Seismic input optimisation for Joint Migration Inversion on complex structures, Malay Basin.

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Abstract. The field of seismic imaging has made a recent breakthrough in migration technique with the introduction of Joint Migration Inversion to aid the imaging process by incorporating multiple scattering into the algorithm. Initially, seismic multiples have been regarded as noise and should be removed prior to migration, but today these multiples could be used to enhance the final seismic images since they carry a vast percentage of energy that was generated from the source during acquisition phase. This new technique could be used to improve the final image of complex structures such as the steeply fractured basement reservoir in Anding Utara Field in Malay Basin. As of now, the efforts of improving the steeply-fractured basement image have been done without the incorporation of multiple scattering. Thus, the application of JMI might shed some light on the potential of this technique. Joint Migration Inversion make use of a Closed-Loop imaging process which means that less wave energy is wasted during processing making the final image more consistent with the input data. In conventional migration process, multiple scattering is removed thus vast amount of energy is wasted that leads to a poor final subsurface image. The two main elements in Joint Migration Inversion are Full-Wavefield Migration and Full-Wavefield Inversion. Apart from including seismic multiples in the imaging process, Joint Migration Inversion also allows the user to automatically update the velocity model of the area under investigation while maintaining very little user intervention.

Keywords: JMI, migration, inversion, seismic, imaging, multiples, Full-Wavefield,

1. Introduction

Recent developments in research in the field of imaging geophysics has brought forth a new insight on how multiple reflections could be used to enhance the final images of the subsurface. The concept of constructing primary reflection data out of multiples goes back to the work of Claerbout (1968) on seismic interferometry. Based on Claerbout (1968), if at two locations passive measurement of random sources that are distributed in the earth are being made, the Green's function between these two locations is obtained by cross-correlation of these two measurements. In simpler words, any wavefield that reaches the surface which gets reflected back down as multiples and gets recorded at larger offsets, can also be seen as reflections from different source.

Recently, research has shown that multiple reflections could in fact assist in improving the final image of subsurface through the implementation of a method called Joint Migration Inversion or JMI. JMI is a combination of closed-loop full-wavefield imaging and closed-loop full-wavefield tomography (Staal and Verschuur, 2012). The implementation of a closed-loop algorithm instead of an open-loop algorithm would eventually be better because the final image of the subsurface is more consistent with the input data since no part of the initial data is removed such as the multiples. In another words, less energy is removed during processing and better energy preservation for the final image.

The next-generation seismic migration and inversion technology considers multiple scattering as vital information, allowing the industry to derive significantly better reservoir models with more detail and less uncertainty while requiring a minimum user intervention (Berkhout, 2012). There are two main aspects that constitute to this revolutionary JMI technique and they are Full-Wavefield Migration (FWM) and Full-Wavefield Inversion (FWI). Both processes have their own key roles to play in the process producing final seismic images by incorporating multiple scattering.

2. Joint Migration Inversion

2.1. Multiple Scattering

Multiples scattering has evolved from just being treated as noise to its incorporation in imaging process to improve the final seismic image of the subsurface. In order to utilise multiple scattering, we must first understand what are multiples, its types are and why it is important to include them in imaging process. Essentially, seismic multiples are reverberation or repetitions of primary seismic waves travelling within the earth. According to Verschuur et. al. (2013), multiples can be categorised by considering the interface where they have their shallowest downward bounce. In general, internal multiples as well as surface-related multiples are the subdivision of multiples which uses the basis of the shallowest downward bounce to categorise multiple reflections.

Apart from classifying multiple reflections based on the shallowest interfaces on which the bounces take place, a distinction could also be made between short-period multiples and long-period multiples. Essentially, long-period multiples are multiple reflections that could be decomposed into primary ray paths. Short-period multiples, on the other hand, are those multiple reflections that cannot be distinguished as separate events in the seismic section from the primaries that generate them. Multiples, in general, not only contributes to a large part to the finally transmitted energy, but they also generate dispersion effects, and an overall delay of the acoustic energy.

2.2. Joint Migration Inversion

The classic seismic processing method make use of open-loop method where only primary reflections are used as input and as a result, multiple reflections were removed prior to migration. This has been the setback in imaging geophysics since multiple reflections that were removed carry a vast amount of wave energy that was generated from a source that could have been used to improve the final image of the subsurface. In general, JMI utilises seismic reflection data in a closed-loop process in a way of matching forward-modelled responses to measured field data in a full waveform manner, with minimum user intervention. The inclusion of primary and multiple reflections means the final image is more consistent to the input data and less energy is wasted for imaging process. JMI aims to combine the best of elements of Full Waveform Migration (FWM), migration velocity analysis as well as Full Waveform Inversion (FWI).

Traditionally, the standard migration practice will offer limited information about the inconsistency between the input and the output seismic images. Well known migration algorithms such as the Reverse Time Migration and Wavefield Extrapolation Migration apply an open-loop algorithm that means multiple reflections are ignored. If multiple scattering is to be included in the migration processes, an open-loop approach will no longer be feasible.

In essence, FWM and FWI utilise multiple scattering in their own ways, and both are closed-loop type processes between the input and the output data. The difference between these two is that, in FWM the subsurface is described in terms of grid point reflectivity, while in FWI, the subsurface is described in terms of grid point contrast. In addition, FWM up and down wavefields are computed by recursive wavefield extrapolation while in FWI wavefields are computed by non-recursive, iterative wavefield modelling process (Berkhout and Verschuur, 2016).

3. Methodology

Mainly, in the first phase of these project, the original seismic data of Anding Field will be reprocessed to obtain the input necessary of JMI process. The reprocessing steps aim to remove unwanted noise, such as linear and swell noise from the raw data. The raw seismic data will be reprocessed using conventional seismic processing module and the steps are illustrated in part 4. Next, with the incorporation of multiple scattering, JMI algorithm will be applied to the reprocessed data in MATLAB to see whether the seismic image of the basement reservoir in Anding Field could be generated and to see whether it has been improved from the previous image or otherwise. Based on the final seismic image obtained by using JMI algorithm, the improvements made to the data will be analysed and compared to the previous image generated without the incorporation of multiple scattering. The effects that the new algorithm has on seismic data will also be analysed to further understand the potential and limits of JMI. The general research workflow is illustrated in Figure 1.

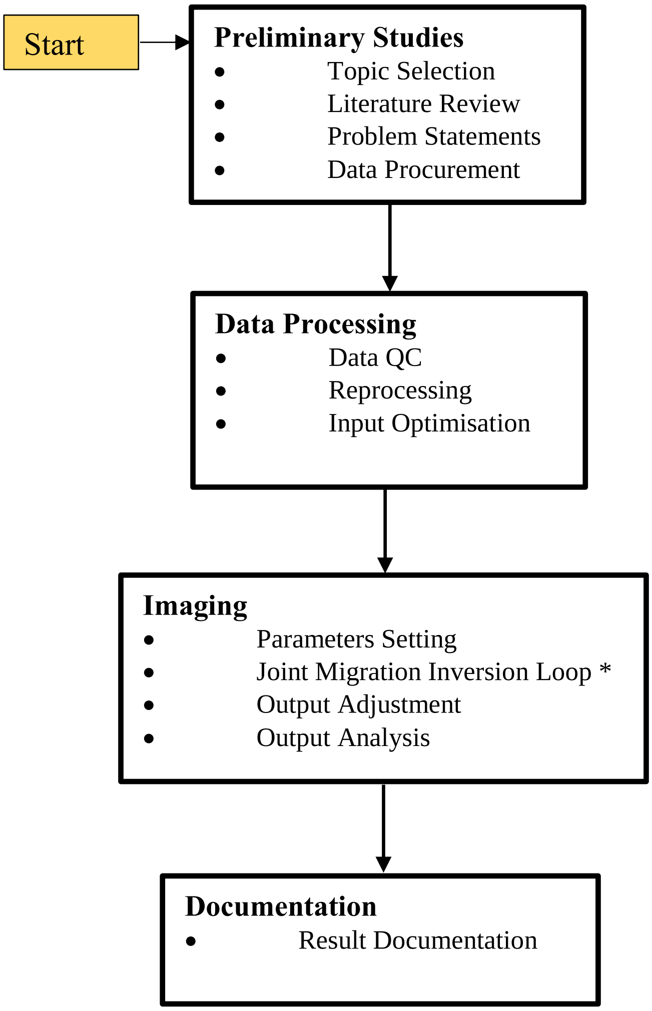

Figure 1. General research workflow.

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4. Results and Analysis

The main objective of the reprocessing stage is to eliminate unnecessary noise prior to migration. Apart from that, multiple reflections are the essential elements in JMI technique. Thus, the reprocessing steps of the seismic data should not include multiple reflection elimination. Multiple reflections should be preserved in an effort to test the robustness of JMI and to enhance the final image using JMI.

Figure 2 shows the initial stacked section of the raw seismic data of the Anding Field. As expected, the seismic data is contaminated with much noise originated from the acquisition process as well as some instrumental noises. After each processing step, the data is QCed by analysing its stacked section to see whether the particular process has eliminated the targeted noise or whether the parameter was too harsh that some of the much needed data is also removed. The main key is to find the suitable processing parameters such as the frequency filter and linear noise attenuation parameters to remove unnecessary noise yet still maintain the primaries. Apart from presence of noise in the section, the issue of unbalanced amplitudes can also be observed from the stacked section. Thus, amplitude balancing is also included to the optimisation process. When observed in the shots record domain, a few bad traces as well as dead traces could also be observed and to mitigate this problem, trace editing and interpolation steps are also applied.

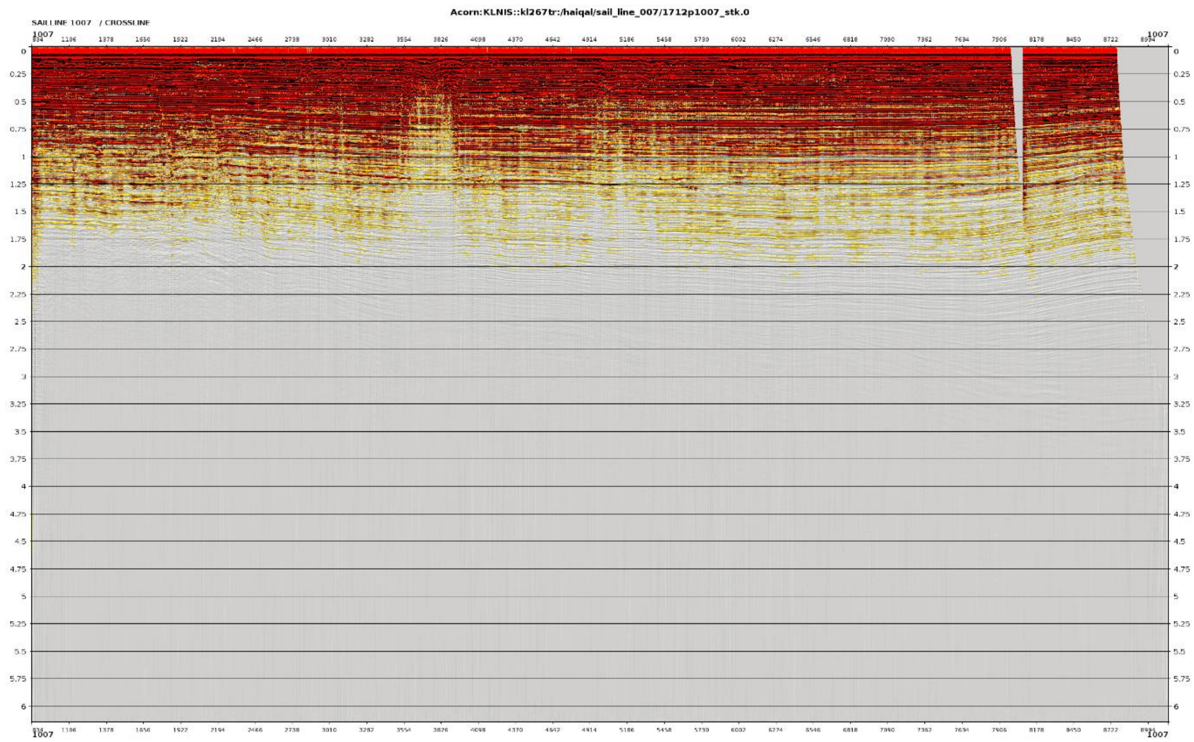

Figure 2. Shows stacked section of raw seismic data.

Figure 3 shows the stacked section of the same line after de-noise process. Generally, the processing workflow was done by utilising resources from CGG Asia Pacific located in Kuala Lumpur. The entire algorithm used was develop by CGG. Initially, the author considered utilising 3D data for JMI migration. Unfortunately, time constraint limited the project to use a single source and cable configuration, to save computing time.

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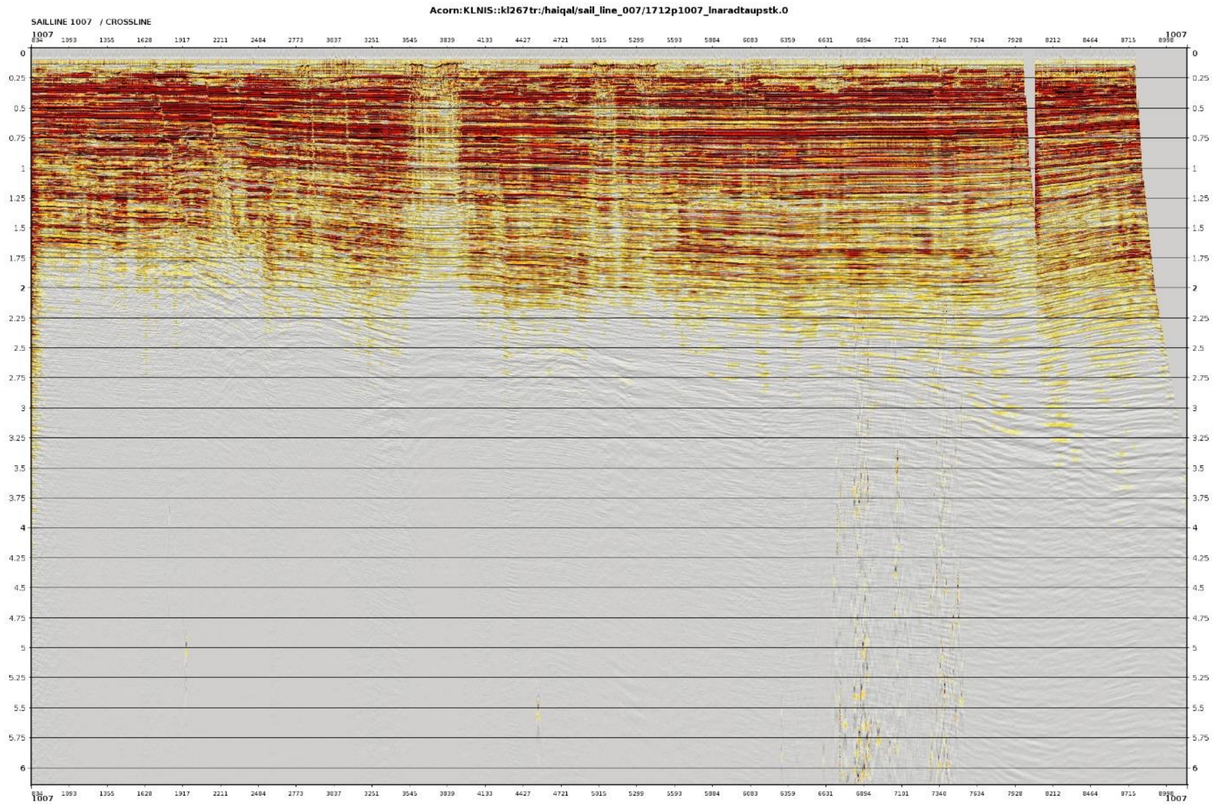
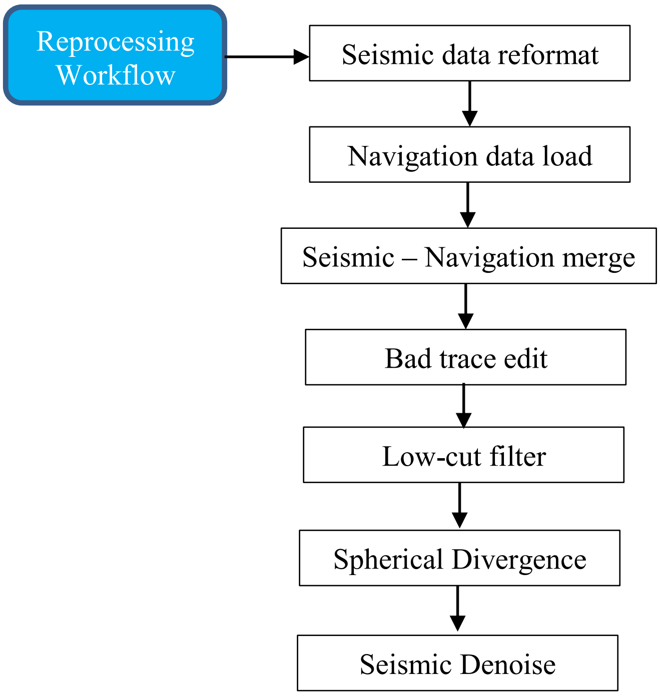


Figure 3. Shows seismic stacked section after de-noise. Low frequency noise is significantly reduced but remnant noise is still present after linear noise attenuation due to de-noising module was set too harshly. Further refining is needed. Amplitude balancing is still under par.



The de-noised stack section was produced by conducting noise removal modules. The workflow is illustrated by Figure 4. Subsequently, after noise attenuation process is done, the data will be tested if it is compatible with JMI input and adjustment will be made if necessary.

Figure 4. Processing steps in removing noise from the seismic section.

Noise removal stages start with the elimination of bad traces which were recorded during seismic data acquisition due to receivers malfunction. Bad traces could damage the overall data quality if they were kept, thus, they need to be removed. The noise removal processes continued with the Low-cut Filter process where the low frequency noise is removed. Low frequency waves that were < 2 Hz was removed by designing a filter from the filter module so that only waves of frequency of 2 Hz and above were kept. Next, seismic de-noise process aims to remove seismic noise such as linear noise, swell noise and random noise. By utilising specific module, linear noise and swell noise were reduced. Unfortunately, as depicted in Figure 3, some remnant noises are still present in the lower section. This is due to a few parameters used in the module such as the linear noise velocity and tau-p parameters that were set incorrectly thus, it did not successfully remove some of the noise. Therefore, in the future, some refining should be done to address this issue.

5. Conclusion

The primary objective of this work is to reprocess the raw seismic data for JMI application. A few issues have been identified concerning the size of the data and its quality and require some adjustments and modifications such as reprocessing and reducing the size of the data by only selecting certain shot points instead of using the overall data to be migrated with JMI algorithm. If the seismic data could not be used with the JMI, a set of synthetic data could be considered instead. This is due to the fact that synthetic data is much smaller in size, with no noise and in return, shorter computing time. Currently, the applicability of this new migration technique is still limited especially to a real dataset. Research on JMI has mostly revolved around synthetic data. Thus, for future work, this research will focus on making JMI technique more feasible to be used with real and larger dataset. Producing workflow for JMI could be important if this technique to be widely used in the future.

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