Seismic attribute delineation of lineaments and reservoir compartmentalization: An example from the Devonian Dollarhide field, Central Basin Platform, west Texas.

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Summary

Reservoir compartmentalization of the Dollarhide Field has to be understood in order to optimize recovery of remaining reserves. Porosity and permeability heterogeneity is a function of the interaction of stratigraphic and structural elements such as fractures, faults, subcrops and channels. Diagenesis and dissolution play an important role on the heterogeneity of the reservoir. Some of the reservoir-scale features are small and beyond the resolution of conventional seismic. Research is being conducted on the use of 3D seismic attributes to better delineate reservoir parameters important for fluid flow models.

This paper presents our current understanding of the lineaments of the field after using some computed 3D seismic attributes. Coherence with two passes of edge-preserving smoothing has been a helpful attribute.

The Dollarhide Field is a north-south trending asymmetric anticline bound by major reverse faults on its east flank. The anticline is associated with a northeast striking, right-lateral, strike-slip fault, and it is cut by an en-echelon system of northeast striking, right lateral, synthetic, Riedel-shear faults. Conjugate, northwest striking, antithetic shear faults have been identified on the downthrown block of the field. Some lineaments in the upthrown block with the same trend could have the same origin.

The structure was formed during the Late Paleozoic orogeny as the result of the collision of North and South American plates, when the Central Basin Platform was uplifted. The structure is truncated at its crest by the unconformity at the base of Early Permian carbonates. Subcropping belts of carbonates, cherts, and shales show the configuration of the structure before Early Permian times. Reactivation of pre-existing faults may have occurred during Early Tertiary Laramide orogeny.

When compared with porosity-thickness maps of the reservoirs, the subcrop pattern and conjugate shear faults show a strong correlation with porosity trend segmentation.

Introduction

The Dollarhide Field is located on the Central Basin Platform in the Permian Basin of West Texas (Figure 1) (Saller et al., 2001). This field has produced 70 million bbl of oil from cherts and dolomites of the Devonian Thirtyone Formation (Saller et al., 2001) with estimated oil in place of 175 million barrels (Ball, 2002).

Optimization of the recovery of remaining reserves depends greatly on the understanding of the reservoir compartmentalization. Well productivity is highly variable, from 50,000 bbl to 2.5 million bbl of oil during primary and secondary recovery. The variability is related to differences in the thickness, quality, and continuity of the reservoirs (Saller et al., 2001).

A complex interaction of faulting and fracturing, reservoir facies and diagenesis, and subcrop patterns determines the locations of the sweet spots within the main reservoirs (Ruppel and Barnaby, 2001; Ruppel and Hovorka, 1995). This is a common problem of many fields in the area.

The objective of this research is to delineate stratigraphic and structural features at or below conventional seismic resolution in order to build a high-resolution geologic model. Understanding the fracture geometries and fault kinematics, and their impact on reservoir compartmentalization is critical. A key part of the research is to test which 3D seismic attributes best image different features (faults, subcrops, and channels).
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Method

Unocal has provided a 3D seismic survey of the field acquired in the late 1980s, and well logs to calibrate the seismic. Core data will be also incorporated to the study for facies, diagenesis, and fracture analysis. A geologic model will be built from interpretation of 3D seismic attributes, logs, and cores, and then it will be calibrated using production data. Some seismic attributes have been computed and interpreted and show better delineation of lineaments and the geometry of the structure than conventional seismic. Additional attributes, such as seismic coherence, spectral decomposition, eigenvector-derived dip and azimuth, amplitude gradient attributes, and thin bed tuning have been computed and used in the interpretation. Core and log data will be incorporated to the analysis of reservoir facies and diagenesis.

Lineaments

The Dollarhide structure at the top of Devonian reservoir is a north-south striking asymmetric anticline bounded to the east by two reverse faults. The main reverse fault has a vertical separation of approximately 2,500 ft. The anticline is cut by two high angle fault systems, one with a northeast trend and a second one with a northwest trend (Figure 2). The second system is better seen in the downthrown block of the field. The northeast-striking faults show a clear right lateral and reverse displacement, while the other system shows minor reverse separation and no clear strike-slip displacement (Figures 2 and 3).

The section of interest is partly truncated at the crest of the field by an unconformity at the base of the Permian. Subcropping belts of cherts, carbonates, and shales show a prePermian deformation phase below the Early Permian carbonates. The deformation pattern is interpreted as the result of a right-lateral simple shear movement related to a northeast-striking principal displacement zone, as is shown in the model (Figure 4; Sylvester, 1988). The pattern is characterized by en-echelon arrangements of faults in a relatively narrow zone (Figure 5; Sylvester, 1988). The model predicts five sets of fractures: 1) Riedel R strike-slip shear faults, 2) Conjugate Riedel R’ strike-slip shear fault, 3) Secondary synthetic strike-slip faults P, 4) Extension fractures or normal faults which develop at 45° to the principal displacement zone, and, 5) Faults parallel to the principal displacement zone (PDZ).

In the Dollarhide Field, a conjugate set of Riedel shears that make an angle of approximately 60° has been interpreted. The fold axis parallel to the dominant reverse fault is oblique to the principal direction of shear as predicted by the model.

Fig. 2. Shallow and deep time slices that show the lineaments of the Dollarhide Field. Coherency time slices with two passes of edge-preserving smoothing is shown at (a) 1.060 sec and (b) 1.300 sec, and basic data where black is the peak is shown at (c) 1.060 sec and (d) 1.400 sec. Notice the north-south trending faults that bound the east flank of the anticline, the northeast striking lineaments that displace the bedding, and on the downthrown block D, the northwest trending lineaments that are not so visible on the upthrown block U. East-west lineaments are interpreted as acquisition footprint.
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Fig. 3. Reverse faults that bound the field to the east are shown in blue and green on the east-west and southeast-northwest cross-sections. High angle, northeast striking, reverse faults with right lateral displacement are shown in pink to purple colors. The conjugate northwest striking faults have not been interpreted on the upthrown block. Multiple right lateral strike-slip faults (in blue) mask the presence of these lineaments. Light blue=base of early Permian unconformity. Light green=Mississippian to Pennsylvanian unconformity. Dark blue=top of Thirtyone Formation of Middle Devonian age. Pink=top of pre-Cambrian granite. Location of cross-sections is in black.

Most of the deformation of the area occurred during the Mississippian-Pennsylvanian to early Permian orogeny associated to the collision of the North American and South American plates. Reactivation of the faults may have occurred during the early Tertiary Laramide orogeny. Other fields in the area show similar reactivation (Winfree, 1995). Many authors have attempted to relate local features to a subregional model of the Central Basin Platform. Most recently, Yang and Dorobek (1995), and Shumaker (1995) published models calling upon clockwise block rotation associated with strike-slip faulting. The difference between their models is that Shumaker attributes the rotation to left-lateral displacement along east-west trending cross faults, whereas Yang and Dorobek attribute the rotation to dominantly right-lateral displacement along NNW-SSE fault zones, which bounded the Central basin Platform during its initial stages of formation. The Dollarhide Field structure fits in the block rotational model.

Fig. 4. Right simple shear Riedel model (After Sylvester, 1988) that explains the lineaments found in the Dollarhide Field. Northeast, right-lateral strike-slip faults of the field are interpreted as the Riedel R synthetic shear faults, and the northwest striking high angle faults more visible in the downthrown block are interpreted as the conjugate antithetic Riedel R’ shear faults. The Riedel R shear faults occur in an en-echelon pattern (block diagram). A pure shear model can also explain the lineaments found in the field, but the en-echelon pattern favors the simple shear model.

Fig. 5. Different stages of maturity of strike-slip faults showing the development of multiple features and en-echelon arrangements (After Sylvester, 1988). The Dollarhide Field represents the intermediate stage.
Reservoir compartmentalization

Saller et al. (2001) published a map of porosity-thickness for the lower Devonian reservoir of the Field, which includes the main chert facies. We have found that there is a spatial correlation between lineaments and porosity trend compartmentalization. Porosity trends are controlled by the subcrop pattern, and northeast and northwest striking faults (Figure 6). These are sealing faults and are segmenting the porosity trends. Reservoirs are partially eroded towards the crest of the structure where the map shows lack of porosity.

Fig. 6. Comparison of lineaments of the Dollarhide Field and porosity trends within the chert facies published by Saller et al. (2001). The figure to the right is a two pass edge preserving smoothing + coherency at time slice 1.060 sec that shows the interpreted faults. The northeast and northwest striking faults are segmenting the porosity trends.

Conclusions

- The Dollarhide structure is a truncated asymmetric anticline formed during the Late Paleozoic due to contractional strike-slip faulting. The lineaments are the result of at least one phase of strike-slip movement along a northeast-striking right lateral fault.
- Reactivation of preexisting faults occurred in a post-Permian phase of compression, possibly during the Laramide orogeny.
- Porosity-thickness trends are segmented by the conjugate shear faults.
- The structure fits in the block rotational model of the Central Basin Platform.
- Lineaments of the Dollarhide Field structure are better interpreted using 3D seismic attributes on time slices and horizon slices that assist the interpretation of cross-sections, where some of the features are beyond seismic resolution.

References


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