

# Mapping of Salt Dissolution Edge of Prairie Evaporite in South-Central Saskatchewan

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## Summary

Salt of the middle Devonian Prairie Evaporite Formation extends over much of the south-central Saskatchewan. Prairie salt collapses are among major structural disturbances of the Phanerozoic strata. The present study focuses on improving the delineation of the salt dissolution edge along the southeastern margin of Prairie Evaporite using 2D seismic data acquired by the industry. Thirteen seismic lines were re-processed with an emphasis on improvement of high-frequency recovery that would allow detection of thin beds and salt edges of the Prairie Evaporite. Interpreted seismic sections show that salt collapse could be located off salt where salt has been dissolved and removed completely. They also could exist within the body of Prairie Evaporite. High-frequency seismic data display marked improvement in the accuracy and in the quality of the mapping of salt edge of the Prairie Evaporite.

In a collocated gravity study, a 33 km NE gravity profile along seismic line NOR-83314 was modeled using GM-SYS software. A detailed two-dimensional gravity model was constructed using well and seismic data. Although the ~4 mgal gravity anomaly is mainly related to the lateral variation of the basement rocks, the effect of the Phanerozoic has been noticed. Based on the interpretation of seismic line NOR-83314, the thickness of Prairie Evaporite Formation is 60 m, leading to ~0.4 mgal contribution to the gravity anomaly. Performing high-resolution gravity survey with station interval ~100 m might still be useful to constrain the overburden and help detect salt collapses.

## Introduction

Seismic and well log data have been used to improve the accuracy and the quality of subsurface mapping of the southern edge of the Prairie Evaporite Formation in Saskatchewan. The study area is located south and south-southeast of Regina. Deposits of the Elk Point Group contain the largest amount of salt in Western Canada sedimentary basin with approximate volume of salt ~ 6\* 10 km (Zharok, 1988). Most of the salt is located in four Formations of the Elk Point Group: 1) Lotsberg. 2) Cold Lake. 3) Prairie Evaporite. 4) Dawson Bay (Meijer Drees, 1986). The middle Devonian Prairie Evaporite is the most wide-spread of these deposits which underlies much of southern Saskatchewan with salt up to 220 m thick (Holter, 1969). Bailie (1953) introduced the term "Prairie Evaporite" for the evaporites found between the Winnipegosis and the Second Red Bed of the Dawson Bay Formation. In some parts of the study area, the Prairie Evaporite is dissolved and removed either partially or completely by ground water (Holter, 1969).

Salt dissolution and salt collapse structures are considered the most prominent geological features of the Phanerozoic subsurface of Saskatchewan. Knowledge of the locations and dimensions of salt collapse structures is essential for avoiding mining into hazardous zones and for evaluating the hydrocarbon exploration potential. Salt dissolution and resulting subsidence are perhaps the most important hydro-carbon-trapping mechanism in western Canada (Edmund, 1980). In the study area, collapse structures may be multistage structure located off salt where all salt has been removed (e.g., the Hummingbird structure). They may also be located on salt within the Prairie Evaporite Formation, such as Kisbey.

## Seismic data acquisition

A total of ~330 km of seismic reflection lines of this study were acquired in 1979 and 1980 and donated by Encana Corporation, Petro-Canada, Simonson, Olympic Seismic Ltd., and Kary Data Consultants Ltd. Thirteen seismic lines were acquired using different recording systems and a variety of dynamite and air gun sources. Spread lengths extended mostly from 1.5 to 3 km. Station intervals ranged from 25 to 67 m, and shot intervals from 75 to 200 m. Recording lengths were 3 s at 2ms sampling intervals.

## Seismic data processing

Field data were received by the University of Saskatchewan on magnetic tapes in SEG-B and SEG-Y formats and completely re-processed using PROMAX software (©Landmark Graphics). The primary goal of re-processing seismic data was to recover sufficiently high seismic frequencies to identify thin beds and map the salt dissolution edge of the Prairie Evaporite. In order to

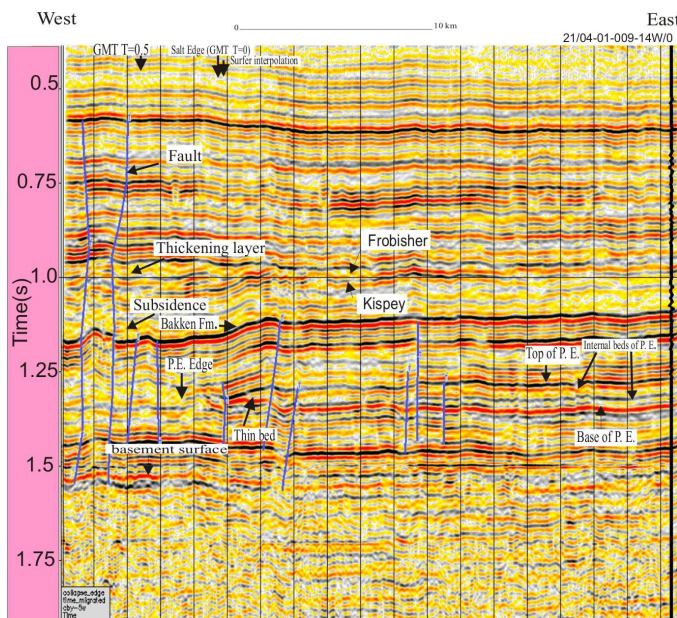
increase the resolution of seismic imaging, the data was re-processed in a uniform manner, with an emphasis on the techniques for high-frequency enhancement. The processing steps can be subdivided into four groups: 1) pre-processing including SEG-Y-input, Geometry, Trace editing, and Refraction static. 2) pre-stack processing, including FK-filtering, Deconvolution, Normal Move Out correction (NMO), Residual static, Radon filter and stacking the data. 3) post stack processing, including Automatic Gain Control and time migration. 4) special application included F-X deconvolution and Time Varian Spectral Whitening (TVSW). TVSW boosts the amplitudes of all frequencies within a certain bandpass filter to the same level by applying a series of gain functions to each narrow bandpass filtered trace. The first three groups are standard processing procedure, while the fourth one contained special steps required for improving the high frequencies. In order to increase the resolution and enhance the high frequencies, post stack TVSW followed by F-X deconvolution were applied.

### Seismic Interpretation

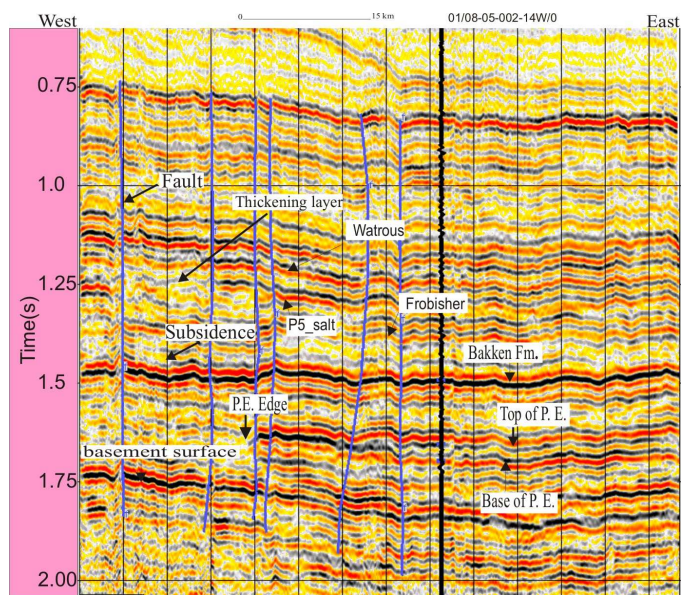
For this study, we selected seismic lines that crossed the salt edges, so that the seismic interpretation would help to delineate the positions of the edges more accurately. The data indicated a major salt dissolution of the Prairie Evaporite located off salt, and local salt dissolution within the Prairie Evaporite. In the study area, seismic sections indicate that salt dissolution occurred in Mississippian, Triassic, Jurassic, and more recently as it disturbs all of the overlying seismic horizons. Seismic line CBY-5W (Figure 1) represents salt dissolution occurred during the Mississippian. Salt dissolution structures, basement uplift and vertical throw faults are well imaged in the seismic line. Some of the faults are deep, rooted in the basement and appear to extend to the surface; others are shallow and penetrate into the Devonian strata. The salt dissolution caused subsidence of the overlying sediments. Time structure anomaly is observed within the zone of the subsidence suggesting that extensive faults system is presented in the salt collapse zone. The seismic line displays a relatively wide front salt edge of about ~3 km.

The image from line CBY-5W indicates that the Prairie Evaporite Formation decreases in thickness from 110 m in the east to zero near the western part of the section. All overlaying layers above the Prairie Evaporite were collapsed, including the Late Devonian Bakken Formation whereas the layers above Bakken Formation between ~ 980 and 1100 ms thicken. Thicken layers represent Mississippian Frobisher Formation. This suggests that the salt was dissolved and removed during the deposition of Frobisher. The dissolution thus apparently took place during the Mississippian.

Line CBS-8 (Figure 2) represents salt dissolution occurred in Triassic and Jurassic. Features which generally can be seen on the section and related to the salt dissolution are faults and disruption of the normal phanerozoic column in the Williston basin. Variations in thickness of the Prairie Evaporite and overlying layer sediments are essential to set a time where salt dissolution occurred. Salt removal of the middle Devonian Prairie Evaporite is compensated by thickening of the Mesozoic Watrous Formation. This means that the salt dissolution took place at the same time as Watrous was deposited. No evidence for further salt dissolution is identified in this seismic section.

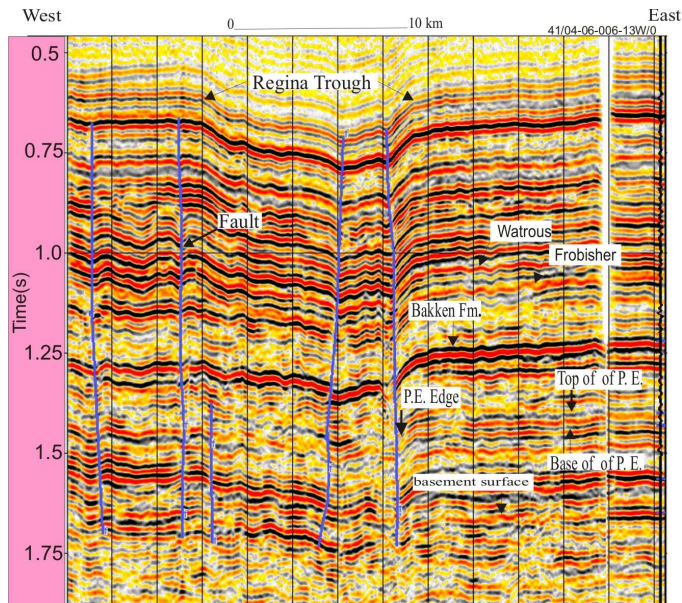


**Figure 1- Salt dissolution induced subsidence that did not affect strata shallower than about ~980 ms seismic line CBY-5W). P.E. - Prairie Evaporite.**



**Figure 2- Strata slumping due to salt removal, basement uplift and several deep faults (seismic line CBS-8). P.E. - Prairie Evaporite.**

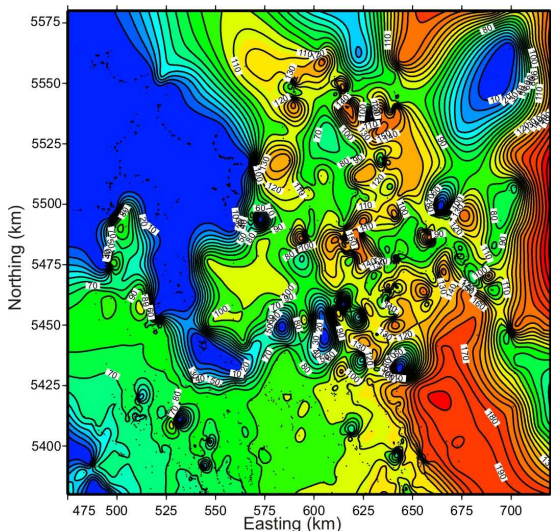
Line NOR-83314 (Figure 3) represents a salt collapse that may have occurred more recently. The line displays a depression which has affected all the seismic horizons above the Prairie Evaporite. This salt dissolution could occur more recently than those discussed above. Seismic line NOR-83314 (Figure 3) also shows subsidence related to the Regina Trough, showing that Regina Trough could be associated with faults rooted in the basement. The salt dissolution has no indication of thickening layer in the seismic sections. However, thickening could occur in the upper Cretaceous or Cenozoic layers which are not displayed in this seismic section. The seismic line shows that the front salt edge is relatively sharp, with changing in thickness from 70 to Zero within ~800 m which could be an indication of activated faults.



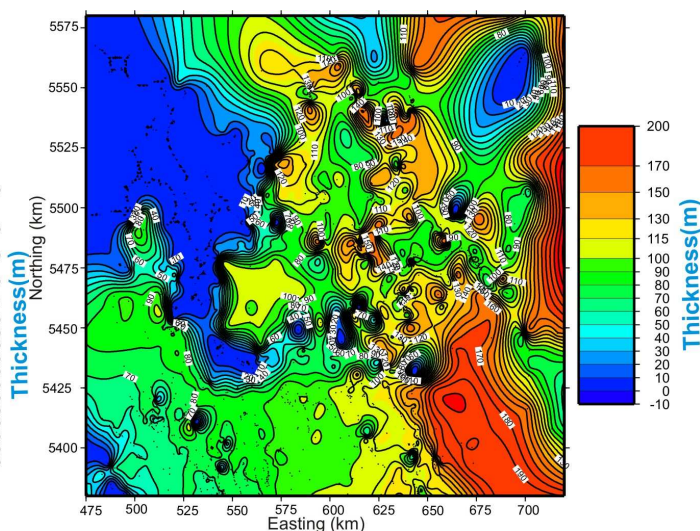
**Figure 3- Seismic Line NOR-83314 shows conventional section of Regina Trough. P.E., Prairie Evaporite.**

### Sub-surface mapping

Seismic and well logs data provide point or linear readings that need to be interpolated to produce subsurface maps. However, such interpolation is not unique and may depend on the method employed and data available. This is particularly important where the data are interpolate/extrapolated in poorly constrained areas, such as the salt edges of this study. In order to evaluate the effectiveness of the interpolation techniques on the isopach contours, well picks and maps of Middle Devonian strata in the IEA Weyburn CO<sub>2</sub> Monitoring and Storage Project area (Kreis et al., 2003) were used. Isopach maps of Prairie Evaporite created in Surfer, Matlab and Generic Mapping Tool (GMT) products were compared to evaluate the dependence of isopach map on the interpolation techniques. After several experiments, GMT was chosen as the preferred option. GMT programs offer a choice of “spline tension” parameter  $0 \leq T \leq 1$ , with tighter splines resulting in smoother maps (Smith and Wessel, 1990). Different values of parameter T were used to generate the isopach map of Prairie Evaporite. Value of T=0 was finally chosen as the preferred mapping option, and a Prairei salt isopach map based on well data alone was created (Figure 4). Further, combining the well logs with seismic data also allows the construction of more detailed and consistent map (Figure 5). The results of seismic Interpretations fill in the gaps where well log data are not available. Thus, inclusion of additional seismic information improves mapping of the Prairie Evaporite salt edge.



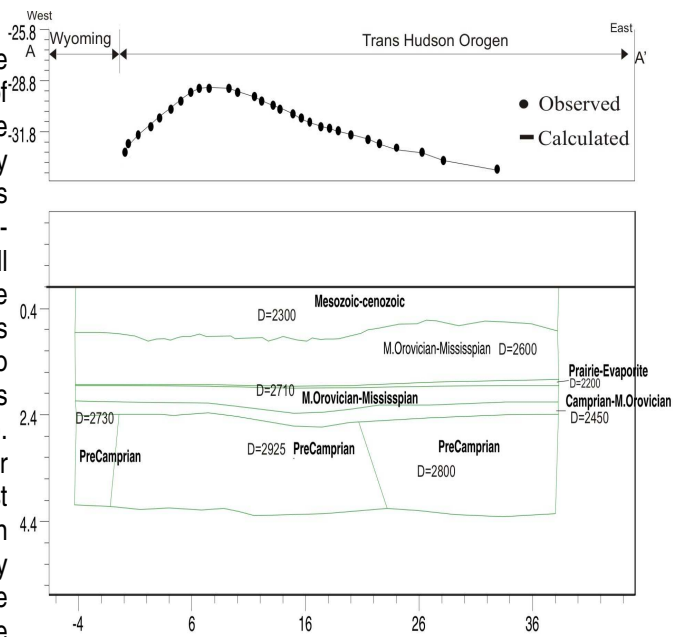
**Figure 4-Interpolated isopach maps of the Prairie Evaporite Formation using well data alone. Coordinate are UTM in km.**



**Figure 5-Interpolated isopach maps of the Prairie Evaporite Formation using well and seismic data. Coordinates are UTM in km.**

## Gravity

In the present study, an attempt was also made to investigate the relationship between the basement structure and salt collapse of the Prairie Evaporite using gravity data available from the Geological Survey of Canada. From the interpolated 2D gravity grid, a ~33 km E-W profile along the seismic line NOR-83314 was extracted. 2-D modeling of gravity data was performed using GM-SYS software. Gravity model was constructed using combined well log data and seismic cross-section in order to develop as accurate geological model as possible. Average densities of the various formations were assigned based on well log data, taking into account their ages and physical properties. As a result of this procedure, 5 blocks were established within the model (Figure 6). Basement densities were assigned based on the studies by Leclair et al. (1993, 1994) and were increasing from 2.73 gm/cc in the west (the granitic complex of the Wyoming Craton) to 2.82- 3.03 gm/cc in the east (within the Trans-Hudson Orogen). The observed gravity profile shows a major positive anomaly (~4 mgal) occurring in the vicinity of a known the salt collapse west of the gravity profile. The observed gravity decreases sharply close to the margin of Trans-Hudson Orogen and Wyoming province.



**Figure 6-Gravity model of ~33km gravity profile across the salt collapse.**

Although the gravity anomaly is caused mainly by the high densities within the crystalline crust, the effect of the Phanerozoic cover has been also noticed. Seismic interpretation of the line NOR-83314 and well log data was used to determine the effect of the Phanerozoic cover and especially of the salt dissolution edge of the Prairie Evaporite. Modeling of the observed anomaly displays a depression in the basement rock which affects all the sedimentary layers. As the maximum thickness of Prairie Evaporite in the proposed model is 60 m, the Prairie salts would have an effect of 0.4 mgal, or ~10% of the total anomaly. High resolution gravity survey with station spacing of 100 - 200 m might be useful to detect the salt collapse and thin beds in study area.

## Conclusions

1) High-frequency enhancement seismic data processing techniques help improve the resolution and result in improved images of the salt edge and thin beds. 2) Inclusion of seismic information into the interpolated subsurface maps of the Prairie salts improves mapping of its edges in some of the critical areas; 3) In the seismic sections, indications of Mississippian, Mesozoic and a more recent salt collapse structures were observed. 4) Gravity anomalies within the region are mostly related to lateral variations between deep-seated structures within the basement, with salts potentially accounting for ~10% of the gravity signature. High-resolution gravity surveying with station spacing of ~100 m, in combination with seismic imaging, are likely to be useful in detecting salt collapses in study area.

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