

Imaging Pitfalls around Salt Domes from the Picanha area, offshore Brazil

Anton Pavlov, Juergen Fruehn, Jeff Faw, and Hayden Faw, ION

The imaging condition for reverse-time migration is known to produce various classes of imaging artefact due to the cross talk between physical and non-physical travel paths from the source and receiver sides of the wavefield propagation. In the case of very strong impedance contrasts, such as at top salt, these artifacts can seriously mislead interpreters, giving rise to sub-standard velocity models.

Here we present an example of these artefacts from the deep-water Picanha region, offshore Brazil, and propose strategies to avoid this particular pitfall.

Introduction

Salt dome imaging is a great challenge for model builders, as it is often associated with near vertical dips and the cumbersome interpretation of overhangs. It is common practice to use reverse time migration (RTM) to optimize the picking of the salt geometry. This strategy generally works well for deeply buried salt bodies, but as we show in this paper, in areas where the allochthonous salt has penetrated the shallow, low-velocity sediment cover, a low-frequency RTM image can be misleading, as small errors in the top salt picking can produce coherent RTM cross-talk artefacts.

Background

The area to the east of the pre-salt polygon in the Campos basin offshore Brazil (Fig. 1), where domes of highly mobilized salt are widespread. Great interest in this area has recently reenergized the E&P community, after the Brazilian government opened the area for international exploration. We show examples from a reprocessing programme utilizing publically available 3-D seismic data which had the objectives of developing a basin wide, unified PreSDM image (Figure 1).

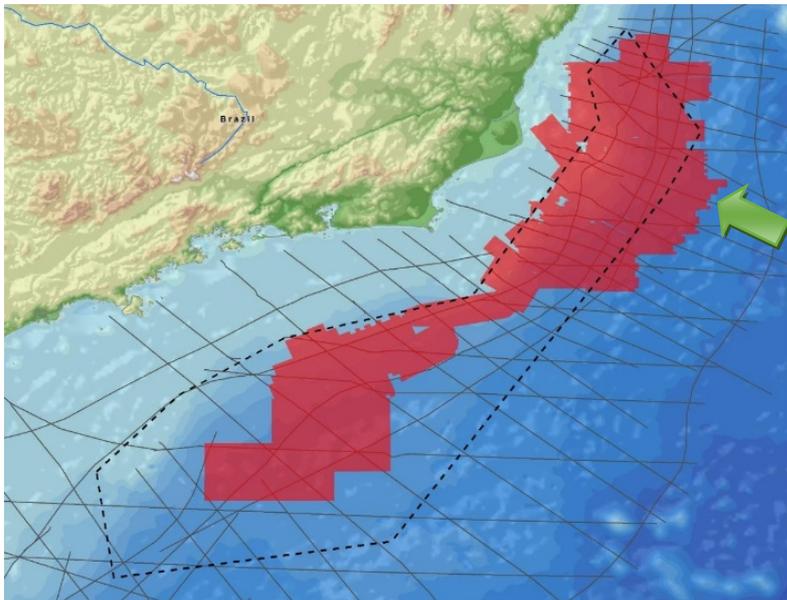


Figure 1. Location of the 3-D re-imaging program (red), Pre-Salt polygon (black dashed line), extension area (green arrow)

The main imaging objective of the program is to build the best possible overall image, which will then allow a large-scale re-evaluation of the hydrocarbon potential at all possible levels, from the overhanging salt domes of the Eastern areas to the deeper targets trapped by carbonates in the central and Western areas and the very deep sub-salt regions. This is a very challenging task, as the thickness of salt bodies varies greatly from a few dozen metres to 3-4 kilometres, locally with the added complications such as overhangs and fast carbonates capping salt. The general strategy for model-building of such complicated salt bodies is to undertake a staged approach (Jones and Davison 2014).

Model Building Strategy

Firstly, the overburden – the sediment flood model – must be finalized. Then the top salt is generally picked on an RTM stack produced with that model. In areas where the top salt is rugose, a Kirchhoff stack may be more appropriate in capturing the fine detail. In areas with overhangs the top salt is simply dropped down to the autochthonous level. We will call this first version of Top Salt - ToS1, as depending on the number of overhangs there may be several tops and bases. Below we describe the model-building steps required for a single overhang.

ToS1 is used to create a first salt flood model. Migration with this model will allow us to pick the base salt, BoS1, at autochthonous level (mother salt) and the overhangs in the allochthonous salt. A second sediment flood can then be created to image the area under the overhangs and pick ToS2, which in

turn is being used in a second salt flood migration to pick, BoS2, which is the base of the mother salt in the areas with overhangs. To ensure consistency of picking, it is recommended to use the same imaging parametrization in all migrations and if overhangs are present, RTM should be an algorithm of choice. An added complication offshore Brazil is the change in phase at Top Salt level as it emerges from underneath the carbonates, where it marks a decrease in acoustic impedance, to the shallower levels, where it reverses polarity to become an increase in acoustic impedance. In practice, the sediment flood model was built with six iterations of TTI generalized move-out tomography (Luo *et al.*, 2014), showing a good match with well data and producing reasonably flat gathers over the entire area.

The imaging pitfall and its origins

The sediment flood migration produced a 40Hz, generally good quality, RTM image that was used for ToS1 picking. The validation of the salt flood model that was built using this horizon was performed on a more cost-effective 30Hz RTM, which highlighted the pitfall: in locations where the salt dome was close to the seabed, i.e. the velocity contrast across the top salt is high, coherent events appeared above the top salt. A comparison of RTM and Kirchhoff salt flood stacks on the 30Hz RTM image confirmed that the observed events were an RTM specific artefact (Figure 2).

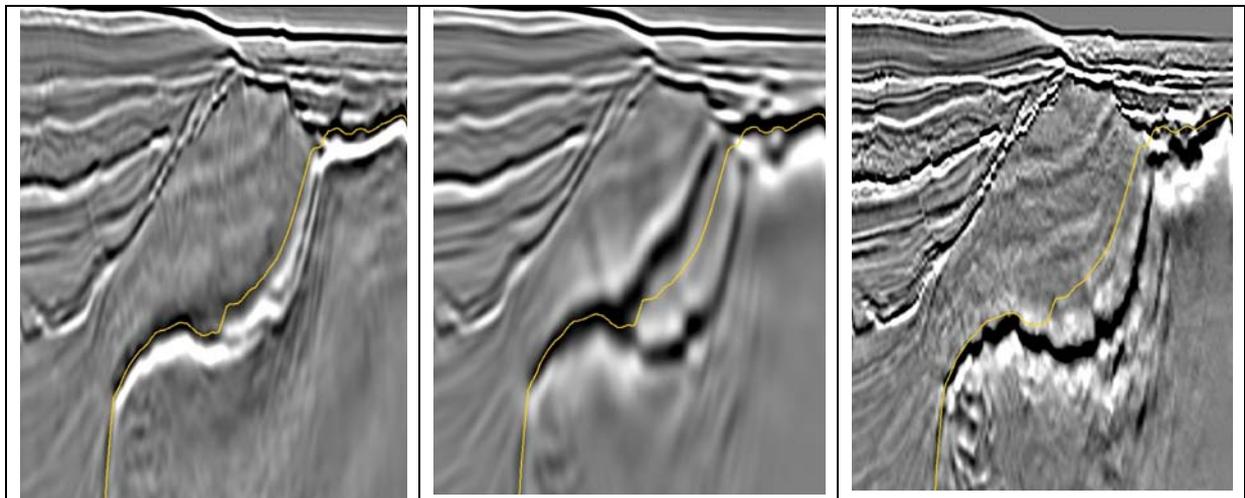


Figure 2. Example sediment-flood and salt-flood images – left: 40Hz sediment flood image on which the top-salt was picked. Centre: 30Hz salt-flood RTM; right: Kirchhoff salt-flood image. All with the top-salt interpretation superimposed

RTM is highly sensitive to model errors and we believe that this event is a cross-talk artefact between down-going and up-coming wavefields. Jones (2014) shows that at the imaging condition stage of a two-way migration algorithm, we form the final image of the reflectors, but we also stack in unwanted energy from the down-going and up-coming wavefields. This artefact usually blurs the primary image with a very low frequency swell noise that can be safely filtered out. In this case however, a small error in the picking of the high velocity contrast top salt led to a strong and coherent event, indicative of a model error requiring re-picking of the top salt. The artefact was observed in several locations across the survey in similar settings at the edge of shallow salt domes. The artefact did not appear deeper in the section.

Based on the made observations we formulated a hypothesis: the shallow part of the section has high-frequency energy that is forming reflection events, however, at same time the relatively low-frequency RTM image (30-40Hz) cannot provide enough resolution for whole frequency spectrum and offer a definitive interface pick. Instead the RTM is cross-correlating ringing side-lobe energy from the low-frequency waveform used in the source-side and receiver-side wavefield propagation, and as a consequence spurious events appear in the vicinity of strong reflectors.

Hypothesis validation

In order to test the hypothesis we picked the top salt event on RTM and beam migration sediment flood images with the same frequency range. We then created a salt flood model with each of the picks and validated the subsequent image with both Kirchhoff and RTM imaging. The RTM validation is designed to show the effect of any mis-pick on the image. The Kirchhoff image as validation method offers the most resolution and allows the general pick quality to be assessed. We illustrate this test with examples from a different location to that shown in Figure 2.

Figure 3 illustrates typical RTM and beam migration images migrated with maximum frequency of 30 Hz. The top salt was picked on the images created with both algorithms – in Figure 3 the red surface was picked on the RTM and the yellow surface on the beam migration (picking the top-salt impedance contrast as the first ‘black’ event). Subsequently, two salt flood models were created with each of the surfaces.

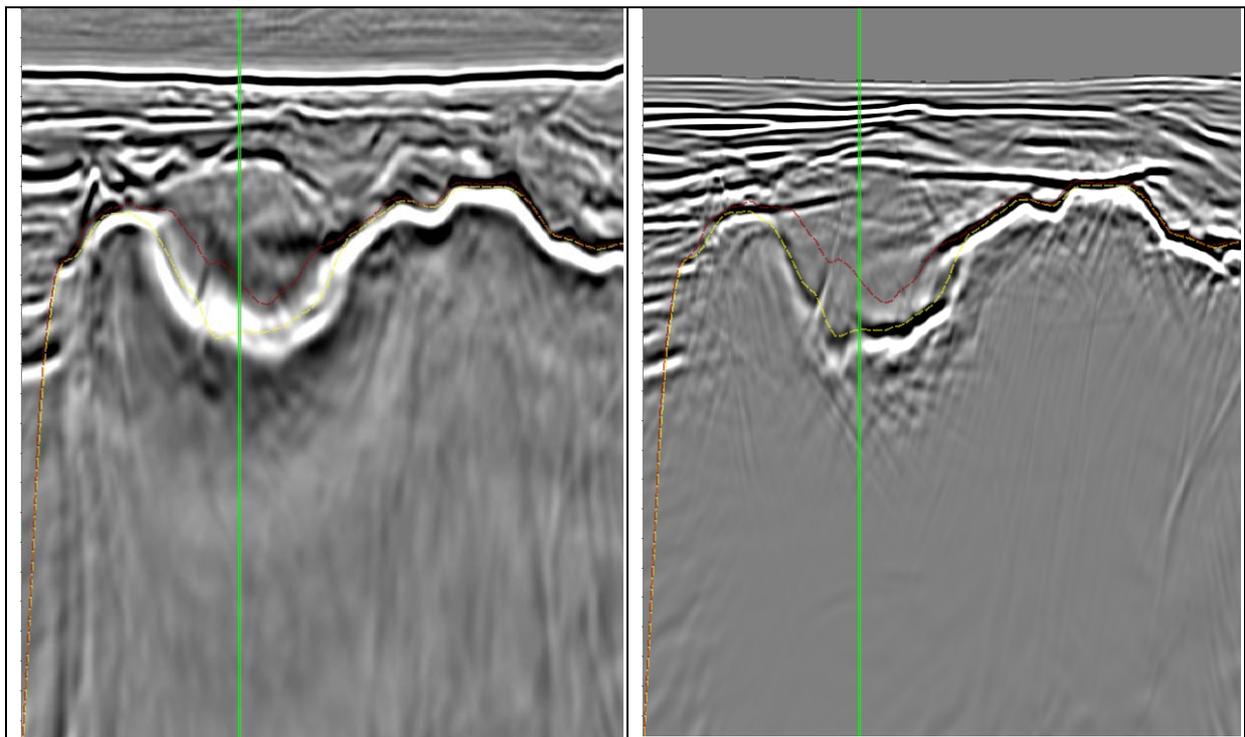


Figure 3. Sediment-flood migrations for 30Hz RTM (left) and 30Hz beam migration (right) images with model created with their independent corresponding top salt picks. The beam top-salt pick is shown in yellow, the RTM pick in red.

The validations (Figure 4) show that the RTM image produced with top salt picked on the sediment flood beam migration matches with the corresponding Kirchhoff image (also produced with a top salt picked on the sediment flood beam). However, this model does not image the top salt event perfectly (as the ToS1 pick is enhanced but still has some inaccuracies). The horizontal red line on the Kirchhoff images in Figure 4 marks the zero-crossing point for the deepest phase of the top salt. If the salt flood model has been built perfectly then all validations should align on this event. The observed displacement of the top salt event even with the optimum salt flood model comparing to the sediment flood confirms that surface picked on the 30Hz beam migrated image is still not perfect.

Conclusions

We have shown that the use of a migrated image that has insufficient bandwidth for picking of high velocity contrast interfaces like top salt can lead to mis-picks. We have illustrated that subsequent salt flood velocity models will impose leakages of incorrect velocities that may make image even less accurate. Care must be taken to validate picking in such areas with a variety of migration methods (Kirchhoff, beam, and RTM).

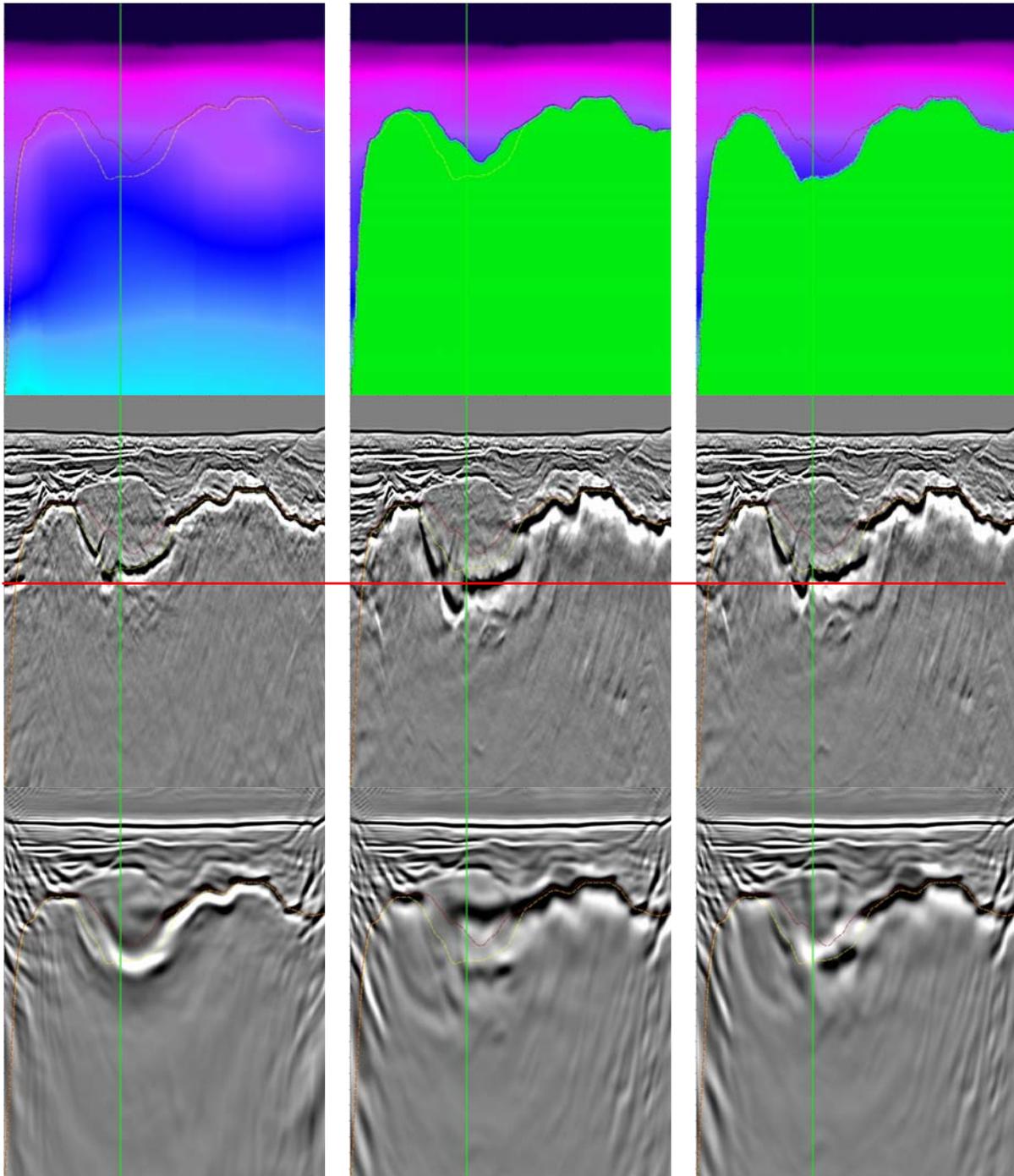


Figure 4. First Row are models, second row - Kirchhoff validations, third row - RTM validations. Left column – Sediment flood, centre column – salt-flood with ToS1 picked on RTM, right column – salt-flood with ToS1 picked on beam migration

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References

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