Robust demultiple toolkit for shallow water – Malvinas Basin case study

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Summary

Shallow water seismic surveys can present a challenging free surface multiple attenuation problem. In this paper we present the application of a suite of demultiple techniques to data from the Malvinas Basin and demonstrate the effectiveness of this tool kit on the shallow hard water bottom in that basin.

Introduction

The Malvinas Basin offshore south Argentina can be defined as a frontier exploration area, as there has been limited 2D and 3D seismic acquisition and only 16 exploration wells. Recent modern 2D programs, along with renewed industry interest, have helped the Argentine government define large marine exploration blocks, which are partially covered by our 2019-2020 3D dataset.

The Malvinas Basin lies east of Tierra del Fuego, between the Dungeness arch and the Malvinas Islands. The Austral and Malvinas sub-basins are divided by the Chico High with wedge-shape depo-center deepening towards the SW, mostly mud-prone marine silico-clastic sediment up to 7,000 m in thickness. There are multiple proven source rocks within the Jurassic and Cretaceous, with potential in Coniacian and Eocene marine shales and claystones. Perspectivity of the basin is supported by multiple reservoir levels starting with Lower Cretaceous and Upper Jurassic Springhill formation channels, fluvial and estuarine bars and marine sandstones.

Upper Cretaceous turbidite sandstones and shelf carbonates and Paleocene and Eocene turbidites are also clearly delineated and interpreted in legacy and modern 2D seismic images (Figure 1). Shallow shaly sediments are crosscut with minor gas pockets and larger gas hydrates (bottom simulating reflectors), proving a working petroleum system but at the same time obscuring imaging of the deeper section. For most of the Malvinas Basin the water depth is from 100m to 200m, with very shallow 50m depths in the Austral Basin and up to 450m towards the Malvinas Islands. The water bottom is relatively hard and flat with variable reflectivity and minor scale rugosity.

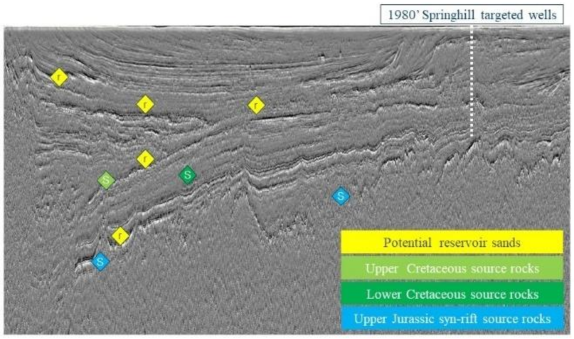

Figure 1. 2D PSDM stack (pseudo-relief attribute) highlighting various depth of imaging targets in Malvinas fold belt and foredeep.

2019-2020 acquisition of dense 3D NAZ data in the Malvinas Basin was reasonably challenging as there were a number of operational restrictions. Remoteness of the area, along with a very short summer season and inclement weather combined with strong tidal current, are a few of the reasons why acquisition was planned with 2 vessels over a short period of time. Two 3D vessels were used to acquire swaths of NAZ data in a roughly N-S direction. Each boat towed 14 streamers of 8,100m length with nominal cable separation of 75m. Streamer depth was 15m, with source depth of 8m. A triple source configuration was utilized, with 12.5m shot point interval and continuous recording of 11s with 4.5s of "clean" record length. Near offset of the inner cables was 150m, limited by operational and safety concerns. The importance of near offset coverage was well

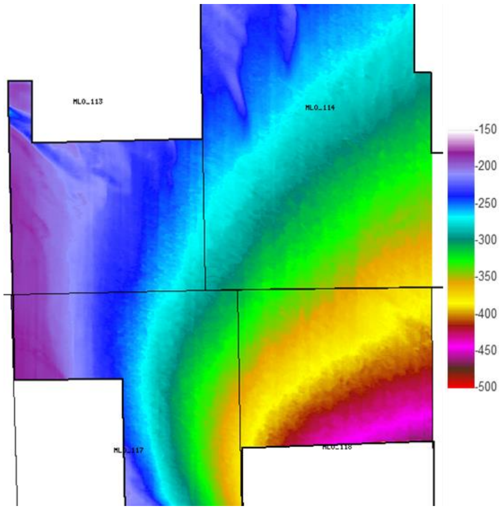

Figure 2. Water bottom two-way times in milliseconds over the survey area.

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understood, based on modeling and the number of previous TGS projects in shallow water settings, and was mitigated during acquisition by steering for near offset coverage.

Method

The shallow hard water bottom in this region creates a challenging set of multiple arrivals. To deal with these multiples we used a pair of demultiple prediction techniques, Shallow Water Multiple Elimination (SWME) and Surface Related Multiple Elimination (SRME). The multiple models were subtracted from the data using a simultaneous adaptive match.

Shallow Water Multiple Elimination (SWME) is a 3D deterministic technique, where the data is convolved with the Green's function corresponding to the water bottom, similar to the method described by Moore and Bisley (2003). Separate predictions were made for the source and receiver side multiples. This method predicts multiples generated by the sea floor but is not affected by the higher angle water bottom measurements present in a shallow water survey. 3D Surface Related Multiple Elimination (SRME) as described by Cai et al. (2010) was also used to predict multiples from all the multiple generators. SRME and SWME pair well, with SWME giving an accurate high bandwidth prediction of water bottom related multiples and SRME giving a good prediction of the multiples from other generators.

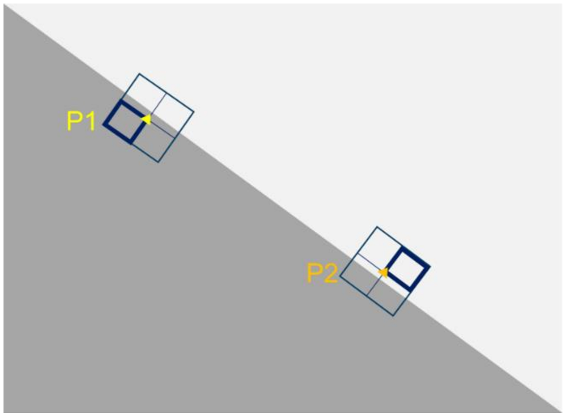

Figure 3. A diagram of the quadrants in a structural Kuwahara filter. The center sample is replaced by the mean sample value of the quadrant with the lowest standard deviation. The presence of a plane here would cause points below the plane (e.g. P1) to come from below the plane, and points above (e.g. P2) to come from above the plane, thus the filter will preserve the edge while smoothing each region.

The multiple models from SWME and SRME were subtracted from the input data through multi-dimensional and simultaneous adaptive matching like that described by Ala'I and Verschuur (2003). The simultaneous adaptive matching creates a good combination of the two prediction techniques without the damage to primaries that can come from cascaded subtraction.

After the application of SRME and SWME, a second pass of multiple attenuation was performed on the output, using a simple phase shift prediction using shot gathers to predict the water bottom pegleg multiples. This technique is fast, broadband and accurate on near offsets. The target for this second pass was any residual pegleg multiple remaining after SWME and SRME.

After these multiple attenuation processes were done, there was some remaining multiple energy generated by a layer of diffractors just below the water bottom. The tails of the multiples from these diffractors were difficult to model using the previously mentioned multiple prediction techniques. We used a structurally oriented thresholded Kuwahara filter to model them, which is an edge preserving filter common in image processing, originally developed for medical imaging by Kuwahara et al. (1976, p. 187). The structural

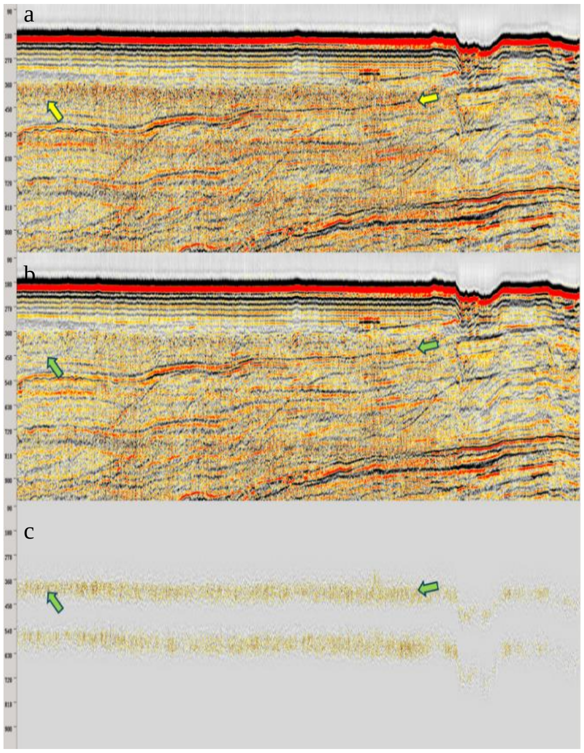

Figure 4. A near channel showing the diffracted multiples as indicated by the arrows a) before attenuation with a Kuwahara filter, b) after the diffracted multiples are attenuated and c) the multiple energy removed.

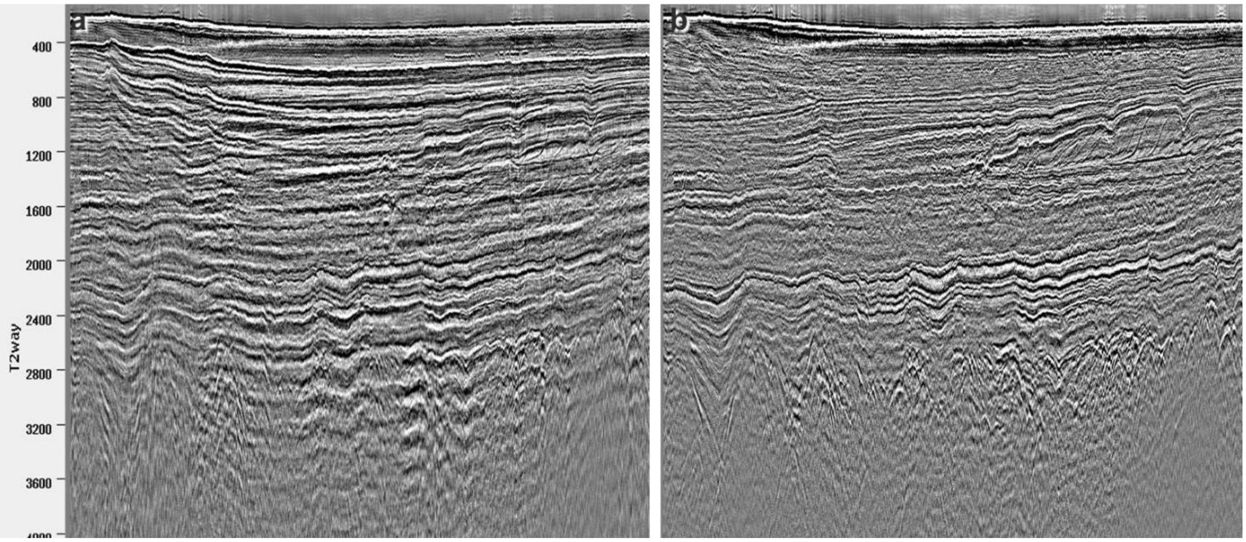

Figure 5. An inline stack a) without demultiple and b) with demultiple

Kuwahara filter computes the mean and standard deviation of 4 quadrants aligned with the predominant dip in an image (see Figure 3). The center sample is replaced with the mean of the quadrant with the lowest standard deviation. The result is similar to a structurally aligned box car smoother, but with good edge preserving properties. The results of the Kuwahara filter are then compared with the input data in dip panels, and a threshold is used to select events for a noise model. This filter does a good job of attenuating the spurious dips from the diffracted multiples, with little to no impact on the primary events. The results of this filter are shown in Figure 4.

Results

Figure 5a. shows an inline through the Malvinas Basin. The multiples are strong and overpower the structure underneath them. Figure 5b. shows the attenuation of the multiple energy after the demultiple workflow. Figure 6a. shows a time slice over this survey. The multiples are clearly seen as cross-cutting events, as indicated by the arrows. Figure 6b. shows the cross-cutting events have been removed by the multiple attenuation workflow.

Conclusions

We successfully attenuated the free surface multiple in a challenging shallow water environment. The workflow was a combination of deterministic Green's function based Shallow Water Multiple Elimination (SWME), Surface Related Multiple Elimination (SRME) and a second pass using phase shift multiple prediction. The results of the workflow presented here show successful multiple attenuation in the Malvinas area.

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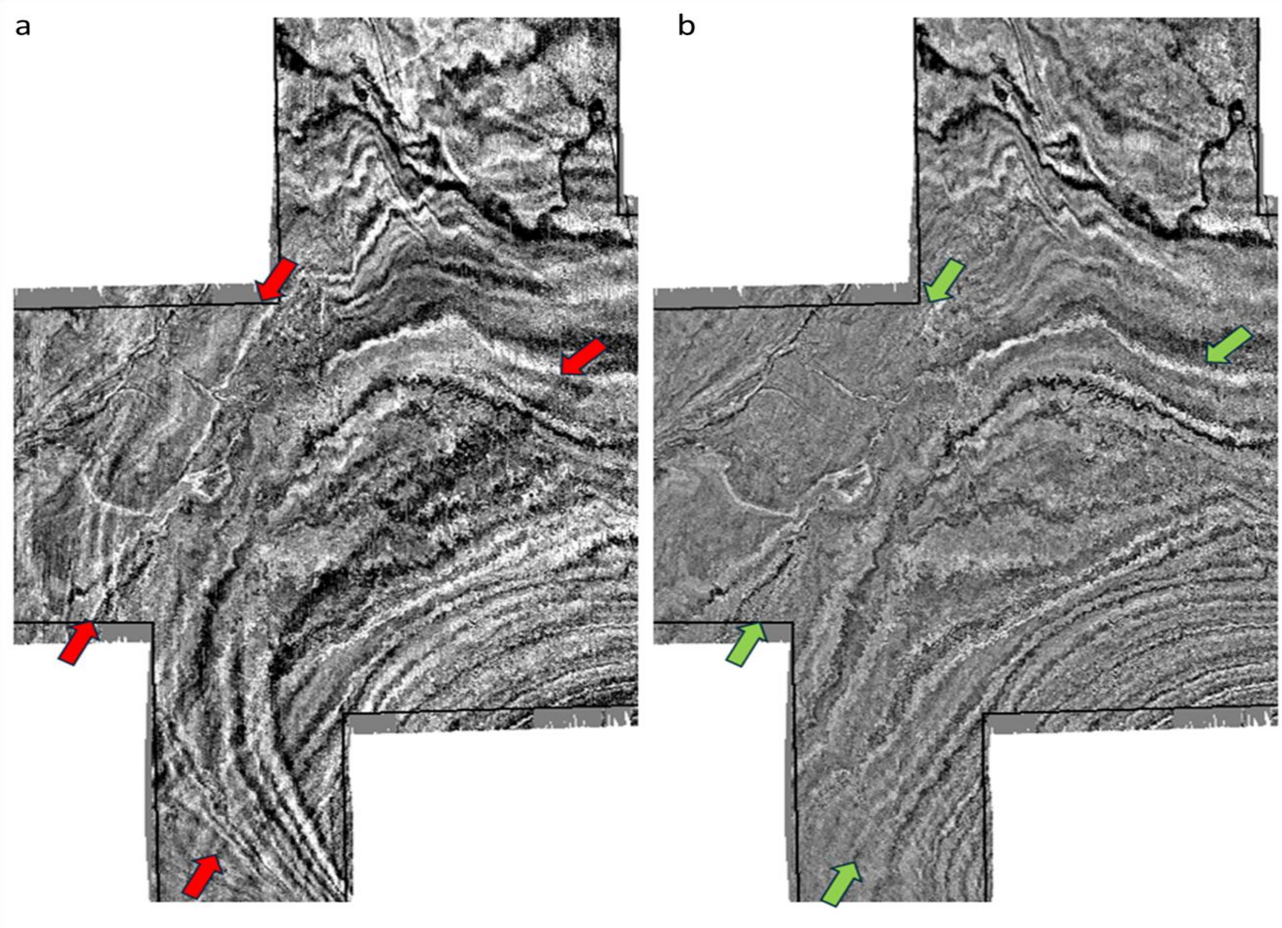

Figure 6. A shallow time slice a) without demultiple and b) with demultiple

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