

Modeling noise in five dimensions: A case study from Sarukawa oil field in Japan

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Introduction

Located in the Akita prefecture of Japan, the Sarukawa oilfield reservoir dates back to 1958. Despite hundreds of wells drilled, several uncertainties still remain for interpreters resulting in structural risk defining the main reservoir. One of these risks include remaining uncertainties defining the complex geological structure associated with a major regional fault. The latest seismic survey conducted over the oilfield was acquired in 2003. The survey area covered a transition zone and was acquired with mixed sources. Strong noise, contaminating onshore and offshore records and sparse geometry resulted in a poor image after prestack time migration (PSTM) processing.

The same dataset was reprocessed in 2015 with the latest available noise attenuation and interpolation technologies resulting in dramatic improvements of the PSTM image.

Herein we describe the key strategy and algorithms applied in a reprocessing effort including curvelet-domain noise modelling and a simultaneous approach for interpolation and noise attenuation using a matching-pursuit algorithm performed in a 5D implementation (Schonewille et al., 2009). These algorithms in combination with higher-resolution time imaging provided significant uplift versus vintage processing. Further image improvements are expected after depth imaging of the complex structure.

Survey description, objectives and challenges

The Sarukawa 3D seismic survey covers approximately 16 km² and is comprised of land and shallow-water transition-zone data types. The survey was acquired in 2003 to obtain a better structural image over the northern part of the oilfield. There were only ten receiver lines deployed with a NW-SE orientation perpendicular to thirteen source lines and the shore line (Figure 1a).

Vibroseis sources were used for two source lines located onshore while a further eleven source lines were shot with an air-gun source of variable depth for the remaining transition zone. The receiver lines were comprised of geophone sensors and two-component ocean bottom cables (OBC) for the onshore and transition offshore zones respectively. The geophone (vertical) component of the OBC cables was considered unusable due to extremely low signal-to-noise ratios. The onshore part of the survey and the shallowest transition zone were also contaminated by strong noise masking the underlying signal. The land shot records were also dominated by very high-amplitude and heavily scattered surface waves. This noise significantly limited usability of the land portion of the data (Figure 1b).

The signal-to-noise ratio was seen to improve towards the deeper offshore part of the survey. However this only constituted a small portion of the survey with 70% of the data being significantly contaminated by noise.

Sparse and irregular geometry characterized by high noise content were the key challenges while reprocessing the dataset. A complex workflow was devised utilizing a step-by-step data and noise

separation in various domains to allow for more robust noise attenuation whilst protecting the primary events.

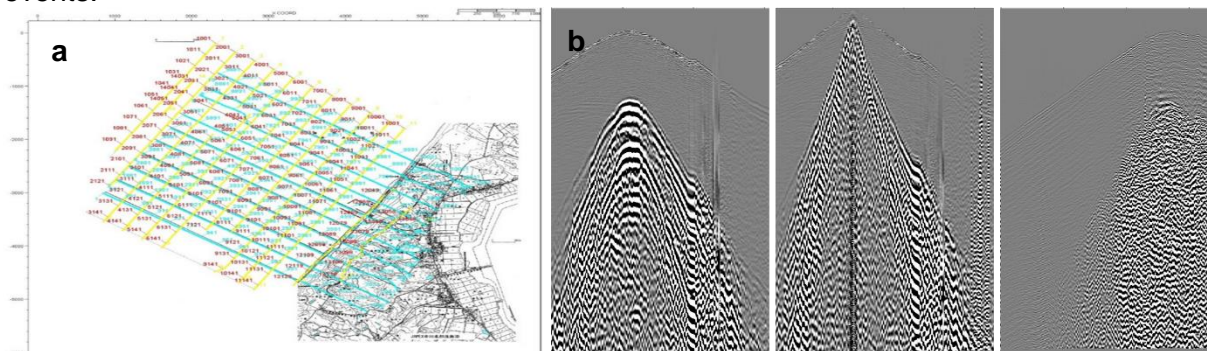


Figure 1, a) Acquisition schematic Diagram. b) Raw records example: left and center – OBC. Right – land side

To address these challenges, curvelet domain noise attenuation, 5D anti-aliasing, matching pursuit Fourier interpolation and noise attenuation techniques were employed.

Curvelet-domain noise modelling

The curvelet transform is a higher-dimensional generalization of the wavelet transform designed to represent images at different scales and different angles (Candes and Donoho, 1999). The forward curvelet transform decomposes data into curvelets, which are multiscale, multidirectional, anisotropic, localized frequency-wavenumber domain operators. From a geophysical perspective, curvelets can be seen as local plane waves. The curvelets are optimal to sparsely represent the local seismic events and can be effectively used for wavefront-preserving seismic processing (Ma and Plonka, 2010). The transform is fully invertible .i.e. the output after a combination of forward and an inverse curvelet transforms is the same as the input to the forward curvelet transform.

In data processing the curvelet transform can be used to separate events using multiple attributes simultaneously such as frequency, amplitude, dipping angle and time/space location. Therefore, the curvelet transform provides a very useful tool for modelling linear, locally coherent noise (such as scattered ground roll), or random noise in seismic data processing. It is also actively utilized for adaptive subtraction of noise models such as water-surface-related multiple reflections to minimize potential damage to primary events.

In processing the Sarukawa dataset the curvelet transform was utilized at multiple steps during the processing sequence. Strong amplitude contrasts and relatively high dips of scattered surface waves were used as differentiating factors while modelling the noise in various domains using the curvelet transform. (Figure 2) The curvelet transform was also beneficial to protect signal during the matching-pursuit-based noise attenuation steps.

Matching pursuit Fourier interpolation

Interpolation and regularization techniques play important roles in processing data from spatially sparse and irregular acquisition geometries. A wide range of seismic data interpolation techniques were developed and have evolved over the last decades (Yen, 1956; Hale, 1980; Chen and Allebach, 1987; Moore and Ferber, 2008; Schonewille et al., 2009).

Spatial irregularities and aliasing are key challenges for all interpolation algorithms. Recent developments have made significant progress to address these challenges. A matching-pursuit Fourier interpolation algorithm used in the Sarukawa reprocessing project was able to overcome aliasing problems associated with signal reconstruction by using prior information from non-aliased frequencies to interpolate the aliased high-frequency signal. This technique can also employ additional priors from

another dataset (Schonewille et al., 2013). It is worth mentioning that matching pursuit Fourier interpolation was performed in five dimensions (inline, crossline, offset, azimuth and time).

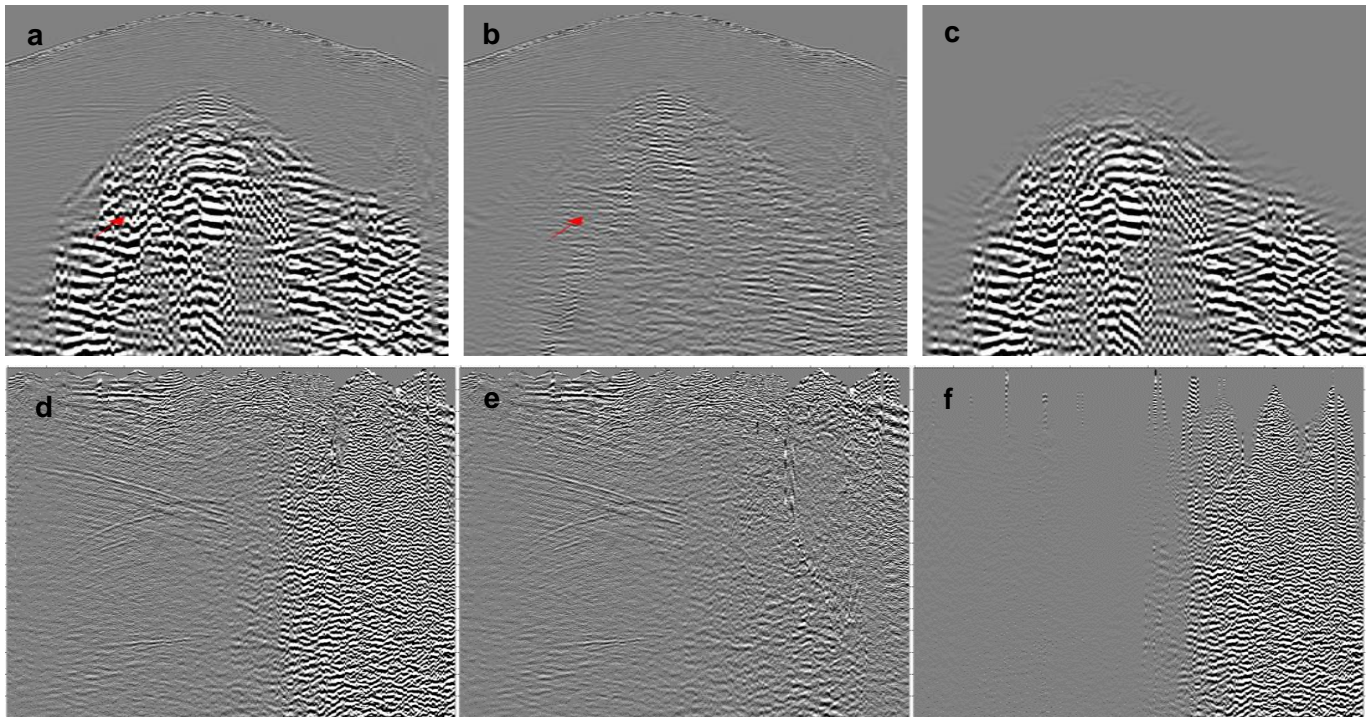


Figure 2, Shot record: a) after initial surface waves suppression, b) after Curvelet-domain noise attenuation, c) noise model, Inline stack section: d) after initial surface waves suppression, e) after curvelet domain noise attenuation, f) noise model.

During the interpolation stage it became obvious that the original source and receiver line spacing was not sufficient for confident reconstruction of shallow high-frequency events and steep geological dips away from existing original locations. The small spatial scale length geological of these features was not sufficiently sampled during acquisition. Under this condition creating additional source and receiver lines between original lines was not an optimal solution for the dataset. A 5D interpolation strategy was performed ensuring that the reprocessing project would improve imaging shallow and deep events by reconstructing new source/receiver locations close to their original locations (Figure 3). Significant improvement in the signal-to-noise ratio and event continuity for the entire volume is evident.

Matching-pursuit Fourier noise attenuation

The concept of matching pursuit can also be extended to noise attenuation. The matching-pursuit algorithm separates the maximum Fourier component present in the seismic signal in an iterative fashion. One logical way of using a matching-pursuit Fourier algorithm is to model the inconsistent noise as they will not be contained in the early iterations where the maximum Fourier component is selected. Signal projection techniques can be further applied to ensure that the noise model is subtracted from the data for optimal removal of the noise and preservation of the primary events.

In the Sarukawa reprocessing project the matching-pursuit concept was used for noise suppression. The noise suppression was conducted in several iterations in conjunction with other noise attenuation techniques.

In combination with high-resolution prestack time migration the multistep noise attenuation techniques and 5D interpolation using matching-pursuits resulted in a more interpretable final image of the complex target (Figure 4).

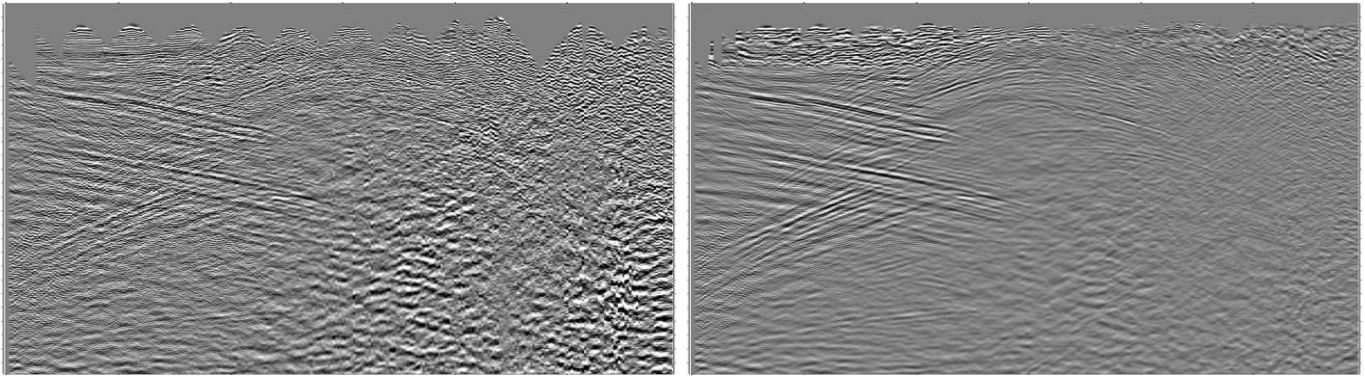


Figure 3, Inline stack section before (left) and after (right) matching-pursuit interpolation and noise attenuation

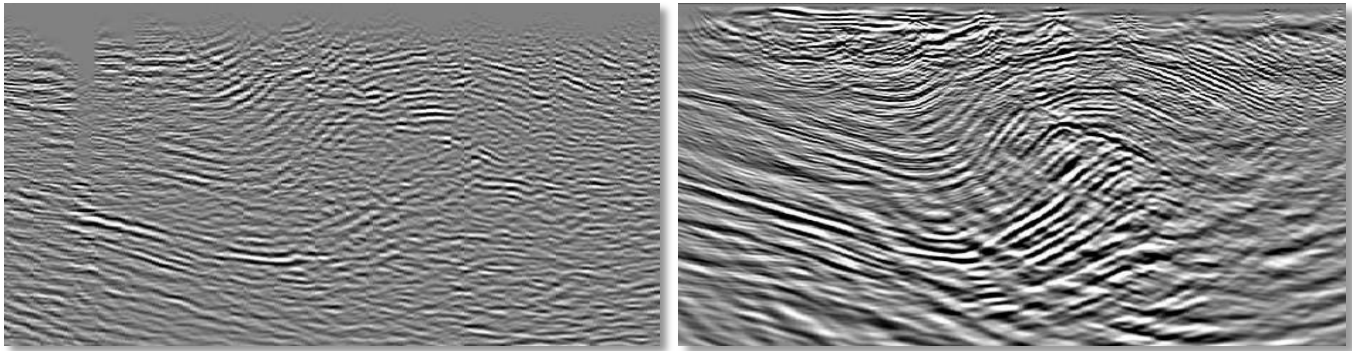


Figure 4 Final PSTM migrated stack: vintage stack (left), newly reprocessed 2015 stack (right).

Conclusion

Even with highly challenging seismic data, modern processing algorithms produced significant uplift in imaging complex geological structure over the Sarukawa oil field.

Significant elements of noise contamination were addressed with help of the curvelet transform which is a powerful and flexible tool for multiattribute noise modelling in seismic data processing. Application of multidimensional antialiasing matching-pursuit Fourier interpolation and noise attenuation enabled high quality signal reconstruction and noise suppression at desired locations. Such a tool is especially important for sparse and irregular seismic datasets with significant noise contamination such as the Sarukawa survey.

The combination of new technologies and correct processing strategy was applied to transform vintage dataset and bring new value for interpretation and reservoir characterization.

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