Observation of azimuthal anisotropy on multicomponent Atlantis node seismic data

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Summary

In this paper we report on the analysis of a multi-component ocean bottom node dataset collected over Atlantis field in the deep water Gulf of Mexico. Our primary goal is to determine shallow velocity structure in the area. The unique true 3D shooting geometry allows us to carry our azimuthal traveltime analysis of compressional and converted shear wave data recorded on hydrophones and horizontal geophones. The P-wave data show systematic azimuthal variation of traveltime which is analyzed using NMO ellipse. After successful rotation of the horizontal geophones, we notice negligible direct P-wave energy in the transverse component. However, significant energy is observed at later times that can be interpreted as converted S2 mode. Joint analysis of S1 and S2 phases as a function of azimuth reveals systematic shear wave splitting that is consistent with the observation on P-wave data. We determine a NS oriented stress pattern that is consistent with general understanding of stress field in the area.

Introduction

In 2005, BP commissioned Fairfield industries to conduct a large, wide-azimuth seismic survey over the Atlantis Field in the deepwater Gulf of Mexico (Clark et al, 2007). The major goal of the survey was P-wave imaging of the complex salt bodies, utilizing the wide azimuthal coverage (Beaudoin and Ross, 2007). This survey is the first large-scale, deepwater seismic survey using four component autonomous nodes (Ross and Beaudoin, 2006). Details of the survey design and instrumentation can be found in the work of Clark et al (2007) and Ross and Beaudoin (2006).

BP donated a part of this rare dataset to Jackson School of Geosciences at the University of Texas at Austin, for conducting research aimed at the near surface events. The acquisition geometry of the received data is shown in Figure 1. The geometry of the data shows that a limited number of nodes were placed on the seafloor (Blue dots) and millions of shots (red dots) were triggered from the sea surface. The nodes were placed in a hexagonal pattern with a node spacing of 456 m (not clearly discernible in Figure 1).

This wide azimuth 4C survey and the special geometry of the data are a perfect setup for investigating azimuthal variation of velocity which can be caused by lateral heterogeneity or anisotropy if the lateral variation is negligible. Our work is restricted to the shallow part of the data in regions where the bathymetry and the near surface structure is fairly flat. The presence of fracture at this level is not obvious, but we are motivated by several studies from different parts of the world, which reported stress induced anisotropy from near surface marine data (Lynn and Thomsen, 1990; Olofsson et al, 2003). We analyze the data forming a 360° azimuthal common receiver gather and observe S-wave splitting (diagnostic of anisotropy) and P-wave traveltime anisotropy signature. The primary focus of our paper is to document our observation of existence of azimuthal anisotropy in the Atlantis node data.

Data Preparation

From Figure 1, it is obvious that due to limited number of nodes, we cannot perform our analysis in the CMP domain. To overcome this difficulty we decided to perform our analysis in the common receiver domain. For this purpose we first select one arbitrary node located in the flat part of the bathymetry with a water depth of 2000 m. We then select shots along the circumference of a circle with 1 km radius around that node. We prepare an azimuthal gather by binning the data in every 15° azimuthal bins. Figure 2 shows our receiver-node geometry of the azimuthal gather. Figure 3 and Figure 4 show the radial and transverse components of the gather respectively after performing the required rotation. The rotation angles are determined from the receiver node azimuth and hodogram analysis of the direct wave. We then align the direct arrivals in one line. This is equivalent to trim statics that accounts for small variation in the assumed shot locations to make the shots positioned perfectly on the perimeter of the circle shown in Figure 2.

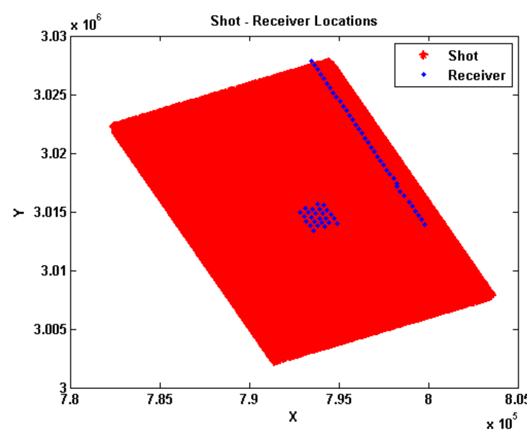

Figure 1: Shots (red dots) and node (blue dots) locations of the data received by us. In this study we used one of the nodes from the center of the study area.

Analysis

From the analysis of the radial component, we observe periodic variation of the traveltime (fast and slow) with azimuth in several layers. In the transverse component we observe the presence of coherent signals. Both of these phenomena indicate S-wave splitting (Tatham et al, 1992; Gaiser, 1999; Haacke et al, 2009). Figure 5 shows the periodic variation of the time picks with azimuth in the radial components in the top layer. Figure 6 shows the corresponding transverse component data where amplitudes are changing sign in every 90° azimuth interval. These observations clearly suggest splitting of the S-wave (Gaiser 1999). In Figure 5 we mark the fast and slow direction of S-wave.

To verify our observation we further use the hydrophone data present in the node for the same set up. We observed periodic variation of P-wave traveltime also in the azimuthal gather (Figure 7).

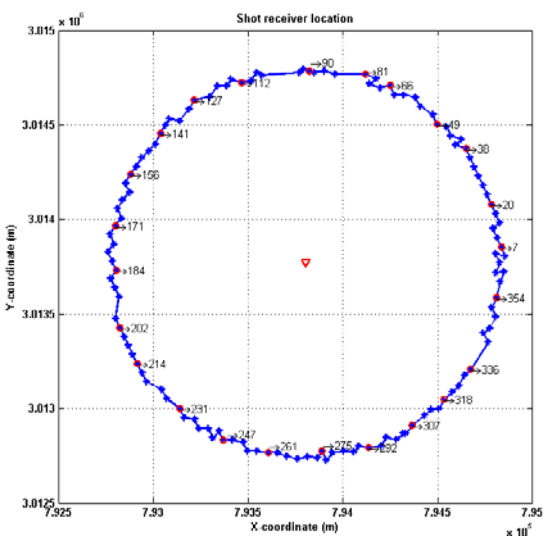

Figure 2: Shot node setup for preparing azimuthal gather used in this study. Center is the node location (red triangle), and blue stars are the shots. We perform 15° binning at each azimuth shown as red circle in the perimeter of the circle.

Results

S-wave splitting suggests a fast direction of wave propagation along the north-south direction and slow direction is in the east-west. We perform the NMO ellipse analysis (Grechka and Tsvankin, 1999) using the picked P-wave traveltimes (Figure 7). NMO ellipse analysis suggests similar fast and slow directions as observed in the S-wave splitting. Since short offset (1 km) data are used in our analysis, we find that the NMO velocity equation of an HTI medium (Tsvankin, 1997) is suitable for the NMO ellipse analysis. Figure 8 shows the result from NMO ellipse analysis. For this layer we obtain a δ value of -0.04 and a vertical RMS P-wave velocity of 1.67 km/s. Since this is the top layer showing anisotropic signature, we believe that the δ value obtained from this layer is the interval δ value (devoid of any effect from top anisotropic layer).

Discussion and Conclusions

In this paper we report on the results of analysis of an ocean bottom node data. Unlike a conventional CMP analysis, we perform our analysis on a common receiver gather and examine traces corresponding to shots at nearly constant offsets from varying azimuths. We examine the travel time and amplitude variation of P, S1 and S2 waves recorded in the hydrophone and geophones. We restricted our analysis to a node situated in a fairly flat region and therefore, interpret the P to SH conversion, azimuthal variation of P-wave travel time and azimuthal variation of SV and SH amplitude and travel time as signatures of anisotropy in the shallow subsurface layer. We rule out the possibility that our observation is caused by lateral heterogeneity. Presence of dip in the bedding can generate periodic signals in the azimuthal gather but in that case the periodicity of the signal always has one cycle, whereas periodicity due to anisotropy shows two cycles in the 360° azimuthal gather (Perez, 2009). We observed that the fast wave propagation direction is in the north-south direction, and slow direction is in the eat-west direction. From P-wave NMO ellipse analysis, we obtain a realistic δ value of -0.04. We have not performed any analysis on S-wave parameters yet but plan to do so in future.

Even though we observe seismic anisotropy in the form of S-wave splitting and P-wave NMO ellipse, the cause of anisotropy is not known yet. From our personal communication with Gerard Beaudoin and others at BP, it appears that the observed anisotropy is stress induced. In future we aim to perform similar analysis with several other nodes.

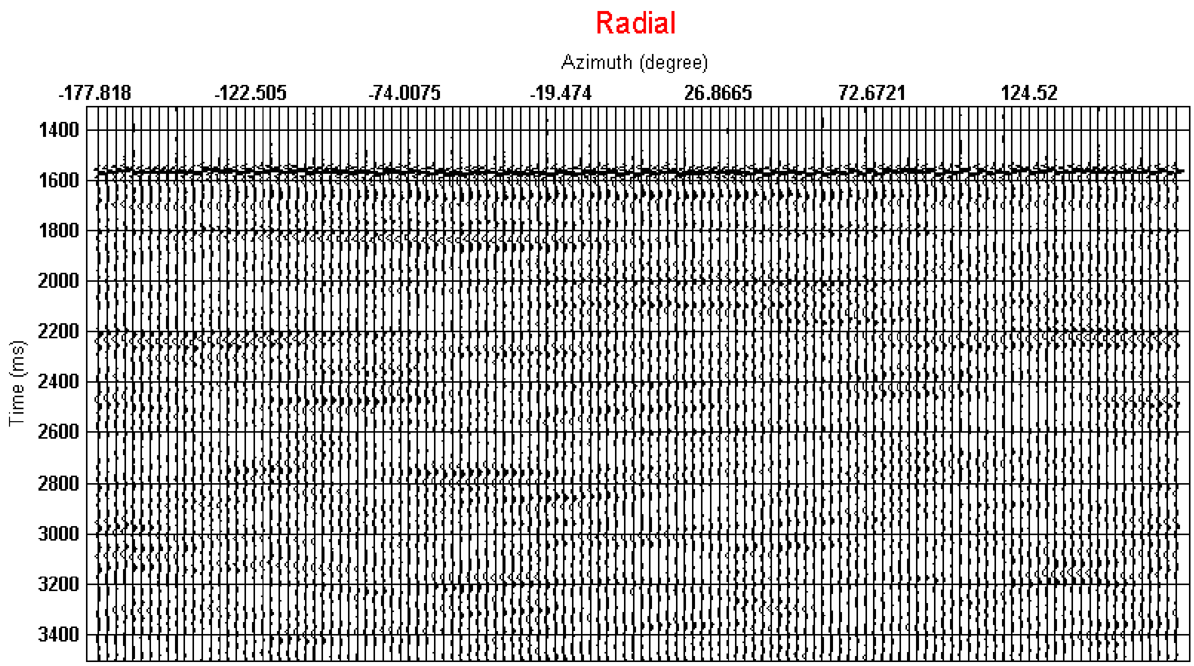

Figure 3: Rotated radial component of the azimuthal gather: Top layer is the aligned direct arrival. Alignment helps to make the shot location precisely on the perimeter of the circle shown in Figure 2.

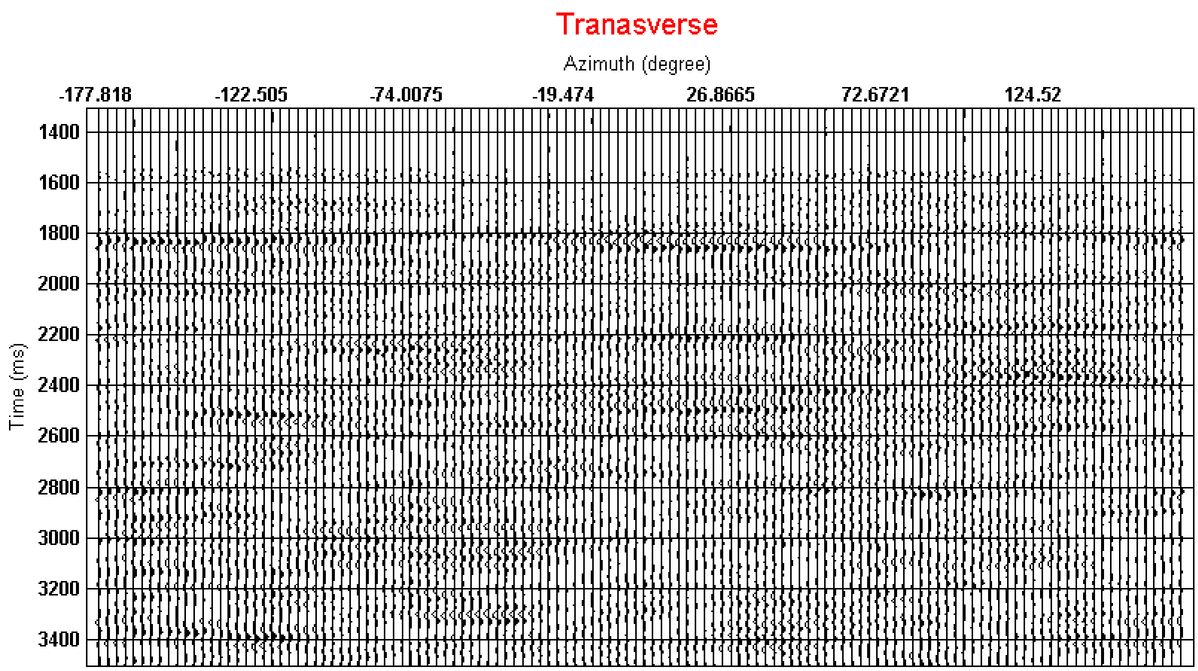

Figure 4: Rotated transverse component of the azimuthal gather: Similar direct arrival time shift is applied as the radial component. Coherent signal patterns are observed in this component.

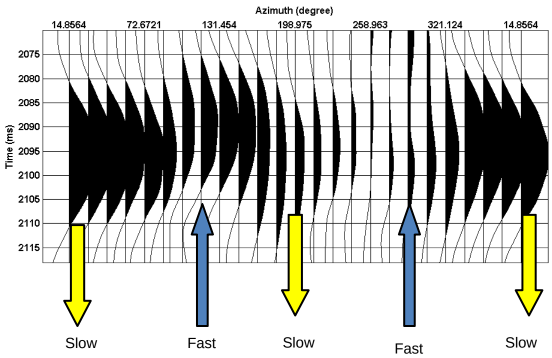

Figure 5: S-wave splitting observed in the radial component of the azimuthal gather from the shallow layer. Yellow and the blue arrows are the slow and fast directions of S-wave. Fast direction is around 90° azimuth direction.

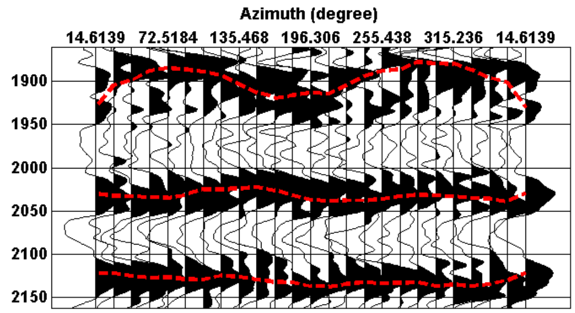

Figure 7: Variation in traveltime observed in the P-wave data observed in the azimuthal gather. Top layer corresponds to the observed converted S-wave splitting events. Time picks are shown by red lines (based on maximum amplitude). Picked time shows periodic variation with azimuth.

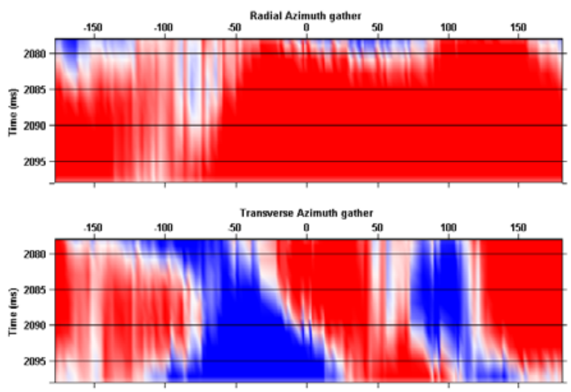

Figure 6: Amplitude pattern observed in the radial (top panel) and in the corresponding transverse component (bottom panel) of the event shown in Figure 5. Transverse component shows sign changes in amplitude in every 90° interval.

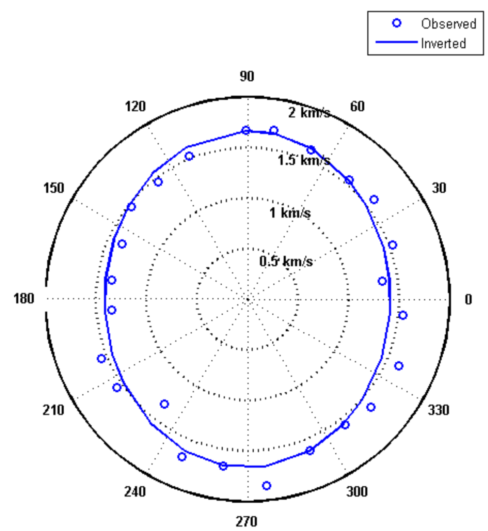

Figure 8: Result of NMO ellipse analysis using the picked P-wave traveltime from the top layer (shown in figure 7). Fast velocity direction is almost along 90° azimuth (north-south) as also observed from the S-wave splitting.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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