Transmission imaging: Moving Source Offset VSP (MSOVSP) Case Study

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Summary

In this paper we highlight some fundamental and robust application involving the use of offset vertical seismic profiling (VSP) for imaging with transmitted energy. The efficiency of two imaging methods which include a time-shift and a reversed-time migration based approach were implemented and assessed on synthetic and real seismic (MSOVSP) data from the Bosumtwi Impact crater. Results support that the transmitted energy contains structural information which can be relevant to image the contact between the post-impact sediment and underlying breccia rock unit in the vicinity of borehole LB-08A.

Introduction

The objective of seismic imaging techniques is to obtain optimal information about the structure or region being investigated. Processing of the seismic data necessitates the use of quality information on travel times, velocities, amplitudes, acquisition geometry, and a good understanding of variations in the physical properties of the medium. Offset VSP data contain both direct (transmitted) and reflected energy. In order to obtain information of the subsurface structure especially in the borehole vicinity, data processing often involves the use of the reflections generated at interfaces where the impedance contrast is sufficiently large. For VSP data, imaging practices require transformation of the reflections through a process called VSP-common depth point mapping (VSP-CDP, Hardage 2000) to give a vertically oriented stacked seismic section that extends laterally from the borehole location. Although analysis of reflections from seismic (both surface and offset VSP) data is often used to probe for structural heterogeneity at the subsurface (Yilmaz 1989, Scholz et al. 2002), it is however not the only part of the recorded seismic wavefield with information on structure (geology). McMechan et al (1988) demonstrated that direct energy also contains structural information and could be used to delineate the interface separating two geologic units with sufficient contrast in their respective elastic properties. They used a Reverse Time Migration (RTM) algorithm to propose a solution for the salt proximity problem (imaging the flanks of the salt dome). The purpose of this paper is to demonstrate how direct waves recorded in offset VSP setting can be used to image the contact between the sediments and the consolidated breccias rock unit below it within the Bosumtwi impact crater in the vicinity of the borehole.

Background

In this study, we use offset vertical seismic data acquired in the Bosumtwi impact crater. The Bosumtwi impact crater, located in Ghana is the largest young (~1.07 Myr) and well preserved crater in the world. The impact structure is covered by an 8km diameter Lake Bosumtwi. The base of the impact is covered by a layer of post impact sediments as revealed in the reflection section in **Figure 1a**. The Offset VSP study was done as part of the interdisciplinary Lake Bosumtwi drilling project of the International Continental Scientific Drilling Program (ICDP) of 2004 to study the subsurface of the crater structure. VSP (Zero offset and offset) studies were performed in order to understand the insitu seismic properties of the sediments and the impacted rocks in the vicinity of borehole LB-08A. Details of the drilling configuration and acquisition parameters have been discussed by Schmitt et al. 2007. The offset VSP acquisition was done with sensors positioned at 100m, 150m, 200m and at 450m depth (**Figure 1b**) along the borehole. The airgun source was located at a water depth of ~3m. **Figure 1c** shows a scaled amplitude plot of the receiver gather at 450m depth.

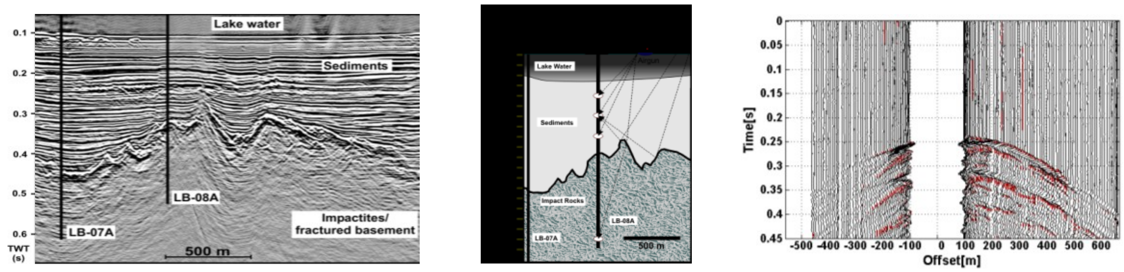


Figure 1: *a)* Depth (two-way travel time: TWT) section acquired via multichannel surface seismic Survey (Scholz et al., 2002). Borehole LB-08A was drilled through the central uplift whereas LB-07A was drilled at the outer rim of the uplift. Note absence of reflections in the hard rock (fractured basement) environment; b) Cartoon of Offset VSP acquisition geometry; c) Scaled amplitude plots of the offset VSP data for the receiver at 450m depth. Gaps in the data represent locations with no information.

Imaging the Sediment-bedrock contact

i) Methodology

We present two methods and assess their efficiency in providing accurate information about the structure (contact) in the vicinity of the borehole using synthetic and real data. For the purpose of simplicity these methods shall be referred to as time-shift and the migration-based methods. These methods require extrapolation of the recorded wavefield as well as the implementation of a travel time imaging condition. Both methods differ in the processes by which the wavefield extrapolation and the travel time imaging condition are implemented. The wave extrapolation and the travel time imaging condition are similar to prestack migration (Chang and McMechan 1986). The imaging condition in this case is applied to the direct energy.

In the time-shift method, the traveltime imaging condition is implemented by using ray tracing that assumes normal incidence at the interface to be imaged. Thus, with accurate knowledge of the receiver and source locations as well as the velocity information, Pythagoras theorem can be used to estimate the time of propagation within the sediments (t_s) and the breccias (t_b) where (t_b + t_s) represent the observed travel time from first break picks. Hence the location of the interface at depth can be obtained. The output image of the interface is constructed by applying to each recorded trace a corresponding time shift that represents the propagation time within the breccia unit. For the Bosumtwi data, approximate information on depth can then be obtained by doing a product of the one-way time axis with the velocity of the sediment layer. The migration-based method on the other hand is slightly more involving. A full description of the methodology has been given by McMechan et al. (1988).

ii) Transmission wavefield modeling and imaging

We use the von karman autocorrelation function as described by Geoff & Jordan (1988) to characterize the perturbations (stochastic component) of the velocities and densities within the Bosumtwi impact crater. The scale lengths within the sediments are anisotropic (a_x/a_z= 200) while the scale lengths within the brecciated unit are isotropic (a_x=a_z=3m), (L'Heureux et al. 2007).

Synthetic seismograms were modeled using a 3D viscoelastic finite difference code (Bohlen, 2002). The data acquisition was symmetric about the borehole location with maximum offset of 600m on either side. **Figure 2** shows the vertical component record of the shot gather. Note the asymmetry in the direct arrivals which can be associated to the irregular shape of the sediment-bedrock interface (**Figure 1b**). In processing the synthetic shot gather to image the sediment-breccia interface, some preprocessing was done to mute all secondary events. Although the predicted interface from both methods provide some hint on the asymmetry of the contact in the vicinity of the borehole location, the migration based approach does a better job at delineating the contact. **Figure 3** shows the predicted sediment-breccia contact using the migration (RTM) method. The results suggest the lateral delineation of the contact in the borehole vicinity can be done reliably within absolute offsets of 200m.

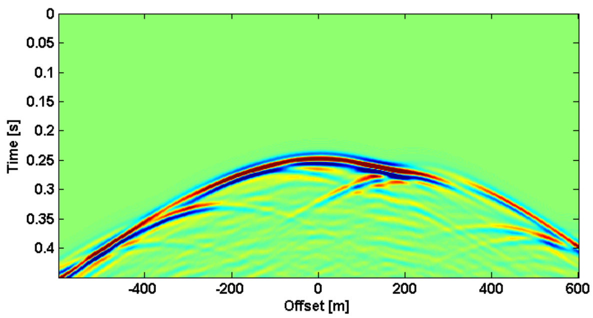
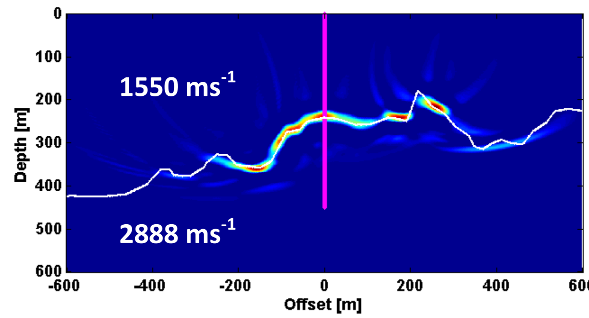


Figure 2: Vertical component plot of the recorded wavefields (synthetic) at the receiver locations (Trace interval 2.4m). Note the asymmetry of the recorded wavefield about the borehole location (0m offset).



superimposed white line represents the true model contact. The P-wave velocities are for the soft sediments and the breccia unit respectively.

iii) Transmission imaging with Bosumtwi offset VSP data

The Bosumtwi offset VSP receiver gather at 450m depth (R-450) was considered for imaging the interface separating the sediments and the brecciated rocks since the acquisition parameters are identical to those applied to the synthetic model example (assuming reciprocity). Unlike the synthetic dataset where the surface absolute offsets range from 0-600m, allowing for contact imaging over a large aperture, the R-450 data samples a limited aperture of the contact since no shots were recorded for small offsets (<100m). Thus, complete information about the lateral continuity of the contact in the immediate vicinity of the borehole will not be achieved with the R-450 data. **Figure 4a** shows the preprocessed data that is input in the backward wavefield extrapolation (2D acoustic) algorithm in a reverse time order. Without loss of generality and assuming the principle reciprocity, the recorded wavefield from the pseudo receivers (shot positions) was backpropagated with the average velocity within the soft sediment package(1550 ms^{-1}), whereas ray tracing from the pseudo source (receiver position) was done with the average velocity of the breccia unit (2888 ms^{-1}).

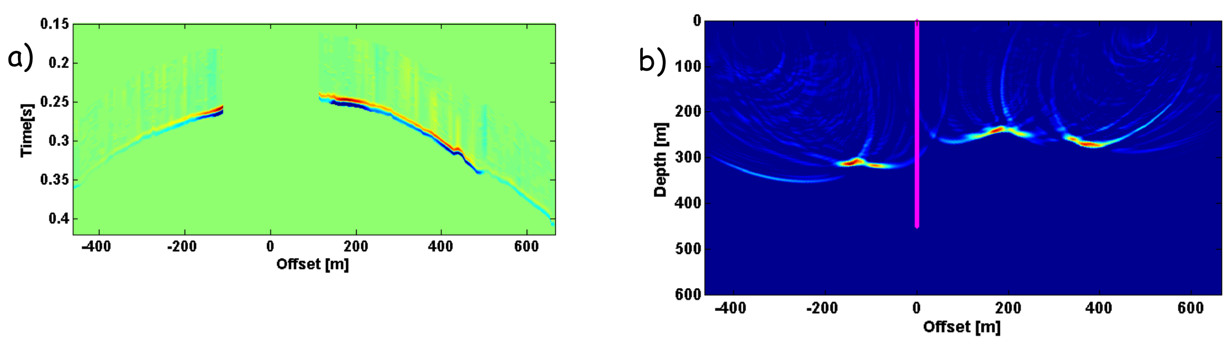


Figure 4: a) Preprocessed data from R-450 (muting and trace interpolation). Traces for small absolute offsets (<100m) were padded with zeros; **b)** Reconstructed sediment-breccia contact image from R450 using the migration method.

The reconstructed interface image is shown in **Figure 4b**. The result provides first hand information on the asymmetry of the contact around the borehole.

The efficiency of the transmission imaging methods discussed above depends in part on correct information of the acquisition parameters and the spatial locations of the sensors and receivers. Not accounting for location errors results in a flawed image reconstruction of the sediment-breccia contact. Moreover, out of plane diffractions can influence the direct wavefields recorded in the plane of the 2D spread of receivers, thus introduce some errors in the interface (contact) image reconstruction.

Conclusions and Outlook

Analysis of the offset VSP data from Bosumtwi provides additional information to improve the characterization of rocks underneath the lake. We have used synthetic models (constrained by other geophysical observations) to demonstrate that transmitted energy (direct arrivals) can be used to provide structural information in the vicinity of the borehole. Two methods including the time-shift and the migration-based methods were tested on synthetic seismograms. Results support that the migration-based approach provides a reliable reconstruction of the sediment-breccia contact image. Implementation of the migration-based algorithm to the Bosumtwi Offset VSP data revealed the asymmetric structure of the sediment-breccia contact in the vicinity of the borehole despite errors associated to source locations especially for near offsets. Future work will involve applying this imaging technique to assess velocity models.

Acknowledgements

This research work was achieved with financial support from the International Continental Drilling Program (ICDP), the U.S. NSF-Earth System History Program under Grant No. ATM-0402010, Austrian FWF (project P17194-N10), the Austrian Academy of Sciences, Canadian NSERC, and by the Canadian Commonwealth scholarship plan. Drilling operations were performed by DOSECC. Local help by the Geological Survey Department (Accra) and KNUST (Kumasi), Ghana, was invaluable.

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