Case study: On the impact of interpretation uncertainty over velocity modeling for time-depth conversion

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Abstract

On this work we present a case of the Campos Basin, where a velocity model creates false structural lows in the interpretation converted into depth. We investigated different reasons that could be causing these undesirable artifacts, which included: - using different velocities in creating the velocity model; - testing an image ray approach to the depth conversion stage; - and considering uncertainties in the original interpretation and its associated influence on building model. The main objective of this work is to provide an insightful perspective on how the variation of parameters and subtle changes in input data can substantially affect the speed model and consequently the depth conversion.

Introduction

The largest Brazilian reserves are located in the Campos, Santos and Espírito Santo basins (ANP, 2016). These basins have remarkable salt tectonics and an immense exploratory potential of sub-salt (WEBSTER & PAULA, 2005). However, the presence of large evaporite bodies provides a challenging environment for seismic imaging and under-salt interpretation (JONES & DAVISON 2014). The type of survey - 2D or 3D - and processing (e.g. PSTM, PSDM, Kirchhoff migration, RTM) generate results with different image qualities and event positioning (BIONDO, 2006; LINER, 2016), directly impacting seismic interpretation, well tie and velocity modeling for depth conversion.For the past couple of decades there was significant improvement in acquisition and processing techniques, which yield more accurate images of complex subsurface structures (e.g. COGAN, 2011; ZDRAVEVA, 2011; COOKE, 2012), helping the mitigation of uncertainties of seismic interpretation. However, it is still common to encounter data which those or other current techniques were not applied. In cases like this, picking events such as the salt base, extrapolates the science and art of interpreting, and becomes something closer to an educated guess. Using a conceptual geological model, it is possible to rule out unreal possibilities, but the task is still tricky. The presence of large structures with varying thickness and considerable velocity contrast, such as salt bodies, can result in false highs or false lows, when converted from time to depth. Etris et al (2002) address this subject in a very clear and enlightening manner, and show how this can affect the final interpretation in depth.

Building a velocity model for time-depth conversion is one of the most important stages during the construction of a geological model. Initial quality control should be done by checking important information such as the size of the area, the structural complexity of the bodies of interest, the type of data and their quality, the lateral speed variation and the availability of wells to calibrate and adjust the model (BULHÕES et al., 2014; MENEGUIM et al, 2015). The overall velocity modeling workflow has the following input: processing velocities, horizons and well data (time-depth tables, well logs and well markers tied to the interpreted horizons). All three of them are subject to uncertainties on the interpretation due to data quality, but for this work we will be focusing on the velocity values and horizons interpretations.

The method for time-depth conversion – e.g. vertical or image ray – is another critical aspect for depth-converting horizons and seismic data. According to Liner (2016), in environments with strong lateral velocity variations, to depth convert interpreted horizons, the most accurate method would be ray depth migration (sometimes called section or map migration). However, the vertical ray approach can provide fairly accurate results. The choice of which method to use depends on: the type of migration applied before interpretation, the intensity of velocity lateral variations and the amount of well control. From Liner (2016):

> *"Vertical ray conversion assumes the migrated travel time represents information directly below each bin location. (…) In areas of gentle structure and weak lateral velocity variation, the vertical method is quick and reasonably accurate for time-migrated data. If the data have been depth migrated and displayed in time, the vertical ray method works even in presence of lateral velocity variations".*

For this work, most seismic data available were 2D PSTM. The interpreted horizons had to be merged from several different surveys and grids. The starting point was the regional velocity model for the Campos Basin (BULHÕES et al, 2014), which has an extension of over 247.000 km². Our interest concentrates at the northern part of this model, where the presence of the salt structures was greatly impacting the depth-conversion. At this particular stage of the project, we analyzed examples of interpretations for top and bottom limits of a salt structure, in a region of considerable structural complexity, where the bottom of the salt was not properly imaged.

Method

On this work, we focused at the northern part of the original model of Campos basin, in a region with 190 km long (N-S) and 150 km wide (E-W). At this region we observed the salt base was undergoing structural inversions, with structures representing local highs in time (Fig 1-A), becoming local lows in depth (Fig 1-B). These regions are correlated to the salt thickness, as shows Fig 1-C. These are also the regions where the seismic imaging was not clear, and consequently, the interpretation has a higher degree of uncertainty.

The observed structural inversions could be caused by different sources, from which we considered the following three:

1) the constant velocity values used for salt velocity, meaning the problem could be the velocity model itself;

2) the use of the vertical ray approach for depth conversion;

3) or the issue could be caused by uncertainties related to the interpretation of the horizon(s).

We addressed the first hypothesis by creating different scenarios, with the velocity from salt bodies varying from 4500 m/s to 3500 m/s. These models were then used to depth-convert the interpreted salt base. The resulting horizons for the base of the salt, displayed on Fig 2, still show some marks of inverted structures, represented by yellow and green spots inside the region of interest, delimited by the polygon. These marks tend to be less expressive as the value used for salt velocity decreases. However, we only stop seeing significant structural inversions when we used a velocity of 3500 m/s for the salt. But this is not compatible with the velocity values expected for Halite, which would be 4500 m/s (JONES & DAVISON, 2014).

To investigate the second hypothesis, which concerns the type of depth conversion, we compare the resulting horizons from vertical and image ray conversions, which are displayed on Fig 3. Since the structural inversions are present on both results, we disregard the conversion using image ray, and we decide to use the vertical approach to evaluate the third hypothesis. The appraisal of interpretation uncertainties involved creating new horizons for the base of the salt, based on the original horizon in time. The original horizon was disturbed below the thicker salt bodies, with different degrees of intensity. This resulted in different scenarios, where the interpretation varies locally, below the areas where the salt is thicker, while maintaining the overall aspect, where the evaporite layer is thinner or inexistent. Five of these scenarios are displayed on Fig 4, showing how an apparent subtle distortion in time could result in a more plausible horizon in depth. These scenarios are seen in more detail on Fig 5, where we can see the seismic depth converted using the original horizon, and using a constant velocity value of 4500 m/s for the salt. The different horizons are displayed in different colors, and the seismic was converted using the base case (original horizon).

On Fig 6 it is possible to compare the horizons obtained from hypothesis 1 and 3. On Fig 6-A we can see the original horizon after depth converting it using the original model with a salt velocity of 4500 m/s. On Fig 6-B we have the horizon converted using the velocity model with a salt value of 3500 m/s, which is the same case showed on Fig 2-E. And on Fig 6-C we have the horizon generated by disturbing the original interpretation, creating a smooth local high on time, and which lead to a more horizontal surface in depth. This is exactly the same case as Scenario 5 from Fig 4.

We have on Fig 7 an overall view of the interpretation of evaporite base, considering scenarios 1 and 5. Notice how the interpretations in time (Figs 7-A and 7-C) illustrate the differences where there is an increase in salt thickness. These are regions where we have a higher degree of uncertainty, due to the lack of visible structures under the larger salt bodies. After creating a different velocity model for each scenario, both using a constant velocity of 4500 m/s for the salt layer, we depth-converted the horizons, and the results are depicted on Figures 7-B and 7-D. As we can see, a different interpretation can have a great impact on the final converted horizon, and in this case, was enough to address the issue of inverted structures.

Discussion

Our work line consisted of a qualitative evaluation of the salt base, before and after its conversion, using different speed models. We raise three hypotheses for what may be causing the false basses: - the velocity value used for the salt layer; - the use of vertical radius instead of image radius for deep conversion; - or the interpretation of the horizon of the salt base, due to the low imaging in the seismic sections. The first two hypotheses were discarded because (1) the velocity values needed to convert to depth coherent with the geology were not plausible, and (2) the use of the radius of the image instead of the vertical radius had no results compatible with the geology of Generate the same artifacts in structures. However, this last hypothesis is not completely refuted, although this algorithm has better results in areas where there are no large lateral variations of velocities. According to Jones and Davison (2014), the seismic velocity values for the main evaporite minerals vary from 3500 m/s (Tachydrite) to 6500 m/s (Anhydrite), but the most common is Halite, with a velocity of 4500 m/s. Of the wells within the region of interest, we know that most of the evaporite consists of Halite, with some portions of Anhydrite. If we consider an Anhydrite buffer for the models, the velocity would increase, and as we can see in Fig. 2, to obtain the horizon of the base of the flatter salt in depth we would need to decrease the velocity value for the salt. For this reason, it is not possible to assume a velocity of 3500 m/s to be realistic when constructing the velocity model.

Using image ray for depth-converting is also a valid approach. However, after realizing there was no effect on the task of avoiding the creation of inverting structures, we opted to keep the vertical approach. The rationale was to work on the hypotheses independently, avoiding mixing the influence from different factors. This does not mean that image ray was not suitable. It just means that it was not able to explain alone the false lows created in depth by the model. For that reason we investigated further into the third hypothesis.

The results from the interpretation uncertainties approach were the most significant and instructive, showing how subtle changes on the interpretation in time can lead to unrealistic behavior from the horizons in depth. This evidence is supported by the horizons shown on Figures 4 and 5. The horizon represented in light blue (scenario 1) is the original interpretation, and was interpreted as a smooth upward variation in time, which lead to a false low in depth. The purple horizon (scenario 5), on the other hand, was interpreted in a more prominent manner, and resulted in a more flattened horizon in depth, which would be the expected result. In other words, there was less salt than expected in the system, and when we altered the evaporite thickness we corrected its base to a geologically plausible depth.

From Fig 7 we can have a clear view of the entire region of interest, and acknowledge that the inverting structures were caused because the salt thickness was overestimated. But as stated before, given the available seismic data, interpreting the base of the salt was not a trivial task. In this particular case, considering different interpretation scenarios is the quickest and most feasible approach to reflect geology, that is, by considering thinner layers of salt.

Conclusions

In this work we investigated the causes for issues in depth-converted horizons. We noticed local structural highs in time were changing to local structural lows in depth, especially under large bodies of salt. Using different approaches, we tested possible motives that could lead to such results, and concluded that the most prominent motive was a misinterpretation of the base of the salt, notably in regions where the evaporite is thicker. By using slightly different interpretations we managed to achieve more plausible results in depth.

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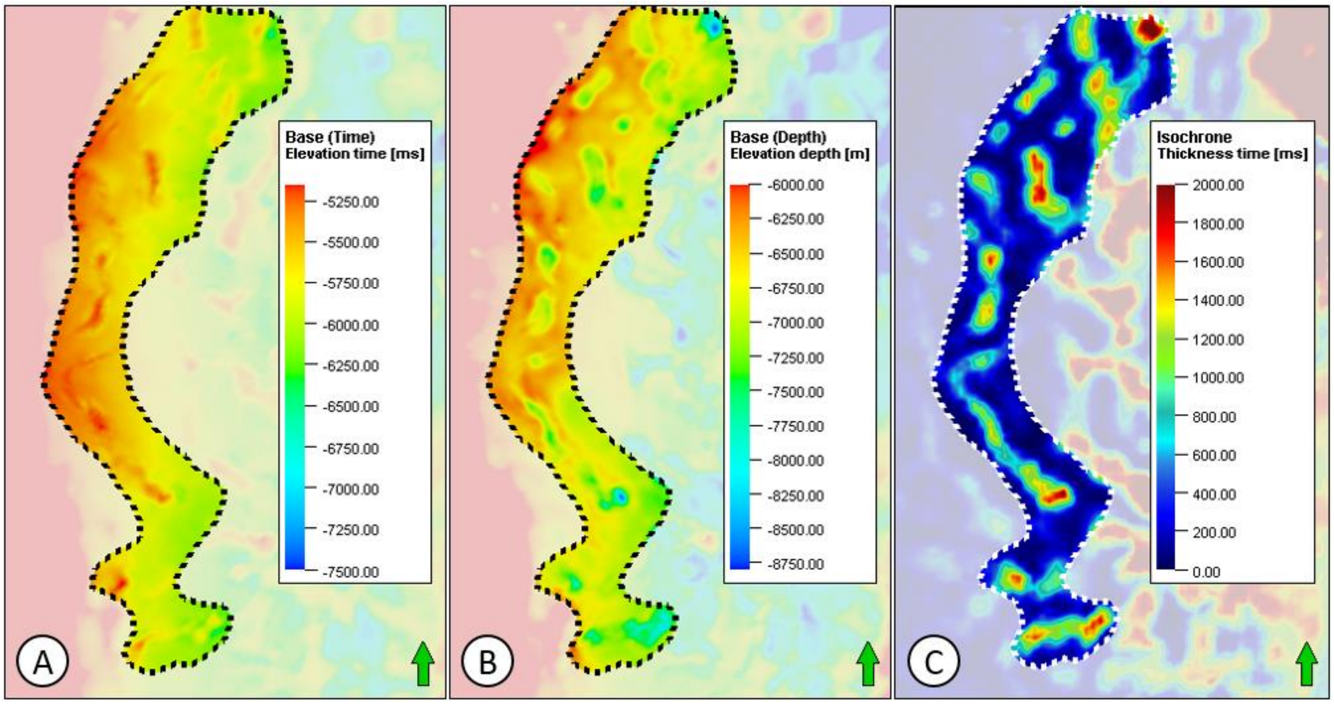

Figure 1: Horizon from the base of the salt, in time (A) and depth (B). The inverted structures, shown as local highs in time and local lows in depth, coincide with the regions where there's an increased thickness in time of the salt, shown on (C)

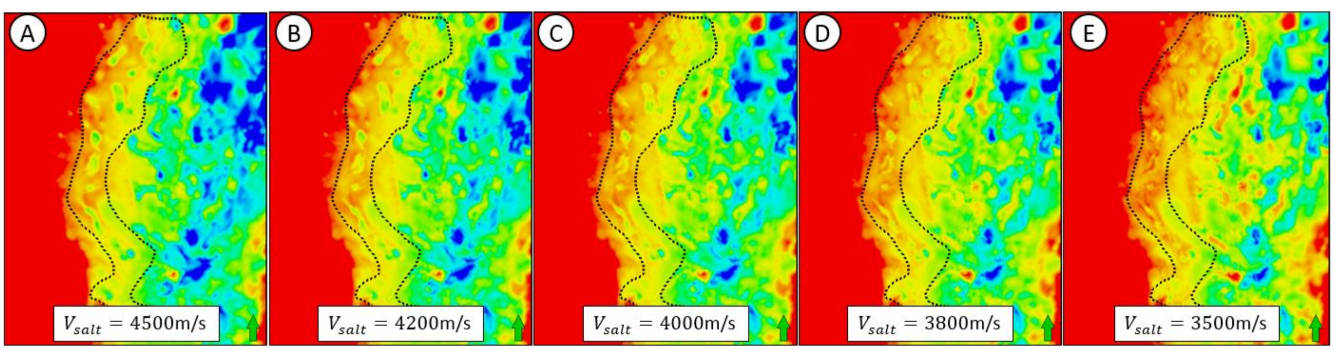

Figure 2: Base of salt in depth, converted using different velocities for the evaporite layer: A) 4500 m/s; B) 4200 m/s; C) 4000 m/s; D) 3800 m/s; and E) 3500 m/s. The region of interest is delimited by the dashed line.

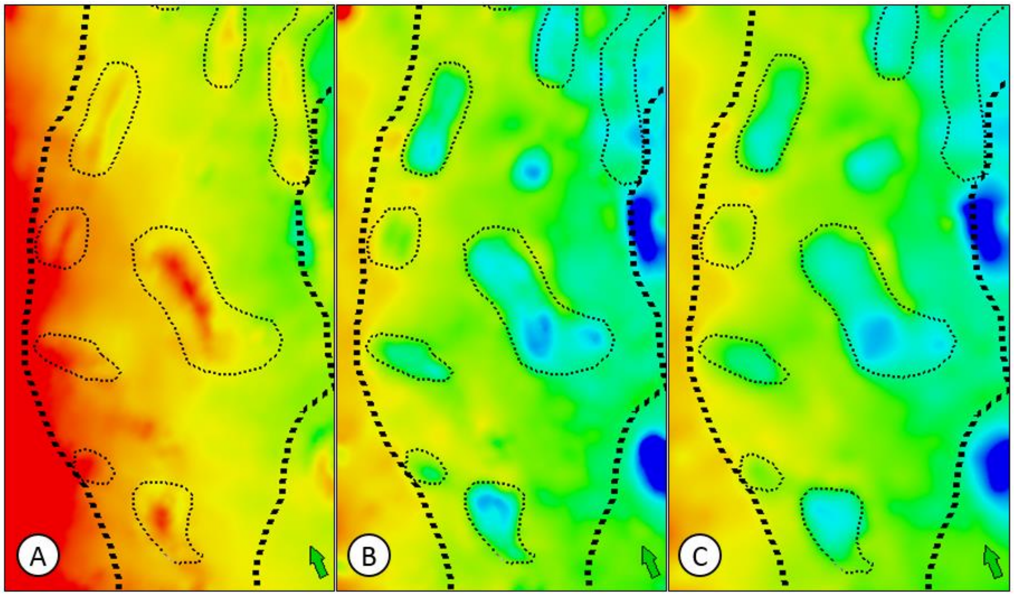

Figure 3: Comparison between A) original horizon interpreted in time; B) horizon in depth, converted using the vertical ray approach; and C) horizon in depth, converted using the same model as B, but through image ray approach. The thick dashed lines represent the area of interest, and the thin dashed lines highlight some of the bodies which underwent through structural inversion after domain conversion.

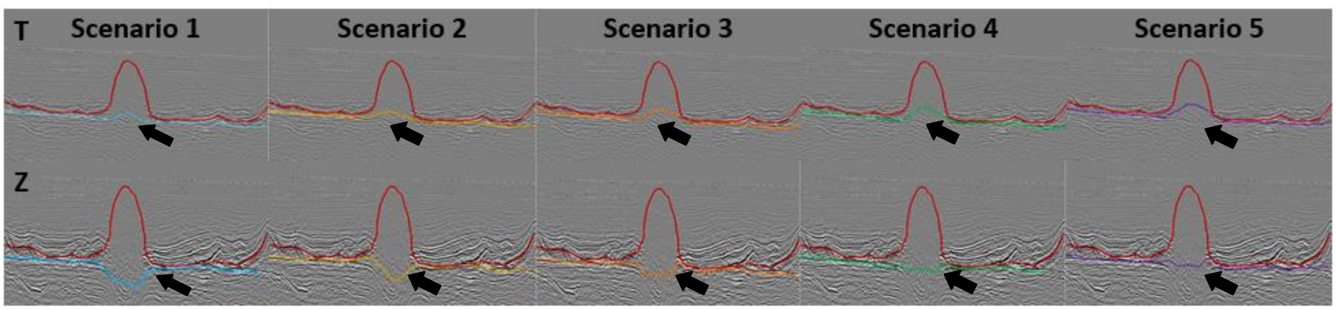

Figure 4: Five different interpretations (scenarios) for the base of the salt. The top of the salt is shown as reference. On the upper part, the sections in time, and on the bottom the same sections after depth conversion. For all scenarios, the salt velocity was kept constant at 4500 m/s.

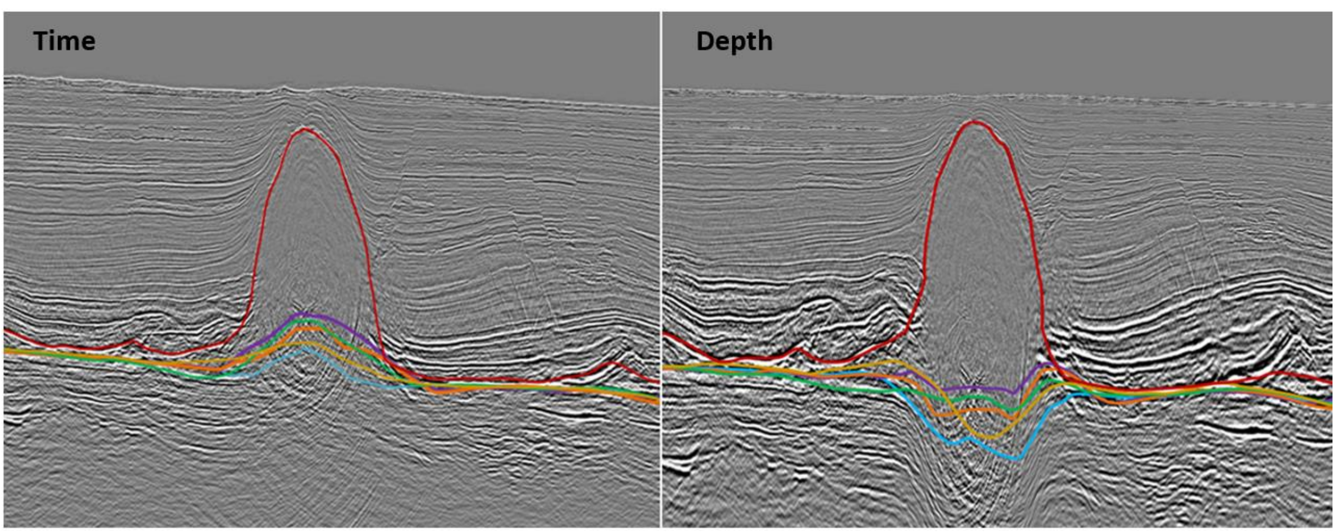

Figure 5: On the left, detailed seismic section in time with the 5 different interpretations for the base of the salt. On the right, seismic section depth converted using the original interpretation (horizon in light blue), and the horizons from the other scenarios.

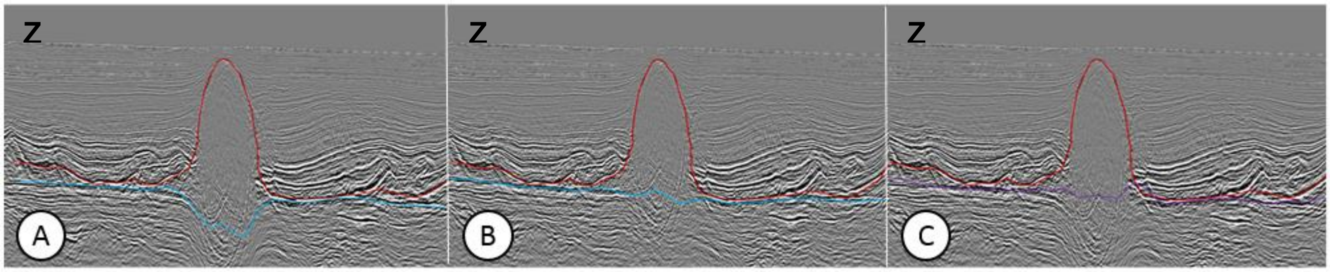

Figure 6: Comparison between approaches from hypotheses 1 and 3. A) Scenario 1 (base case) for the base of the salt, when depth-converted using a salt velocity of 4500 m/s; B) Scenario 1 for the base of the salt, depth converted using a salt velocity of 3500 m/s; and C) Base of the salt from scenario 5, using the constant value of 4500 m/s for the evaporite.

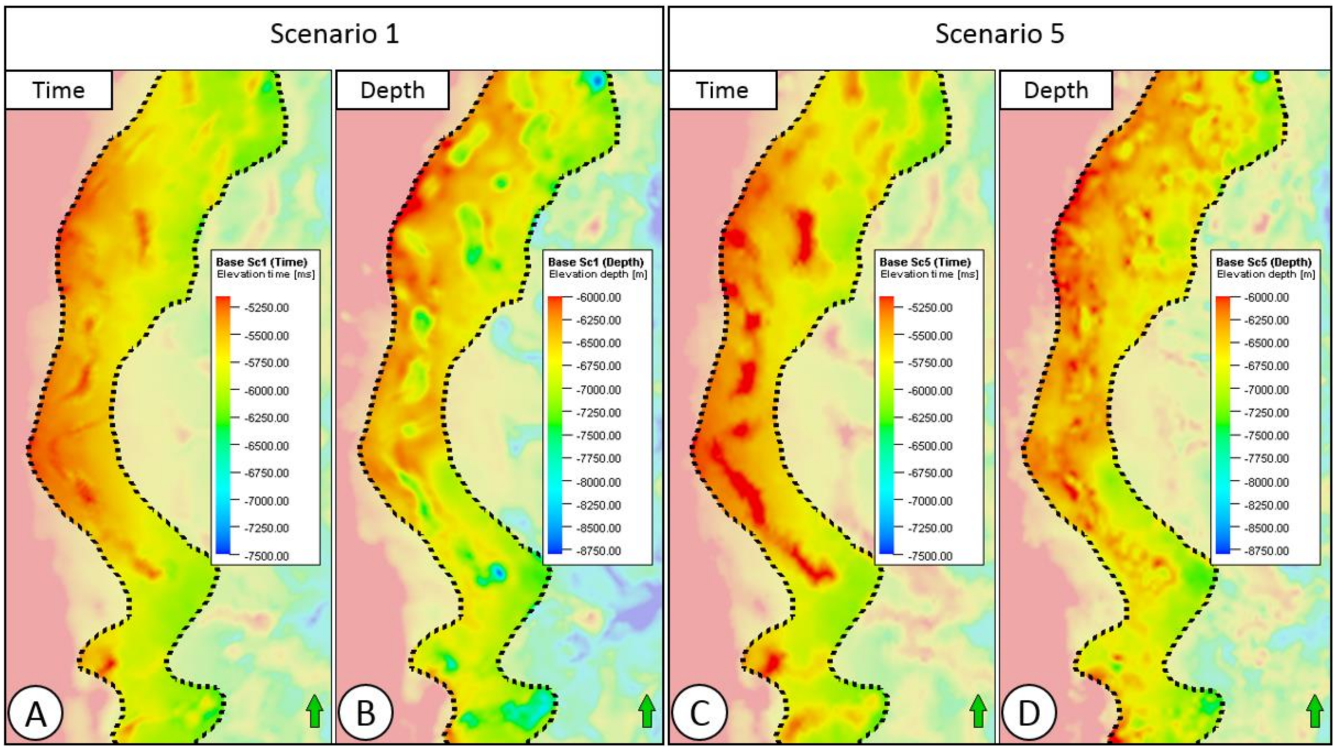

Figure 7: Maps showing the scenarios 1 and 5 for the interpretation of the base of the salt, in time (A and C) and after depth conversion (B and D).