Th P3 10

Dip Constrained Tomography as Applied to Subsalt North Sea Data

D. Carotti* (CGG), C. Brillatz (CGG), P. Guillaume (CGG), A. Prescott (CGG) & A. Cavalié (CGG)

SUMMARY

Developed for the shallow channel anomalies in the North Sea, the dip constrained tomography can also be effective in subsalt areas, when geological dip constraints are known. Subsalt areas often suffer from noisy residual move-out information and limited angular coverage. In this work, we show that the introduction in the non-linear slope-tomography cost function of an additional term related to the offset-dependent imaged dips helps in stabilizing the inversion and the computed velocity perturbations. We use a North Sea example to demonstrate that the use of geological constraints in this extended tomography below complex overburdens improves the seismic image focusing and provides a more geologically plausible velocity model.

Introduction

Velocity model building through non-linear slope tomography (Lambaré, 2008) aims at computing an accurate velocity model for seismic imaging. As the inverse problem is non-linear and ill-posed, it requires both a non-linear optimization process and the introduction of pertinent constraints. A wide diversity of constraints has been proposed in the past. More recently, the industry focused on the smoothness and the structural constraints on the velocity and the anisotropic model (Zdraveva *et al*., 2013; Woodward *et al*., 2014). The offset-dependent dip information measured from migrated data (Guillaume *et al*., 2013) has been introduced to solve localized lateral variations for avoiding artifacts in the migrated image (Pape *et al*., 2014; Chen and Hu, 2014). The aim of this work is to demonstrate the effectiveness of using such dip-based constraint in the subsalt area, thanks to the measured diversity of structural dips in the offset domain.

Multi-layer dip-constrained non-linear slope tomography

Multi-layer non-linear slope tomography (Guillaume *et al*. 2012) was developed to model strong velocity contrasts such as the ones found in the central North Sea. It also offers the capability to partition the model into distinct layers, allowing high flexibility in the model and in the inversion parameterizations, as well as the use of different geological constraints in each layer. Among all of the geological constraints, one can be linked to the dip of the seismic image itself. In particular, we can minimize the discrepancies between offset-dependent dips, dip_j, and the reference dips of picked reflectors, dip_{jref}, with no assumption on the position of the reflectors themselves. For example, in the case of the push-down distortions observed in Figure 1, we would actually expect the spatial dip to follow the generally flat trend of the structure. The offset-dependent spatial-dip distortions that are measured below localized velocity anomalies can be introduced in the cost function for delineating and quantifying those velocity anomalies. As a result, the multi-layer non-linear slope tomography cost function is extended as follows:

$$C(m) = \sum_{rmoevents} \alpha_i \|\delta RMO_i\|^n + \sum_{dipevents} \beta_j \|dip_j - dip_{jref}\|^n + R(m),$$

where the first term represents the minimization of the residual move-out (RMO) slopes, the second is the additional term that allows for considering the geological constraint in data domain and *R(m)* is a regularization operator. Both the RMO slopes and the dip distortions can be converted into kinematic invariants (Figure 2) as defined in (Montel *et al*., 2009), and they are simultaneously inverted to update the velocity model *m*. The additional term allows minimizing the misfit between the offset-dependent dip of the re-migrated facets dip_j and an expected dip dip_{jref}, with β_j denoting the weight associated with each facet. Non-linear iterative local optimization is used to minimize the new cost function. Note that the volumetric dip constraint is structural and does not constrain the depth location of the seismic reflectors. The offset dependent dip distortions can result from localized strong velocity contrasts and/or variations in the overburden. The use of the geological dip constraints in the subsalt area, together with the simultaneous non-linear inversion of all layers in the model, brings more information into the inversion. This should stabilize and improve the inversion and the computed velocity perturbations. In the following example, we show that a more geologically plausible velocity model and seismic image can be obtained with this extended tomography.
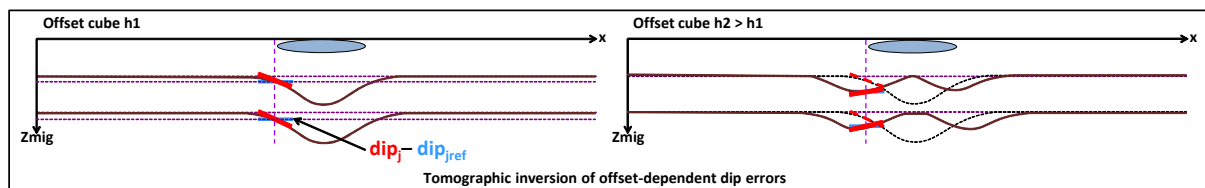

Figure 1 *Offset-dependent Dip error term added to the tomography misfit function.*
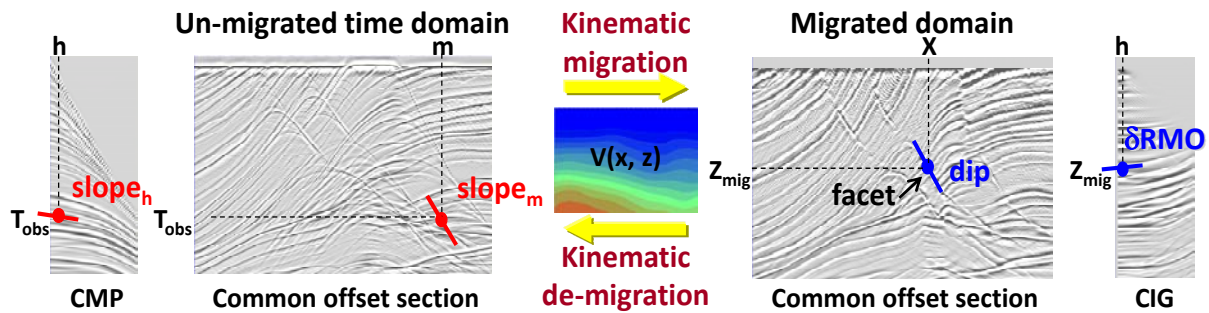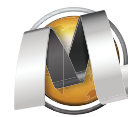
Figure 2 Kinematic invariants in un-migrated domain (left) and corresponding facet (right) in depth migrated domain after kinematic migration. m is mid-point position in un-migrated domain, X is facet position in migrated domain and h is the source-receiver offset. Non-linear slope tomography aims at flattening gathers minimizing RMO slope δRMO.

A subsalt example

In this North Sea example, the model contains six layers including the water and the Zechstein salt. Tilted fault blocks are known to exist in the sub-salt area (Figure 3). We first perform a high-definition simultaneous inversion of all the layers using a dense set of RMO picks for each layer. The result gives a good imaging, but there is a visible lack of focusing in the sub-salt reflectors of the tilted faulted blocks (Figure 4 – left). This issue can be explained by the relatively small maximum offset of the acquisition (3000 m), characterized by a too limited angular range (25 degrees), resulting in large velocity uncertainties. For this reason, given the interpreter geological knowledge of the tilted faulted blocks in the sub-salt area, we introduced the offset-dependent dip constraint. In practice, the offset-dependent dips, dip_j, are picked over 800 m depth from the base of salt.
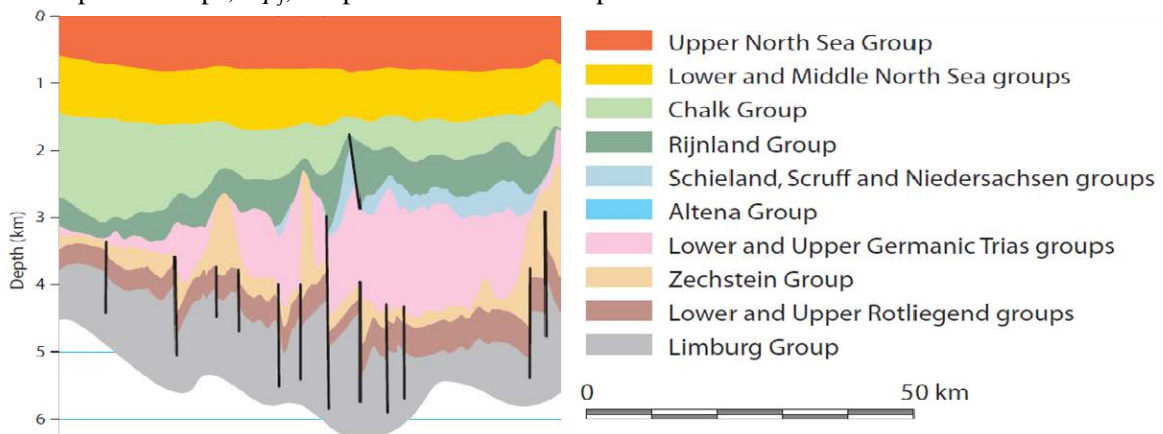

Figure 3 SW-NE geological cross section closer to the survey showing the existence of tilted faulted blocks in the pre-Zechstein groups (Duin et al., 2006).

The reference dip model, dip_{jref}, has been built using the PreSDM stack and few conformal horizons between the base of salt and a deeper horizon. Adding these dip constraints improved the overall image focusing of the deep target (Figure 4 – right). The velocity model (Figure 5 – right) shows a better lateral consistency in the sub-salt compared to the tomographic result without dip-constrained tomography (DCT) (Figure 5 –left). Moreover, the PreSDM common image gathers validate the overall improvement of the imaging results (Figure 6).

In addition, similarly to the QC of the RMO re-migrated facets, the extended tomography can also output the re-migrated facets dips. In Figure 7, we quantify the uplift of DCT by comparing the facet dips migrated in the final models with (Figure 7 - bottom) and without DCT (Figure 7 - top). The colour scale represents the error, in degrees, of the migrated dips with respect to the expected dip. Note that the success of the inversion can also be appreciated by simply looking at the migrated facet dips. The good superposition of the migrated offset-dependent facets with the associated seismic image confirms the effectiveness of this inversion QC.
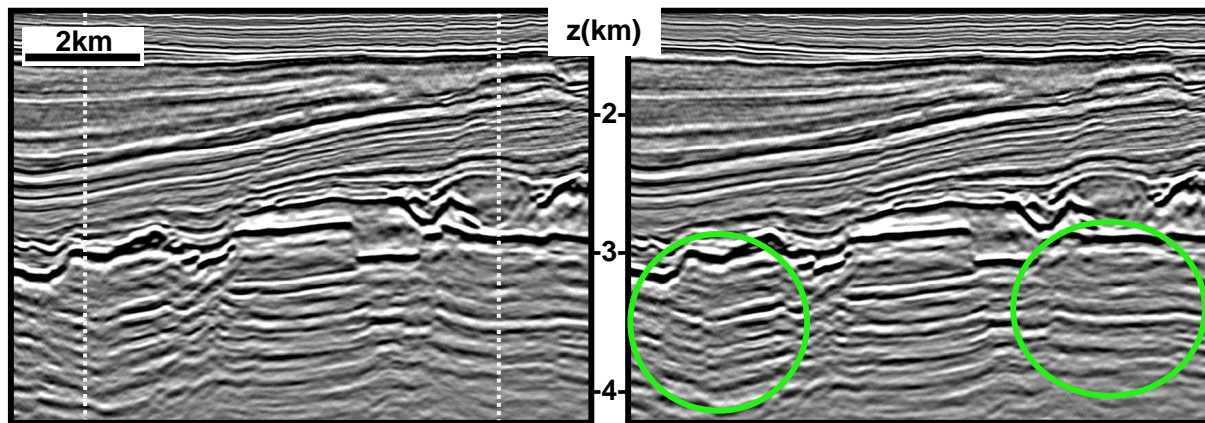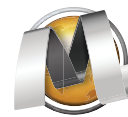
Figure 4 PreSDM stack: Left) without dip-constrained tomography showing the distortion in the subsalt faulted tilted blocks; Right) after dip constrained tomography, the fault plane are well defined, the migrated image is better focused and less distorted (see green circles).
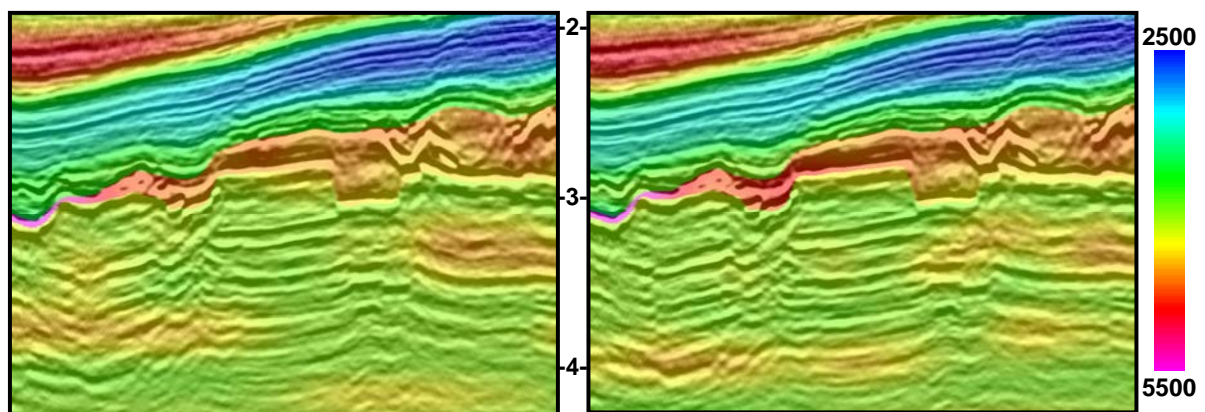

Figure 5 PreSDM stack with velocity model (m/s) overlaid: Left) without DCT; Right) with DCT, showing a better lateral consistency of the velocity with the subsalt faulted tilted blocks.
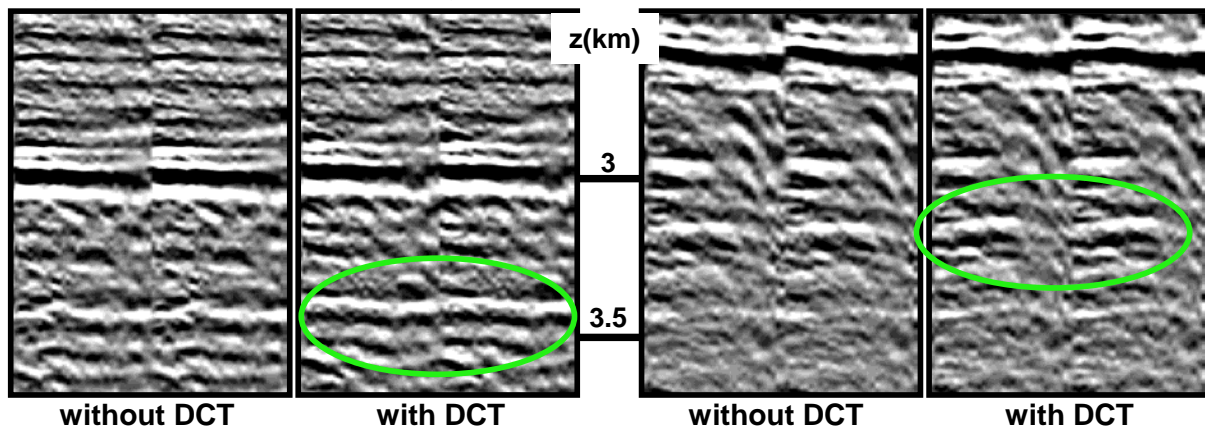

without DCT   **with DCT**   **without DCT**   **with DCT**

Figure 6 Two PreSDM gathers at two locations (dashed lines in Figure 4): Left) without DCT; Right) with DCT, showing better flattening and less noise.

Conclusions

In this work we have demonstrated how the application of dip-constrained tomography can be successfully extended to deeper targets below complex overburden. As illustrated with this North-Sea dataset, the offset-dependent dip-constraint formulation is fully compatible with multi-layer and high-definition tomography.
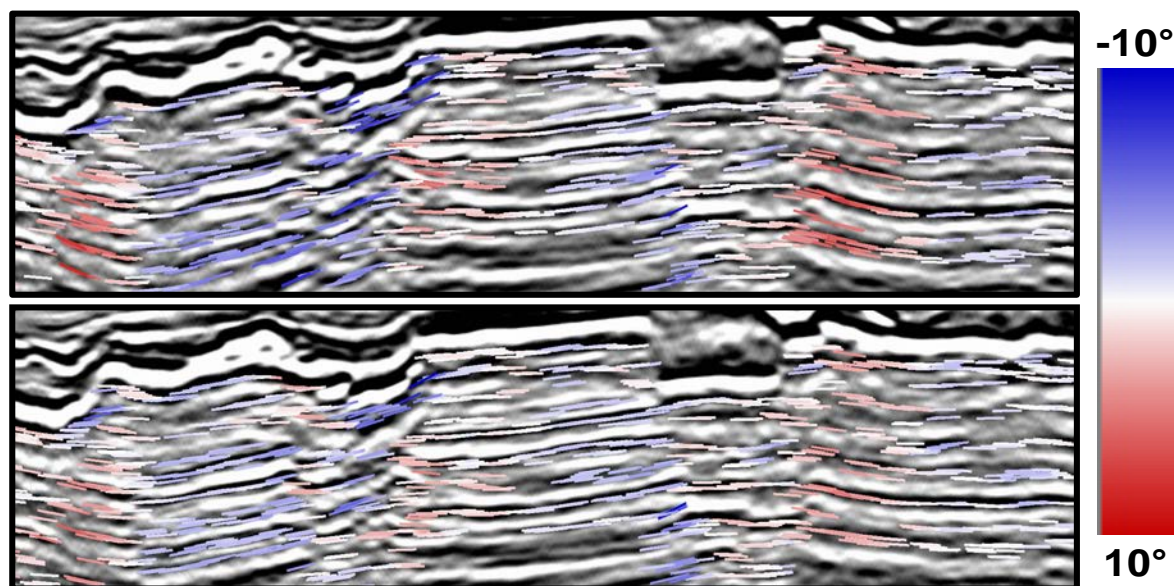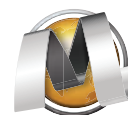
Figure 7 *PreSDM stack with overlaid dip-error facets (in degrees): Top) without using DCT, showing big dip errors in the subsalt faulted tilted blocks; Bottom) using DCT, the dip error is generally reduced.*

Acknowledgements

References

Chen G. and L. Hu [2014] Dip-constrained tomography with weighting flow for paleo-canyons: a case study in Para-Maranhao Basin, Brazil. *84th SEG Conference & Exhibition*, Expanded Abstracts, 4718-4722.

Duin, E.J.T., Doornenbal, J.C., Rijkers, R.H.B., Verbeek, J.W. and Wong, Th.E. [2006] Subsurface structure of the Netherlands – results of recent onshore and offshore mapping. *Netherlands Journal of Geosciences*, **85**(4), 245-276.

Montel, J.-P., Deladerriere, N., Guillaume, P., Lambaré, G., Prescott, A., Touré, J.-P., Traonmilin, Y. and Zhang, X. [2009] Kinematic invariants describing locally coherent events: an efficient and flexible approach to non-linear tomography. *71st EAGE Conference & Exhibition*.

Guillaume, P., S. Hollingworth, X. Zhang, A. Prescott, R. Jupp, G. Lambaré and O. Pape [2012] Multi-layer tomography and its application for improved depth imaging. *82nd SEG Conference & Exhibition*, Expanded Abstracts, 1-5.

Guillaume, P., M. Reinier, G. Lambaré, A. Cavalié, M. Iren Adamsen, and B. Munch Bruun [2013] Dip-constrained non-linear slope tomography: an application to shallow channel characterization. *75th EAGE Conference & Exhibition*, Tu 02 09.

Lambaré, G. [2008] Stereotomography. *Geophysics*, **73**(5), VE25-VE34.

Pape, O.I., P. Fallon, J. Tatat, F. Varriale, S. Hollingworth, B. Duquet, X. Lu and E. McManus [2014] Recent Advances in Sub-BCU Processing and Imaging in the Central North Sea. *76th EAGE Conference & Exhibition*, Th D201 13.

Woodward, M., Y. Yang, K. Osypov, R. Bachrach, D. Nichols, O. Zdraveva, Y. Liu and A. Fournier [2014] Geological and Rock Physics Constraints in Anisotropic Tomography. *76th EAGE Conference & Exhibition*, WS12-B01.

Zdraveva O., S. Hydal and M. Woodward [2013] Tomography with Geological Constraints – An Alternative Solution for Resolving of Carbonates. *75th EAGE Conference & Exhibition*, Th 04 04.