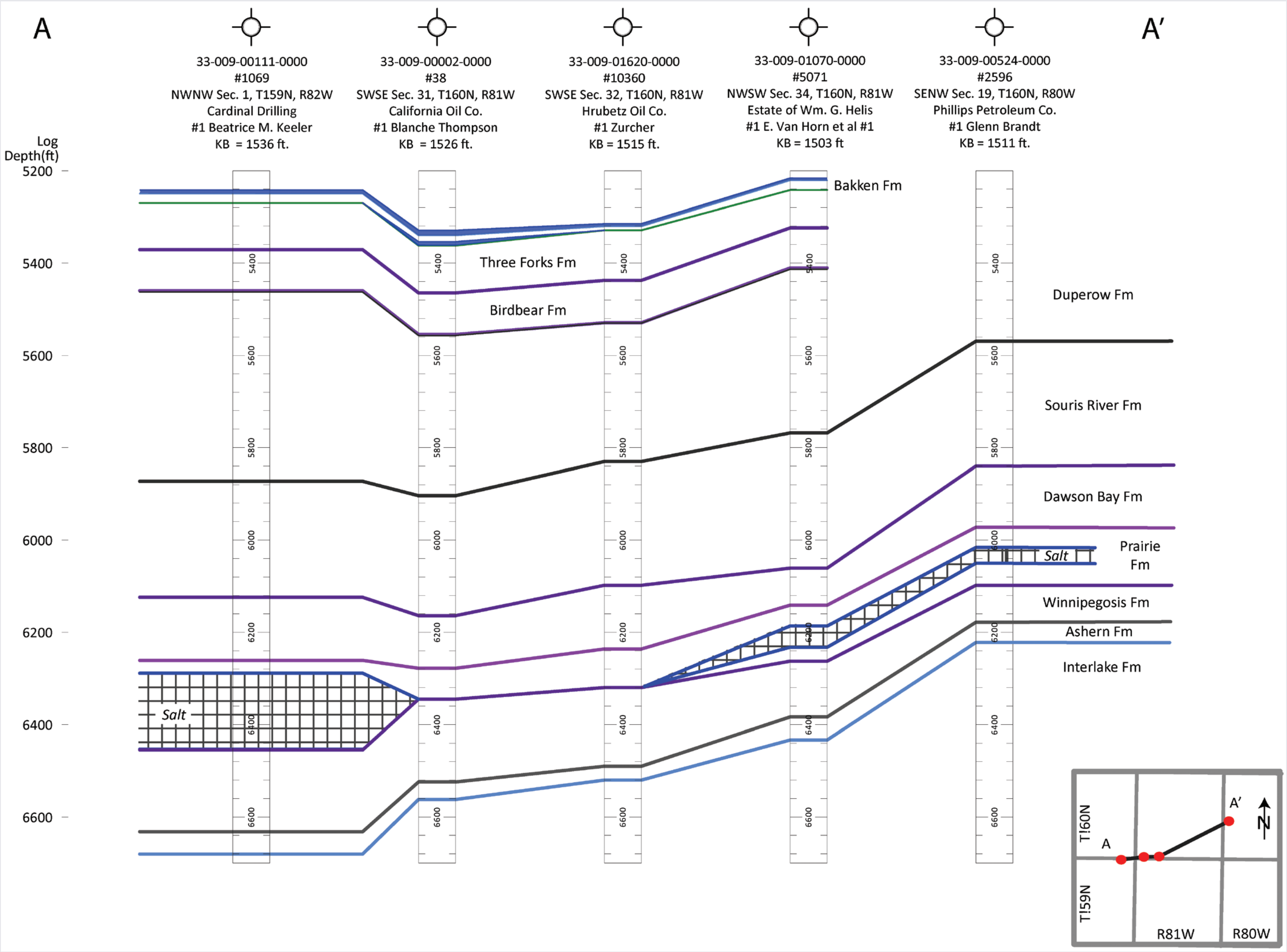

Figure 4. West to east schematic structural cross section from the Cardinal Drilling - #1 Beatrice Keeler to the Phillips Petroleum Co. - #1 Glenn Brandt well. Prairie salt is indicated by the hachured line. Notice the constant gradual thickening to the west towards the center of the basin of the formations below the Prairie Formation. The salt is absent in the California Company - #1 Blanche Thompson and Hrubetz Oil Co - #1 Zurcher well. Formations above the Prairie display a trough-like feature with the Blanche Thompson preserving all three members of the Bakken Formation (indicated in blue).

Figure 5. Core photograph of a polymictic breccia consisting of multiple lithologic clasts floating in a mudstone matrix from the Prairie section in the California Company - #1 Blanche Thompson (API #33-009-00002-0000; Depth: 6345 ft..; SWSE Sec. 31, T160N, R81W). The breccia is the result of the dissolution and removal of the Prairie salt and the subsequent collapse of the overlying strata.

north-central North Dakota. The dissolution and removal of the salt resulting from movement of basement rocks was suggested as a possible cause of the mapped gravity anomalies. When the salt is dissolved a small sag or hole in the rocks develops allowing for the deposition of additional sediment. This results in an anomalous thickness on an isopach map and is referred to as compensating section. Based on the data available at that time, compensating sections were also observed in isopachs from the Duperow Formation (Devonian) through to the Madison Group (Mississippian). In addition to changes with the isopachs of the area, the collapse area provides the conditions necessary to deposit additional salts in the higher Madison portion of the rock section.

Evidence for basement faulting is prominent in the study area. It overlies the boundary between the Trans-Hudson orogenic belt and the Superior craton that has been well documented in the literature (fig. 6). This boundary zone is in alignment with the north-south structural trend referred to as the Birdtail-Waskada axis (Nicholas, 2012). Straddling this boundary zone is the north-south trending Newburg syncline that disrupts the subcrop trends of the area (figs. 7 and 8).

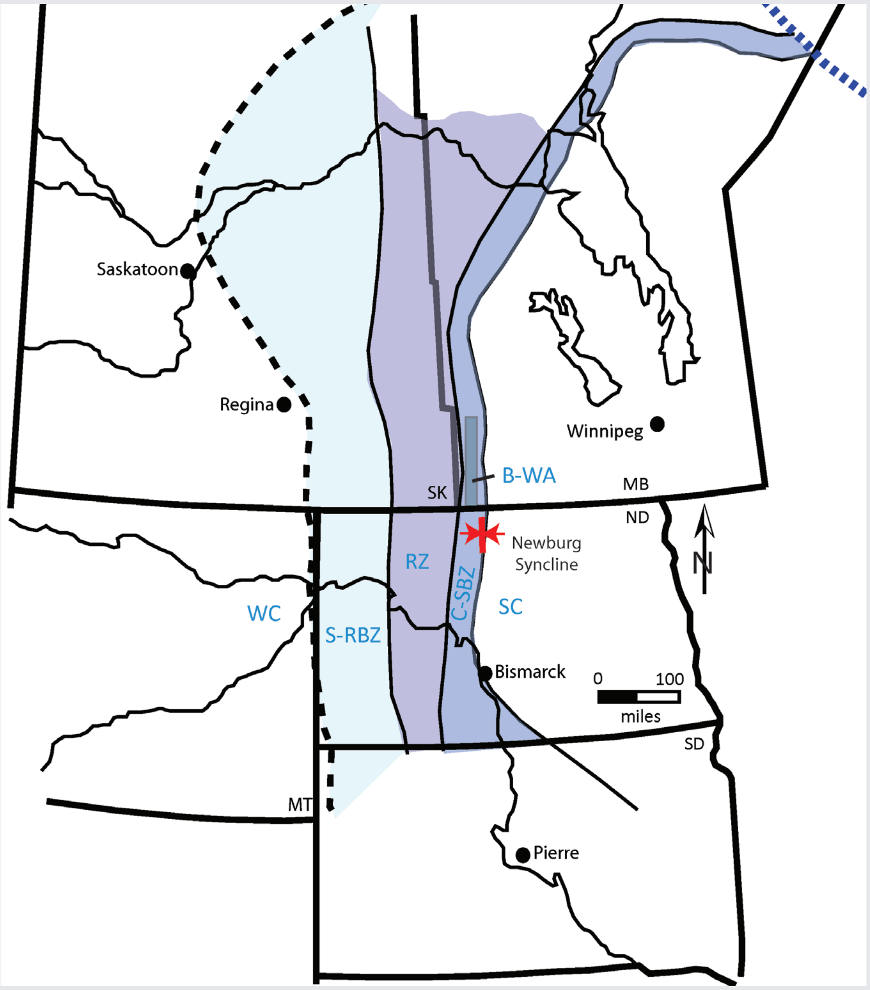

Figure 6. Tectonic elements of the basement underlying the Williston Basin. Basement zones from east to west include the Superior Craton (SC), Churchill-Superior Boundary Zone (C-SBZ), Birdtail-Waskada Axis (B-WA), Reindeer Zone (RZ) Saskatchewan-Reindeer Boundary Zone (S-RBZ), and the Wyoming Craton (WC); (Li and Morozov, 2007; Nicholas, 2012).

Significant production in the north-central portion of the basin results from traps related to salt collapse. An example of this is the Newburg syncline which overlies the province boundary and its associated faults. The faults allow for water to migrate upward and dissolve the Prairie salt resulting in the formation of the syncline. Migrating oil is then trapped along the updip edge of the Newburg syncline where the Berentson beds of the Madison Group are unconformably overlain by the Spearfish Formation resulting in Newburg and South Westhope fields (Cumulative Production through April 2012 – 42.2 MMBbls of Oil). Additionally, there are a number of smaller fields that produce in the area from the Madison Group and Spearfish Formation that have similar trapping mechanisms. This continues into the Canadian portion of the basin.

Exploration for deeper objectives has been limited in the north-central area of North Dakota and this leaves some of the formations that may have salt-related traps for oil virtually untested. One indicator that can be used in this area to determine where the salt is absent in wells that do not penetrate the Prairie is the presence or absence of the lower Bakken Shale. If the well has all three members of the Bakken, then the salt is absent in the study area. If only two members are present then there is probably a remnant of the salt underlying the well. Using the Bakken as an indicator may help delineate potential areas of multiple stage salt collapse where deeper control is missing.

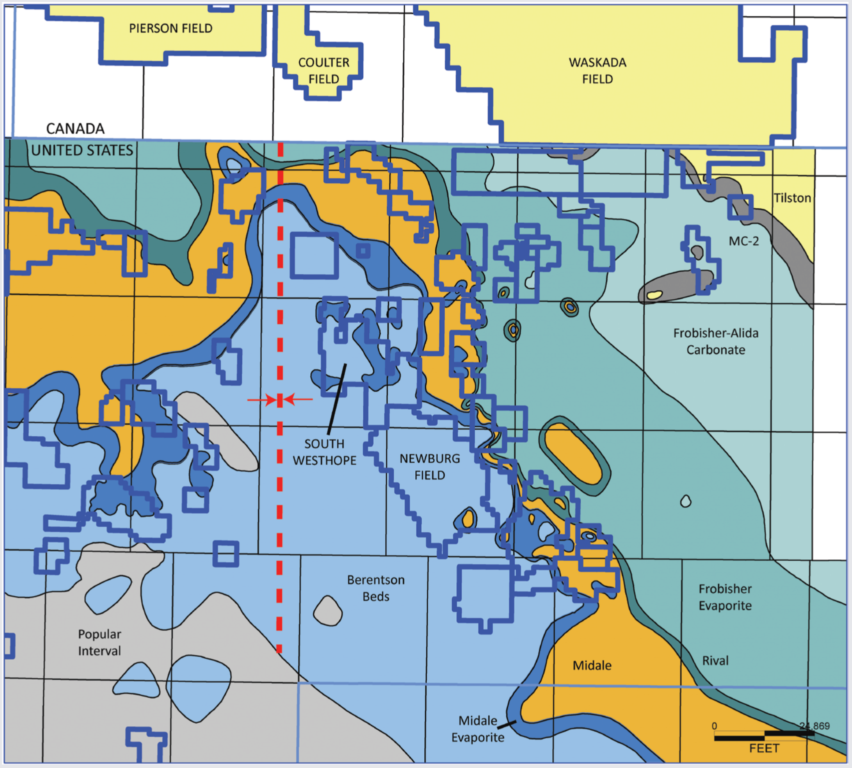

Figure 7. Madison subcrop map of the north-central study area (LeFever et al., 1986). Oil fields are designated by heavy blue lines. Note the deflection of the orange subcrop towards the Canadian border that results from the dissolution and collapse of the Prairie salt and the formation of the Newburg syncline indicated by the dashed red line.

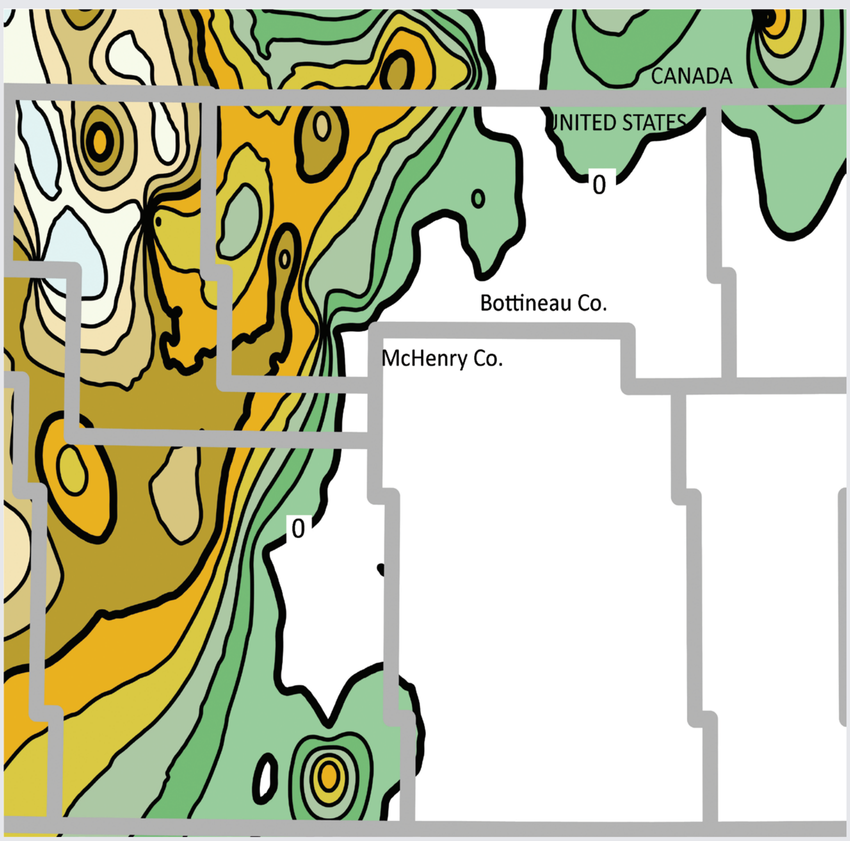

Figure 8. Isopach map of the Prairie salt in the north-central study area. Notice the break in the isopach that is coincidental with the Precambrian province boundary and the Newburg syncline (see figs. 6 and 7). Contour interval is 50 feet. Light green is the thinnest measurable salt thickness, gray is the thickest.

References Cited:

Anderson, S. B., and Hunt, J. B., 1964, Devonian Salt Solution in North Central North Dakota, in Leskela, W, Brindle, J., and Harris, S, eds., Third International Williston Basin Symposium, Billings Geological Society, North Dakota Geological Society and Saskatchewan Geological Society, p. 93-104.

Burke, R., 2001, Some Aspects of Salt Dissolution in the Williston Basin of North Dakota: NDGS Newsletter, v. 28, no. 1, p. 1-5.

LeFever, J.A., Anderson, S.B., and Carlson, C.G., 1986, Madison Subcrop – North Central North Dakota: NDGS Report of Investigation No. 85, 1 sheet.

LeFever, J.A., and LeFever, R.D., 2005, Salts in the Williston Basin, North Dakota: NDGS Report of Investigation No. 103, 45p.

Levin, H.L., 1996, The Earth Though Time, 5th Edition: Saunders College Publishing, New York, p. 312.

Li, J. and Morozov, I., 2007, Geophysical Investigations of the Precambrian Basement of the Williston Basin in south-eastern Saskatchewan and south-western Manitoba: TGI Project Map #24 –Interpreted Structural Units and Domains http://www.manitoba.ca/iem/mrd/geo/willistontgi/downloads.html), retrieved on June 12, 2012.

Nicholas, M., 2012, New insights into the Three Forks Group, southwestern Manitoba – Stratigraphic Changes and new Sedimentological Model: CSPG Geoconvention 2012, Calgary, AB

Parker, J.M., 1967, Salt Solution and Subsidence Structures Wyoming, North Dakota, and Montana: AAPG Bull., v. 51, no. 10, p. 1929-1947.

Reed, H.E., 1961, Salt Deposits of the Williston Basin – United States Portion, *in* A. C. Berstícker, ed., Northern Ohio Geological Society Symposium on Salt, p. 147-165.

Sonnenberg, S.A., and Pramudito, A., 2009, Petroleum Geology of the Giant Elm Coulee Field, Williston Basin: AAPG Bulletin, v. 93, no. 9, p. 1127-1153.