Upper Cretaceous faulting within the Great Plains polygonal fault system

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Summary

This paper presents a polygonal fault system model for fine grained Late Cretaceous sediments deposited within the Western Interior Seaway. Polygonal fault systems (PFSs) are layer-bound normal faults and fractures that form in fine-grained sediments early after deposition. The initially simple normal faults grow vertically and intersect laterally. The fault traces coalesce to form polygonal geometries in plan view. The faulting is initiated during sediment dewatering and mud particle consolidation and can occur independent of external stresses. The Great Plains PFS (GPPFS) have faulted strata throughout Canada and the United States. Individual faults can have up to 80 m of vertical relief, 100 to 1000 m of inter-fault spacing. The GPPFS may occur over an area 2,000,000 km^2 in size. Faulting may be responsible for wide ranging processes such as reservoir enhancement, slumping at outcrop and other geotechnical hazards, or hydrocarbon seal integrity loss.

Introduction

Beneath the Great Plains of North America lie sediments deposited in the Cretaceous Western Interior Seaway (WIS, Figure 1). The Western Interior Seaway was an inland sea that spanned across North America from the Tethyan Sea in the Gulf of Mexico north to the Boreal Sea in Alaska from the mid-Cretaceous to the early Paleogene (Catuneanu et al., 2000). The WIS split the North American continent into two land masses - Laramidia to the west and Appalachia to the east. The WIS hosts a succession of sediments, including a large volume of continental muds and clays (see Schultz et al., 1980, Roberts and Kirschbaum, 1995, for example), bentonite, and other fine-grained material (Leckie et al., 2000). The GPPFS is hosted within these sediments.

PFS are geological phenomena first identified on 2-D seismic data by Henriet et al. (1991) and on 3-D seismic data by Cartwright (1994). The faulting in PFS is almost exclusively normal faulting (Cartwright, et al., 2007) that occurs shortly after deposition and can occur with no external stress (Dewhurst, et al., 1999). The faulting occurs in fine-grained muds and chalks that subaqueously dewater. A number of mechanisms have been proposed to explain the fluid expulsion dewatering. Syneresis, the spontaneous contraction of a gel without solvent evaporation (Cartwright, 2011), low coefficients of residual friction in muds (Goulty, 2001) and the expulsion of biogenic gas developed in the sediments (Maher, 2014) have been proposed as PFS initiators. However, the mechanisms are still under review (Lopez, et al., 2015). Since 1991, there have been hundreds of PFS identified throughout (in basins along continental margins and identified using 3-D seismic data). Cartwright and Dewhurst (1998) identified a number of PFS characteristics (Figure 2) that summarized their observations and that compare well to the observation for the GPPFS.

Method and Examples

Initial work identifying faulting within the are outlined on Figure 1 resulted in a quick method to indentify PFS. For 2-D seismic data, the data were interpreted to identify faulted strata above the Second White Speckled Shale Formation seismic reflection. A 2-D seismic line from southeast Saskatchean (Figure 3) shows the shallow faulting. Reflections above the Milk River Formation reflction are faulted by as much as 80 ms (~80 m, as v_{INT} ~ 2,000 m.s). The 2-D seismic data images the shallow faulting, but the true characteristics of the PFS can only be observed on 3-D seismic data. Also, wellbore logs can show faulted areas that are not imaged on the seismic data, either because of low S:N data or weak or absent impedance contrasts.

Figure 4 shows a two well cross section from southeast Saskatchewan showing about 20 m of missing section at the Niobrara level. The beds above and below the missing zone are correlative. The correlations can be used to determine the timing of the faulting as shown. The presentation will show that faulting can occur quickly and over a very large area.

Figure 5 shows an amplitude map for a 3-D dataset in southwestern Manitoba. Seismic datasets were ‘time-sliced’, where reflection amplitudes were extracted at constant time intervals above the Second White Specks Formation reflection. The Lea Park faulting imaged on the map 1) occurs over an area greater than 10,000 km^2, 2) has arcuate fault traces, potentially indicating a lack of external stress on the beds during faulting.

A number of additional observations will be made with data from throughou the Great Plains area. These observations include:

- An example of PFS faulting from an area southeast of the large Milk River Formation biogenic gas pool at Hattaon/Bigstick in southeast Saskchewan.
- Slumping at outcrop and how the slumping be be along reactivation of PFS faults.
- Examples of highway movement, dam failure and other geotechnical engineering occurances that may have involved PFS affected rock.
- The possibility that a PFS faulted zone interpreted to be a vertical hydrocarbon seal may be a 'leaky' vertical seal.

Conclusions

This paper has presented some characteristics for the Great Plains polygonal fault system. Further characteristics will be presented using seismic data, outcrop observation and wellbore logging. The GPPFS covers a large area and the faulting may be responsible for a number of processes such as reservoir enhancement within shallow Upper Cretaceous hydrocarbon reservoirs. Since the PFS is at or near outcrop, there are a number of geotechnical examples that will show such projects may be adversely affected by the faulting and fracturing within the polygonal fault system.

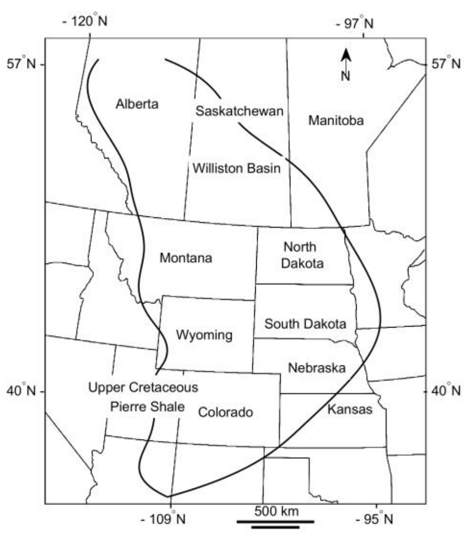

Figure 1. Map of the Great Plains are of Canada and the U.S. showing the depositional outline for the Upper Cretaceous Pierre Shale Formation (Roberts and Kirschbaum, 1995).

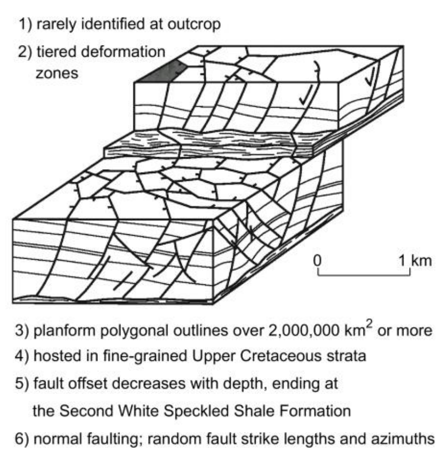

Figure 2. The Great Plains PFS characteristics are consistent with other PFS (Cartwright and Dewhurst, 1998).

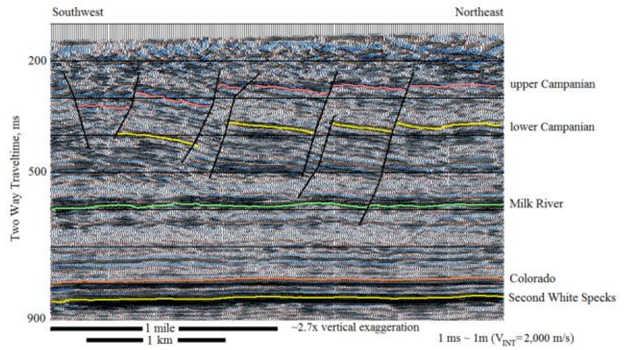

Figure 3 – Two dimensional seismic line from southeast Saskatchewan showing faulted Upper Cretaceous sediments. The 200 ms time is ~ 200 m below ground surface. The deeper reflection from Colorado Formation strata and deeper are unfaulted

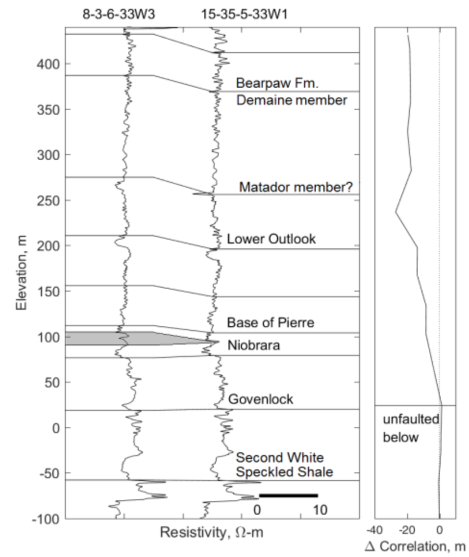

Figure 4 – Two well cross section from southeast Saskatchewan a missing ~20 m of section in the Niobrara Formation. And the fault timing based upon correlative markers in the two wellbores.

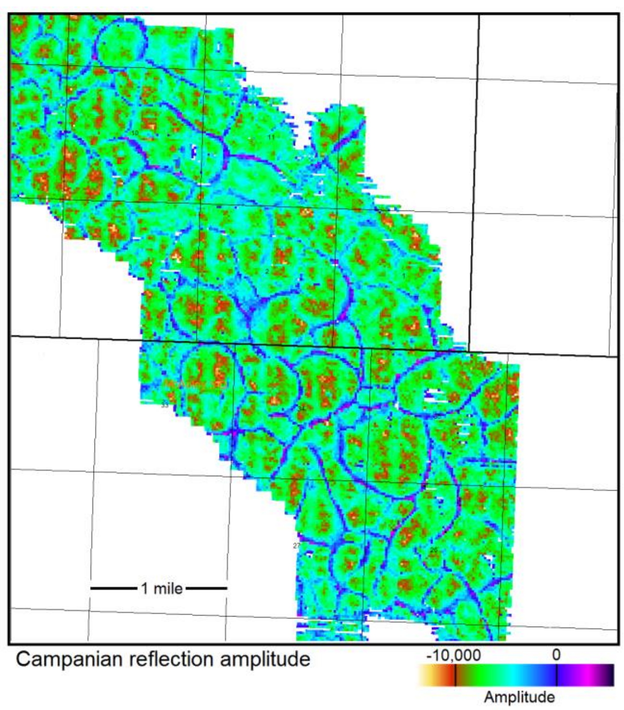

Figure 5 – Campanian Lea Park amplitude reflection for a confidential 3-D survey acquired in Manitoba near the Saskatchewan border approximately at Twp 15. The low amplitude areas map arcuate fault traces that have ~15 m of vertical offset in the Lea Park beds.

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