AVO Analysis with Multi-Offset VSP Data

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ABSTRACT
Multi-offset vertical seismic profiling (VSP) techniques can be employed to image reservoir zones in complex geological settings. The integration of borehole geophysical logs, offset VSPs, and 3D elastic modeling studies provide new insights in the internal structure of a target zone. We present 3-D elastic modeling results for multi-offset VSP data acquisition. Forward modeling is based on the implementation of 3D elastic FD codes on massive parallel and/or distributed computing resources. In order to obtain information about the angular reflection response of the target zone at about 1000 m depth, we compute the synthetic VSPs for offsets 0 to 2000 m. VSP data acquisition geometry enables us to evaluate the angular-dependent reflection and transmission response from the target zone. Complex overburden conditions such as thick permafrost layers, however, limit the usefulness of the large offsets as much of the seismic energy gets trapped in a near-surface high-velocity zone. In the field, broadband Vibroseis source signal (8-180 Hz, linear sweep) was recorded with a 3-component 5-level tool. True amplitude processing of the multi-offset VSP data focused on velocity analysis and wavefield separation. The multi-offset VSP acquisition geometry provides valuable information about the vertical distribution (layering) within the reservoir zone and information about information about the bulk elastic properties from the reflected P-wave and converted S-wave amplitude-versus-offset response.

Introduction

AVO (amplitude-versus-offset) provide useful information about changes in petrophysical parameters in layered earth models. Zero-offset VSP provide important links between surface seismic and borehole geophysical data. Multi-offset VSP data allows us to extract AVO (or amplitude versus angle of incidence) information from 3-component borehole seismic data. Single or low fold VSP data, however, are challenging for AVO analysis as multiples, converted wave, shear waves and tube waves may introduce a low signal-to-noise environment. Multi-offset VSP data can be utilized to study angular-dependent reflection and transmission responses for CMP or common receiver geometries. Figure 1 shows reflection and transmission geometries suitable or amplitude versus angle of incidence studies. It is important to note that the VSP geometry offers unique opportunities to calibrate AVO-trends by analyzing simultaneously the reflection and transmission response. In practice, AVO-analysis is based on plane wave reflection coefficients (Zoeppritz equations or small angle approximations). For small and intermediate depths of investigation, however, plane wave approximations do not suffice and geometrical spreading corrections must be applied. For multi-offset VSP experiments, the direct (transmitted) wavefield can be used to compensate for offset dependent geometrical spreading. Finally, heterogeneities at the source (static corrections) are best identified in common shot records.

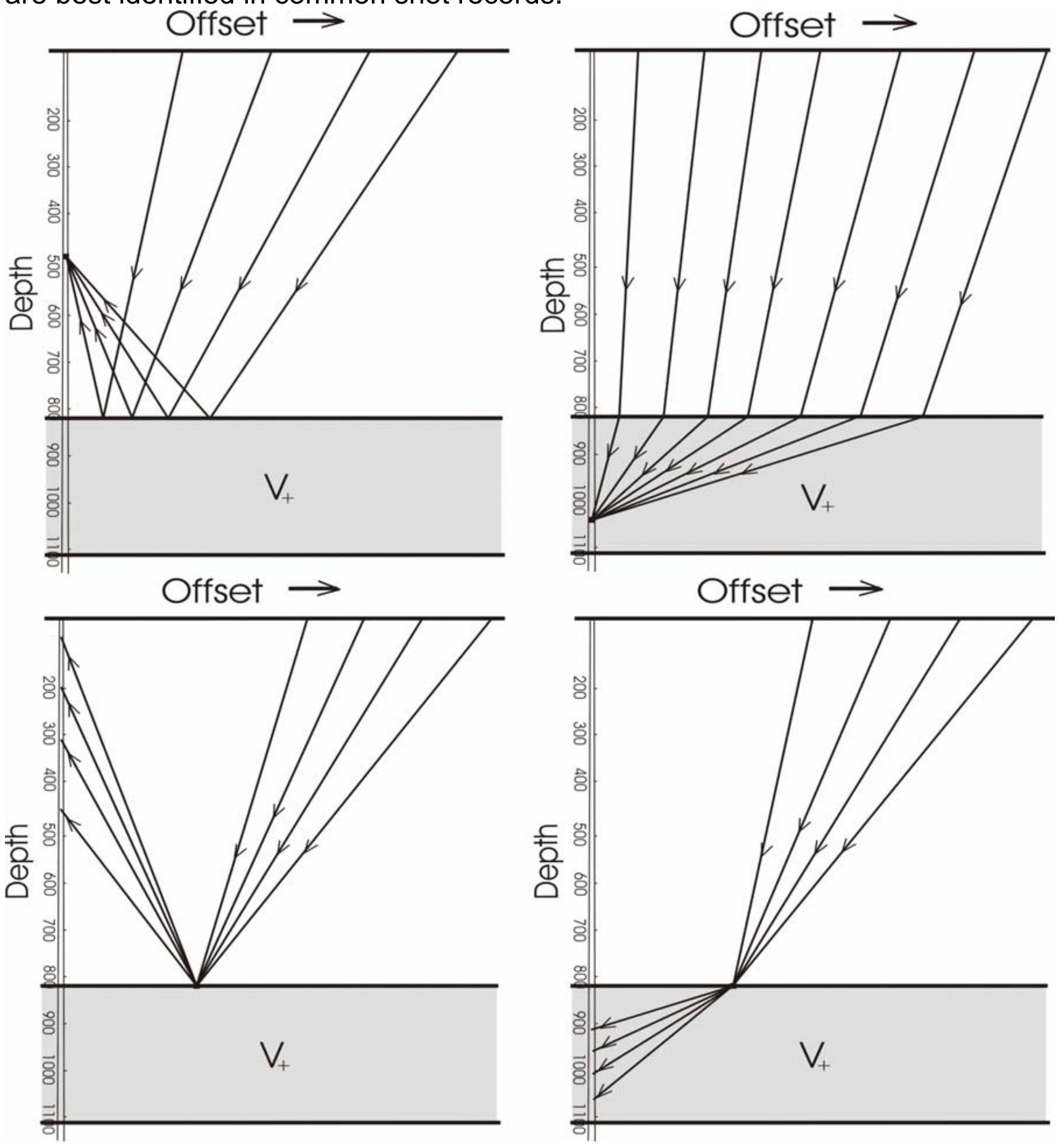

Fig. 1: Offset VSP data acquisition geometries providing common midpoint and common receiver gathers for reflected and transmitted wavefields.

Modeling

In our modeling study, the reservoir is characterized by strong variations in elastic parameters. Figure 2 shows the acoustic impedance model for the study area (Collett and Dallimore, 2002). Base of the high-velocity permafrost is at 650m. Gashydrate bearing lithologies are located at approximately 900 - 1100 m depth. Within the model, the Poisson's ratio varies from 0.15 to 0.48 (Milkereit et al., 2002). Direct solutions of the elastic wave equation by finite differences (FD) must be obtained for complex fine-scale 3D subsurface models to better assess the angular (amplitude-versus-offset) and other frequency dependent seismic attributes. Here we present 3-D elastic modeling results for multi-offset VSP and acoustic emission experiments. Forward modeling is based on the implementation of 3D elastic FD codes on massive parallel and/or distributed computing resources using MPI (message passing interface). For parallelization the 3D model (Fig. 2) is decomposed into sub-volumes. Each processing element (PE) or CPU is updating the wavefield within its portion of the grid. For wavefield update, we apply a staggered-grid, velocity-stress finite difference equations which are of 4th order accuracy in space and of second order accuracy in time (Robertsson et al., 1994). The processors lying at top of the global grid apply a free surface boundary condition while the processors at the edges of the model apply an absorbing boundary condition. At the internal edges the processors exchange wavefield information. By clustering conventional PCs, wall clock time for 3D FD modeling can be significantly reduced and and the possible grid sizes significantly increased (Bohlen and Milkereit, 2001).

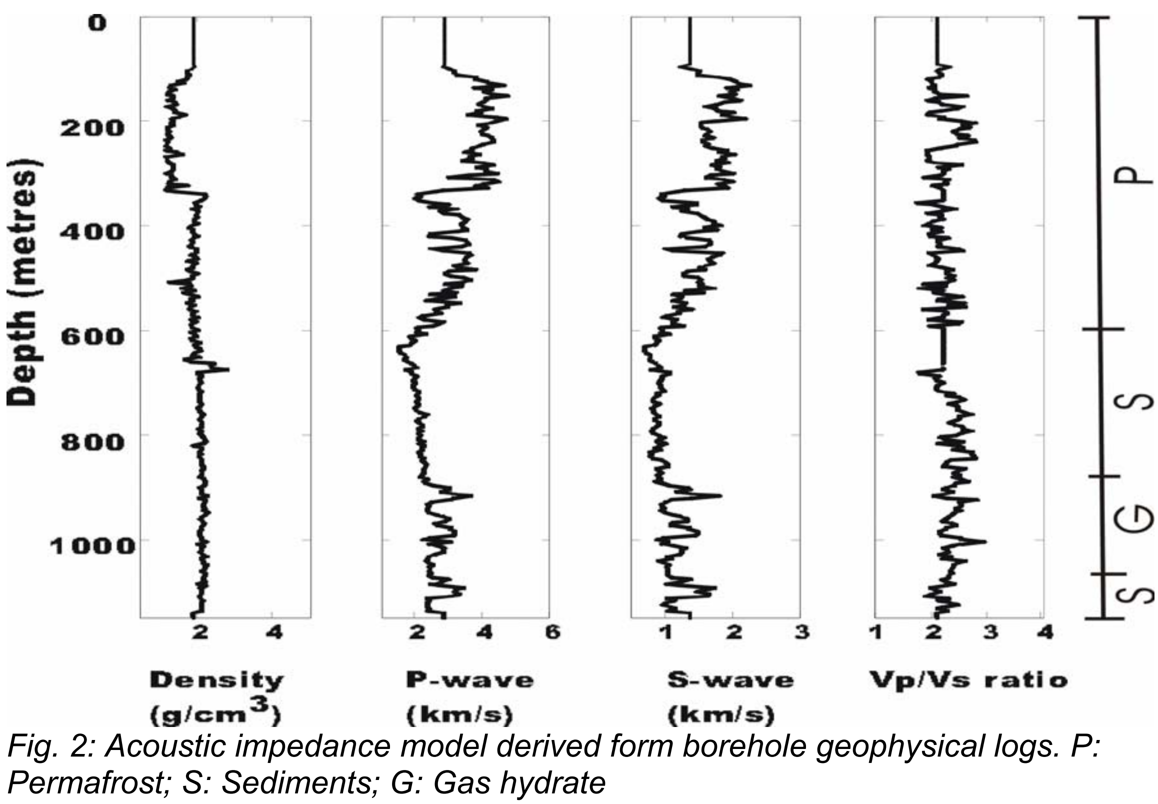

Fig. 2: Acoustic impedance model derived form borehole geophysical logs. P: Permafrost; S: Sediments; G: Gas hydrate

Offset Vsp Modeling Study

Figure 3 shows the synthetic vertical seismic profiling experiment to evaluate the velocity and reflectivity structure of the reservoir. In order to obtain information about the angular reflection response of the target zone, we compute the VSPs for offsets 0 to 1000 m. The thick high–velocity ice–bearing permafrost layer produces prominent multiple events. The true amplitude horizontal and vertical component recordings of the target zone are shown in Figure 4. The prominent AVO response of the reservoir zone is evident. The complex overburden, however, limits the usefulness of the large offsets as much of the seismic energy gets trapped in a near-surface high-velocity zone. In addition, lateral variations of true amplitudes point towards complex geometrical spreading corrections for large offset recordings. The modeling study indicates that offset-VSP data acquisition geometry will yield new information about the spatial/size distribution of the targeted reservoir.

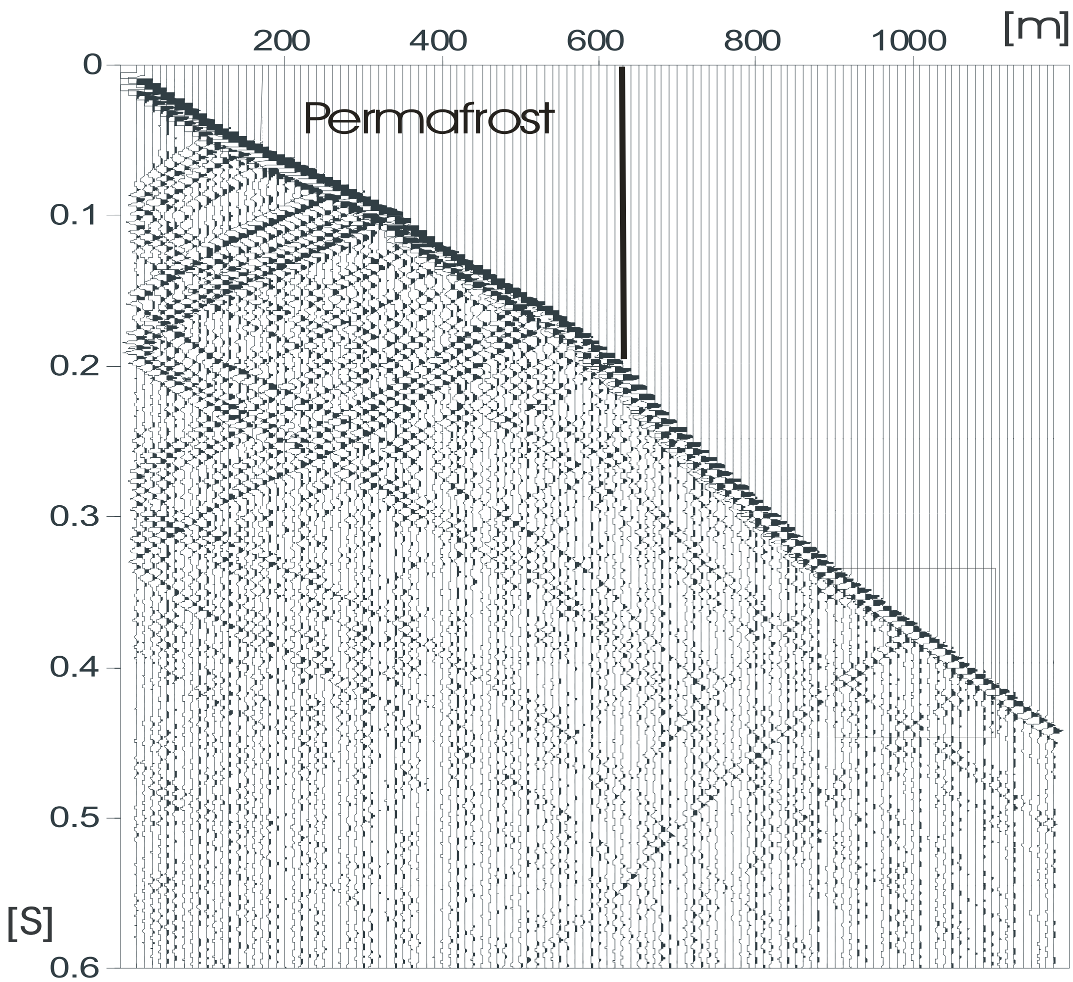

Fig. 3: Vertical component VSP for the model shown in Fig. 2. The target reflections from the reservoir zone are marked by box.

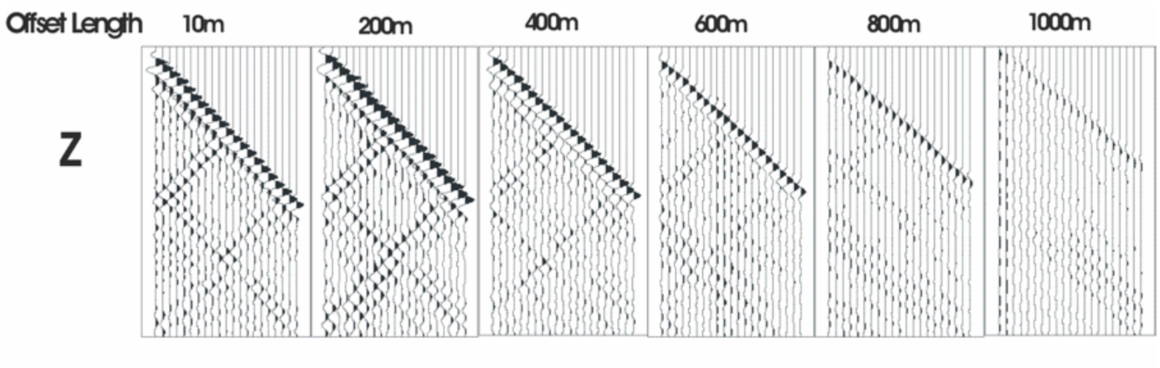

Fig. 4: Synthetic true amplitude recordings (vertical component (top) and horizontal component (bottom)) with reflections from the reservoir for offsets ranging from 0 to 1000m.

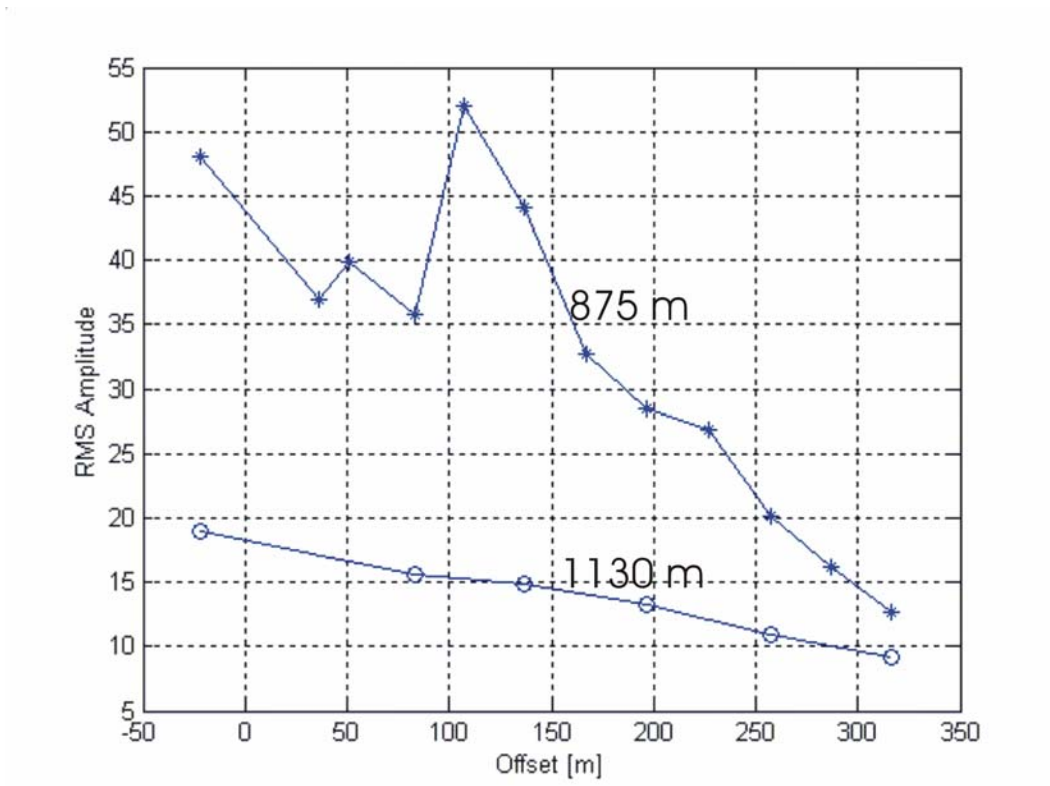

Fig. 5: Field data example of direct (transmitted) arrivals from multi-offset above and below the reservoir zone.

Conclusions

A 3D seismic elastic modeling study helps to fine tune the acquisition parameters for an offset VSPs survey targeting a reservoir at 900 m depth. The study (based on the available log and velocity information) is used to determine the optimum source-receiver offset for the borehole seismic survey. Based on the modeling results, acquisition of a walk-away VSP is highly desirable to better evaluate the

AVO reflection and transmission response from the reservoir zone.

References

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