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Sub-salt Model Update and RTM Image Enhancement - An Example from Deep Water Angola

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SUMMARY

Sub-salt velocity model update and associated imaging is fraught with many difficulties, primarily related to illumination, critical angle effects at both the top and base salt, and the determination of suitable two-way imaging conditions to yield gathers amenable for tomographic model update. In this case study, set in Block 31 of the Angolan deep-water offshore region, working with data obtained using wide azimuth seismic acquisition over a complex salt body, we show the results from a tomographic inversion using subsalt RTM angle gathers. In addition, we have used scenario testing to modify the base salt geometry and enhanced the final images using azimuth sectored imaging and shot offset aperture partitioning with adaptive stacking. In a companion paper we demonstrate the effectiveness of suppressing shear mode contamination of the sub-salt P-wave image by adaptive subtraction of RTM imaged forward modelled converted mode shot gathers.
Introduction
Subsalt velocity model update and subsequent imaging is notoriously difficult. Even when we have reasonable subsurface illumination, as offered by many contemporary acquisition configurations, the uncertainty in determining the salt geometry and sub-salt velocities makes it difficult to obtain reliable images (e.g. Leveille et al., 2012; Jones and Davison 2014).

In this case study from the deep water offshore Block 31 in Angola, we outline our attempts to converge on an interpretable sub-salt volume, by using a panoply of methods designed to facilitate salt geometry update via scenario testing, to tomographically update sub-salt velocities, and finally to enhance the RTM image using shot-offset gathers and adaptive stacking for the final image.

Methodology
Following conventional tomographic update of the sediment overburden and initial interpretation of the top and base salt horizons, we used rapid scenario testing to investigate the uplift in image quality from adjusting the salt body geometry for several plausible scenaria. Once an acceptable salt geometry was determined, tomographic velocity model update was run using RTM angle gathers in order to update the sub-salt sediments as the final stage of the model building process.

Given that the data were acquired using multi-vessel shooting so as to provide a WAZ data volume, we were able to partition the data using various approaches. In the first one, several azimuth volumes were produced using sectored angle gathers derived from RTM vector offset gathers (e.g. Sava and Fomel 2003, 2006; Jones 2014). In the second approach, prior to summation of all the various migrated shot contributions to form the final image, we partitioned the output from the RTM into 25 azimuth and offset classes. These 25 volumes were then subjected to various weighting schemes prior to summation to form the final image. Finally, attempts were successfully made to suppress the base-salt converted mode image contamination by performing forward modelling of the converted modes and adaptive subtraction of their RTM images from the final stack image (Kobylarski et al., 2015).

Results
Figure 1 shows the initial and final salt keel geometries obtained after testing various scenaria. Selecting the reduced salt keel resulted in flatter sub-salt image gathers and a sharper sediment image.

RTM time-shift gathers were produced and converted to angle gathers ready for input to an autopicker to facilitate the tomographic update. Picking residual moveout on the RTM angle gathers was performed over an angle range of 3-30°. These RMO values and associated coherencies were fed to the tomographic solver so as to update the sub-salt velocities. Figure 2 shows the velocity model and image for the initial and final sub-salt updates. Flatter angle gathers were obtained, but primarily the reflection strength and continuity was enhanced, perhaps most noticeably in the synclinal sediment basin below the salt.
Figure 2 Sub-salt image before (left) and after (right) tomographic inversion of residual moveout as picked from the time-shift angle gathers. Continuity of events in the sub-salt syncline is improved (and associated gathers flatter and stronger after the update.

Figure 3 Azimuth sectoring used to partition the WAZ data for azimuth-and-angle-class analysis. Each azimuth sector spanned 30°.

Figure 3 shows the coverage of the acquisition as a function of offset and azimuth. Maximum offset values ranged from 6km to 8km. For our analysis here, we partitioned the data into six azimuth classes. The maximum angle produced for analysis was 41°. Figure 4 shows the angle gathers for an inline for the six azimuth sectors, and their associated RTM images. These images can be used to analyse dependence of illumination on the acquisition azimuth and show that WATS acquisition is required to effectively illuminate sediment beneath complex salt bodies and overhangs.

In Figure 5 we show the image partitioning strategy to facilitate final stack enhancement (Xia and Rietveld 2013). Twenty-five offset-azimuth sectors were employed, in which the central sector (#12) sits over the image point. Contributions to the image from each input migrated shot are gathered for a range of contributing shot-offsets and azimuths, and partially stacked. Different parts of the subsurface structure are illuminated in each of the 25 sub-stacks, depending on the interrelation between the structural dip and the direction of the incoming energy from a given shot location. A weighting strategy is used so as to enhance the coherent energy between the 25 partial stacks. This has the effect of suppressing unwanted migration noise that detracts from the image. Figure 6 shows two such sub-stacks in more detail, whereas Figure 7 shows the simple stack of the 25 partial-stacks versus the enhanced stack. The simple stack is the same as the normal output from an RTM. In this procedure we are simply delaying the summation of image contributions to permit some post-processing to suppress unwanted migration noise.
The maximum frequency in the final RTM offset partitioned images was 40Hz, for azimuth sectored gathers it was 25Hz, and 20Hz was used during the model building. In total, eight iterations of velocity model update were performed.

Judicious combinations of several techniques have been successfully employed to enhance the sub-salt sediments image. Adjustment of the salt geometry and production of sub-salt RTM angle gathers enabled tomographic inversion of residual moveout to be performed so as to update the sub-salt sediment velocities. The final image was further enhanced using post-processing of image contributions so as to suppress unwanted migration noise. This approach, in combination with suppression of converted mode events has facilitated easier picking of the sub-salt events, which in turn should help de-risk any potential prospectivity.
Figure 6 Two sub-stacks. Left: the image for an inline for contributions from sector #17, comprising image contributions from shots that were at intermediate offsets to the south of the image point. Right: image from sector #7.

Figure 7 Left: simple stack of the 25 image partitions (this would simply be the usual output of the RTM). Enhanced stack of the 25 partial stacks.

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References


