Making New with Old: Reprocessing Vintage Seismic Data from the Western Arctic Islands using Modern Methods

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Summary

In 1997 the Geological Survey of Canada (GSC) signed a Memory Of Understanding (MOU) with Panarctic Oils, the Arctic Islands Exploration Group and the Offshore Arctic Exploration Group joint ventures parties allowing GSC researchers a privileged access to 38 000 km of various quality 2-D seismic data collected in the Western Arctic Islands. The dataset contains many artifacts related to the uniqueness of this ice-covered acquisition environment such as coherent noise and local changes in frequency content both respectively attributed to the presence of permafrost and to variations of its physical properties as well as transition areas (i.e. land to sea-ice). Other artifacts include acquisition footprints that hamper shallow subsurface interpretation, seafloor multiples which plague entire sections and hyperbolic reflections caused by steeply dipping geometries that preclude imaging deeper geological units properly. Each of these processing challenges is tackled individually using modern pre-stack and post-stack methods. Qualitative and quantitative quality control (QC) of the reprocessing show that artifacts are greatly attenuated as both the signal-to-noise (S/N) ratio and the coherency of the reflections have been significantly improved.

Introduction

Although seismic data acquisition is a prerequisite in any hydrocarbon exploration project, it still remains expensive. More so for Arctic seismic exploration the cost of mobilization, demobilization and operation increase significantly due to the distance to market and the harshness of the data acquisition environment. Therefore vintage datasets from this frontier area still possess a high value despite the fact they were shot using outdated technologies. Their value can be also increased if they are reprocessed using modern techniques. Ultimately, analyzing the reprocessed data can lead to important cost saving in the planning of future surveys by identifying more accurately prospective areas.

The reprocessing of vintage seismic data collected between the 1960s' and the early 1980s' in the Western Arctic Islands is one aspect of the GSC's Geo-mapping for Energy initiative that intends to map the subsurface of Sabine Peninsula and adjacent offshore areas. The reprocessing strategy aims to: 1) identify the artifacts and their cause, 2) tackle each artifact individually by testing different processing algorithms, 3) incorporate each algorithm into a processing flow and 4) select the best flow based on a qualitative and quantitative QC. In this paper the origin of the data artifacts and the processing strategy are addressed and their implication on the quality of the reprocessed data is briefly discussed.

Dataset

Data access has been obtained through a MOU between the GSC, Panarctic Oils, the Arctic Islands Exploration Group and the Offshore Arctic Exploration Group joint ventures parties signed in 1997. The data set consists of 38 000 km of original seismic field tapes transcribed from 21, 7 and 9 track media to different digital SEG file formats. Acquisition configuration for both land and sea ice data was split-spread. Land data were collected using a dynamite charge of 20 to 30 kg shot at ~20 m below the surface. On the other hand, sea ice data were generally gathered using a dynamite charge of 2 kg shot at a depth of 10 m. Shot point spacing was variable ranging from 300 m to 67 m, the later of which was used for most surveys. The majority of the acquisition campaigns used 48-channel recording systems. Channel stations were generally deployed using 9 receivers distant of ~8 m and channel interval varied from 50 to 70 m. The common-midpoint multiplicity of the dataset is mainly low ranging from single to 12 fold coverage. Recording length is on average 6 s however some lines have been recorded on 9 s. The application of the processing steps in the pre-stack domain as opposed to the post-stack domain depends on the availability of already digitize shot gathers. When digital shot gathers exist pres-stack processing is performed.

Types of artifacts

Data artifacts can be regrouped in 2 different noise categories: coherent and random. When noise is said to be coherent, it means that it possesses a systematic phase relation between adjacent traces. Coherent noise is generally distributed according to repetitive patterns along a seismic section. Permafrost or ice breaks are typical coherent artifacts recorded on the Western Arctic Island dataset that are caused by the fracturing of the permafrost triggered by the energy of the shot (Merrit, 1973). Acquisition footprints are another coherent noise observed on the data. They possess a ‘criss-cross’ signature attributed to the geometric distribution of shot and receiver stations at the surface (Marfurt et al., 1998). Sea ice data quality is significantly lower than land data due to coherent noise induced by bubble pulses that formed in the water adding a noisy wavetrain to the source signature, guided waves that travels trough the ice mass and water bottom multiples that interfere with first arrivals (Beaudoin et al., 1992). Finally, hyperbolic reflections caused by steeply dipping geological structures hamper the subsurface imaging, mainly at depth. Steep dips are the likely cause of these artifacts because of an inadequate spatial sampling when data were collected.

Random noise is attributed to energy that does not correlate in the time versus distance space between adjacent traces. Local changes in the frequency content are one type of random noise caused by both the occurrence of permafrost and variations of its physical properties and but also to land to sea ice transitions (Brent, 2006). An additional type of random noise is inconsistent amplitude and frequency scaling of adjacent traces introduced during the transcription of original seismic field tapes to digital SEG file formats.

Reprocessing results

Permafrost breaks have been successfully suppressed by carefully designing Frequency-Wavenumber (FK) filters based on the approximate P-wave velocity of the direct arrival of the permafrost. Acquisition footprints have been also greatly attenuated by cautiously designing FK-filters based on the acquisition geometry parameters of each survey (Figure 1). Different methods have been tested so far to remove water bottom multiples, namely predictive deconvolution (Robinson, 1957), adaptative multiple attenuation (Verschuur et al., 1992) and the Karhunen-Loéve (KL) Transform (Jones and Levy, 1987). Best results are obtained using the KL-Transform as the energy of the multiples is almost completely removed from the data. Hyperbolic reflections were successfully collapsed using FK filters for hyperbola included within shallower time-depths (<3 secs) and post-stack Kirchhoff time migration for hyperbola present at greater time depths (>3 secs) (Figure 1).

Frequency content of the sections has been harmonized to limit the negative effects that have local changes in the band-pass of data. The lateral continuity of the reflections was enhanced by using a combination of time-variant Omrsby and FK filters. This processing algorithm is used to determine frequency similarities (i.e. common band-pass) between zones where frequency variations exist in order to facilitate seismic horizon picking. Inconsistent trace scaling of adjacent traces was easily corrected by a joint application of an Ormsby filter along a Root-Mean-Square ensemble trace scaling. Finally, the overall S/N ratio was greatly improved by employing a frequency-distance (FX) random noise prediction algorithm that eliminated most of the background noise (Figure 1; Canales, 1984).

Conclusions

So far reprocessing efforts have proven to be valuable in terms of increasing the S/N ratio and the coherency of the data. Because seismic data were collected between 1968 and 1984 by different companies using different acquisition parameters, there is not a unique processing flow that fits the entire data set. Thus, the reprocessing effort requires a case by case approach. Nevertheless, most flows included the same main processing steps such as RMS ensemble trace scaling, FK-filtering, FX-filtering and Kirchhoff time migration. Upcoming development of processing routines will tackle the improvement of existing velocity models to increase the performance of time migration and focus on enhancing the imaging of salt diapirs using the available pre-stack data. Hopefully, the use of the newly reprocessed data to map the subsurface of the Western Arctic Islands will increase the confidence level of seismic-to-well ties and lead to the observation of new direct hydrocarbon indicators in the area.

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References

Beaudoin, B. C., ten Brink, U. S., and Stern, T. A., 1992, Characteristics and processing of seismic data collected on thick, floating ice: Results from the Ross Ice Shelf, Antarctica: Geophysics, **57**, 1359-1372.

Brent, T.A., 2006, Seismic reflection interpretation of gas hydrates and permafrost in the High Arctic of Canada: Fourth International Conference on Arctic Margins.

Canales, L. L., 1984, Random noise reduction: Extended SEG Abstracts Meeting, 525-527.

Jones, I. F. and Levy, S., 1987, Signal-to-noise ratio enhancement in multichannel seismic data via the Karhunen-Loéve Transform: Geophysical Prospecting, **35**, 12-32.

Merritt, R. K., 1974, Seismic reflection measurements in the Canadian Arctic Islands: Proceedings of the 1973 National CSEG Convention, 89-105.

Robinson, E. A., 1957, Predictive decomposition of seismic traces: Geophysics, **22**, 767-778.

Verschuur, D. J., Berkhout, A. J. and Wapenar, C. P. A., 1992, Adaptive surface-related multiple elimination: Geophysics, **57**, 1166-1177.

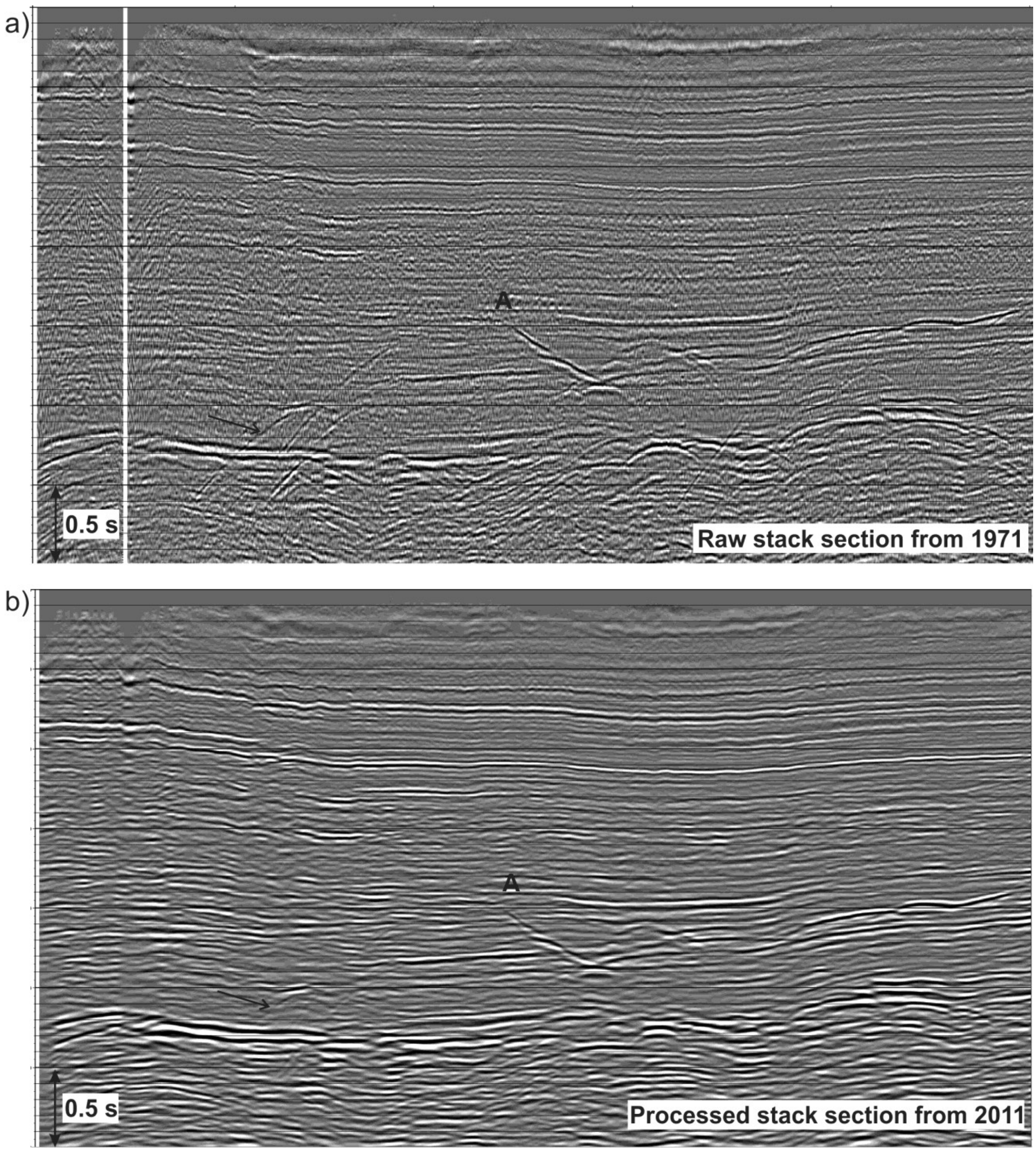

Figure 1: Example of application of a processing flow on vintage seismic data. a) Raw section from 1971 and b) processed stack section from 2011 using RMS ensemble trace scaling, FK-FX filtering, time-variant Ormsby filtering and Kirchhoff post-stack time migration. A denotes the typical 'criss-cross' pattern of acquisition footprints and the arrow points out a hyperbolic reflection. Both artifacts have been successfully attenuated after the application of the processing sequence. Moreover, the S/N ratio of this data window has increased from 2.2 to 12.