P-Wave Ocean-Bottom Node Processing in Gulf of Mexico: a test survey

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Abstract

High-quality data from the sea floor can be acquired with ocean bottom nodes. Usually, the data is acquired in deep waters with a large distance between receivers that makes the conventional processing a challenge when applying to sparse nodes data sets. The challenge is to maximize the quality of seismic imaging by using an effective processing capability. Limitation in conventional marine seismic has driven the development of a 3-D Prestack Depth Wave Equation Processing Package, which provides high quality resolution imaging, even for sparse receiver geometry. We present the processing results (wave-field separation, velocity analysis and imaging) from a test survey in Gulf of Mexico.

Introduction

Imaging techniques have been optimized for many years since large deposits of hydrocarbons are associated to the presence of complex overburdens (Higginbotham *et al*., 2010).

High costs in drilling through such areas, in deeper water, increases the exploration risk emphasizing the need for detailed geophysical investigation over these structures and sub-salt sediments.

The OBS nodes techniques with the proper geometry design provide full azimuth distribution being able to illuminate under complicated geology.

The need for an effective processing tool led to the development of the work flow presented in this paper. Here we outline a processing test survey from Atlantis field in Gulf of Mexico. The data set imaging was performed through the shot record migration using reciprocity. The results are impressive considering the number of seismic nodes.

Imaging Technique

The processing package was developed to perform P-wave imaging from hydrophone and vertical geophone data in two different ways using a technique that was originally developed for vertical-cable data technology (Guimarães *et al.* 1998).

When imaging bottom node data for the P-wave, we process for two sets of energies:

1. We can image the energy that has traveled down from the source on the surface and reflected up into the receiver on the sea bottom. We call this the direct reflection and refer to it is as up-coming energy.

2. We can process for and image energy that has traveled down from the source on the surface to a reflector in the subsurface, back to the surface of the water and reflected (mirrored) from the water back down to the receiver on the sea bottom. We call this the mirror image and refer the energy as down-going energy.

Wave-field Separation:

We start by separating the up-coming and down-going wave-fields: since pressure is a scalar quantity, a pressure wave sensed by a hydrophone will have the same polarity when approaching the hydrophone from any directions; a geophone planted in the sea floor will display opposite polarity for the down-going wave as for the up-coming wave. Therefore, wave field separation into up-coming and down-going is obtained by combining hydrophone and geophone using the Co-sensor sum and difference techniques, respectively. Both wave fields are migrated separately, and then adaptive summed up to improve resolution.

Prestack Depth Wave Equation Migration:

Prestack migration is performed by the downward continuation (backward propagation) of the receiver wave-field recorded at the surface and followed by the forward propagation of the source wave-field using either a simulated source or the actual recording of the source wave-field. Imaging at a given depth level and image point are obtained by cross correlating the down- going wave-field with the up-coming wave-field and picking the amplitude (Claerbout, 1985).

The ocean bottom node technique migrates the multiples in order to obtain a better structural image of subsurface from wider angles, providing more information than primaries, since multiples consist of up-coming primaries that reverberate once in the water layer. This is equivalent to migrate the wave field that would be recorded by a receiver in a mirror position relative to the surface. The mirror migration is able to image a reflector out to a larger lateral extent, by reason of the reflection point for the mirror migration is closer to the source than the reflection point for direct migration. Conversely, the up-coming wave-field (primary reflections) is able to image deeper. Therefore, it is correct to state that both fields complement themselves (Holden *et al*., 2013).

Velocity Focusing Analysis and Model Building:

The velocity focusing analysis is applied to determine the best imaging velocity by examining how the energy from a reflector "focuses" near the reflector location during the migration. The principle is based on examining at each downward continuation level a window about the t=0 imaging condition in the downward continued wave-field after applying the source term correction. These windows are stacked for all source records contributing to a given pre-stack migration and displayed in a Tau-Deviation record'.

If we let DT represent the Tau-Deviation (where the energy best focuses on the Tau Deviation axis) we can estimate a corrected velocity from expression 1:

$$V_{new}(T) = V_{old}(T)*(1-DT/T), \qquad (1)$$

Where: V_{old} and V_{new} are average velocities.

Migration of the receiver records using a velocity that is in error will lead to "focusing" errors and a poorly resolved stacked section. This imaging error may not be apparent by examining a single migrated record but requires that we examine how the energy is focusing near a given image location as seen from several different source locations. Compare this to velocity analysis applied to a common midpoint gathers, which examines how energy "focuses" at a midpoint by applying NMO (*Normal Move-Out*), and stack using constant velocities. The "focusing" errors can be measured and they can be used to estimate an improved imaging velocity.

If the correct velocity is used in the migration then the downward propagation of the source wave-field and the backward extrapolation of the receiver wave-field followed by the cross-correlation will remove the right amount of time and the image of the reflector will be well resolved. If the incorrect velocity is used the energy will be moved either too fast (high velocity) or too slow (low velocity).

This procedure is repeated until obtaining optimal velocity model.

Multiple Attenuation:

Wave equation multiple suppression is one of few multiple suppression techniques (Xiao et al., 2003) especially well adapted to 3D shot record data or common receiver data (ocean bottom node data).

The technique is based on first identifying a particular subsurface reflector that is generating an annoying surface related multiple. This is typically a strong water bottom reflector or top-of-salt reflector which has introduced relatively strong multiples in the deeper section. Insufficient fold may prohibit adequate suppression of these multiples by the stacking process after migration.

1. Identify a reflector that is causing the multiples, for example, the water bottom or top-of-salt.
2. Determine a good velocity model down to the top of the multiple causing reflector and map the event.
3. Use the acoustic wave equation to extrapolate the surface recording (polarity reversed) downward from the surface saving the extrapolated wave-field at the top of the multiple causing event.
4. Apply a reflection coefficient and extrapolate the recorded wave-field back to the surface.

The result is a predicted multiple-only section consisting of surface related multiples generated by introducing an additional wave-field path from the surface down to the multiple causing reflector and back to the surface. This only accounts for multiples which have taken this particular path. If other reflectors are causing additional multiples then these reflectors would have to be treated separately.

The predicted multiples are suppressed from the original (multiple + primary) section by least squares adaptive subtraction.

The following example illustrates an application of the developed ocean bottom nodes imaging technique.

Examples

The 3D 4C OBN Atlantis Seatrial data set is a test survey that was acquired by SeaBird Exploration in 2009. It is located on the west part of the Gulf of Mexico Atlantis field (Howie et al., 2008)). This example is based on selecting 18 nodes (sorted as Common-Receiver Gathers) whose sea bottom positions were sufficiently different to consider them as separate locations. Receivers are 426m spaced with a dense shot grid of 26.85m x 46.5m. Figure 1 illustrates the acquisition design.

Figures 2 and 3 shows the pre-processed up-coming and down-going record for node 1071, respectively. The following procedures were applied:

1. Sort into Hydrophone and Vertical Geophone
2. Resample to 12s at 4mls.
3. Balance
4. Binning (25m x 25m)
5. Deconvolution (3 window)
6. Wave-field Separation

After the wave-field separation into up-coming and down-going records (Figure 2) the set of conventional and mirror PSPI migrations are ready to be executed using an initial sedimentary velocity model. Subsequently, several iterations of Focusing Velocity Analysis technique are applied to update the velocity model defining the top and bottom of salt as illustrated in Figure 3. Velocities vary from 1500m/s (water) to 4500m/s (salt).

Figure 4 shows the final stacked migrated image (3-D PSDM) for the up-coming and down-going wave-fields. The water-bottom multiple is quite weak on the mirror migrated stacked section in Figure 4, however the top-salt multiple (surface->top-salt->surface) is quite strong. The wave equation multiple attenuation process is applied to suppress that multiple (Figure 5).

Both mirror and direct migrations are adaptively summed up and the compound image is displayed in Figure 6.

The Seabird Seatrial has only 18 nodes for the 3D data set with only a few nodes above the 'nose' of the salt. Despite the low fold on the top of salt, the results illustrated in Figure 7 show the processing technique potential.

Conclusions

This paper presented an effective processing tool, which brings competitive features for seismic nodes imaging.

The Atlantis node data set provided the opportunity to work with a great quality P-wave seismic data. Despite the limited number of available nodes (only 18), the processing package yielded excellent P-wave results.

Usually, a sparse receiver interval is used to acquire the data (due to high costs), which contribute to poor illumination (shadow zones), particularly on the shallow areas. The migration of the up-coming primary wave field is not good enough for sparse node geometry to image shallow areas. After we migrate the up-coming and down-going wave fields of both hydrophone and geophone data, we have a set of independent images. Stacking these images effectively increases the fold, which significantly increases the signal-to-noise ratio.

Acknowledgments

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References

Claerbout, J.F. [1985] Imaging the Earth's Interior. Blackwell, Oxford.

Guimarães, M.G., Sekharan, K.K., Sukup, D., and Krail, P. 3-D pre-stack depth migration of vertical cable data over SEG/EAGE physical model, Expanded Abstracts, SEG Meeting, p. 1182-1185, 1998.

Howie, J., Mahob, P., Shepherd, D., and Beaudoin, G., 2008, Unlocking the full potential of Atlantis with OBS nodes, SEG, Expanded Abstracts, 363–367.

Holden, J.P., Drummie, S., Deeds, J., Mitchell, P.P., Brown, S., and Gosling, R.D. Deep water Ocean-Bottom Node Processing - A West of Shetland Case Study. 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013.

Higginbotham, J., Brown, M., and Macesanu, C., Depth migration velocity model building with wave equation imaging, First Break Volume 28, p. 27-33, April 2010.

Xiao, C., Bancroft, J.C., Brown, R.J., and Cao, Z. Multiple suppression: A literature review, CREWES Research Report, Volume 15 (2003).

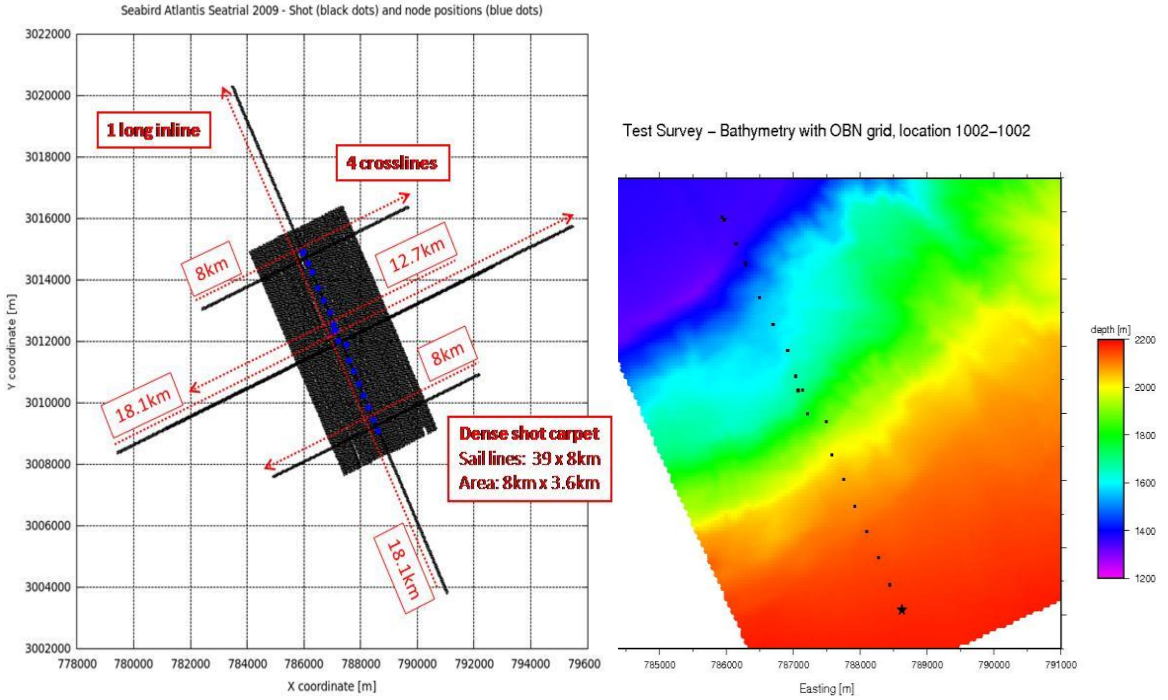

Figure 1: Atlantis Seatrial design: 41 nodes in 18 locations (3-D), 1 inline and 4 crosslines (for 2-D). Nodes spacing is 426m and 26.85m x 46.5m carpet of shots.

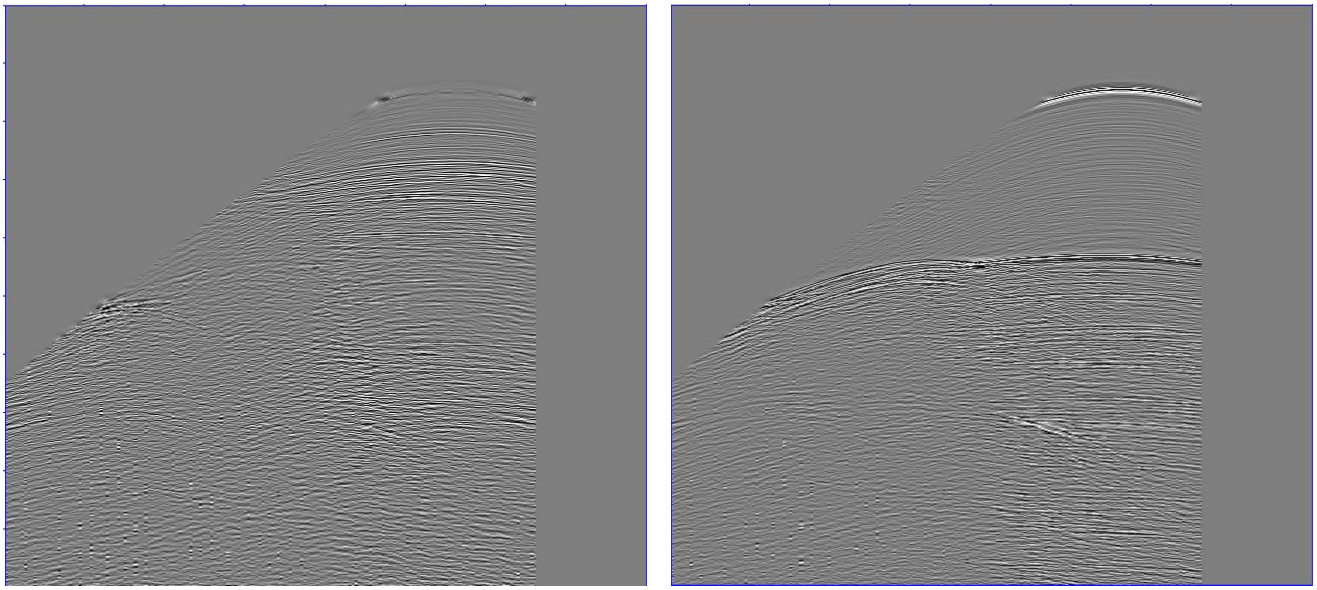

Figure 2: Pre-processed up-coming (left) and down-going (right) wave-field on node 1071. Inline 51.

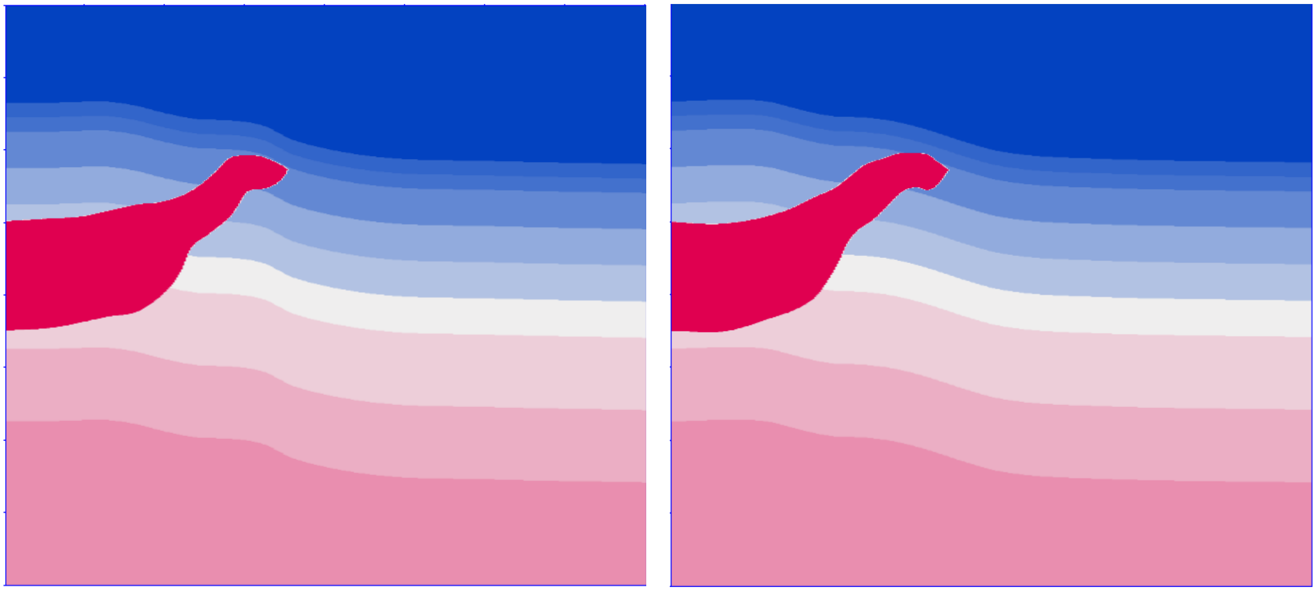

Figure 3: After several depth focusing velocity analysis iterations the final velocity model is derived. Inline 31(left) and 51 (right).

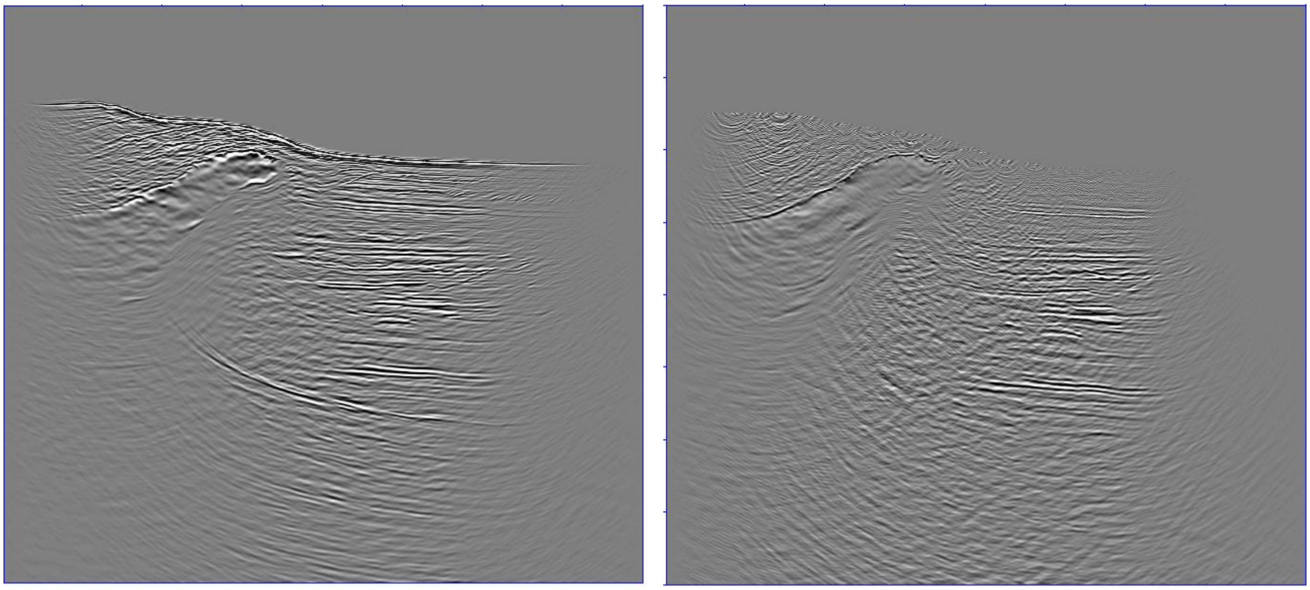

Figure 4: 3-D PSMD Direct (left) and Mirror (right). 18 nodes were processed and stacked. The sea-bottom cannot be imaged by the direct migration since the nodes are on top of it. Inline 51.

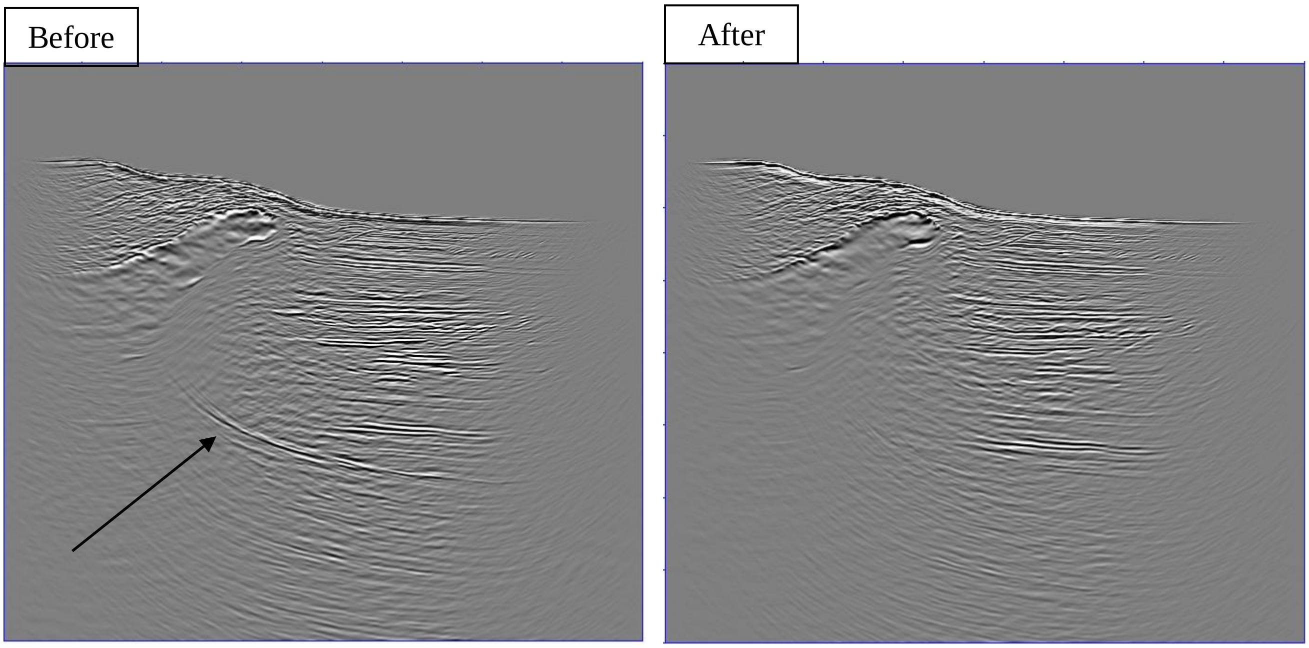

Figure 5: Multiple Attenuation on 3-D PSDM Mirror stacked section. Inline 51. The multiple reflection from the top of salt – sea-bottom is attenuated. Inline 51.

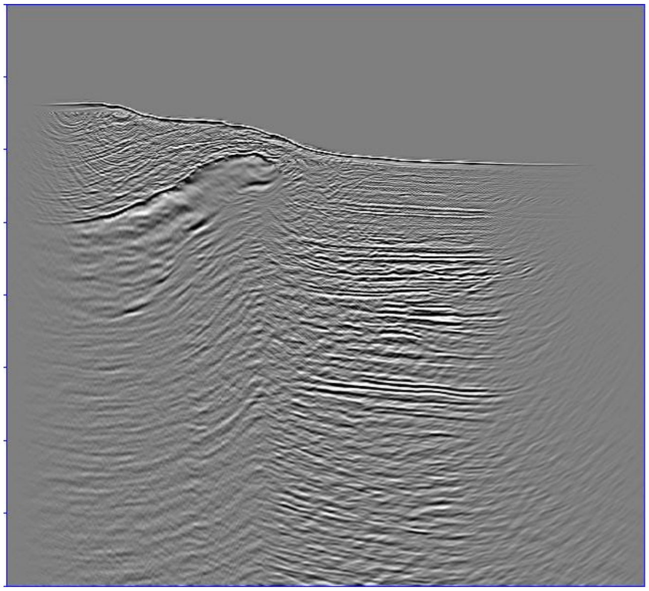

Figure 6: Direct + Mirror Migration Imaging: the 3-D migrations were adaptively added up, improving signal-to-noise ratio. Inline 51.

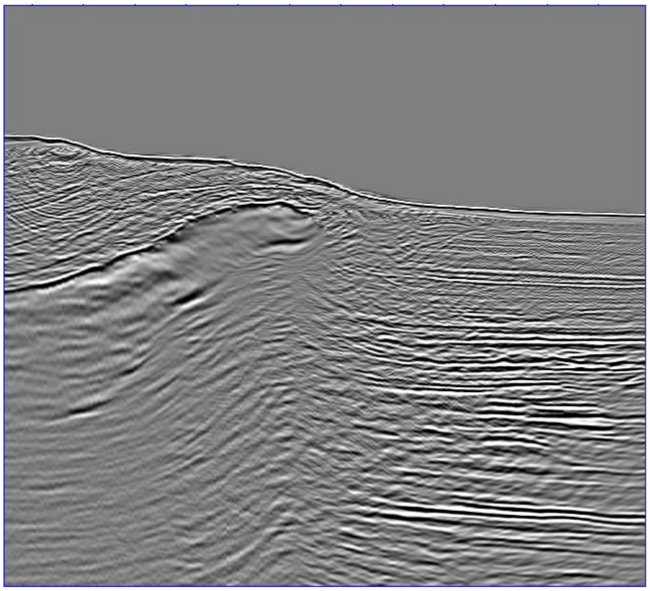

Figure 7: Compound of migrated images (direct and mirror) zoomed in: the 18 nodes were able to provide a great image from the bottom of salt. Inline 51.