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Seismic Imaging Below "Dirty" Salt

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SUMMARY

Base and sub salt seismic imaging is still an unresolved issue. To solve this problem both improved processing algorithms and acquisition geometries have been heavily researched the latest years. However, there is less effort trying to explain why sub salt imaging is sometimes so difficult. Often one assumes to have a constant velocity within the salt to simplify the processing of seismic data. However, there may be several complex structures and/or rapid velocity changes within the salt body, which strongly affect the wavefield propagation and might cause severe imaging problems.

Imaging of a 2D seismic line in the Nordkapp Basin shows no sign of the base salt or any other sub salt reflectors, although independent data suggest the existence of a base salt reflector. In synthetic data we are able to recreate the effects seen in real seismic data by perturbing the salt velocity. Modelling of different "dirty" salt models results in severely distorted synthetic data. After imaging using a clean homogenous salt, the base and subsalt reflector are either barely visible or vanishes altogether in the stacked image. These examples may explain why the base and sub salt are not visible in the real seismic data.

INTRODUCTION

Seismic imaging of complex structures is challenging. There is a strong ongoing effort in the geophysical community to improve the way we both acquire and process the seismic data in such areas (Thompson et al., 2007). Problems with salt imaging are often related to either getting a clear image of the base salt, or of the salt flanks. This could be due to non-suitable and dip-limited migration algorithms. Farmer et al. (2006) showed the usefulness of applying two-way wave equation migration, e.g. reverse-time migration, which handles both turning waves and multi-arrivals. Better acquisition geometries may also improve the salt and sub salt imaging. Areas which are poorly illuminated with conventional geometries are better illuminated with wide- or full-azimuth acquisitions (Houbiers et al., 2008).

High-quality imaging of seismic data from complex geology requires an accurate model of the velocity field in the subsurface. In real life this may not be achievable. Building models of salt bodies (or other intrusions) is often related to finding the correct shape of the salt body after sufficiently accurate background velocities are found. A trial-and-error approach is usually used to delineate the salt body.

To simplify seismic processing it is often assumed that salt bodies are homogeneous with constant velocity and density. However, geologically speaking, they may not be as homogeneous as we like to believe. For example, while the inner core of a salt dome may consist of mainly pure halite, the rest could be a mix of salt, sediments and other rocks or minerals (Richter-Bernburg, 1987). It is not unusual that other layer-like structures exist in the outer salt zone. An example of this “dirtiness” is shown in Figure 1, which displays a velocity and gamma log from a salt structure. Here one can identify rapid velocity anomalies from the background velocity in the salt, which has its top salt at circa 1400 m (Figure 1(a)). These anomalies can also be found in the gamma response shown in Figure 1(b). Rapid velocity changes within the salt structure may distort the propagation of the wave front, which will affect the recorded seismic data.

Problems in imaging the base salt reflector will likely impact also the sub salt imaging. The focus in this work is therefore the imaging of the base salt and a sub salt reflector. By seismic modelling (Haugen et al., 2008) we try to recreate the effects in the seismic data from a 2D line recorded in the Nordkapp Basin offshore Norway. We test different salt models which distort the data in such a way that the base salt reflector will be imaged with very poor quality or not at all.

MODELLING AND IMAGING

The Nordkapp Basin, located in the Barents Sea, is an exploration area with very complex geology. It contains several salt diapirs with shallow crests immediately below the seabed, which make imaging of seismic data difficult. Especially deeper parts of the salt flanks below the Base Cretaceous and also the base of the salt are poorly imaged or not imaged at all, although e.g. gravity data suggest a base salt reflector above 5.0 km. Several seismic exploration surveys have been conducted in this area from which we selected a 2D line, which exhibits the base salt imaging problem. This line covers two salt diapirs, where we have focused on one of them. We used an existing velocity model as basis for our

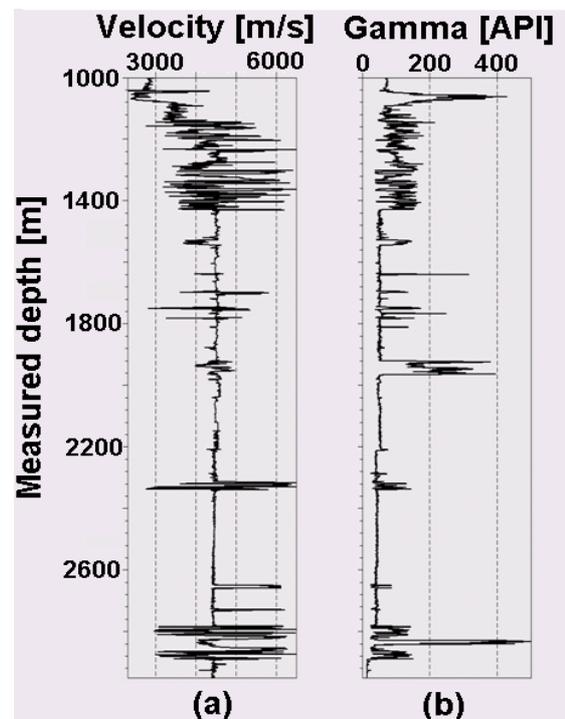


Figure 1 Well logs from a salt structure. (a) is the measured P-wave velocity and (b) is the gamma response. The top salt is at circa 1400 m.

models in this work. Since the real 2D line for this survey was shot in two directions, we used a "marine split-spread" survey to simulate the data.

The models used in this study consist of one main salt structure in the centre. In Figure 2 the velocity models of the reference model and a "dirty" salt model are shown, referred to as Model 1 and 2,

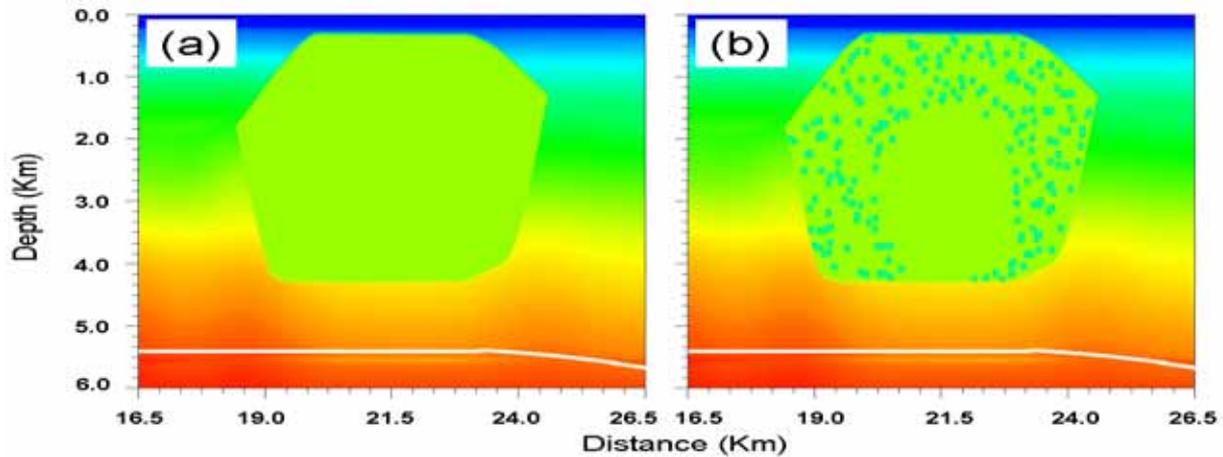


Figure 2 Velocity models of (a) homogeneous salt body (Model 1) and (b) perturbed salt body (Model 2). Salt velocity is 4500 m/s, and the velocity of the perturbations is 70 percent of the salt velocity. The white line marks the position of a high density contrast.

respectively. At an approximately depth of 5400 m there is a high density contrast to simulate a sub salt event, marked as a white line in Figure 2. To make "realistic" data we performed the modelling with a free surface and used an acquisition geometry that resembled the real geometry: 12.5 m receiver spacing, 25 m between each shot and 100 m / 8100 m as minimum / maximum absolute offset. The reference model (Model 1) shown in Figure 2(a) has a homogeneous salt body with a constant velocity of 4500 m/s and sharp boundaries. In order to simulate the effects of "dirty" salt, we added square velocity perturbations inside the salt body. Different "dirty" salt models were tested by varying the size of these perturbations and the velocity contrast between the salt and their perturbations. For Model 2 the velocity of these perturbations is 70 percent of the salt velocity and the size is approximately 120 m in both directions. The perturbations were randomly scattered but an inner zone was kept clean. The synthetic pre-stack datasets were modelled with a 2D acoustic finite-difference method. A 6.25 m grid spacing in both directions and a 25 Hz Ricker wavelet were chosen for this study.

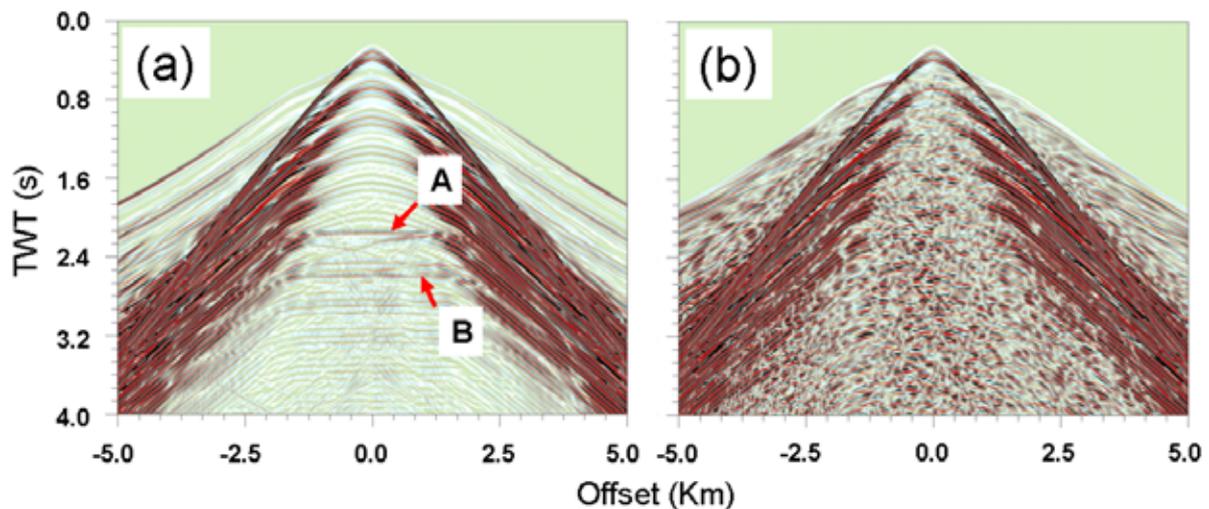


Figure 3 Synthetic shot gathers from (a) Model 1 and (b) Model 2. Events A and B are the base and sub salt reflection, respectively.

The preprocessing of the real data has been kept to a minimum with designature, true amplitude recovery and swell noise attenuation. Neither the synthetic nor the real data had any demultiple applied to it to avoid any removal of primary energy.

RESULTS AND DISCUSSIONS

Figures 3(a) and 3(b) show one synthetic shot gather for Models 1 and 2, respectively. The displayed gathers cover absolute offsets up to 5000 m. The shot position was approximately above the centre of the salt diapir. In Figure 3(a) the reflection of base salt is visible at a TWT of circa 2.2 s and marked as event A. Event B is the sub salt reflection which arrives at a TWT of circa 2.6 s. Modelling of “dirty” salt gives distorted synthetic data which are shown in Figure 3(b). Events A and B are no longer visible in the data. Comparing Figure 3(b) with Figure 4 we can clearly see that the data for Model 2 resemble the real data, especially at near-offsets. The degree of distortion will depend on the size of the perturbations and the velocity contrast between the perturbations and the salt. Lowering the velocity contrast or decreasing the size of the perturbations the data get less distorted and events A and B start to be visible in the data.

The depth image of the real data using split-step Fourier migration with Model 1 as velocity model clearly points out the problem of delineating the salt body (see Figure 5). The sediments surrounding the salt structure are fairly well imaged, but it is neither possible to identify the base salt reflector, nor the lower salt flanks. In addition there are some disturbances visible within the salt. The image does not improve much by replacing split-step Fourier migration with a more accurate migration scheme.

Figure 6 shows the images of the synthetic seismic from Models 1 and 2. The synthetic data were migrated with split-step Fourier migration with Model 1 as velocity. In the migrated Model 1 section, the base and sub salt are clearly visible at a depth of 4250 m. We can also see (as expected) multiples of the top and base salt interfaces. Conversely there is no sign of neither the base, nor the sub salt reflector in the migrated Model 2 section (see Figure 6(b)). The perturbations in the salt body distort the wavefield to such extent that the imaging of the base salt reflector fails, when using the “clean” salt as migration velocity model. Observe that the image of Model 2 resembles the image of the real data.

We remark that more accurate wave equation migration, e.g. reverse time migration, of the data from Model 2 with the exact velocity model yields a representative image of the model, as shown in Figure 7.

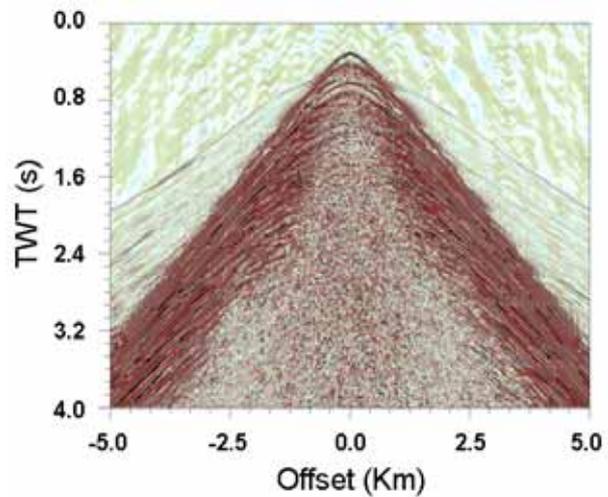


Figure 4 Real shot gather.

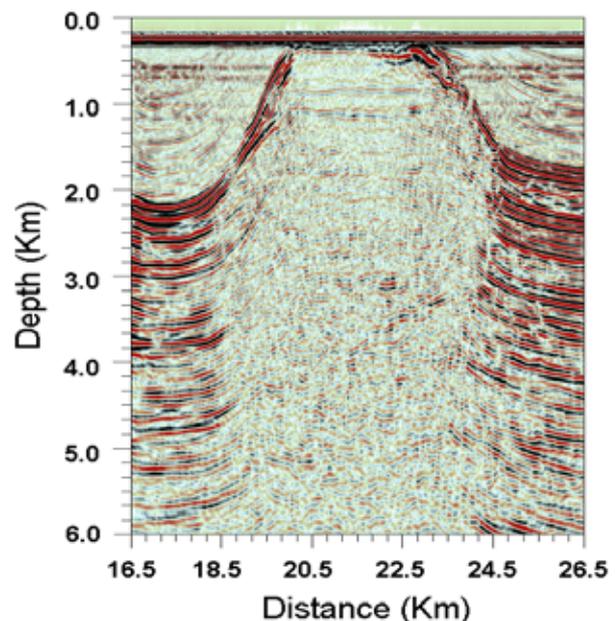


Figure 5 Depth image of the real seismic data using split-step Fourier migration. The migration velocity used was Model 1.

CONCLUSIONS

We have shown modelling results of two different models, one homogenous salt model (Model 1) and one “dirty” salt model (Model 2). Shot gather data from Model 2 mimic real recorded data. Depth-migrating this synthetic dataset with the homogeneous salt model showed that we are not able to image neither the base salt reflector, nor the sub salt event. Everything below top salt appears to be disturbed due to the velocity perturbations in the salt body. One can conclude that significant velocity perturbations within the salt distort the wavefield in such a way that an accurate velocity model and thus good images of base salt or sub salt reflections are difficult to obtain.

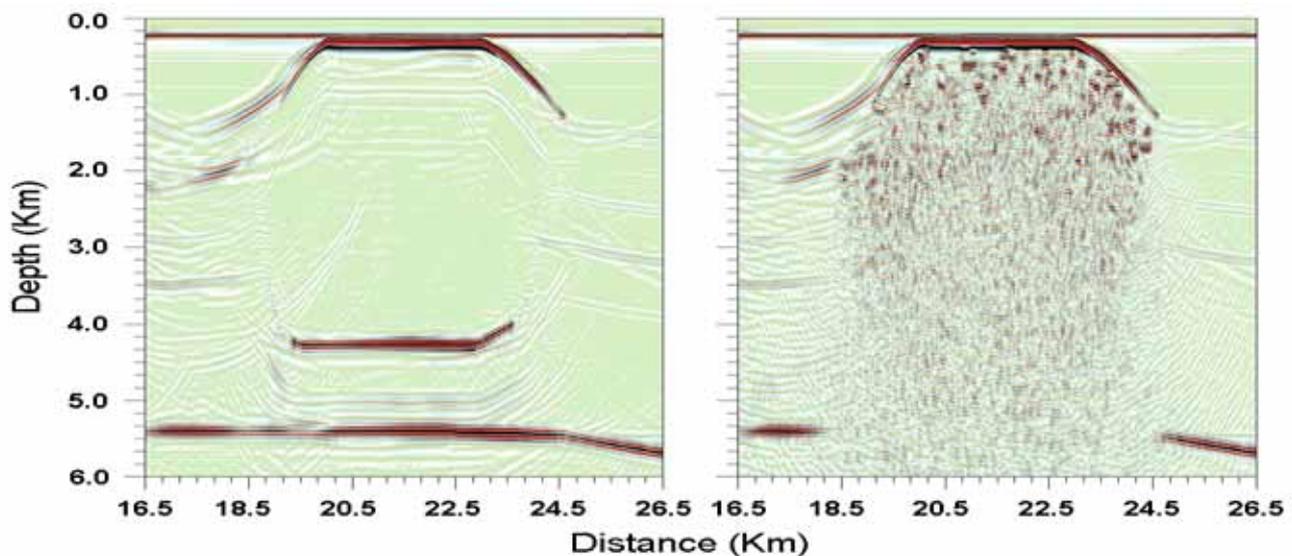


Figure 6 Depth images migrated with a split step Fourier migration. The image of the synthetic data from Models 1 and 2 are shown in (a) and (b), respectively. The migration velocity used for both migrations was Model 1.

ACKNOWLEDGEMENTS

The authors would like to thank StatoilHydro, for providing data and the permission to publish this work.

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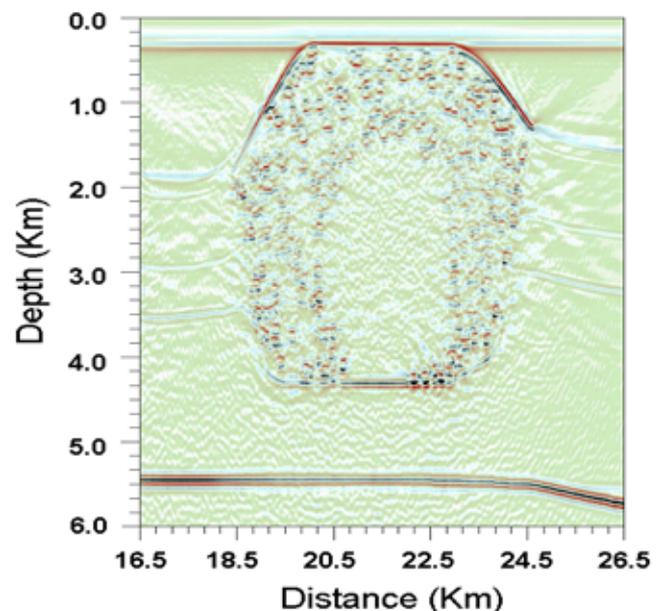


Figure 7 Depth image of Model 2 data using reverse time migration and exact velocity model.