The effect of interpolation on imaging and AVO: A Viking case study

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ABSTRACT

The use of prestack interpolation prior to prestack migration to improve AVO analysis on image gathers is demonstrated on an exploration play. The interpolation achieves this improvement by reducing migration artifacts. AVO analysis attempts to estimate fundamental information from surface seismic data and likely will be used more frequently if the estimates can be more accurately produced. Land 3D seismic typically has poor and irregular sampling. This poor sampling creates migration noise, which is a material cause of inaccurate AVO estimates. Prestack 5D interpolation is applied prior to prestack migration and AVO analysis on the imaged gathers to address this noise problem. The interpolation algorithm includes offset and azimuth dimensions that preserve AVO information. This method is evaluated by comparing the results to those of alternate approaches, such as superbinning, that suppress this kind of noise in AVO analysis. The evaluation is determined by comparing our ability to predict the reservoir quality of a gas-charged sandstone reservoir with 48 well penetrations. We compare migrated gathers, AVO attribute stacks, and attribute maps in our analysis. We also note scatter plots of the AVO attribute values against measures of reservoir quality at the well control points to allow a quantitative measure of the improvements. The interpolation method yields gath- ers, stacks, and maps that all appear to be better resolved and less noisy than the other methods. The scatter plots demonstrate a measurable and significant improvement from the interpolation method, especially compared to superbinning. This work suggests interpolation before imaging, and imaging before AVO analysis, should be performed on land 3D surface seismic data.

INTRODUCTION

Multizone drilling in west-central Alberta (Canada) often includes thin targets. The Viking formation sands are one of the stacked targets that commonly are drilled for. They are structured, thin, and erosionally preserved (Boreen and Walker, 1991). Three-dimensional surface seismic coverage exists over the entire area, but only simple amplitude maps of the Viking initially were used to identify the gas sands. We considered amplitude variation with offset (AVO) analysis to improve reservoir prediction and drilling results. AVO has been studied in detail with respect to gas sands. Ostrander (1984) addresses the advantage of AVO over classic stack amplitude methods, and Rutherford and Williams (1989) demonstrate dramatic AVO effects for sands within various encasing materials.

The thinness of the Viking reservoir provides a challenge to most seismic methods. Pan et al.’s (1994) demonstrate success using AVO effects to predict reservoir thicknesses of gas sands down to about one-tenth of a wavelength. Whereas Pan et al.’s (1994) work employed an inversion, we chose to utilize a simple comparison using AVO attributes without seismic inversion. We used a simple combination of the P-wave impedance reflectivity $R_p$ and the shear-wave impedance reflectivity $R_s$. Castagna and Smith (1994) demonstrate that the difference $R_p-R_s$ is a useful gas indicator in clastics, and is even simpler than the fluid factor method of Smith and Gidlow (1987). We chose this simple approach to the AVO analysis so that the results would be directly dependant on the quality of the gathers.

The use of prestack migrated, or imaged, gathers is required by the structural complexity and erosional nature of the Viking reservoir distribution. Allen et al. (1995) show the importance of migration in collapsing the Fresnel zone and accurately resolving and mapping AVO anomalies. Further, Mosher et al. (1996) illustrate that prestack migrated gathers enabled a cleaner, higher signal-to-noise ratio AVO result by the elimination of diffractions and through the inherent advantages of imaging the wavefield correctly. Mosher et al.’s (1996) work was performed on marine 3D seismic data, which generally is...
much more regularly sampled than land 3D seismic. By contrast, the 3D coverage we used has source and receiver line geometries that are both irregular and widely spaced. This type of 3D geometry gives rise to gross irregularities in the offset and azimuthal distribution of the data, which causes distortions in the prestack time migration (PSTM) gathers and AVO analysis (Gardner and Canning, 1994; Canning and Gardner, 1998). AVO analysis is more sensitive than the stack to these distortions because the analysis takes place in the image gather domain. Zheng et al. (2001) illustrate the use of fold compensation and area weighting to reduce these migration artifacts. Some land 3D surveys are so poorly sampled that additional methods are used to address this problem. These techniques are used in conjunction with area weighting and fold compensation, and include: ignoring the problem (or doing nothing), working with unigrated data and subsequently migrating the AVO attribute stacks, or generating supergathers (Ostrander, 1984; Xu and Chopra, 2007) for AVO analysis of migrated gathers. We introduce an additional technique to reduce migration artifacts: interpolation before PSTM.

Trad (2007) developed the interpolation algorithm by extending Liu and Sacchi’s (2004) minimum weighted norm interpolation (MWNI) to five dimensions, including offset and azimuth. Sacchi and Liu (2005) use this method to demonstrate that the interpolation reduced migration artifacts and preserved AVO information on synthetic and real data imaged gathers. Gray et al. (2009) demonstrated the interpolator of Trad (2007) would preserve AVO information and minimize prestack migration artifacts in a physical modeling study. Gray’s (2009) work also showed that processing flows that included interpolation yielded better images than only using bin borrowing, area weighting, and fold compensation.

This work evaluates the results achieved when interpolation is performed prior to PSTM and AVO analysis on a land 3D seismic survey. The evaluation is carried out by comparing the results with a control experiment. In the control, alternative AVO analyses are produced when other means of addressing the sampling-produced migration noise problem are used. Predicting the Viking reservoir quality in 48 wells on the 3D survey is our key criterion for evaluating the usefulness of interpolation. We create gather, attribute stack, and attribute map comparisons of the Viking to illustrate that the interpolated result is superior to the alternative methods in image signal-to-noise ratio and resolution. We also use the quantitative information provided from well-log derived measures of reservoir quality such as porosity-thickness (phi-h). Scatter plots and regressions between phi-h and attributes from each of the AVO methods yielded objective measures of the quality of the data relationship in the form of coefficient of determination, or R-squared (Nagelkerke, 1992) values. The interpolation method yielded the highest R-squared numbers. The superwinning results yielded poor regressions despite looking good on qualitative comparisons such as in maps. This effort also illustrates the superiority of prestack migration over not migrating or poststack migrating attributes. From this evidence we recommend that AVO analysis on irregularly sampled land 3D seismic surveys be carried out on interpolated and prestack migrated data.

The interpolation, prestack migration, AVO method demonstrated here was used to help direct the drilling of wells independent of the progress of the scientific comparisons illustrated in this study. As a consequence, 13 new wells were drilled on data produced using the new method. Some of these wells targeted other formations, and were located where the results were expected to be poor for the Viking. These new wells are indicated in the scatter plot comparisons of our results, and are more tightly clustered with the interpolation method. This behavior decreases the likelihood of false negative predictions. Avoiding false negative predictions is just as important as avoiding false positive predictions. The higher correlations yielded by the new method improve the likelihood of avoiding both.

THE VIKING FORMATION

Viking Formation reservoirs in west central Alberta represent attractive exploration targets. The reservoirs are challenging to resolve seismically due to their depth of burial and lack of thickness. Maximum burial of the Viking Formation was attained during the Laramide orogeny, when most foreland-basin strata in the west central part of the Alberta basin entered the oil and gas window. Viking Formation overpressures developed as a result of compaction and hydrocarbon generation. Since then, the basin has undergone tectonic relaxation, uplift, and erosion, and the rate of hydrocarbon generation has decreased. Overpressures are locally maintained in areas adjacent to the deformation front as a result of continuing gas generation at rates higher than gas escape (Michael and Bachu, 2001).

Sequence stratigraphic units and their bounding surfaces directly control the distributional trends, external geometry, and internal heterogeneity of hydrocarbon-bearing reservoirs in the Viking Formation. Erosionally preserved shoreface sandstone assemblages of the Viking form overpressured, gas-charged reservoirs in the deeper portions of the Western Canada Sedimentary Basin. From an exploration viewpoint, the highly prospective trends appear to occur at erosional sequence boundaries, parasequence boundaries, or other related bounding surfaces (Boreen and Walker, 1991; Reinson et al., 1994). These sandstones often retain 12–14% density log porosity over 0 to 7 m thickness, and occur at depths greater than 2800 m. The structural setting for the study area includes both extensional and compressional tectonic elements interpreted from 3D seismic volumes. The erosional preservation of the reservoir is interpreted to be a result of both eustatic (sea level changes) and tectonic factors that created the complex reservoir distribution that requires 3D seismic to predict. Standard 3D seismic amplitude mapping to predict the Viking reservoir failed to yield acceptable results. The fact that the Viking is gas-charged, underlies a lower velocity shale sequence, and may be anomalously pressured, supported the notion that AVO analysis might be advantageous. Rutherford and Williams (1989) show that similar gas sands gave a strong type II AVO response.

Two representative wells illustrate the potential usefulness of AVO analysis to this problem. Figure 1 shows that Well A has porous, preserved sand with low lambda-rho and high mu-rho (Goodway et al., 1997) characteristics. Well B has no preserved reservoir. These log responses indicate that the compressional (lambda-rho) and shear (mu-rho) properties of the reservoir stand out from the background nonreservoir rock, suggesting that a combination of them will be the best reservoir indicator. Figure 2 compares 0° to 35° AVO models produced from these wells utilizing Shuey’s (1985) equation and a wavelet common to the 3D seismic data in the area. This comparison illustrates how the rock property variations may produce different seismic responses. The Viking is seen as a peak on the near offsets of zero-phase seismic. Well B has a class I AVO response (Rutherford and Williams, 1989; Castagna et al., 1998), while Well A more closely approaches a class II response. The difference in these responses suggests that an advantage may lie with the utilization of this contrasting AVO effect.

Fractional elastic parameters such as the compressional ($R_p$) and shear reflectivity ($R_s$) may be estimated from the prestack seismic
data by AVO inversion such as the two-term approximation to the Gidlow et al. (1992) equation

\[ R(\theta) = \frac{R_p}{\sec^2 \theta} - 8R_p \gamma^2 \sin^2 \theta, \]  

(1)

where \( \theta \) is the average angle of incidence and \( \gamma \) is the average S-wave to P-wave velocity ratio. There exists a wide variety of AVO attributes that could have been used for mapping and validation. We chose a very simple parameter, the damped \( R_p \) to \( R_s \) ratio. The gas-charged porous Viking reservoir should illustrate a drop in the data. The \( R_p \) to \( R_s \) ratio relative to the tighter reservoir. This is consistent with the behavior of other gas-charged sandstones, as Castagna and Smith (1994) demonstrate with a similar \( R'_p \)-\( R'_s \) attribute. We also confirmed that the \( R_p \) to \( R_s \) ratio gave similar results to the \( R'_p \)-\( R'_s \) attribute on this data. The \( R_p \) to \( R_s \) ratio parameter also is desirable because it is calculated from attributes estimated directly from Gidlow et al.’s (1992) equation. The quality of the results therefore is dependent only on the accuracy of the initial AVO estimate, which is dependent on the quality of the gathers.

**INTERPOLATION STRATEGY**

AVO parameters are notoriously difficult to estimate with the fidelity and resolution needed to be useful on many stratigraphic prospects. Li et al. (2007) describe the crucial challenges involved in successfully estimating the elastic parameters. Those challenges include the need to obtain migrated gathers that have sufficient resolution and high signal-to-noise ratios. The structural deformation in this example appears to be significant enough to require that AVO be performed on PSTM gathers. The geometry of the 3D survey is orthogonal, and the receiver lines are oriented in the northwest to southeast direction. The nominal source and receiver line spacing of this 3D survey is 660 m and 600 m, respectively. The source and receiver lines are irregular due to surface considerations, and can be as wide as 1000 m in some areas. The shot interval was 120 m, and the receiver interval was 60 m. Full fold was 27, and the nominal fold at the zone of interest was 27. The data are band-limited to about 55 Hz. It was suspected that this acquisition geometry was sampled so coarsely that area weighting and fold compensation (Zheng et al., 2001) would fail to sufficiently minimize the migration artifacts.

Minimum weighted norm interpolation (Liu and Sacchi, 2004) is implemented in five dimensions (Trad, 2007, 2009) prior to migration to address this problem. The 5D interpolation is performed by solving a large inverse problem. The forward problem is described via the expression

\[ \mathbf{d} = \mathbf{T} \mathbf{x}, \]  

(2)

where \( \mathbf{x} \) is the ideal fully sampled 5D data set, \( \mathbf{d} \) is the data set actually recorded in the field, and \( \mathbf{T} \) is the sampling operator. The sampling operator \( \mathbf{T} \) maps the fully sampled data set into the data set actually acquired as illustrated by the toy example

\[
\begin{bmatrix}
  x(2) \\
  x(3) \\
  x(5)
\end{bmatrix} =
\begin{bmatrix}
  0 & 1 & 0 & 0 & 0 & x(1) \\
  0 & 0 & 1 & 0 & 0 & x(3) \\
  0 & 0 & 0 & 1 & x(4)
\end{bmatrix}
\]  

(3)

The actual problem is solved in the temporal and spatial frequency domain one frequency slice at a time. The frequency slices are coupled following the technique of Herrmann et al. (2000). The underdetermined inverse problem is solved by minimizing the objective function

![Figure 1. Stratigraphic cross section of two key wells within the 3D seismic area. Log displays include gamma ray, bulk density, compressional and shear sonic slowness, lambda-rho and mu-rho.](Image)
where the model norm \( \|x\|_s \) is defined by long-tailed distributions such as the Cauchy-norm or the 11 norm (Sacchi and Ulrych, 1995). Both of these norms have the effect of selecting, among all possible solutions, those that predict the data with fewer elements. These models are known in optimization as “sparse models” and imply that in the spatial frequency domain at least one or two of the dimensions may be characterized by a relatively simple spectrum. This generally is true because even if complex structure exists in the inline and cross-line domain, the amplitude typically can be modeled by simple relationships in the offset and azimuth domain. This is supported by the multitude of linearized polynomial relationships describing AVO and Azimuthal AVO (AVAZ) existing in the literature (Shuey, 1985; Smith and Gidlow, 1987; Rüger and Tsvankin, 1997).

The 5D interpolation solves for the fully sampled 5D data set, but due to input/output (I/O) size constraints only some portion of the fully sampled data set typically is output. The characteristics of the output should be consistent with the subsequent treatment of the data. In this case, we are concerned with AVO analysis on image gathers. The objective therefore was to better sample the wavefield in the offset domain to support the AVO analysis. This is accomplished by doubling the number of source and receiver lines retaining the original source and receiver positions. Fold maps at various offset ranges were observed to determine if additional source and receiver locations were needed to obtain uniform offset fold. For example, in Figure 3, around the x-coordinate 17,500 two extra source lines rather than one were output in order to provide sufficient near-offset fold. Figure 4a shows the original data for one CMP while Figure 4b shows the same CMP after interpolation. The difficulty of detecting which traces are interpolated and which are original is an indication that the data complexities and amplitude variations are well-preserved. Furthermore, as the original data are preserved in this implementation, it is possible to verify that the original AVO trend is unchanged by the interpolation.

Figure 5 shows a comparison of the prestack time migrated (PSTM) gathers (a) without and (b) with interpolation. The migration is run on limited offset volumes. The offset range of the volumes varies according to the sampling of the data. That is, the poorly sampled near offsets of the uninterpolated data have a range that is three times greater than the more finely sampled far offsets. Area weighting and fold compensation (Zheng et al., 2001) also are used on all the prestack migrations we ran. Despite the use of these techniques, the data input to PSTM after interpolation is more continuously sampled within each offset volume. This results in PSTM gathers with fewer migration artifacts and better signal-to-noise ratios. The determination of AVO attributes is sensitive to noise within the data set, so it is expected the interpolated migrated gathers should lead to better AVO results. The noise sensitivity of AVO has been a central preoccupation of many studies, including the modeling discussions of Li et al. (2007) and Cambois (1998, 2001).

**METHOD**

To test the hypothesis that the AVO analysis based on the interpolated prestack migrated gathers is superior, various alternative data preconditioning strategies were produced. These various results were compared by qualitative observations of a number of AVO displays and quantitative comparisons with well control. We used the same starting gathers produced from the same preprocessing flow in every case. The preprocessing flow included AVO-compliant resolution enhancement, multiple attenuation, and both random and coherent noise attenuation. This starting point was a set of final gathers fully prepared for either stacking or migration. Prestack migration collapses the Fresnel zone, improving both the lateral resolution and the signal-to-noise ratio. The interpolation was introduced to reduce the effects of the irregular data. In consideration of this, we ran a series of tests to control the influences of the imaging step and the regularization. These control products included superbinning, interpolations, and well-preservation. Furthermore, as the original data are preserved in this implementation, it is possible to verify that the original AVO trend is unchanged by the interpolation.

![Figure 2. 0° to 35° AVO models created for Well A (good reservoir) and Well B (absent reservoir), respectively. Positive reflection amplitudes are shown in red. The arrows indicate the Viking level.](image1)

![Figure 3. Original source geometry of the 3D seismic survey shown in blue and the interpolated source lines shown in color.](image2)
Interpolation, AVO, and the Viking

This often is done as a preconditioning step for AVO analysis for land 3D data sets. The use of supergathers increases the fold and regularizes the offset distribution, but at the expense of introducing lateral smear. Figure 6 illustrates the relevant points of the processing flows used in this evaluation. There were no other differences in the work applied to each of the volumes we evaluated.

The data were compared qualitatively by comparing offset-binned, or Ostrander (1984), gathers at the well control, AVO-derived P-wave impedance and S-wave impedance reflection sections both in profile view through the well control, and along the Viking horizon in map view. The Viking amplitudes of both the P-wave and S-wave impedance reflectivity consistently were picked for all of these flows, which provided amplitude data from which the $R_p/R_s$ ratio was calculated. The resulting $R_p/R_s$ ratio maps were compared qualitatively for evidence of footprint, noise artifacts and geologic consistency. Then data points for the scatter plots of $R_p/R_s$ ratio and phi-h at the 48 wells were extracted by computer using the

![Figure 4](image1.png)

Figure 4. Comparison of (a) original data and (b) interpolated data. In (b), the original data is interleaved with the interpolated data. It is difficult to identify which is which. The amplitude behaves smoothly as a function of offset, suggesting the interpolation is amplitude-friendly.

![Figure 5](image2.png)

Figure 5. Comparison of the prestack time migrated (PSTM) gathers (b) with interpolation and (a) without interpolation. After interpolation, the data is more continuously sampled within each offset plane, resulting in more complete constructive and destructive interference of the operators resulting in gathers with less migration artifacts and better signal-to-noise ratio.
identical extraction method for each version. Finally, the Viking phi-h was crossplotted and regressed against each version of the $R_p$ to $R_s$ ratio. Measures of the goodness of fit within the crossplots provide an objective, quantitative evaluation of the different versions.

This work originally was performed at an earlier stage in exploration and development. At that time, only 29 wells were available for this analysis. The strong results at that time supported the interpolation imaging AVO concept so further exploration and development proceeded, utilizing attributes produced from this method. Since that time, 19 additional wells became available for analysis, including 13 wells that we drilled. We use all 48 wells in the regressions and identify the 13 new drills in the scatter plots.

**RESULTS**

The first comparison we make is for Ostrander (1984) gathers generated at the same positions as wells A and B referred to in Figures 1 and 2. Figure 7a-d shows a comparison of the original data at well locations A and B versus the interpolated data at the same locations. The AVO trend of the data has been preserved and is similar to the models shown in Figure 2. Similarly, Figure 7e-h compares the prestack migrated (uninterpolated) data to the PSTM gathers after interpolation. The interpolated results have a signal-to-noise ratio superior to the noninterpolated gathers in every case. This partly is due to the higher fold and, in the case of the interpolated PSTM gathers, better sampling of the wavefield prior to the migration, resulting in less migration noise.

The second comparison is of AVO attribute stacks. We examine $R_p$ and $R_s$ stacks, because we are interested in the $R_p$ to $R_s$ ratio, to predict the Viking phi-h. Figure 8 shows a comparison of the P-wave reflectivity section through Well A and Well B. The Viking $R_p$ values that have interpolation prior to PSTM are smoother than the Viking amplitude values that were not interpolated prior to PSTM. Figure 9 is a similar comparison of the S-wave impedance reflectivity sections. In this case, the interpolation results in a larger difference. This makes sense because the S-wave reflectivity estimate is more sensitive to a given noise level than the P-wave reflectivity (Downton and Lines, 2001). The apparent smoothness brought about by the interpolation might be questioned: is this smoothness a result of the smearing and loss of geologic information, or does it represent the reduction of migration noise? If the smoothness in $R_p$ to $R_s$ is geologically expected, then the interpolation has preserved and protected that elastic information from the migration noise. Unfortunately, we cannot answer this question using only qualitative methods. While we may suspect and argue that the changes in the attribute stacks support our hypothesis, we cannot prove it without reference to objective well-control data.

The third comparison is of the amplitudes of the $R_p$ to $R_s$ ratio in map view. Figure 10 illustrates this comparison. The interpolated PSTM result clearly has a high signal-to-noise level and is well resolved in a lateral sense. Trends representing the erosional preservation of the Viking reservoir are obvious on this result. The PSTM result without interpolation appears noisy, with the acquisition footprint being more evident. The superbinning of the PSTM gathers prior to AVO result in an $R_p$ to $R_s$ ratio that appears to have removed the footprint, and has a better signal-to-noise level than the AVO result based only on the PSTM gathers. The overall signal-to-noise ratio of the superbinning result is comparable to that of the interpolated PSTM flow. The question, though, is did the supergathers introduce lateral smearing which will degrade the predictive power of the method? This question is addressed in the Discussion section on the quantitative analysis of the data.

The results involving poststack migration or no migration are so noisy that they do not conform to geologic expectation and are not useful for interpretation. This noise does not conform to a footprint type of pattern, and does not appear to be related to sampling. The poor map images are related to the structural pattern of the area, and represent the importance of imaging the AVO response before stacking. This suggests that prestack migration is key to imaging the Viking, leaving this question: What is the best method to precondition the data prior to the prestack migration?

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![Figure 7](image_url)  
**Figure 7.** Ostrander (1984) gather at (a) Well A and (b) B, interpolated Ostrander gather at (c) Well A and (d) B, PSTM Ostrander gather at (e) Well A and (f) B, interpolated PSTM Ostrander gather at (g) Well A and (h) B. The Viking is at 1.79 s at Well A and 1.82 s at Well B. The arrows indicate the Viking level.
The last comparison is quantitative in nature. We extract the $R_p$ to $R_s$ ratio values for each processed version at the well positions and regress them with the Viking phi-h values. Table 1 summarizes the results of this comparison using the R-squared measure of goodness of fit as an objective criteria. The highest R-squared values were for the AVO analysis on interpolated PSTM gathers. The superbinning results yielded lower R-squared values than either interpolating or doing nothing in every case. The prestack migrated R-squared values were superior to either not migrating or migrating poststack. The poststack migrated R-squared values were only marginally better than the nonmigrated ones. Figure 11 illustrates the scatter plots from each version and highlights the 13 new wells in yellow. It is clear that the interpolated PSTM result has the best behavior as a predictor of phi-h.

**DISCUSSION**

The scatter plots of the AVO attributes and the well control create an objective analysis that brings the other qualitative results into perspective. The R-squared values indicate the smoothing of the interpolated PSTM $R_p$ and $R_s$ stacks was a result of the reduction of migration noise rather than a result of smearing and subsequent loss of geologic information. These R-squared values tell us the same thing with respect to the appearance of the interpolated and imaged $R_p$ and $R_s$ ratio maps. The converse is true for the superbinning. In this case, only the scatter plots and their R-squared values tell us that the smoothing we see from superbinning causes a loss of geologic information due to smearing. In no comparison did the results of AVO analysis on unimaged gathers appear good. These maps were uninterpretablelly noisy. In the R-squared analysis of the crossplots, it was clear that all versions of AVO analysis on PSTM gathers outperformed all versions of AVO analysis on data that was not prestack migrated. Note that Figure 11h illustrates the scatter plot for the interpolated data versus phi-h before PSTM. In this case, the scatter is large, and the R-squared value is low. The problem with this particular data volume is not sampling, but lack of imaging.

The economic consequences of this work can be discussed by referring to the scatter plots of Figure 11, paying special attention to the highlighted new wells. These new wells were drilled for a variety of targets, including the Viking. The fact that some of the new wells did not target the Viking, but were drilled for other targets, provided us the opportunity to observe the accuracy of negative predictions. The key observation to make is how close points lie to the regression line. This is what R-squared techniques measure, and it illuminates...
whether we are likely to drill a false positive prediction (points below and to the left of the regression line), or not drill a false negative prediction (points above and to the right of the regression line). It is not possible to say generally how accurate we need to be, as this is subjective, but it is clear that the lower our accuracy, the higher the probability that we will drill a bad well or miss drilling a good well. The interpolated PSTM result clearly is the most accurate based on spread in crossplot space. The improvement of the prestack migrated

Figure 10. Maps illustrating the \( R_p/R_s \) ratio at the Viking level. Green to red values indicate lower \( R_p/R_s \) ratio values, thus predicting better Viking phi-h, while blues to purples indicate higher \( R_p/R_s \) ratio values and lower phi-h. (a) PSTM. (b) PSTM and 5 \( \times \) 5 superbinning. (c) Interpolation and PSTM. (d) CMP. (e) CMP and poststack migration. (f) 5 \( \times \) 5 CMP and poststack migration.
results as compared to the unmigrated or poststack migrated results was expected from Mosher et al.’s (1996) work, and is objectively demonstrated here.

Table 1. Summary of scatter plots between $R_p$ to $R_s$ ratio and Viking phi-h including the R-squared values.

<table>
<thead>
<tr>
<th>Name</th>
<th>Interpolated</th>
<th>Migrated</th>
<th>Binning</th>
<th>R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSTM</td>
<td>no</td>
<td>prestack</td>
<td>1</td>
<td>0.268</td>
</tr>
<tr>
<td>PSTM + 5×5 gather</td>
<td>no</td>
<td>prestack</td>
<td>5×5</td>
<td>0.243</td>
</tr>
<tr>
<td>Interpolated PSTM</td>
<td>yes</td>
<td>prestack</td>
<td>1</td>
<td>0.423</td>
</tr>
<tr>
<td>CDP</td>
<td>no</td>
<td>No</td>
<td>1</td>
<td>0.171</td>
</tr>
<tr>
<td>5×5 CDP</td>
<td>no</td>
<td>No</td>
<td>5×5</td>
<td>0.143</td>
</tr>
<tr>
<td>Interpolated CDP</td>
<td>yes</td>
<td>No</td>
<td>1</td>
<td>0.230</td>
</tr>
<tr>
<td>CDP gather + poststack migration</td>
<td>no</td>
<td>poststack</td>
<td>1</td>
<td>0.213</td>
</tr>
<tr>
<td>5×5 CDP + poststack migration</td>
<td>no</td>
<td>poststack</td>
<td>5×5</td>
<td>0.203</td>
</tr>
</tbody>
</table>

Figure 11. Images of selected scatter plots between $R_p$ to $R_s$ ratio and Viking phi-h. The 13 wells drilled using the interpolation imaging AVO concept are highlighted in yellow. (a) PSTM gathers. (b) PSTM and 5×5 superbinning. (c) Interpolation and PSTM. (d) CMP gathers with no migration. (e) 5×5 CMP gathers and no migration. (f) Interpolation but no migration. (g) CMP gathers and poststack migration. (h) 5×5 superbinning and poststack migration.

CONCLUSIONS

Interpolation followed by prestack migration proved to yield the most beneficial gathers for AVO analysis. The quantitative analysis employed in this work was crucial in making objective conclusions. This case study not only supports the advantage that interpolation brings to AVO analysis on imaged gathers, but provides additional support for the notion that AVO analysis be applied only on imaged gatherings.

The fact that all versions of AVO analysis on PSTM gathers outperformed all versions of AVO analysis on data that was not prestack migrated clearly supports the importance of prestack imaging for these applications. These results also illustrate that the 5D interpolation did preserve the AVO information, as expected. This outcome is favorable to the consideration of using the same algorithm to support azimuthal migration and azimuthal AVO analysis, a pursuit that is compromised to a much higher degree by poor sampling. The algorithm can be made to output samples to regular geometries, and therefore also can be used in common-offset-vector migrations, which also are of interest for use in azimuthal studies.

The poor performance of superbinning as compared to interpolation was expected since interpolation is a much more sophisticated way of doing a similar thing. The fact that doing nothing was superior to superbinning in our objective analysis was a surprise. The structure and rapid changes in the shape of the erosionally preserved Viking reservoir in this data were not conducive to a method as simple as superbinning. The smearing problem in superbinning might
be reduced by using a smaller superbinning area, such as 3 by 3, but
the poor geometry and sampling of offsets in this survey would trade
off this reduced smear with greater noise. This is illustrative of the
blind alley that the superbinning method has become. Our method
yields improvements because it considers offset and azimuthal in-
formation within a physically reasonable constraint and can output
to a variety of geometries. These geometries can be made to be most
efficient for the imaging algorithm being used. In the extreme cases
of poor sampling, such as in azimuthal AVO studies, the blind alley
of superbinning becomes more intuitively apparent.

In practice we generally have time only to process the data once
before making our first predictions from it. Why, then, would we
change the effects of migration noise compromising our results?
This experience suggests that AVO analysis be performed on inter-
polated (or regularized), then pre-stack imaged, gathers for all irreg-
ular land surveys.

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