

Characterizing fractured reservoir by multicomponent reflection data and VSPs in the Paris Basin

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Xiang- Yang Li*, Colin MacBeth, British Geological Survey, Scotland; Frederic Lefeuvre, Total, France; and Hocine Tabti, Institut de Physique du Globe, Paris

SUMMARY

We process and interpret nine-component (9C, three component recordings of two horizontal and one vertical sources) surface seismic data and two nearby VSPs to characterize the fractured carbonate reservoir in the Dogger Formation in the Paris Basin. This is achieved by analysing differential changes in the various attributes of the vector wavefield: velocity ratios, polarizations, amplitudes and differential travel times. Careful processing is required to preserve and recover these attributes which have diagnostic anomalies associated with the Dogger formation. The interval shear-anisotropy within the Dogger shows an average of 4% with significant lateral variations, which might be interpreted as lateral changes in porosity and permeability. The differential shear-wave amplitude from the top of the Dogger shows an overall dimming. The shear-wave polarization section reveals detailed internal layering, up to six intervals, within the Dogger, which is not visible in the P-wave section. The information inferred from these wavefield attributes can be broadly correlated with the reservoir properties at the inter-well scale in Duval (1990) but with more detailed lateral variations.

INTRODUCTION

In 1991, Total Exploration acquired one line (6.4km) of nine-component surface seismic data and two near-by nine-component VSPs in the Paris Basin in order to test the use of shear-wave splitting for characterizing fractured reservoirs in the Dogger formation. Here these data are examined to evaluate the merit of different processing schemes, and to extract anisotropy information for the reservoir.

The reservoir is in the Dogger formation in the Paris Basin. The trap is very subtle and is a combination of stratigraphic, structural and diagenetic features. Gross porosity is highly variable from 8 to 20% (Duval 1990) with different porosity types. Successful field development is highly dependent on the delineation of high porosity zones. In the study area, the structure is mainly horizontal layers. Vertical fractures in oolitic limestones are the main source of permeability and porosity, and are exploration targets.

The survey includes one multicomponent surface line (Line 1) and two VSPs (VSPs 1 and 2). The multicomponent line intersects the two wells where the VSPs were acquired: VSP 1 at CDP 97 and VSP 2 at CDP 195 (about 2km apart). From a lithology log in well VSP 1, the reservoir is located at 1856m in the lower (early) Callovian and the Bathonian towards the upper part (late) of the Dogger and is about 40-50m thick. The purpose of the survey is to delineate the internal structure of the Dogger and locate highly fractured zones along the lower Callovian in the oolitic limestone.

DATA ACQUISITION AND PROCESSING

The multicomponent line strikes approximately from north-west to south east (N135°E) and is almost parallel to the regional fracture strike of N140°E, as identified from cores from well VSP 2 (Lefeuvre et al. 1992). A fixed receiver spread is used with 160 three-component geophone at 40m spacing. The sources vibrated at every station, and each vibration contains 8 sweeps with frequency ranging from 10 to 100 hz for the vertical vibrator, and 8 to 55hz for the horizontal vibrator. The phones record for 15 seconds with 2ms sampling interval for the vertical, 30 seconds for the horizontal; 4 seconds are retained for the vertical and 5 seconds for the horizontal after vibrator correlation. For the VSPs, both VSPs 1 and 2 contain a far-offset three-component VSP with a vertical source, and a near-offset 9C VSP. The VSPs are of high S/N ratio, and shear-wave splitting is marked by the large off-diagonal energy.

The surface shear-data are relatively noisy, and primary reflections can hardly be identified (Figure 1a). As expected, the signal to noise (S/N) ratio of the P-wave data is much higher, and primary reflection events can be easily identified (Figure 1b). Data conditioning to improve the S/N ratio is essential for processing the shear-components, and includes multicomponent amplitude correction (Li 1994), shear-window trace selection (Booth and Crampin 1985), common offset stacking based on reciprocity and bandpass filters. After data conditioning, conventional stacking procedures are used to stack each individual components, followed by post-stack separation of split shear-waves and

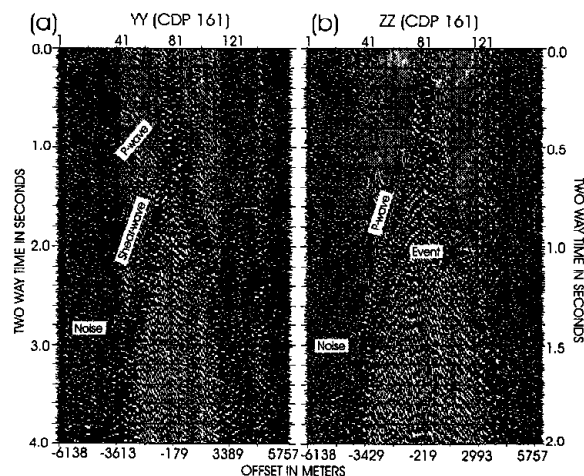


Figure 1. Field CDP gather of (a) the YY- and (b) the ZZ- component at CDP 161. Random and coherent noise dominate the gathers.

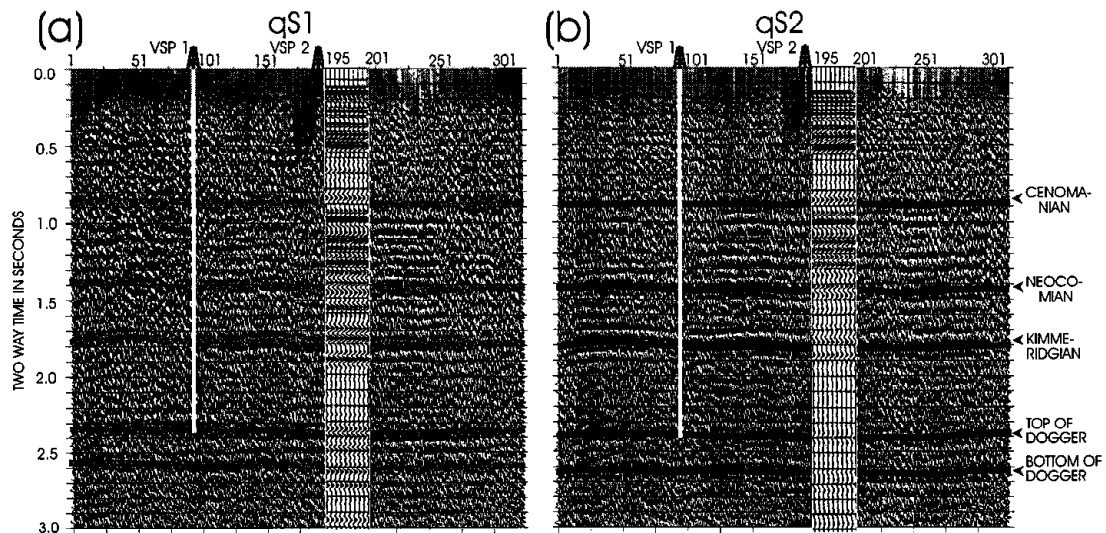


Figure 2. Final stacked (a) $qS1$ - and (b) $qS2$ - section and their correlations with each other and with corresponding VSP corridor stacks from VSP 2. Five horizons are chosen as reference horizons, and are tracked using a workstation and marked in the sections. Note that a dynamic increase of mistie with time can be observed when correlating the $qS1$ with the $qS2$.

overburden amplitude correction (Li and Crampin 1993; Li 1994). A deterministic approach based upon a convolution sequence of 3×3 matrix operators was used to process one of the VSPs. The sequence includes SVD correction for source and geophone mis-orientation, 9C near-surface corrections, conventional F-K filter to separate the up- and down-going wavefield, 9C convolution of the transmission response with the reflection response to yield the up-going wavefield in two-way time, and finally corridor stack of the up-going field (MacBeth and Li 1993).

INTEGRATED INTERPRETATION

We take a straightforward approach to interpret the VSPs and the surface data. First we select some standard horizons, trace them along the seismic sections, and establish their well tie using the VSP corridor stacks. We then quantify depth variations of wavefield attributes from the two VSPs, and lateral variations from the surface data. Thus the well tie is essential. The chosen horizons are the top of Cenomanian, the Neocomian, and the Kimmeridgian, and top and the bottom of the Dogger which is the target. With careful processing, we obtained a very good correlation between the stack sections and their corresponding VSP corridor stacks, and between the $qS1$ - and qP - section, and between the $qS1$ - and $qS2$ - section (Figures 2 & 3).

Correlation of the $qS1$ - section with the qP -section (Figures 2a & 3) reveals a high V_p/V_s ratio (up to 4) in the near-surface and an average ratio of 2 in the subsurface, which agrees with the VSPs (Figure 4). Correlation of the $qS1$ - section with the $qS2$ - section (Figures 2a & 2b) shows an

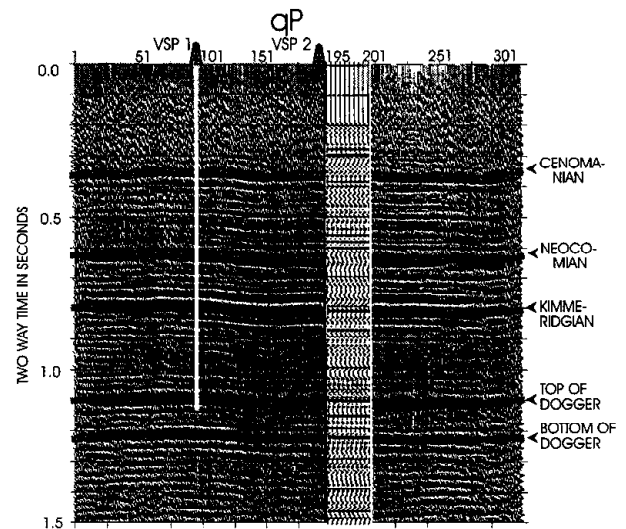


Figure 3. Final stacked qP -section and its correlation with corresponding VSP corridor stack from VSP 2. Note that a time-scale ratio of 1 to 2 is used in displaying the qS - and qP - section, and an initial downward shift of qP - section is required when correlate the qP with the $qS1$, indicating a V_p/V_s ratio of higher than 2 in the near-surface.

increasing mistie with time which suggests that the subsurface is anisotropic for the shear-waves. Overall polarization azimuth from the surface data is in good agreement with the two VSPs; the polarization direction is found at $N140^\circ E$ ($N40^\circ W$), and is constant with depth (Figure 5). The differential shear-wave time delays from the

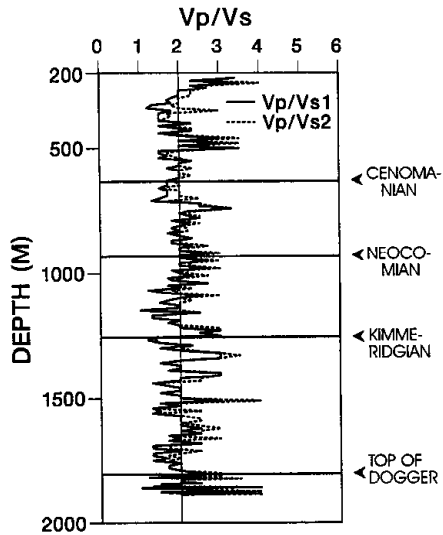


Figure 4. Depth variation of V_p/V_{qs} ratio (V_p/V_s in short) calculated from VSP 1. The solid line represents V_p/V_{qs1} (V_p/V_{s1} in short); the dotted line represents V_p/V_{qs2} (V_p/V_{s2} in short). The thin vertical line is a reference line for V_p/V_s ratio 2.0; the heavy horizontal lines mark formation tops named on the right.

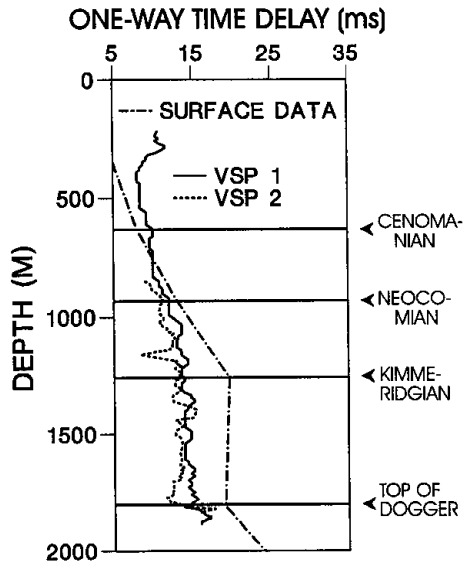


Figure 6. Comparison of depth variations of differential time delay of $qS1$ - and $qS2$ - wave for the two VSPs and the surface data. (a) Time delays of the split shear-waves for the two VSPs: solid line - VSP 1; dotted line - VSP 2. The VSP 2 results are taken from Lefeuvre *et al.* (1992) with the spurious points removed and the reference level shifted from 750m at depth to the surface by adding an extra 10ms time delay. (b) Average time delays of the five chosen horizons in Figure 2; the delays are converted to one way time, and plotted out against the depths of the horizons from the lithology log in VSP 1. Note that there are about 5ms differences between the VSP results and the surface data.

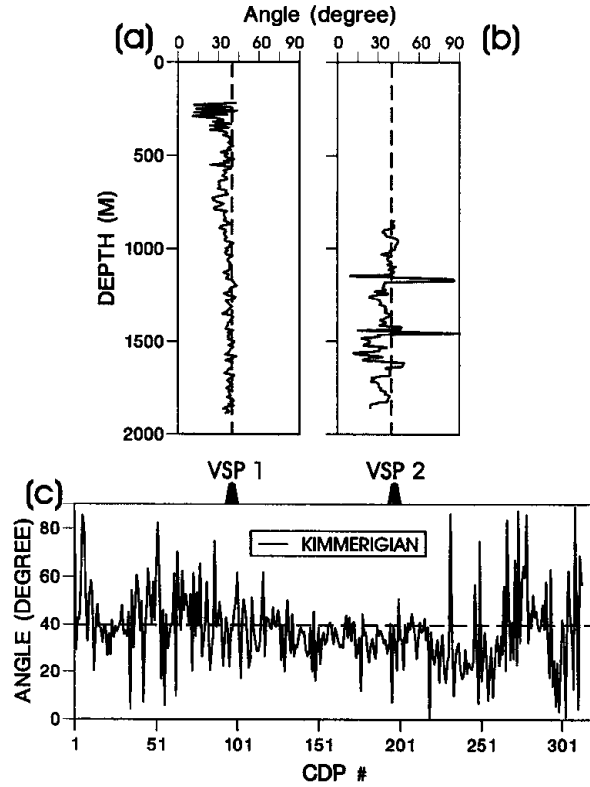


Figure 5. Depth and lateral variations of polarization azimuths. (a) VSP 1, calculated using the Linear-transform technique (LTT, Li and Crampin 1993); (b) VSP 2, after Lefeuvre *et al.* (1992); (c) surface data, calculated by LTT technique using a 300ms window centered on the overburden horizon Kimmeridgian which shows the best quality in the seismic sections. The thin dashed lines in (a), (b) and (c) mark the reference value of 40° .

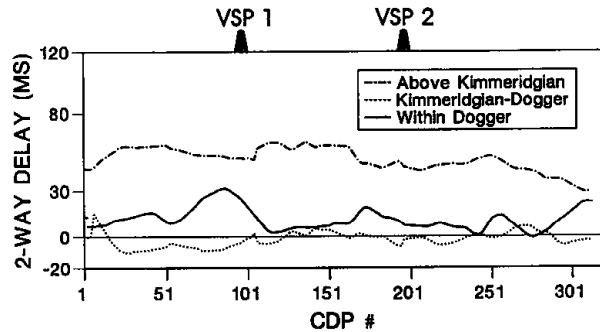


Figure 7. Lateral variation of interval time delays for the three significant intervals defined in the text: above Kimmeridgian - dot-dash line; Kimmeridgian to the top of Dogger -dotted line; the Dogger interval - solid line.

VSPs and the surface data shows three significant anisotropic intervals: from the surface to the top of the Kimmeridgian with an about 3% anisotropy in chalk, shale and limestone sequence, from the Kimmeridgian to the top of Dogger with isotropic limestone formation, and the Dogger interval with 4% anisotropy of fractured limestone (Figure 6).

Interval anisotropic attributes are measured between the top and the bottom of the Dogger in order to characterize the reservoir. The $qS2$ shear-wave amplitudes from the top of the Dogger show an overall dimming, although the overburden horizon (the Kimmeridgian) in the $qS2$ - section show stronger amplitudes and better continuity than that in the $qS1$ - section. (Figures 2a and 2b). The interval time delay within the Dogger shows significant lateral variations (solid line, Figure 7), which might be correlated with the high porosity zones in the Dogger formation. The shear-polarization section reveals detailed internal layering of the Dogger (up to six layers, Figure 8), which is not clear in the P-wave section (Figure 3). These interval anisotropy attributes can be broadly correlated with reservoir properties at the inter-well scale but with more detailed lateral and vertical variations.

CONCLUSIONS

Careful processing procedures including shear-wave-window trace selection, reciprocity stacking and multicomponent amplitude correction are essential for producing quality stacked shear-wave sections while preserving the information of the target (Figure 2). The Dogger formation in the Paris Basin is successfully characterized by the vector wavefield attributes extracted from the multicomponent VSPs and surface data, which yields an internal structure of the Dogger with more detailed lateral and vertical variations than conventional methods.

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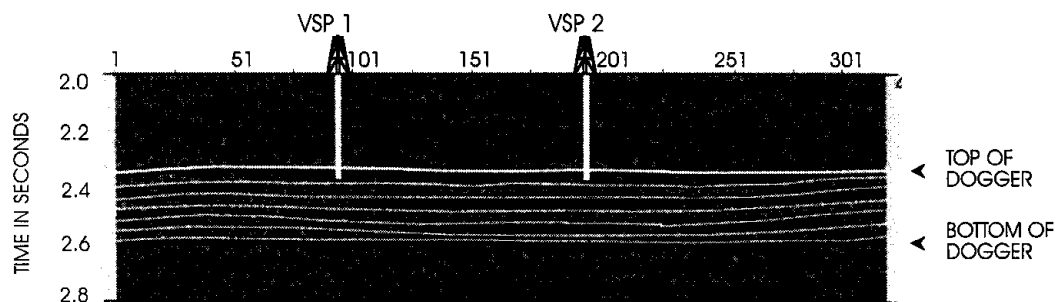


Figure 8. Windowed polarization section, calculated by the complex component analysis (Li and Crampin 1991), showing the internal phase changes within the Dogger, which may correspond to the internal layering of the Dogger. Note that this detailed layering information is not clear in the qP - section in Figure 3, despite the fact that the qP - section is of high S/N ratio.