Introducing Geological Constraints into Preprocessing

Howard Nicholls, Paolo Esestime, Chris Benson and Milos Cvetkovic (Spectrum Geo Ltd)

Introduction

The introduction of geological constraints to seismic data is usually left for more detailed data studies, and is not fully utilised until later stages of the depth model building and imaging process (Foss et al., 2008). The velocity model used for time migration frequently relies on simple Dix conversion of picked root-mean square (RMS) velocities to interval velocities. Here, issues can arise with instability, due to downward propagation of shallow picking errors and velocity inversions, (Al Chalabi 1979). Further issues can arise with the smoothing necessary for a stable conversion and in maintaining consistency in velocity fields across multi-line 2D surveys. There have been numerous potential solutions for this issue, such as the Constrained Dix inversion workflow proposed by (Koren and Ravve, 2006), but most of them will perform poorly in more complex structural settings.

We have developed an efficient workflow which introduces geological constraints into the time interval velocity field with the use of interpreted key horizons. Using horizon based velocity analysis, consistent models can be developed, tied at intersections, and be rigorously quality controlled prior to running final time migrations. This workflow removes the need for a time consuming iteration and quality control of RMS vertical function picking, and any subsequent adjustments needed to achieve a stable interval velocity field. Such models provide better input for depth model building and other inversions, reducing the number of iterations to converge to a final depth model.

In this abstract we show data examples for 2D seismic datasets, illustrating both simple and complex structural settings, in different frontier areas. We find that introducing geological constraints earlier in the time processing sequence, significantly improves confidence in the survey wide consistency of migration models, the tying of the migrated datasets, and the preliminary time to depth conversion. It can also improve imaging quality, and provide a significant improvement to initial velocity models carried through to a depth imaging sequence. The case studies illustrated are from the Outeniqua Basin (offshore South Africa), the Santos Basin (offshore Brazil), and the Congo Basin (offshore southern Gabon).

Using geological information in pre-processing – PSTM velocities

Conventional velocity models for time migration consists of picking a time RMS velocity field, and then converting using Dix formula, either external to, or internally within the migration algorithm. This method usually relies on picks made from vertical analysis of seismic gather data. There can be issues with the stability of the time interval velocity conversion using RMS velocities. Even with consistent RMS picking, rapid lateral and vertical variations within the interval velocities can occur. (Hubral and Krey, 1980). Smoothing, manipulation of original velocities, or other pre-conditioning may still not give geologically plausible models, or produce tied time interval velocities (Figure 1a).

Using the initial time migration section derived from the picked RMS fields, key geological horizons showing significant velocity contrasts are interpreted. Available geological and well data can be utilised to guide this process, and confirm interval velocities are realistic. Horizons may also be picked with reference to changes in vertical velocity gradient using vertical semblance analyses. Interpreted horizons are tied at intersections. Horizon based velocity semblance analyses, and picks are made for each horizon in turn. If the velocity picks made are tied at the intersections, then a 3D unified velocity model can be built up. Picks are made to achieve laterally smoothly varying RMS velocities for each horizon. Time interval velocity fields are generated from these picks incorporating additional vertical smoothing. The water column velocity is then separately re-inserted above the water bottom horizon, and a constant gradient function inserted from ‘basement’. Quality control of

![Figure 1 Deriving geologically consistent model for PSTM. Time RMS model (a), vertical semblance (b), PSTM gather at highlighted location (c) and horizontal semblance along formation (d). Example of velocity ties at intersections (e). Geologically consistent time interval model (f).](spectrumgeo.com/techpapers)
the geologically constrained time interval field is achieved by converting back to RMS, re-extracting the horizon interval velocities and then comparing vertical velocity trends, and gather flattening, against the picked initial RMS field (Figure 1). The objective is to ensure the velocities remain on trend for each horizon, and will broadly flatten the migrated gathers at all times. More structurally complex areas may require a greater number of horizons to maintain control of velocities across these structures. We also apply an additional pass of lateral and vertical smoothing when creating final time interval models in order to maintain structure following velocity gradients. Interval velocity inversions can be readily incorporated given suitable geological or structural justification.

2D marine data Outeniqua Basin, offshore South Africa
This study comprises a 10,000 km subset, from 9 different 2D data vintages, covering the period from 1972 to 2005. Total available data in the area extends to over 40,000 km. The data was processed through a modern PSTM imaging sequence, with careful attention paid to ensure all data vintages were matched in phase and amplitude. The Outeniqua Basin was formed during Late Jurassic to Early Cretaceous break-up of Gondwana (Faulkner, 2002) and the subsequent drifting apart of the African and South American plates. The syn-rift succession marked by angular unconformity regarded as the drift-onset unconformity has been widely recognised on the seismic section.

Major seismic stratigraphic sequences seen within the seismic data are used to determine horizons to constrain the velocity building. A total of five key horizons are interpreted, including water-bottom and top of the syn-rift basin. The chosen horizons are then reviewed against the initial migrated seismic images. To complete the model below the ‘basement’ horizon, a gradient function is derived by testing along dip and strike directions. Horizon times and interval velocities are tied at all intersections to produce a unified velocity model with which to time migrate all data.

Results show interval velocities which follow geological structure and have an accurate boundary with the water bottom (Figure 2). Horizon based picking yields a laterally smooth field. The resulting migration image (Figure 3) shows improved imaging, particularly at water-bottom and the shallow part of the section. We notice better delineation of the faulting at the continental shelf.

2D marine data in more complex structural settings
Two case studies are presented to show the robustness of the workflow in complex geological tectonic settings, namely salt basins. The first example is a 200 km line segment from the Santos Basin (offshore Brazil), which is part of a total of 13,650 km, acquired in 2012. The Santos Basin initially formed as a rift basin during the Early Cretaceous as the South Atlantic began to open (Kamer and Gambaó, 2007). A series of graben and half-graben were filled by non-marine strata, overlain by shallow-marine carbonates. During the late Aptian post-rift, a salt-rich succession was deposited with maximum thickness of 2.4 to 2.6 km (Davison et al., 2012). In this example, seven key horizons are interpreted, including water-bottom and base of the sedimentary basin. Remaining horizons are selected based on available non-seismic geological and compared against velocity gradient changes observed in vertical semblance analyses from the initial time-migrated data. A gradient function is incorporated below the ‘base salt/top basement’ horizon.

Use of geological constraints in this more complex area has allowed the velocities to more closely follow structures (Figure 4). Although salt is present, the surrounding carbonates are of similar velocity, and modelling an interval velocity inversion below salt was found unnecessary in this case. A greater number of interpreted horizons are found necessary for this more complex example.

The second example is from the Congo Basin (offshore southern Gabon), also containing complex salt tectonics,
and created due to rifting of the South Atlantic (Karner and Gambôa, 2007). Along the Gabon margin, onset of rifting commenced in Neocomian to Barriasian times, and is characterized by syn-rift clastic fluvial and lacustrine sediments, Aptian salt, and drift marine deposition. The survey consisting of over 13,000 km of 2D data was acquired in 2008 and 2009. Initial testing on 2 lines (400 km) saw significant uplift achieved using a geologically constrained depth migration. These lines are now re-run with geological constraints applied in the time domain using the method described, followed by an initial depth migration. For this model, a total of six horizons were utilised, including water-bottom, top carbonates/salt formation, base salt, and top synrift. Interpreted horizons are based on non-seismic geological information, two well locations, and with reference to initial migrations. The constrained time interval velocity model is integrated into the depth imaging workflow by 1-D scaling to depth, and ray tracing of interpreted horizons. This gives consistent, tied initial depth models from which to perform iterative velocity updates (Figure 5). The resulting depth image shows some significant uplift, with improved flattening of events in the depth gathers, compared to the unconstrained velocity model. This is close to the imaging achieved after 2 to 3 iterations of velocity updates applied to the unconstrained model.

Conclusions
We have presented a PSTM workflow that utilises geological and other non-seismic information at an early stage of the processing sequence. Lateral inconsistencies in the interval velocities are removed, and models follow geological structure with greater accuracy and detail. By introducing regional interpretation and tying models in the time domain we reduce time spent on manual picking, and adjustment of velocity models. We find such models present a better starting point for depth migration workflows because they need less conditioning, even compared to alternative constrained inversions. There is also potential to reduce the number of iterations required in the velocity update process.

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References