Niobrara Fracture Prospecting Through Integrated Structural and Azimuthal Seismic Interpretation, Silo Field Area, Wyoming

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Summary

A large multi-client, full-azimuth 3D seismic survey of almost 800 square miles in southeastern Wyoming is the basis for a regional structural interpretation and azimuthal velocity analysis of the Niobrara in the area of the Silo Field, in the northern end of the Denver-Jules Basin. The unconventional Niobrara oil and gas play has been compared to the Bakken in North Dakota but variable well results have long plagued operators. Silo Field has produced about 10 million barrels of oil since 1981 but well rates can vary drastically over a short distance. The study integrates seismically derived rock attributes, well and production data, and integrated regional structural interpretation to understand the Niobrara fracturing and to reduce drilling risk.

Introduction

The Niobrara Formation or Niobrara Chalk in the DJ and Raton basins was deposited in the Late Cretaceous Western Interior Seaway from Northern New Mexico to southern Wyoming. The Niobrara, a self sourcing unit of alternating chalk and shale, is the source rock for the billion barrel Wattenberg field as well as the Silo field in SE Wyoming. The formation is over-pressured and has open natural fractures providing a permeability network in a generally low permeability section. Porosity is generally between 5-10%. Well costs are generally half those of the Bakken Formation in the Williston Basin (Montana and North Dakota). Typical weight percent values for TOC in the Type II Niobrara are 2-3 %; considerably leaner than the Bakken and somewhat leaner than the Eagle Ford. Typical drilling depths in the study area are 7,500 -8,500 feet.

Natural fracturing in the Silo Field area is a major factor influencing well performance and the ultimate recovery of Niobrara oil. The cause of fracturing is widely debated and has been attributed to many variables: basement faulting, salt dissolution, lithology variations, compaction over basement highs, hydrocarbon expulsion, strike-slip faulting, uplift, and the present day stress regime. Our approach to understanding the Niobrara fracturing is by integrating: 1) seismically-derived rock attributes; 2) well and production data; and 3) regional structural interpretation.

Seismic Rock Property Analysis

Full azimuth imaging and analysis for this large 3D survey is providing better data for interpreting the deep structural framework and improved regional insight into the variability of the Niobrara - offering clues to optimal well placement (Figure 1). Rock property analysis of the Niobrara involved processing the 3D to address both layer and azimuthal anisotropy, creating gathers with reliable far offset amplitudes for an elastic inversion. Initial analysis of the layer anisotropy was performed on isotropicly migrated gathers using a simultaneous picking tool for velocity and VTI (vertical transverse isotropy). VTI information was then used to update traveltimes and begin scanning for HTI (horizontal transverse isotropy). The approach used to define the HTI involved migrating the gathers approximately 100 times to test the impact of small changes in azimuthal anisotropy (as expressed by elliptical migration operators). The migration scanning result was used to once again update 1-D travel times feeding a second full Kirchhoff pre-stack time migration of the entire Silo 3D. Azimuthal anisotropy was mapped using vectors created from (Vfast-Vslow)/Vfast and Azimuth of Vfast volumes (Figure 1). Stress field changes apparent from azimuthal migration scanning show a rotation of the regional background stress field from a Vfast azimuth of 140 degrees in some portions of the Silo 3D to 40-50 degrees in other parts. Open fractures should parallel these azimuthal anisotropy anomalies. Comparison of local FMI well results with the seismic based HTI data show good agreement with fracture orientations.

Well Data and Elastic Inversion

The migrated gathers were then used for an elastic inversion of the Silo 3D. Limited well data has made the initial inversion of Silo more of an attribute volume than a calibrated rock property prediction – but useful trends appear to be present in the data. Figure 2 shows one well tie from the inversion highlighting rock propery variations within the primary target interval – the Niobrara B1-->B2 section. The inversion shows zones that appear less ductile (more brittle) in the B1-B2 interval using a cross-plot derived attribute based on LambdaRho and MuRho inversion products. Mapping of this package across a portion of the Silo 3D shows areas of more brittle rock – areas one would expect to have greater fracturing (Figure 3).

Structural Interpretation

Interpretation of the Silo 3D suggest that presence, direction and causes of fracturing in the area are variable and no single explanation applies to the whole region. An Archean-Proterozoic fold and thrust belt is imaged below the Niobrara in the Silo area. Paleozoic through Tertiary reactivation of these basement faults shows three major trends: NW-SE; NE-SW; and N-S (Figure 4). These basement fault trends are reflected in the younger stratigraphy, including the Niobrara.

In some parts of the study area basement faulting appears to have been active after the deposition of the Permian salt, causing widespread deformation of the salt/evaporite layers. A period of basement quiescence is reflected in the constant layer thickness of Cetaceous-age Dakota and Niobrara Formations. Laramide-age shortening deformed both the cover and the basement in the area, creating the broad high NW-SE trending uplift related to the Silo field and north-south trending anticlines on the western edge of the 3D area. Some of the faults that cut the Niobrara can be directly linked to underlying reactivated basement faults (Figure5b), while other Niobrara faults (Figure 5a) appear to have no direct correlation with the basement. The large NW-SE trending strike-slip fault zone that goes through the Silo Field is a reactivated basement fault that may have controlled the location of the Permian salt basin and was later used as an accommodation zone linking shortening along N-S trending basement thrusts with NW-SE trending basement thrusts

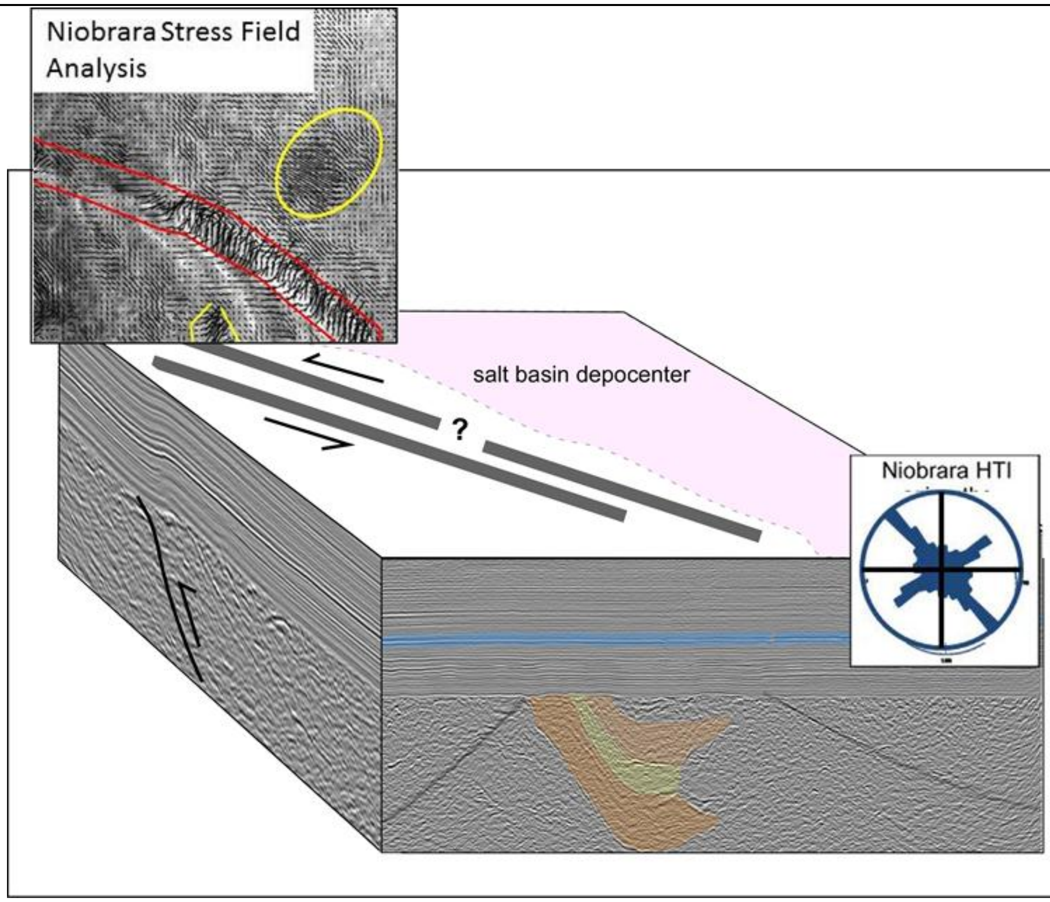


Figure 1: The multi-client 3D survey offers the potential to combine azimuthal anisotropy results with an analysis of the regional structural framework, basement and salt deformation, and stress field.

Niobrara Fracture Prospecting Through Integrated Studies

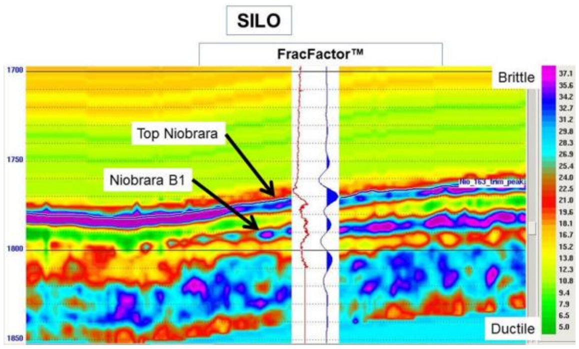


Figure 2. Well tie synthetic and inversion result illustrating spatial changes in the Niobrara B1 (and B2) approaching Silo field from left to right. The stronger purple colors from the inversion indicate increasing brittle rock predicted from a LambdaRho-MuRho inversion product.

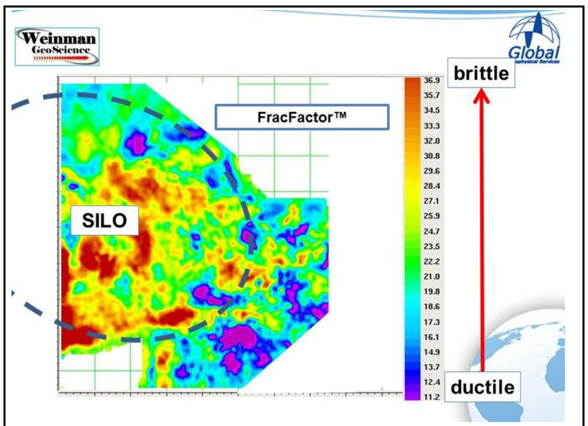


Figure 3. Approximately 60-80 mi2 portion of the Silo 3D inversion on the edge of the Silo Field illustrating spatial changes in the Niobrara B1 and B2 interval. The hotter colors correspond to areas of greater brittle character.field.

Conclusions

Our results suggest that the Niobrara has been a difficult play because fracturing is highly variable and may not be caused by a consistent set of variables everywhere. By understanding the structural segmentation of the area and combining that with rock property results, azimuthal anisotropy products and well data, we explain past well performance and predict areas of future potential

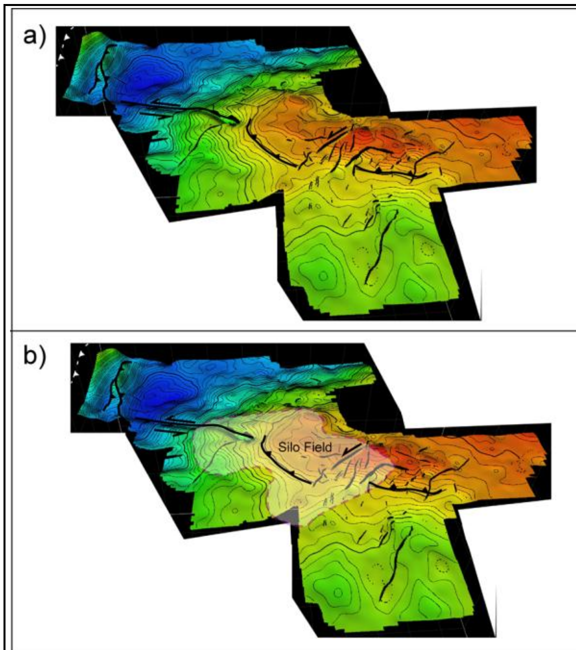
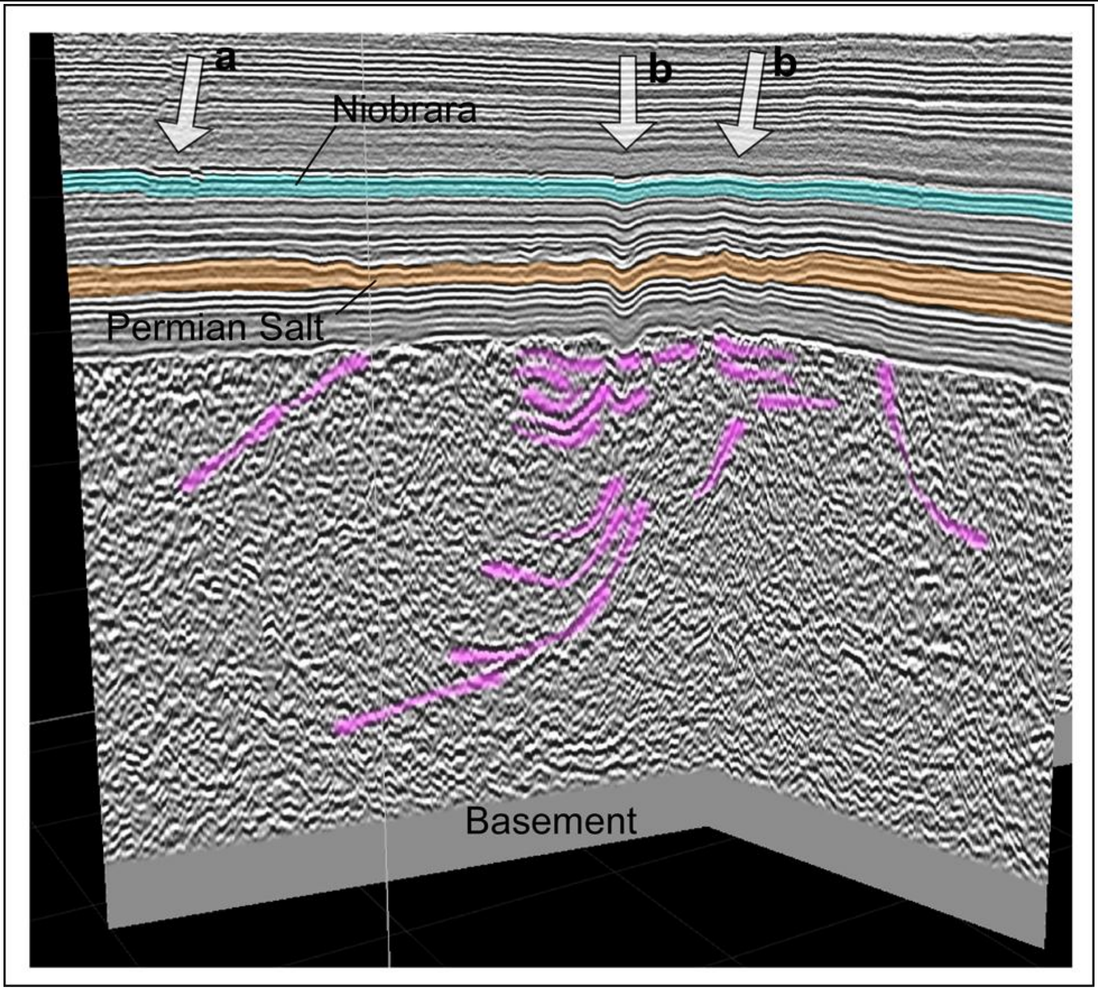


Figure 4. Perspective view of a time structure contour map on the top of the Archean-Proterozoic basement in the Silo area (red areas are high). a) Mapped basement faults were reactivated in the late Paleozoic or Tertiary, causing deformation in the overlying stratigraphic section. The major basement fault orientations are N-S, NW-SE, and NE-SW. b) The large strike-slip fault that cuts the Silo Filed connects the Silo Field basement high with a N-S trending series of basement thrusts. The Silo Field area overlies the NW nose of a large basement uplift.



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