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Detection and analysis of structurally controlled sweet spots in the Bakken/Three Fork oil shale play of the Williston Basin and the Exshaw/Big Valley oil shale play of the foreland basin of Southern Alberta and Northern Montana.

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Summary

The structural fabric of the Williston Basin and the foreland basin of southern Alberta and Northern Montana is dominated by the presence of large scale divergent wrench fault systems that were initiated at early Proterozoic time and continue to be active throughout the tectonic history of these basins. These structures are characterized by the presence of several pull-apart basins that acted as the focal point for the deposition of thick sections of the Bakken/Three Forks and Exshaw/Big Valley shale packages. These unique structural features form the prime location for the exploitation of these two emerging resource plays. Drilling results however indicate that the sweet spots of both plays do not occur in areas of maximum reservoir thickness, they rather occur along the faulted edges of the pull-apart basins where the shale package appear to become more brittle due to the combined effect of differential compaction, dewatering and increased density of natural fractures.

In the foreland basin area, the development of sweet spots along the faulted edges of the pull-apart basins is further enhanced by two main processes: 1) a Triassic-Jurassic extension related to an early development of the foreland basin and 2) late Cretaceous compression related to the development of the thrust belt to the west. The first process reactivated portions of the basins and lead to the development of a well-defined foreland hinge line which defines the eastern boundary of the over pressure zone of this resource play. Whereas, the second process lead to the development of inverted structures and thrust related anticlines which form prospective structural traps for this resource play.

Introduction

Integrated analysis of regional data sets which includes well information, seismic data, gravity and magnetic survey was used to generate a detailed tectonic map of the Williston Basin and the foreland basin of Southern Alberta and Northern Montana. Production information from the mature Bakken/Three Forks formations and the emerging Exshaw/Big Valley resource plays was then used to assess the possible influence of basement structures on the development of sweet spots in both plays. This paper illustrates the methods and data sets that were used to curry out this study and the possible implications of the findings on future exploration and exploitation of this play.

Integrated structural analysis

The results of the integrated structural study of both basins are illustrated with the tectonic map and accompanying cross section in Figure 1a-b. The maps and the cross section illustrate the effect of basement structures on the development of sweet spots in both plays. Note that the sweet spots in the Williston Basin area are largely related to subtle draping of sediments over basement faults which may be accentuated by late structural reactivation and the development of subtle graben features along basement faults.

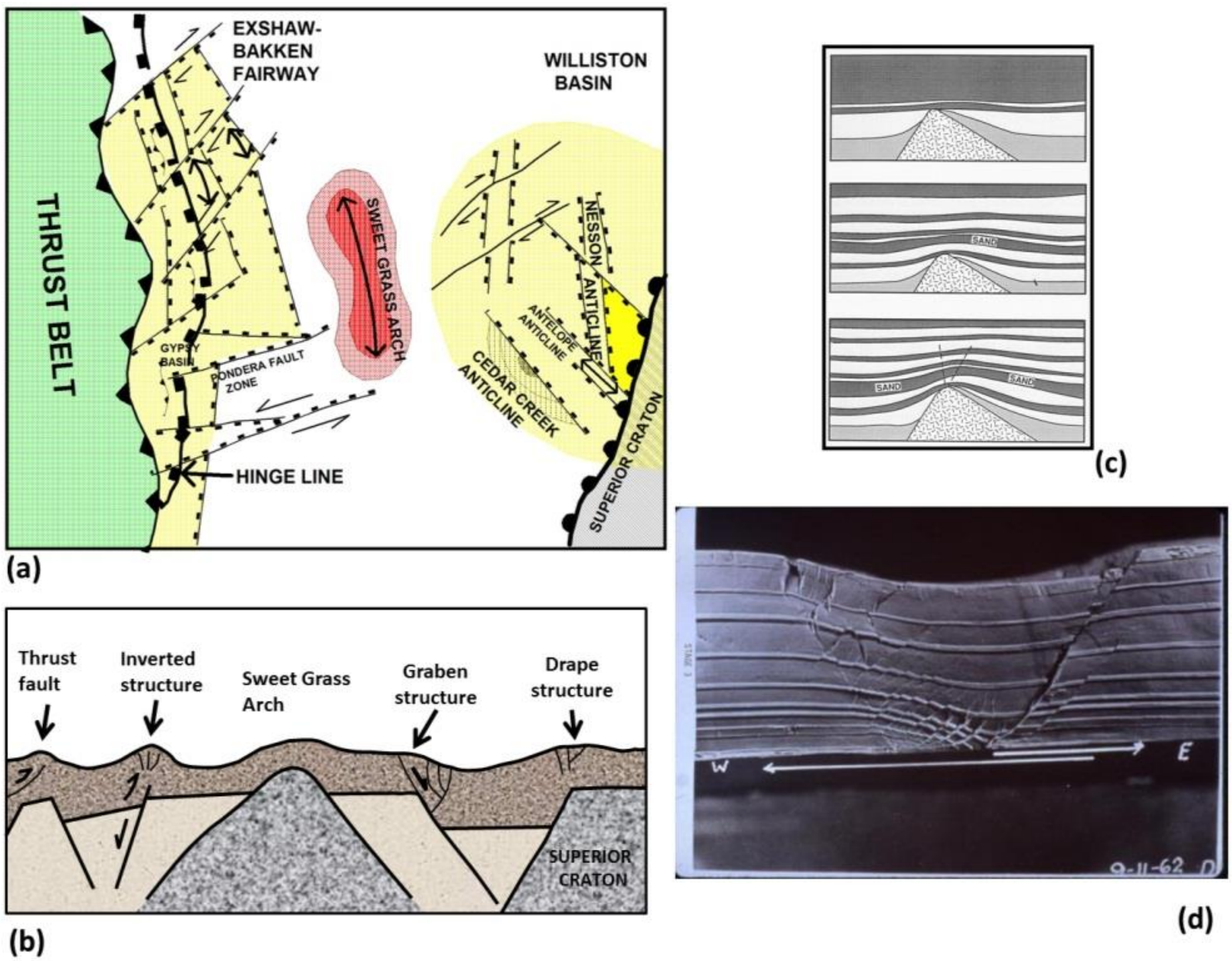

Figure 1 Examples of data used to illustrate the location of pull-apart basins and related sweet spots of the study area. The tectonic map in Figure 1a and the accompanying cross section of Figure 1b are done schematically and are out of scale. Figure 1c illustrates the process of draping over basement structures and the development of fractures over the faulted edge of a basement high. Figure 1d illustrates the development of highly fractured zone along the edges of a graben feature.

Whereas, the sweet spots in the Exshaw/Big Valley play are largely enhanced by late Laramide inversion and thrusting. This in turn makes the Exshaw/Big Valley plays significantly more “structural” then the Bakken/Three Fork play. Two laboratory experiments which are shown in Figure 1c-d are designed to illustrate the development of fractures over basement structures. The first experiment shows how natural fractures may develop over sediments that drape over a rigid basement high. Whereas, the second experiment shows how this fracture zone may be enhanced by structural reactivation and a subsequent development of graben features along the faulted edges of basement highs.

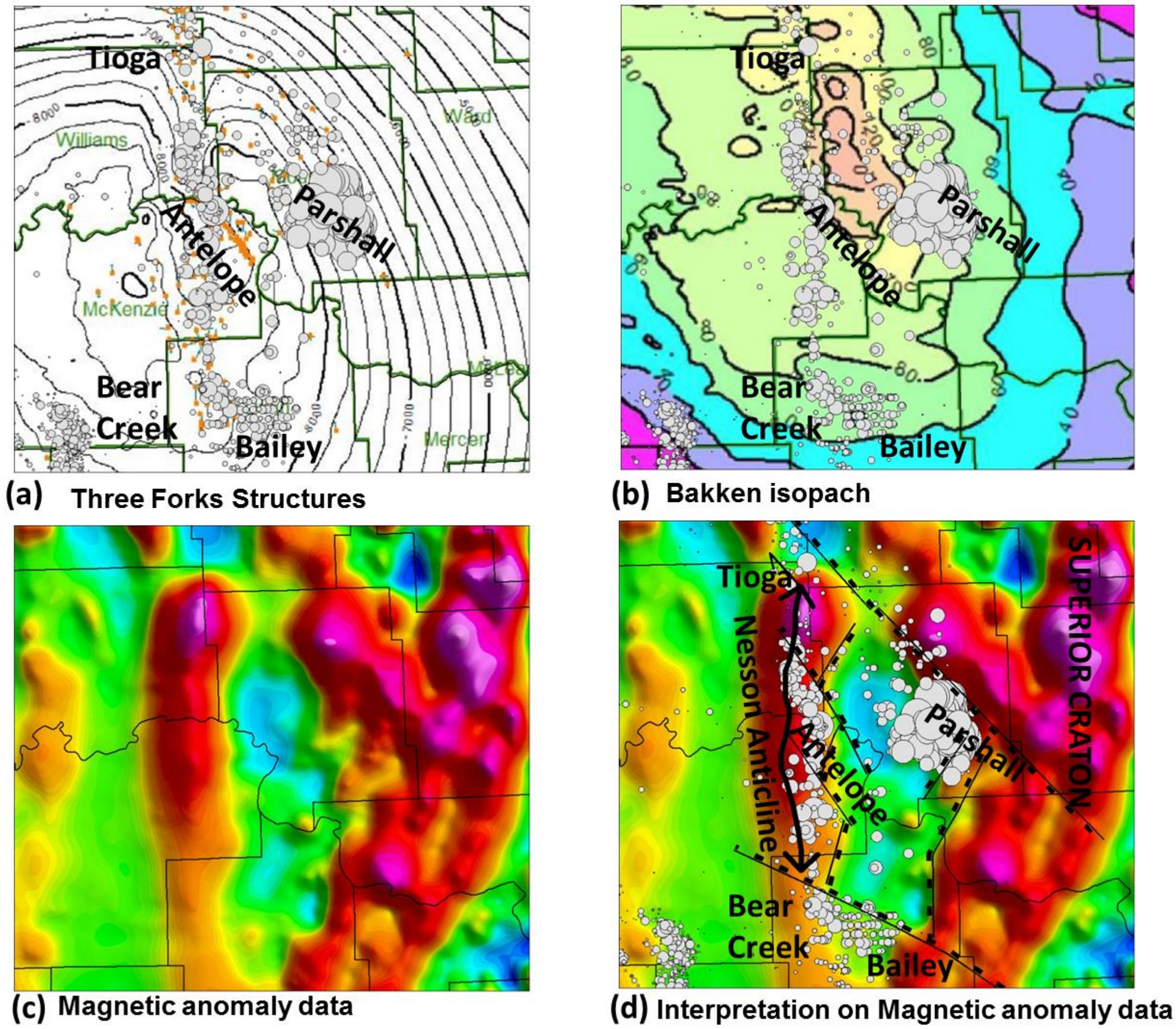

Figure 2 Example of data set that was used to identify the key geological mechanisms that lead to the development of major Bakken oil fields in the central part of the Williston Basin.

The possible influence of basement structures on the development of sweet spots in the Bakken formation can be illustrated with a data set from the central part of the Williston Basin (Figures 2a-d). The first map shows the relationships between present day structures (on top of the Three Forks formation) and cumulative Bakken production of the major oil fields. The map illustrates that the faulted edges of the Nesson anticline exerted a significant control on the development of several small Bakken fields but it fails to explain the location of other large fields such as Parshall, Bear Creek and Bailey. The Bakken isopach map of Figure 2b, also fails to establish a clear correlation between cumulative production and total thickness of the Bakken production. A detailed basement structure map which is interpreted from regional magnetic data appears to provide the best explanation for the development of major Bakken fields in this area (Figure 2c-d). As illustrated, all the major Bakken fields are located along the faulted edges of a major pull-apart basin that developed between the Nesson anticline and the faulted edges of the Superior Craton. These observations strongly suggest that this play is driven by the development of more brittle and fractured shale packages along the active edges of basement faults.

The possible relationships between basement structures and the location of sweet spots in the Exshaw/Big Valley play area are illustrated with a conceptual block diagram of high resolution magnetic data and the accompanying regional seismic lines that are shown in Figure 3.

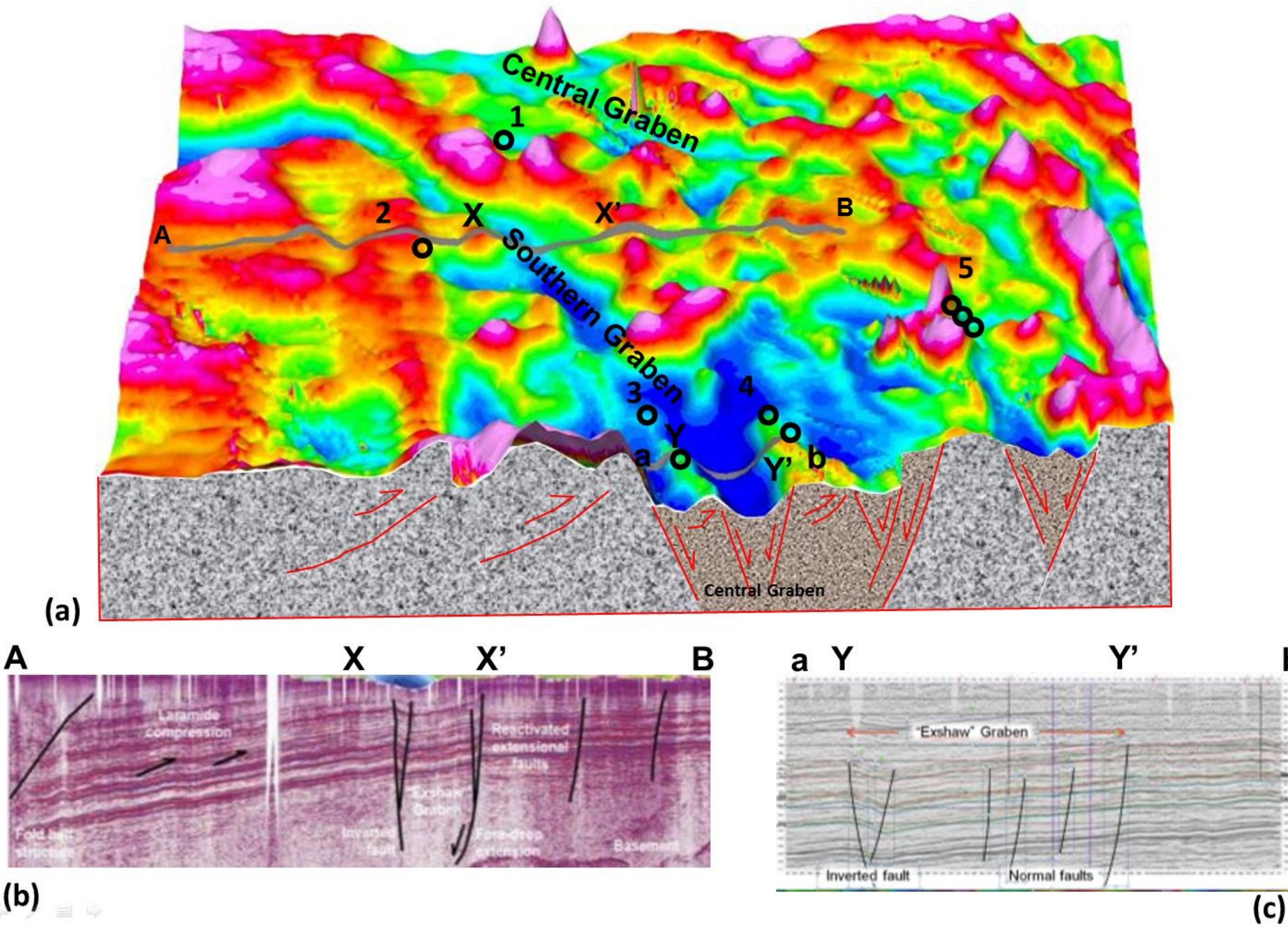

Figure 3 Three dimensional diagram of High Resolution Magnetic data and regional seismic over the Canadian portion of the Exshaw/Big Valley play area. The circles represent Exshaw-Big Valley wells that produced over 250 bbl/d.

As illustrated, the area is dominated by the presence of well defined, basement involved pull-apart basins and related graben features that can be clearly seen on both seismic and magnetic data sets. These basins are filled with a thicker section of Exshaw/Big Valley reservoir rocks which constitute the main reservoir fairway for this play. The sweet spots of this play however are clearly related to structural features that developed along the edges of these basins or over local inverted structures that developed within these basins. Examples of Exshaw/Big Valley wells that produced more than 250 bbl/d are shown as circles on the magnetic data set. Wells that are marked as 1 and 2 are located at the faulted edges of the two major graben features which are shown here. The wells that are marked as 3-5 represent inverted structures within these basins.

Conclusions

The result of this study clearly suggests that both of these resource plays are largely controlled by basement related structures that can be detected through the integrated analysis of regional data sets. A thorough understanding of the control that these structures exert on the development of each resource play could help improve drilling results and accelerate the development of these two important resource plays.