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Absorption Related Velocity Dispersion below a possible Gas Hydrate Geobody.

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Summary

Velocity dispersion is not usually a problem in surface seismic data processing, as the seismic bandwidth is relatively narrow, and thus for most Q values, dispersive effects are not noticeable. However, for highly absorptive bodies, such as the overpressured free gas accumulations associated with gas hydrates, dispersive effects can be seen. In this work I analyse one such data set from the offshore North East coast of India. I demonstrate that the effect is measurable, and that compensating for it in either data processing or migration, can improve the wavelet character, as well as delivering an estimate of the Q values in the associated geobody.

Introduction

The data in the study are from a deep water offshore area from eastern India (courtesy of Reliance Industries), discussed in two recent papers by Fruehn et al. (2008) and Smith et al. (2008). Possible gas hydrate formations form a potential trapping mechanism for free gas accumulation which may become over-pressured, constituting a geohazard. In order to obtain a good depth image below such low velocity geobodies, their velocity structure must be adequately incorporated into the velocity-depth model. A commercial 3D preSDM project conducted in 2007-2008, covering some 2300 km2, used high resolution hybrid-gridded tomography (Jones, et al., 2007) to delineate the gas charged geobodies, and update the velocity model so as to remove pull-down effects below these geobodies

Figure 1 shows an unmigrated stack of the data under consideration: the sequence of flat lying events with arrival times between 3400 and 3900ms shows a severe pull-down effect in the centre of the section (between CMPs 1300-1450). These events are at a depth of approximately 3200m. Events below about 2500ms are dimmed in this region, perhaps due to absorptive effects in the overlying highly reflective geobody. For data in parts of this region of offshore India, it is believed that a gas hydrate layer is present (e.g. Chaudhuri, et al., 2002): indeed, these hydrate layers have been drilled and core-sampled in some studies (e.g. Riedel, et al., 2010). The hydrate layer sits about 200m below the sea bed, in waters of depth greater than about 400m, and appears as a relatively bright reflector which sub-parallels the sea bed, and can cross-cut the sedimentary layers. Because of this, the hydrate layer is sometimes referred to as a bottom-simulating reflector (BSR). If gas is leaking from an underlying reservoir, or being evolved from localized biogenic activity, then free gas can accumulate below the frozen gas hydrate cap. In this case a geohazard can develop if the trapped gas becomes over-pressured.

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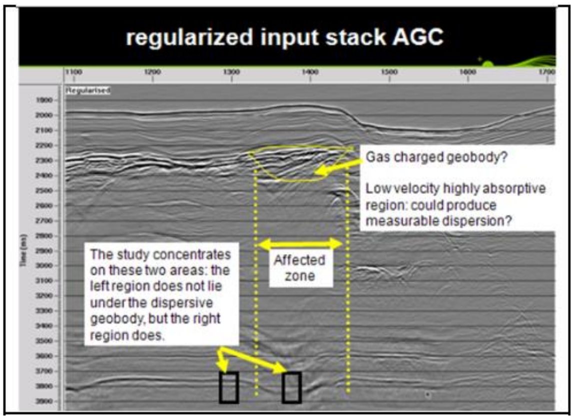


Figure 1: data in study area showing low velocity geobody and associated underlying pulldown and dimming

Geobody average velocity estimation

The background velocity was estimated during preSDM iterative velocity model update, and the velocity associated with the low-velocity geobody was estimated in three different ways:

Method 1) preSDM tomographic inversion of the full bandwidth data, from the 'commercial' imaging project

Method 2) pull-down analysis of the near offset section from the unmigrated full bandwidth data

Method 3) velocity-spectra analysis of the unmigrated full bandwidth data

Method 1) Figure 2 shows the interval velocity model obtained after five iterations of 3D hybrid gridded tomography. At the level of the bright geobody (times 2200 - 2500ms, roughly corresponding to depths 1700 - 1950m), the interval velocity profile from the preSDM tomographic model shows a characteristic increase in velocity at the top of the hydrate layer, overlying a significantly lower velocity region (with Vint perhaps between 1200 - 1400m/s) set in a background velocity of about 1750m/s. These velocities were determined using preSDM CRP autopicking on a 50m* 50m picking grid, with 3D gridded tomographic inversion using a cell size of 500m *500m * 100m (Fruehn et al., 2008). A pure methane hydrate layer has a P-wave velocity of about 3730m/s, but even a slight gas saturation (>2%) in the underlying sediment will cause a significant reduction in velocity compared to the surrounding sediment velocity, typically to the range of about 1540m/s – 2200m/s (Minshull et al., 1994; Collett and Dallimore, 2002; Reister, 2003). In the inset in the upper left of Figure 2, we see a velocity profile extracted through the geobody (the red line) indicating an increase in velocity to about 1700m/s at the top of the geobody, with a drop to about 1300m/s below this (the green line shows the background velocity trend).

Method 2) Using a simple pull-down analysis of the deeper events (at 3200m) measured from the near-trace offset section of unmigrated full bandwidth data, and assuming that the geobody is 200m thick (sitting between depths 1700 - 1900m), set in a background velocity of 1750m/s, with average deeper velocity of about 2000m/s, then the observed time pull-down of 80ms twt (two-way time) implies an interval velocity in the geobody of about 1350m/s.

Method 3) Conventional velocity analysis of the raw full bandwidth data centred over the geobody, suggests an interval velocity of about 1200m/s, although this estimate will be corrupted due to ray-path distortion within the CMP ray-bundle giving-rise to non-hyperbolic moveout behaviour.

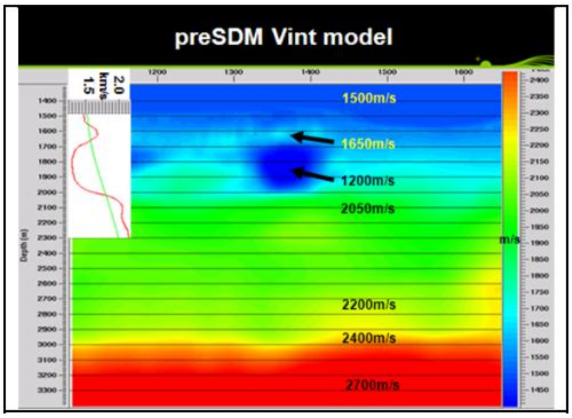


Figure 2: corresponding interval velocity profile used for the 3D preSDM. The inset in the upper left corner shows a velocity profile extracted through the geobody, clearly indicating the increase in velocity at the top of the body

Dispersive effects

Attempts to measure absorption related dispersion on conventional surface streamer marine seismic data are notoriously difficult, in part due to the relatively narrow bandwidth of surface seismic data, but primarily due to the almost negligible effect of velocity dispersion in the measured bandwidth at typical seismic frequencies. If dispersion was found, it would mostly relate to the lowest frequencies in the signal compared to the highest.

In this study, using marine streamer seismic data, we attempt to measure dispersive effects associated with what is thought to be a gas-charged geobody underlying a gas hydrate cap where we have low seismic velocities and significant absorption effects. However, it should be noted that from seismic arrival time data alone, it is difficult to distinguish between an overpressured gas geobody, and a high porosity water saturated clay geobody, as both can have anomalously low velocities compared to the surrounding sediments. In this example, we clearly have low velocities and significant absorption, so the nature of the geobody does not detract from the general thrust of the analysis.

Two approaches are employed in an attempt to obtain a consistent and cross-validated result:

1) Comparison of near-trace arrival times as a function of bandwidth on both raw and migrated data
2) Comparison of velocity spectra a function of bandwidth

Arrival-time analysis

Figure 3 shows a zoom of the stacked data from Figure 1, indicating two small windows to be used for analysis: one outside and one inside the affected zone. For a series of narrow bandpass filters, I measured the arrival time of the near trace event for the deep reflector in the unaffected and affected zones. Within the affected zone, we observe a consistent and increasing delay of the arrival as we lower the bandpass frequency, which is consistent with what would be expected for dispersive body waves, in that the velocity will decrease with decreasing frequency. These two regions were analysed for both the unmigrated near trace data (200-300m offsets), and the near-trace preSDM data. For the purposes of this study, a single 2D line of data was analysed, hence the migrations shown are from 2D preSDM, as opposed to the 3D preSDM data considered in the commercial project (Fruehn, et al., 2008, Smith at al., 2008).

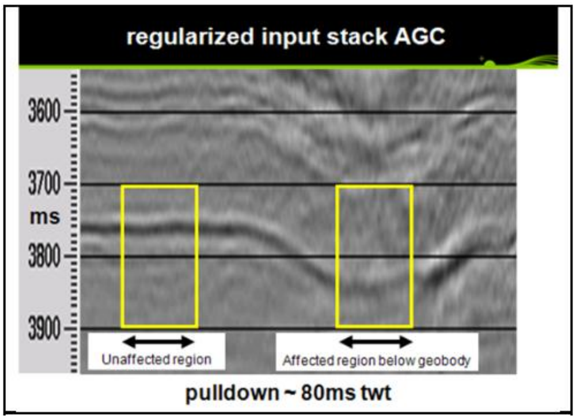
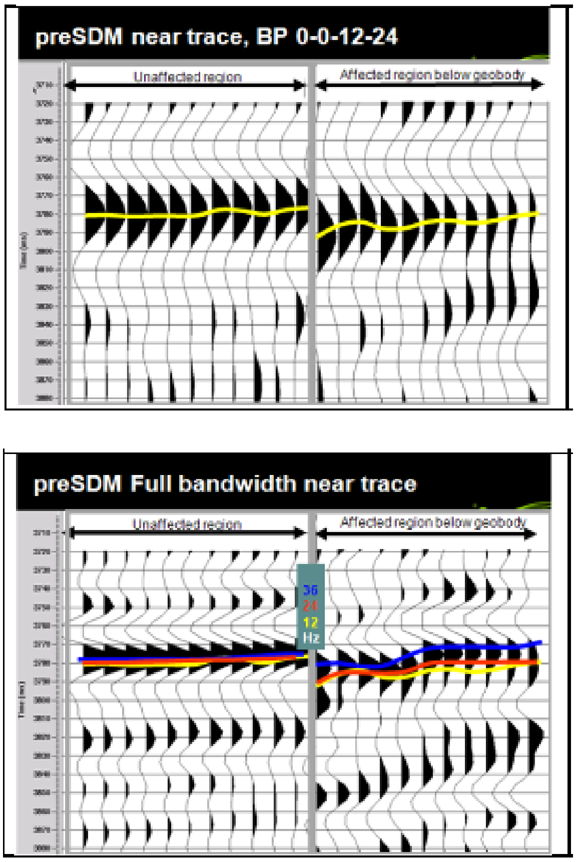


Figure 3: zoom on study areas

In the study, I used several different bandpass widths and shapes, both implemented in the time and frequency domain, all of which lead to comparable conclusions. In Figure 4, we compare the two regions as seen on the preSDM near trace (200-300m offsets) converted back to time with a very smooth model in order to apply the filters, for a selection of three trapezoidal bandpass filters.



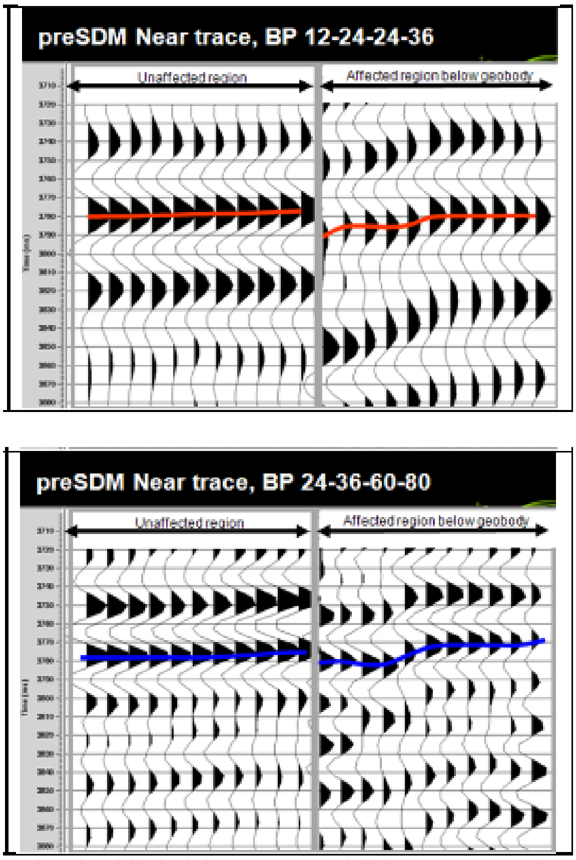


Figure 4: arrival times picked for central peak of wavelet for various band-limited datasets. Lower left image compares the three sets of picked arrival times superimposed on the full bandwidth data.

Dispersion analysis

For the affected zone, we measured a 10ms twt difference on the picked time of the horizon, between the 10Hz and 40Hz centred bandpass filter images, and given that the measured velocity in the 200m thick geobody is about 1450m/s on average, then if we assume that the 10ms twt delay difference was accumulated solely in the geobody (in other words, the underlying sediments have a much higher Q value resulting in negligible dispersion), then we can infer that the slower low frequency velocity would be about 1400m/s

Starting with the Futterman relationship for a constant Q model (i.e. Q invariant with frequency), and using a Taylor expansion for the tangent term for small values of 1/Q (e.g. Liu et al., 1976; Sun et al, 2009), then the approximate relationship for velocity change as a function of frequency, is:

$$v(f2)/v(f1) = 1 + (1/\pi.Q)\ln(f2/f1)$$

Using f1=10Hz, f2=40Hz, and solving for representative values of v(f2)=1450m/s and v(f1)=1400m/s gives Q=13, which is at the low end of values described in the literature (e.g. Carcione and Helle, 2002)

Dispersion correction

Measuring and applying the static shifts required to align the waveform in the different bandwidths, gives us a first order dispersion correction, applied to the data after migration. The high frequency arrival is used as the reference, and the other frequencies are adjusted to match its arrival time. Applying this correction gave a reasonable compression of the dispersed wavelet in the perturbed zone.

As an alternative to using static shifts, we have also migrated the different bandwidth data with a velocity model where the anomaly has been adjusted so that its interval velocity changes as follows to accommodate the dispersion:

(24-36-60-80 Hz) uses the original velocity model (12-24-36 Hz) has the anomaly velocity reduced by 35m/s (0-0-12-24 Hz) has the anomaly velocity reduced by 50m/s

In this study, I have not modified the migration code to accommodate dispersion (Zhang et al., 2010), but have simply partitioned the data and migrated in various frequency bands with different velocity models (the models being locally scaled so as to compensate for the observed travel time delays), so as to demonstrate the dispersive effects and their compensation. The migrated results were then weighted and summed to give the dispersion correction. Figure 5 shows the seismic traces in the perturbed zone, with each trace reproduced three times, once for each bandpass filter. Shown are these trace triplets with and without the corrections for frequency-dependent velocity in the migration. The wavelets are better aligned across the trace triplets after the migration dispersion correction. Stacking these trace triplets produces the sections shown in Figure 6.

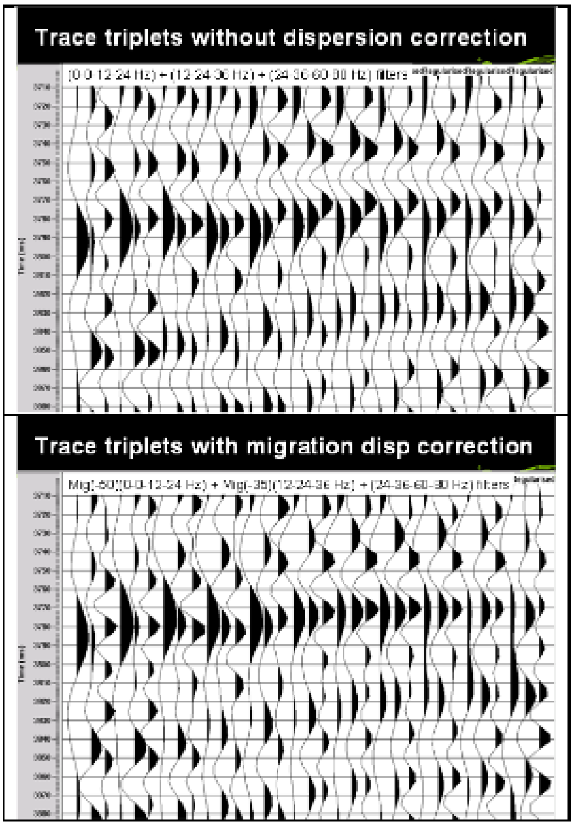


Figure 5: groups of three traces, corresponding to the three bandpass filters, for data within the affected zone. Top figure shows the individual triplets migrated without dispersion correction. Bottom figure shows the migrations with dispersion correction. (The data have been converted to time with a smooth model following preSDM).

Velocity analysis

A similar analysis was performed on velocity spectra for differing data bandwidths, to attempt to verify the conclusions using the offset kinematics. Using the full offset range (0-6km) was influenced by higher order moveout effects, so I limited the offset range for velocity analysis to 0-4km

Table 1 summarizes the results of the velocity analyses of the data in different bandwidths: the error bars are the inherent uncertainties from resolution analysis based on the maximum available offset, peak frequency, arrival time and average RMS velocity (Ashton et al., 1994; Jones, 2010).

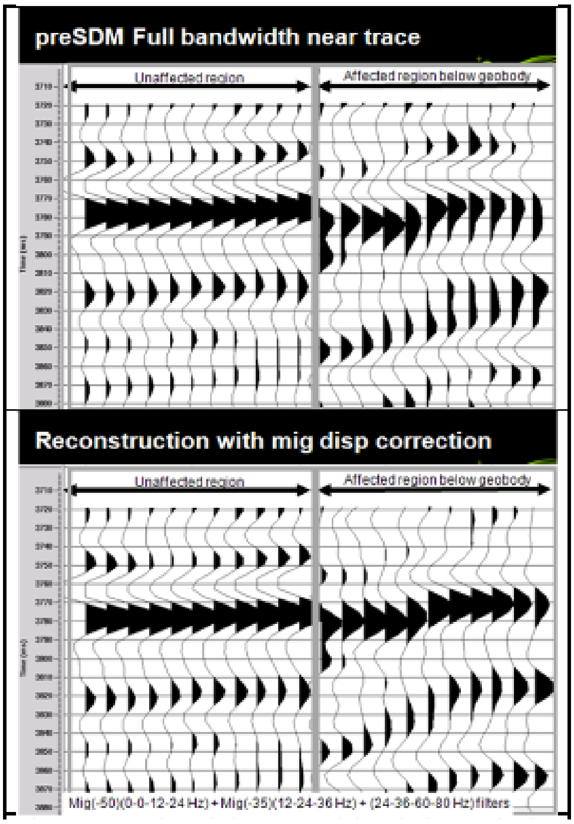


Figure 6: Stacks of the trace triplets before and after dispersion correction. (The data have been converted to time with a smooth model following preSDM).

i.e. $Vrms\_error = T_0 V_{rms}^3 / (4 F_c x_{max}^2)$

As expected for a dispersive medium, the arrival time of the reflection event decreases and the velocity increases with increasing frequency. However, the uncertainties on these estimates are probably too large for them to be considered meaningful.

Band F_c (Hz)	**T_0 (ms)**	**$V_{stacking}$ (m/s)**
10	3832	1710 (±30)
20	3828	1711 (±15)
30	3822	1720 (±10)
40	3820	1730 (± 7)

Table 1: velocity estimates as a function of bandwidth centre frequency, with intrinsic measurement error estimates. The triangular frequency bands used for the velocity analysis were: 0-10-20Hz, 10-20-30Hz, 20-30-40Hz, and 30-40-50Hz.

Discussion

It should be noted that the conclusions drawn here are speculative in as much as the geobody under discussion resembles an overpressured free gas accumulation below a gas-hydrate cap, but this is only inferred from the observed seismically derived properties, and not characterized directly from well measurements. Developing overpressure needs a mechanism such as hydrate dissociation (e.g. Holtzman and Juanes, 2011) or deeper reservoir seepage, and from these seismic data alone, it is unclear as to what mechanism, if any, is in play here..

High attenuation has previously been related to low gas saturation (e.g. Walls, et al., 2002), and low velocity in conjunction with high attenuation related to soft and overpressured sediments (e.g Mavko, 2005). Additionally, low velocity is also associated with high porosity gas-charged, but otherwise un-pressured, sand/shale sequences (Truman Holcombe, pers. com).

The anomalously low interval velocity estimates look reasonable for an overpressured gas, but without elastic impedance inversion with well-calibration, it is still uncertain as to what the geobody actually is. However, the manifestation of dispersion appears to be real, as the geobody is highly absorptive, even if it is not an overpressured zone. For the deep reflectors perturbed by the overlying absorptive region, interval velocity differences of about 3% were inferred between 10Hz and 40Hz components of the data from the travel time delay analysis, and of about 12% from the (more error prone) velocity spectral analysis. These differences are similar to the results of Sun and Milkereit (2008) for a VSP study on the Mallik gas hydrate well.

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