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Velocity anisotropy in the Niger Delta Basin: A case study of prestack time imaging with isotropic and anisotropic velocity models

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Abstract

A recent study of velocity anisotropy in the Niger Delta, shows that the Niger Delta sediments are weakly anisotropic. Based on this finding, we carried out a prestack Kirchhoff 2D time migration of a pre-processed 4,767 Km 2D seismic data acquired in the Niger Delta, using both isotropic and anisotropic velocity models in the migration algorithm. The purpose of the study was to compare the imaged results and highlight the serious problems of mis-positioning and/or mis-focusing of events using the conventional isotropic imaging algorithm. We built our isotropic velocity model from a stacking (RMS) velocity analysis on CDP gathers of the pre-processed dataset while our anisotropic velocity model was based on an approach which calculates interval eta parameter from a Dix-type interval velocity field derived from the final RMS velocity field. A comparison of the imaged data shows a clear coherency improvement in structural definition and event continuity in the anisotropically imaged data than the data imaged isotropically, especially at deeper depths. Therefore, incorporating velocity anisotropy in imaging algorithms performed on long offset seismic data acquired in the Niger Delta will significantly reduce exploration risks in the Niger Delta Basin.

Keywords: Niger Delta Basin, Isotropic Velocity, Anisotropic Velocity, Kirchoffs Time Migration.

INTRODUCTION

In seismology, a layer is anisotropic if seismic waves propagate through it at different velocities in different directions. In a layered earth, seismic waves propagate faster along layers than across the layer boundaries. The preferred orientation of clay minerals in shales causes similar behavior. As a result, seismic velocities derived from surface seismic are faster than well velocities (Fig. 1). This problem is due to velocity anisotropy. The overall effect of the above is that structural depths interpreted from seismic data are not the true subsurface depths of these structures (Fig. 2). This could increase exploration risks. We could remedy this problem by quantifying the degree of seismic anisotropy and accounting for it in imaging algorithms.

Model Building

The dataset used for this study comprised a pre-processed 4,767m 2D surface P-wave seismic data acquired in 1994 in a marine seismic block in the Niger Delta, and a dipole sonic and density log acquired in one single location along the survey. The shooting geometry for the seismic data acquisition is shown Fig. 3. We obtained our isotropic model through a stacking velocity analysis on the pre-processed data. First, we created CDP supergathers of the data at 60 locations spaced 80m apart along the survey (Fig. 4). We then picked stacking velocities at these locations. Velocities in-between these locations were interpolated.

To quality-check the picked RMS velocity field, we plotted both the sonic velocity at the well and seismically derived RMS velocity function at a CDP location closest to the well (Fig. 5), and observed the trend. Table 1 shows a comparison of the seismic and sonic RMS velocity functions at these locations.

Table I: Comparison of Seismically derived rms velocities with sonic rms velocities

Time (ms)	RMS Velocity (Seismic) (m/s)	RMS Velocity (Sonic) (m/s)	Difference (m/s)	Percentage difference
250	1621	1543.8	77.2	5
500	1751	1576.8	180.2	10
1000	1956.9	1700.7	256.2	13
1500	2154.1	1903.3	250.8	12
2000	2359.6	2095.2	264.2	11
2500	2546.2	2323.6	222.6	9
2900	2696.8	2501.6	195.2	7

The sonic and seismic velocity functions correlate very well (Fig. 5 and Table 1). Seismic velocities are also reasonably higher than the well velocities and this compares well with the 10% value of (5). This shows that our initial isotropic model was correct. Thereafter, we smoothed the stacking velocity field to obtain our final isotropic velocity field.

Anisotropic Velocity Model Building

The final isotropic velocity field was used as input to the anisotropic velocity model building. First, we applied the conventional normal moveout (NMO) technique to the CDP gathers using the conventional NMO equation (1). This applies the 2^{nd} order NMO correction to the data.

$$T_{(h)}^{2} = T_{0}^{2} + \frac{X^{2}}{V^{2}_{rms}} \qquad 1$$

In the presence of velocity anisotropy, the second order NMO equation (equation 1) fails to yield the desired results, and this will introduce errors to the final image. Specifically, using the above correction will flatten seismic data only to an offset beyond which seismic events appear to stick up (often called a hockey stick, Fig. 6).

The P-wave travel time equation for a flat reflector in transversely isotropic media with vertical axis of symmetry is given by equation 2 (1, 2).

$$T_x^2 = T_0^2 + \frac{X^2}{V_{rms}^2} - \frac{2X^4\eta}{V_{rms}^2\left[V_{rms}^2 T_0^2 + (1+2\eta)X^2\right]} \qquad 2$$

After correcting seismic data using the 2nd order NMO equation, the moveout travel-time after correcting is given by equation 3 (2):

$$\Delta t^2 = T_h^2 - T(x)^2 = \frac{2\eta_{eff} X^4}{V_{nmo}^2\left[T_0^2 V_{nmo}^2 + \left(1+2\eta_{eff}\right)X^2\right]} \qquad 3$$

where n_{eff} is the effective velocity anisotropy (also known as eta anisotropic parameter) of the medium. Next, we inverted interval velocity V_{int} field from the stacking (RMS) field V_{rms} using the Dix-type equation below:

$$V_{\text{int}(i)}^2 = \frac{V_{rms\,(i)}^2 t_{(i)} - V_{rms\,(i-1)}^2 t_{(i-1)}}{t_{(i)} - t_{(i-1)}} \qquad 4$$

where $V_{rms}(i)$ and $t_{(i)}$ are stacking velocity field and two-way travel time for an individual layer. This was to enable us obtain the eta anisotropic parameter of individual layer (equation 5), which we smoothed to obtain a final anisotropic velocity field.

$$\eta_i = \frac{\Delta t^2 V_{\text{int}(i)}^2\left(T_0^2 V_{\text{int}(i)}^2 + X^2\right)}{2X^2\left(X^2 - \Delta t^2 V_{\text{int}(i)}^2\right)} \qquad 5$$

Imaging

We performed two different kinds of prestack Kirchhoff 2D migration algorithms to image the dataset – a conventional straight ray algorithm which performs the isotropic imaging, and a curved ray algorithm for the anisotropic imaging.

The input velocity field for the straight ray prestack Kirchhoff time migration was the final isotropic velocity field. The output from this migration was isotropically imaged CSP gathers of the subsurface. The input velocity model for the curved ray algorithm was the stratified eta field, used in conjunction with the final isotropic field. The data was migrated using a time step of 4 ms and an aperture of 6,000 m. Finally, we performed a velocity analysis on the migrated gathers to obtain our final true velocity structure, corrected for anisotropy in the subsurface.

RESULTS AND DISCUSSION

The anisotropically imaged CSP gathers are clearly flatter than the isotropically imaged gathers (Fig. 7). A clear coherency improvement is seen in the gathers imaged anisotropically as compared to those imaged isotropically. The anisotropically imaged gathers will therefore give a better stack response than those imaged isotropically, and this will give better event continuity and structural definition of the stacked dataset.

Table 2 gives a comparison of the final isotropic velocity and anisotropy-corrected RMS velocity functions at a CDP location within the survey. Fig. 8 shows a plot of the velocity functions for comparison at the well location.

Table II: Seismically derived rms velocity function at a location within the survey

Time (ms)	Isotropic RMS Velocity function (m/s)	Time (ms)	Anisotropic RMS Velocity function (m/s)
0	1490.6	45.5	1495.9
250	1621	272.2	1648.1
500	1757	465.9	1757.9
1000	1956.9	761.7	1850.9
1500	2154.1	1080.5	1953.9
2000	2359.6	1475.2	2125.3
2500	2546.2	1933.3	2356.6
2900	2696.8	2296.7	2498.5
3000	2720.9	2948.5	2587.7
3500	2841.4	3366.7	2640.5
4000	2947.4	4011.5	2710.3
4500	3045.3	4589.9	2752.7
5000	3149.4	5133.1	2781
5500	3253.7	5797.5	2802.1
6000	3326.7		

Both the isotropic and anisotropy-corrected velocity functions correlate well at shallow depths, but the anisotropy-corrected velocity field becomes significantly slower at larger times. Since longer times are due to reflections from deeper targets, which in turn, are due to longer offsets, Fig. 8 therefore shows that the effect of velocity anisotropy will become mainly pronounced on long offset data. Near offset or shallow events, as can be deduced from Fig. 8 will be flattened to almost the same extent whether the data are corrected for anisotropy or not whereas, the deeper structures will be mis-positioned in both depth and lateral location if anisotropy is not accounted for, because they will be migrated with a velocity much faster than the true velocity of the subsurface. The imaged structures at these depths will become deeper than their true depth. The result agrees well with published work of 4, 3 and 5.

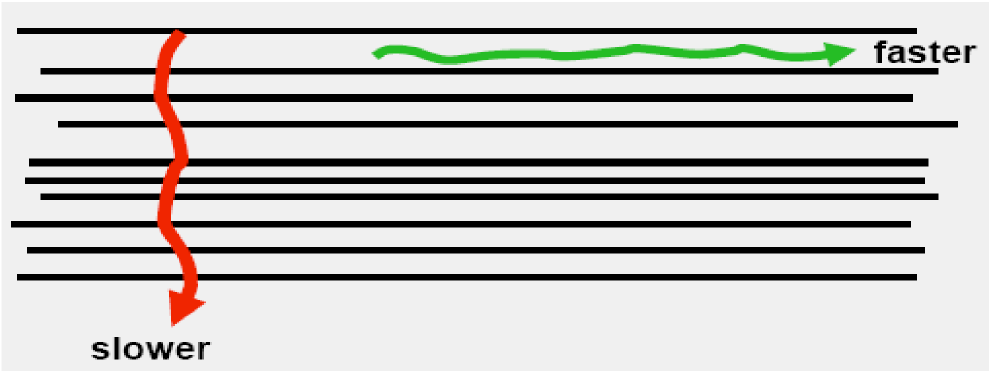

Fig. 1: Propagation of seismic wave in an elastic earth model

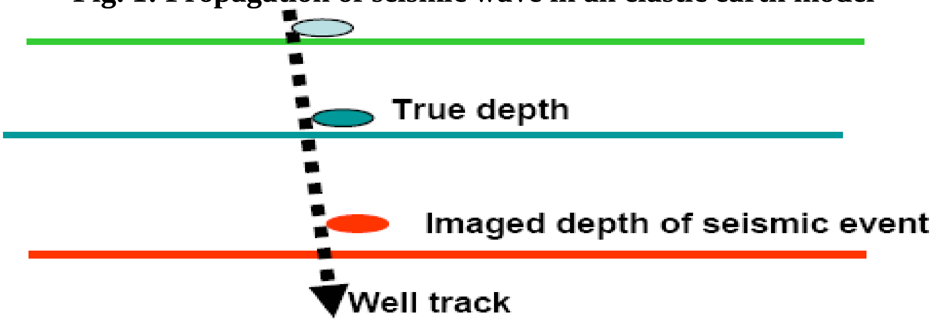

Fig. 2: Structural imaging using the conventional isotropic model

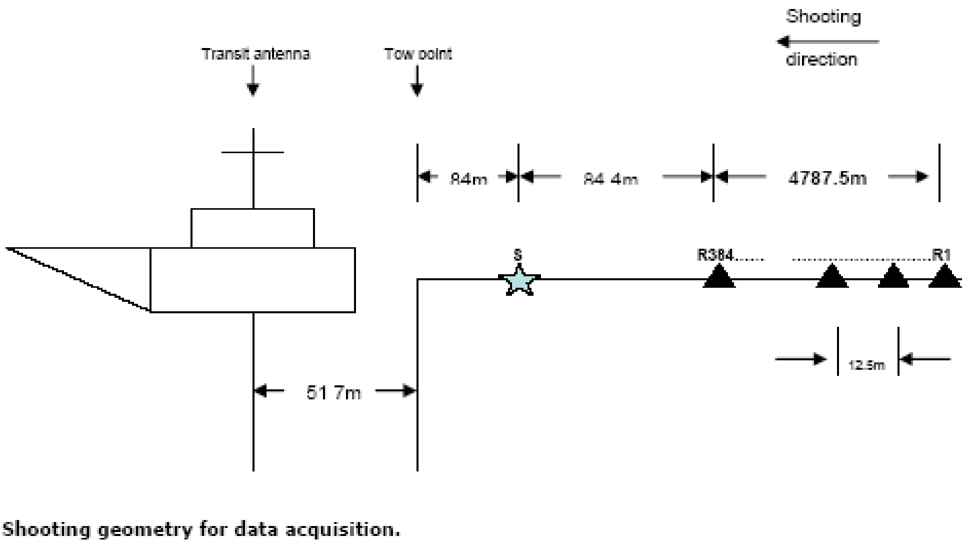

Fig. 3: Shooting geometry for the data acquisition.

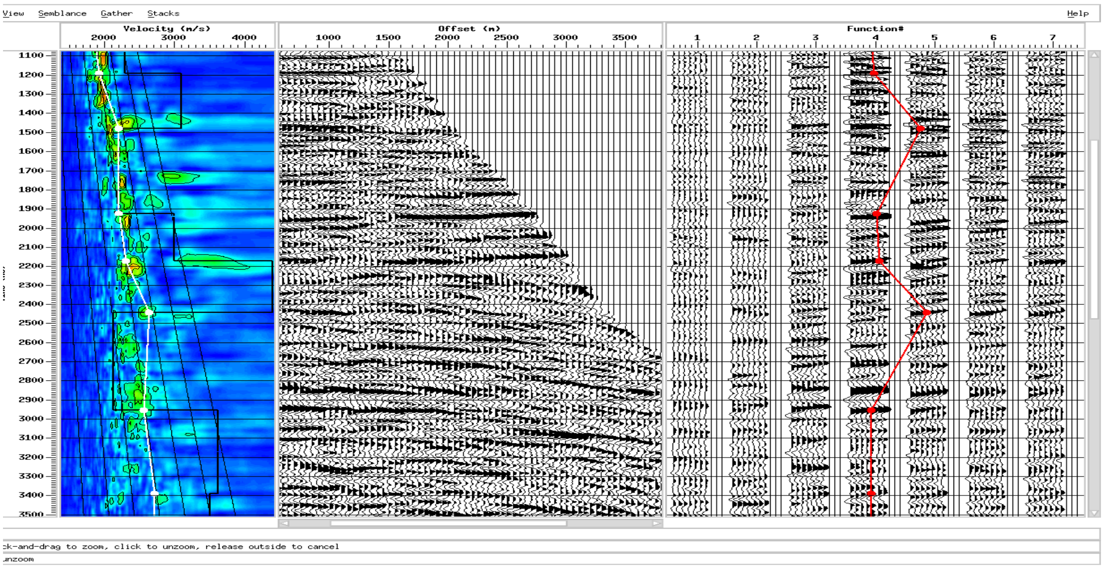

Fig. 4: A CDP supergather

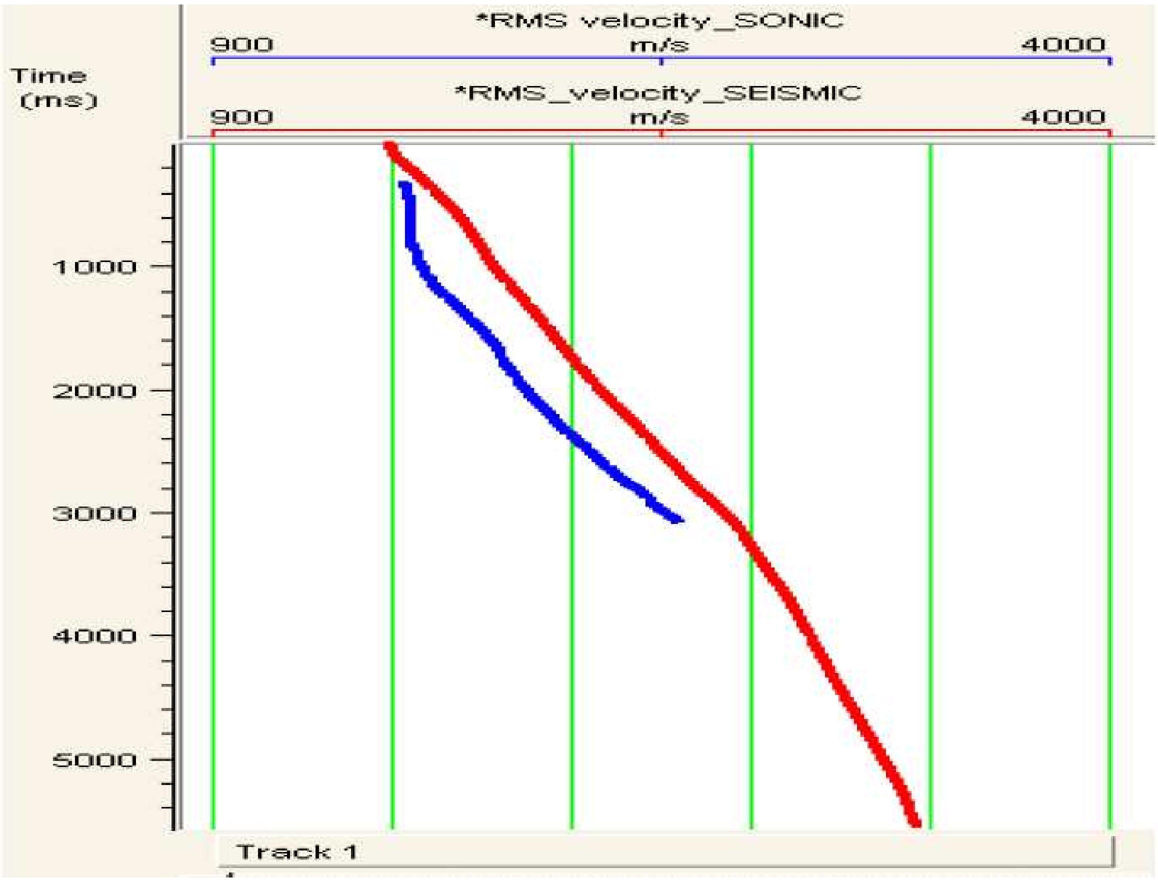

Fig. 5: Sonic (blue) and Seismically (red) derived RMS velocity fields

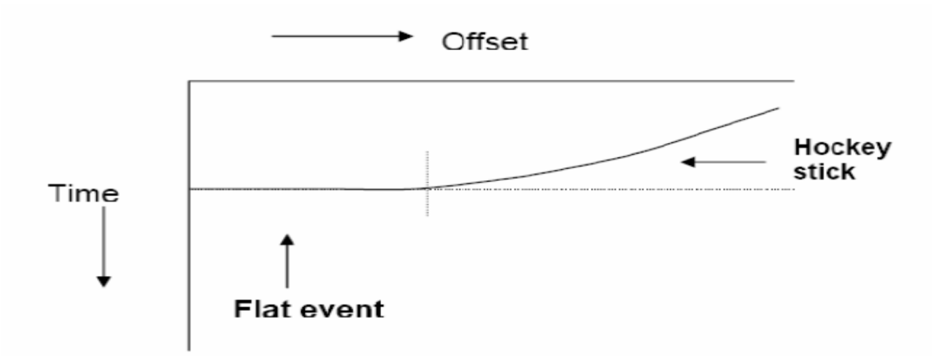

Fig. 6: 2nd order NMO correction applied to anisotropic data

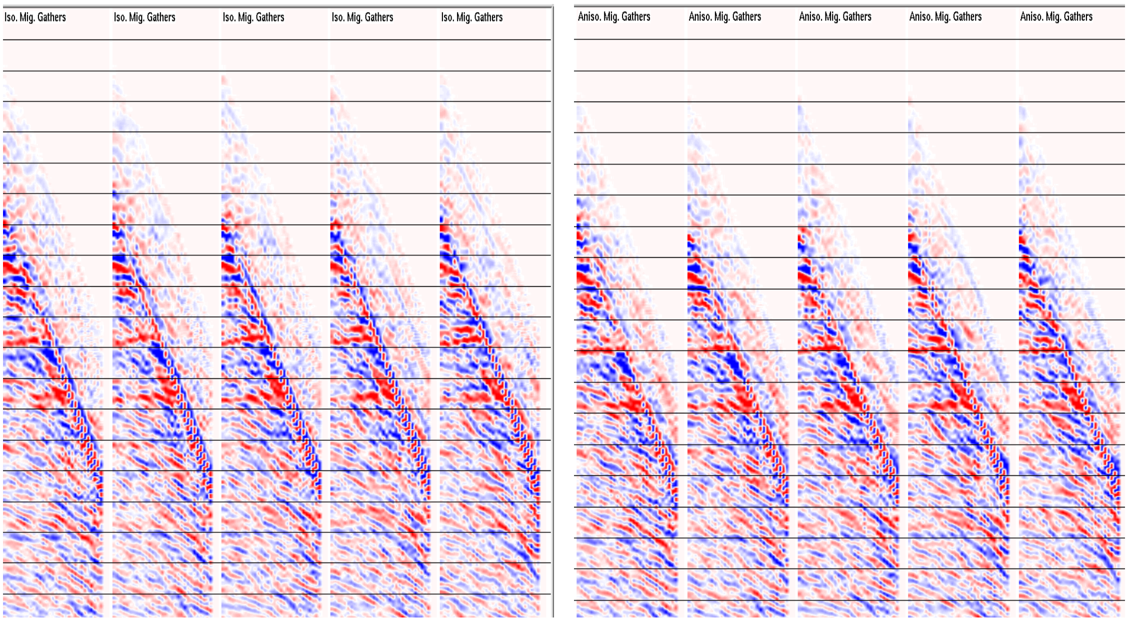

Fig. 7: Isotropically and anisotropically migrated gathers

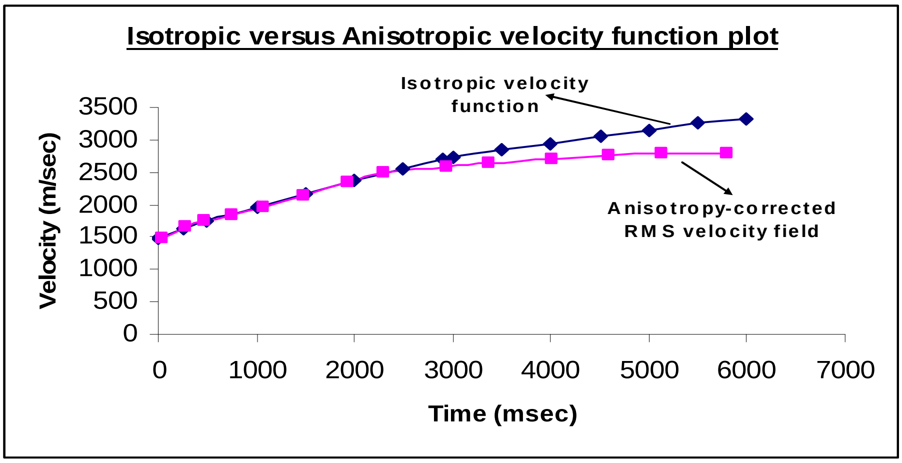

Fig. 8: Final isotropic and anisotropy-corrected velocity functions at a CDP location along the survey

CONCLUSION

In most cases of seismic processing and interpretation, seismic isotropy is assumed. However, velocity anisotropy is found to exist in most subsurface media. Hence, there is a fundamental inconsistency between theory on the one hand, and practice on the other. If anisotropy is not accounted for in seismic processing, it could lead to mis-interpretation of seismic data. We found that seismic data processed with anisotropic model produced flatter CDP gathers which would give clearer structural definition and event continuity than data processed isotropically. Deeper events are seen to be imaged with a higher velocity and this would have an adverse effect on the position of imaged structures. This result is very important especially since most of the exploration and production companies operating in the Niger Delta are now seeking explorations interests in the offshore areas of the Niger Delta, where long offset seismic data acquisition would soon become the order of the day. There is the need to account for velocity anisotropy in the algorithms for imaging such data.

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