Interpretation driven salt scenario modelling with examples from the Dutch offshore and West Africa

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Summary

Historically, velocity model building (VMB) in salt terrains has followed a layer stripping progression, where interpretation is confined to defining salt boundaries with the primary focus on defining the macro attributes for the post-salt, salt & pre-salt volumes. The imposition these horizons have on local and deeper imaging has generally been of lesser importance to the construction of the macro model, whilst the bulk of the interpretation effort has followed final imaging. This may result in subsequent ambiguity over the influence of the overburden model on the final interpretation. We propose an alternative flow where significant interpretation effort is involved at an early stage during the VMB process in order to assess the effect of the overburden model on the final image. This leads to the dual advantage of a progressive interpretation phase combined with increased confidence in the reliability of the final interpretation.

Introduction

Recognising the optimal velocity model in the presence of complex salt bodies is important for positioning of exploration wells and better understanding of known pre-salt fields. Traditional VMB encompassing salt bodies follows a linear workflow whereby sediment velocities are determined, followed by top salt picking. Salt velocities are then flooded below and base salt picked before imposing a suitable pre-salt velocity flood. Within this framework there are a number of factors upon which improvements in sub-salt imaging rely. They may be summarised as:

1. Background sediment velocity upon which the salt is impressed.
2. Salt geometry / interpretation.
3. Velocity heterogeneity of both autochthonous and allochthonous salt.
4. Sub-salt velocities.

As all of these factors are interconnected, a traditional, linear salt velocity model building strategy struggles to disentangle their effects to produce an optimal salt model. An improved workflow allows for the creation of multiple realisations in order to judge the optimal salt interpretation based on a combination of sub-salt images allied with the perceived geological plausibility of models. For this we require the ability to quickly iterate salt scenarios in a parallel fashion before drawing conclusions based upon the optimal image. This iterative approach allows the interpreter to drive the model building based on observations of how changes in the model influence the imaging at and below base salt.

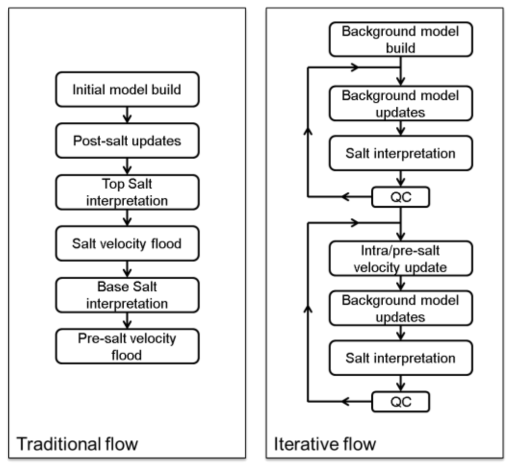

Figure 1: Comparison of the traditional linear and iterative flows.

Basic Methodology

<u>Background/Sediment model:</u>

The importance of the background sediment model in salt model building is often overlooked. The iterative workflow outlined in Figure 1 relies on the ability to alter the salt geometry, meaning that more or less of the background velocities may be revealed as the salt geometry is adjusted. Inappropriate sediment velocities may then arise within the vicinity of the salt leading to an incorrect choice of salt geometry; *e.g.* if sediment velocities are too slow, then inserting more salt may result in a better image at base salt purely because the average velocity has been increased where actually less salt but higher sediment velocities are required; giving rise to ambiguity in the positioning of all the salt interfaces in the model. This is where an iterative workflow has a clear advantage over traditional linear flows; if a revision is made to adjust the salt geometry considerably, then there exists provision in the workflow for a subsequent revision of the background velocity.

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Fast Beam Migration:

In order to make feasible the iterative workflow proposed it is important to choose a suitable PreStack Depth Migration (PSDM) algorithm. This algorithm should show good signal-to-noise in areas of complex structure and be capable of running migrations in minimal time whilst retaining the facility to image multiple arrivals common within these heterogeneous terrains. For the examples demonstrated below, a fast beam migration algorithm was implemented (Sherwood *et al.*, 2009); an example comparison with Kirchhoff PSDM is shown in Figure 2. With a fast migration algorithm, some higher frequency detail is lost. However, the user is able to run multiple salt scenario migrations in a relatively short space of time in order to generate noise suppressed images to assess the optimal model.

The fast beam migration algorithm begins with an upfront decomposition phase, in which beam wavelets are selected in a multi-dimensional slant stack domain. The position, dip and offset of these wavelets allow for a fast point-to-point mapping from un-migrated time to migrated depth positions for a particular velocity model. Each migrated wavelet retains information relating to, amongst other things, angle of incidence, structural dip, and ray trajectory.

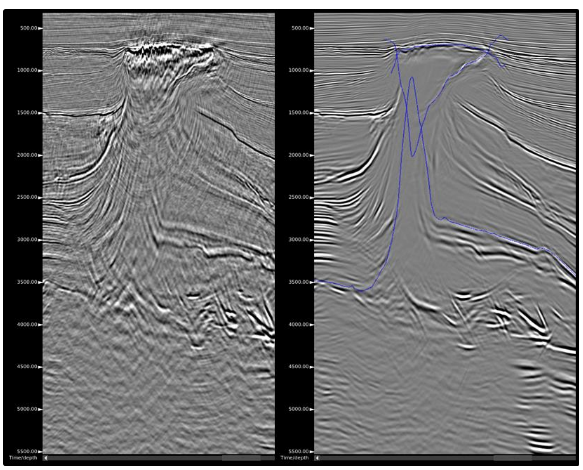

Figure 2: Kirchhoff PSDM image (left) vs Fast Beam migration (right). Note improved signal-to-noise of the Beam image.

A major advantage of the wavelet decomposition is that it allows the user to easily select a subset of the data for imaging. This sub-selection is put to use in the iterative salt modelling workflow by the use of raypath discrimination; wavelets for which the associated raypath passes through the top salt are selected off and labelled as 'salt wavelets', while those for which the associated raypath does not encounter the top salt are labelled as 'sediment only wavelets'. This discrimination is useful in two main ways: tomographic updates to the background model can be run using 'sediment only wavelets' so that salt events do not have adverse effects on the inversion; salt wavelets can be migrated with a salt flood velocity then the resulting image co-rendered with a sediment velocity migration of 'sediment wavelets'. This co-rendered image allows the interpreter to get a better handle on the position of complex salt overhangs by viewing correctly imaged salt wavelets in conjunction with sediment truncations unaffected by salt velocities; an example of such a co-rendered image is shown in Figure 3. Note rays that are transmitted through a salt body before reflection within sediments still require a more accurate representation of the salt volume to ensure appropriate imaging. These events may be identified by noting the number of times a ray impinges on a particular salt interface and selecting appropriately before reconstructing the co-rendered image.

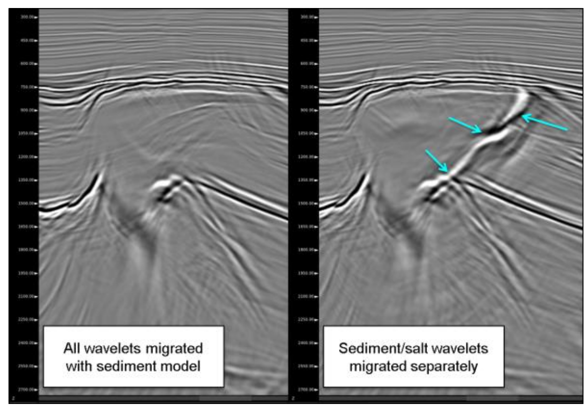

Figure 3: Co-rendered salt and sediment images with separated sediment/salt wavefields using raypath discrimination.

Salt geometry scenario modelling:

With regards to salt scenario modelling, the basic workflow is to run multiple geometry scenarios picked on a coarse grid to get a feeling for the optimal basic geometry of the salt. The ability to quickly construct multiple salt geometries is facilitated by employing a horizon construction whose primary constituents comprise simple fault stick elements. The interconnection/triangulation between points on the fault sticks and handles is applied dynamically with controls on the density of points and their associated smoothness and accuracy. This allows for relatively complex shapes to be constructed from a minimal number of handles; an important factor when considering changing a geometry significantly which would otherwise engender a significant interpretation effort. An example of such an interpretation grid made by manipulation of such Multi-Z surfaces is shown in Figure 4.

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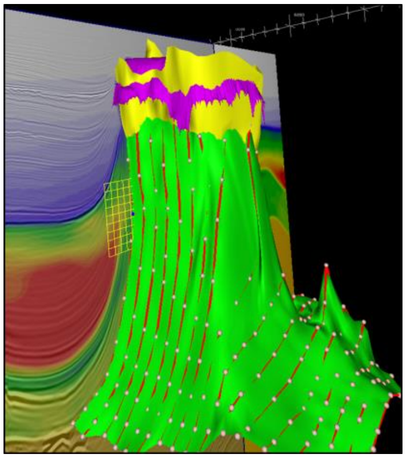

Figure 4: Sparse salt geometry picking with Multi-Z surfaces.

Comparisons are made of imaging at base salt and pre-salt reflectors with improved gather flatness and structural continuity the main criteria judged in selection of an optimal model. As mentioned above, it is important to keep in mind the influence of the background model when making these assessments; Figure 5 shows an example where a background sediment model update in a North Sea example has considerable effect on the salt flank interpretation; note correct imposition of strong velocity contrasts such as chalk layers have particularly large impact on base-salt imaging. Once the approximate salt geometry is in place, more detailed interpretation is required in order to make imaging improvements for which specialized interpretation is required; an example of such an update is shown in Figure 7. After a refined set of salt geometry scenarios, a further pass of background velocity updates are performed. This process of iterative salt geometry refinement and sediment velocity model update is iterated until minimal updates in base/pre-salt imaging are observed.

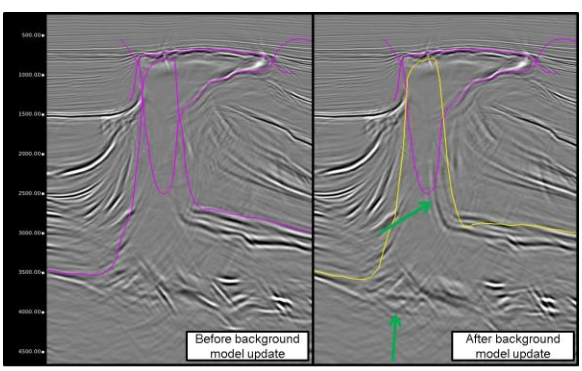

Figure 5: Importance of background model - after updates the salt flank is considerably easier to interpret.

Potential Geological Salt Scenarios:

The ability to build multiple salt scenarios allows the interpreter to test scenarios to better understand the geometry. In cases where the historical movement of the salt is unclear, the scenarios can be geared toward understanding this more clearly. Iteratively adjusting the surrounding sediment velocities will also contribute to this understanding. For example, in the case of salt movement that is contemporaneous with deposition, the surrounding velocities should be consistent with onlapping sediment packages whereas post-deposition movement may coincide with gravitational collapse and hence slower velocities against the salt than in the surrounding sediments; see Figure 6 and Hudec and Jackson (2007) for examples.

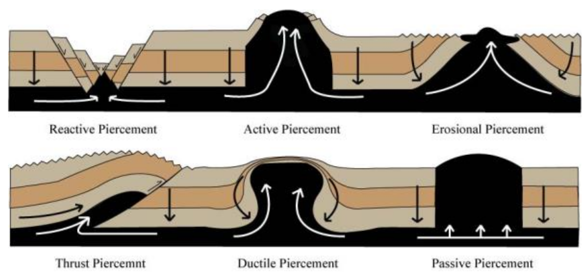

Figure 6: Diapir piercement scenarios, Hudec and Jackson (2007).

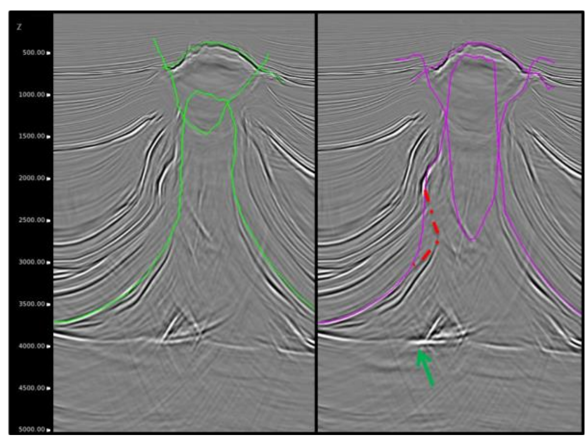

Figure 7: Salt scenario testing - improvements in base salt imaging lead to adjustments in salt geometry (dashed red line).

Intra/pre-salt velocity updates:

After good approximations to the salt geometry and post-salt model are obtained, two further factors need to be considered. Intra-salt velocity heterogeneity arising from anhydrite inclusions or other factors must be determined. As a starting point, salt velocity scans can be analysed to determine a suitable starting velocity profile. Initial intra-

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salt velocity functions may be mono-valued or else derived based on depth of burial or layer thickness dependent on the result of the scans. From this starting model, an intra-salt tomographic update can be performed. In the case of localised anhydrite rafts within a massive salt, the result of tomographic update should be carefully checked for updates which exhibit scale lengths appropriate to the inclusions; given the lack of reflectivity within most salt layers, it can be difficult to correctly position small scale velocity anomalies so they should be avoided in general. A masking technique may be used whereby updates are focused on the deeper part of the salt where the majority of reflectivity driving the intra-salt updates is located.

Long wavelength pre-salt updates can be run in conjunction or following velocity scans. Once a suitable salt and pre-salt update are determined it is advisable to repeat the overburden model updates and finalise the salt geometry interpretation where time allows, since events may be repositioned and conclusions regarding base/pre-salt imaging may change.

Advanced workflow elements

An advanced workflow may be advantageous where illumination is more complicated than a standard narrow azimuth acquisition: *e.g.* WAZ/FAZ wide or full-azimuth acquisition. As with the separation of salt and sediment wavelets described above, it is possible to determine the origin of particular events by further sub-selection of wavelets prior to imaging. This azimuthal wavefield segmentation can be helpful for understanding the overprint of coherent noise trains within the seismic image, or simply to better understand where a particular event is illuminated from; an example of such azimuthal segmentation is shown in Figure 8.

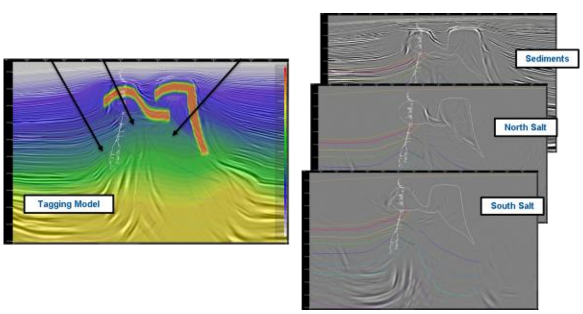

Figure 8: Wavefield separation example - illumination through complex salt bodies can be better understood, Gerea *et al.* (2014).

A further technique that may be of value to further reduce uncertainty on salt-sediment interfaces is to use converted S-wave events. In the case where P-S conversions within the salt appear as noise within a standard P-wave velocity migration image, the wavefield impinging on the top salt may be selected off and migrated with both P-wave and S-wave velocities within the salt body. The resulting images may then be overlain to establish whether a coincident base salt event may be interpreted.

Metrics of success

The iterative workflow introduced in this paper relies on visual QC after migration with a particular salt model. In most cases improvement in imaging at base/pre-salt is a suitable metric for determining whether a given change in model is suitable. However, additional quantitative metrics may be considered.

In the presence of existing wells, one such metric that has been put to use within the context of the interpretation driven salt scenario modelling workflow is comparison of dipmeter logs to migrated seismic structure. Confirmation that the structural dip of pre-salt structures conforms to those measured in situ gives added confidence in the resultant model. Existing well measurements can also be used to carry out a miss-tie analysis at the base salt; where miss-ties are small, the confidence of a given salt geometry increases.

In the absence of more quantitative metrics to establish the appropriateness of a salt model, the method itself provides a suitable alternative. The ability to have multiple realizations of the salt geometry and to have the interpreter work closely in the early stages of the project mean that once the final model is selected, the set of possible salt configurations is narrowed down. By comparing the multiple realizations, a reasonable estimate of the confidence in the optimal salt model may be attained; in addition and no less important the converse, namely the possible ambiguity in the model caused by acquisition limitations etc, may prove beneficial.

Conclusions

By distributing the interpretation effort and allowing the interpreter to influence the velocity model building of salt plays more directly, the uncertainty on the final images can be minimised and better understood. To achieve the best results the velocity model build has to both be adaptive to changes in scope and allow for recursive revision of the model elements.

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EDITED REFERENCES

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