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P- and S-wave reflectivity modelling of basement seismic reflections in Athabasca Basin

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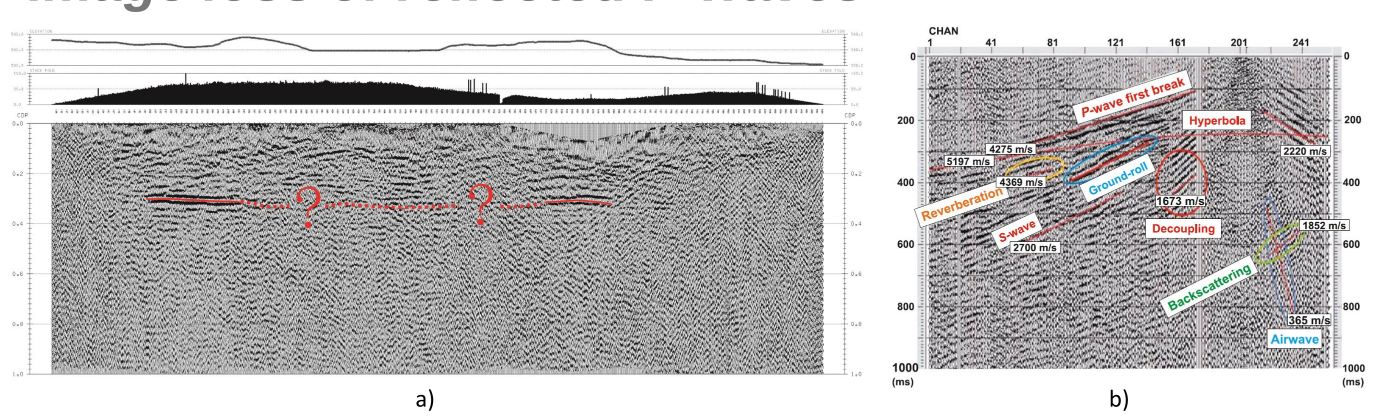
Introduction

Previous interpretations of seismic data in Athabasca uranium exploration projects were based on structural images of reflected P-waves, but the seismic profiles displayed significant loss of image quality at several sections along the unconformity underlying the sedimentary strata. P-wave imaging problems could be caused by either the strong interference with ground roll due to small reflector depth, or attenuation of reflections by common mid-point (CMP) stacking due to weakening or phase changing at far offsets. In contrast, S-waves with different amplitude versus incident angle (AVA) property have the potential to image such target structure. Our study focuses on demonstrating the suitability of converted S-waves for enhancing reflected P-wave images of the basement reflector based on forward modelling of P-P and P-S reflectivity.

Motivation

Image loss of reflected P-waves



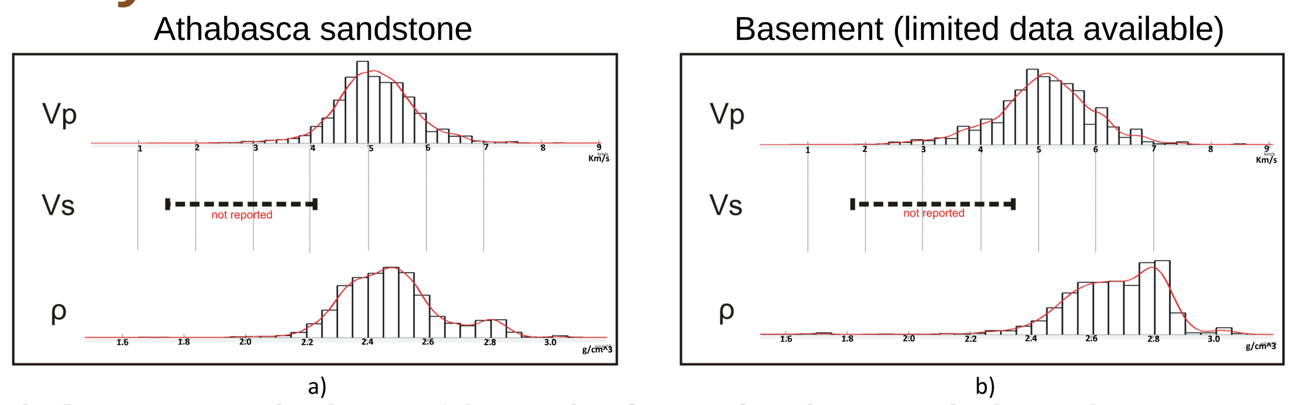
(**Fig. 1** Various types of noise interference with P-wave reflection (hyperbola) from the unconformity could be a major cause of the image loss. a) A CDP stacked profile along high-resolution line No.14 near the McArthur River Mine (White, 2007). b) A raw common source gather from a McArthur River surface seismic survey (Hajnal, 2010).)

Distinguishable basement reflection can be found along two solid red lines, but estimation of unconformity depth is difficult in between. P-wave reflection (hyperbola) displays early arrival time due to shallow depth. Airwave, ground-roll and reverberation smear P-wave reflection from near to far offset. On the other hand, the low-velocity S-wave stands out from earlier noises in the shot gather.

Petrophysical data

Constrains of forward modelling

P- and S-wave velocity and density can be compiled from archived dataset of in-situ multidisciplinary geophysical study.



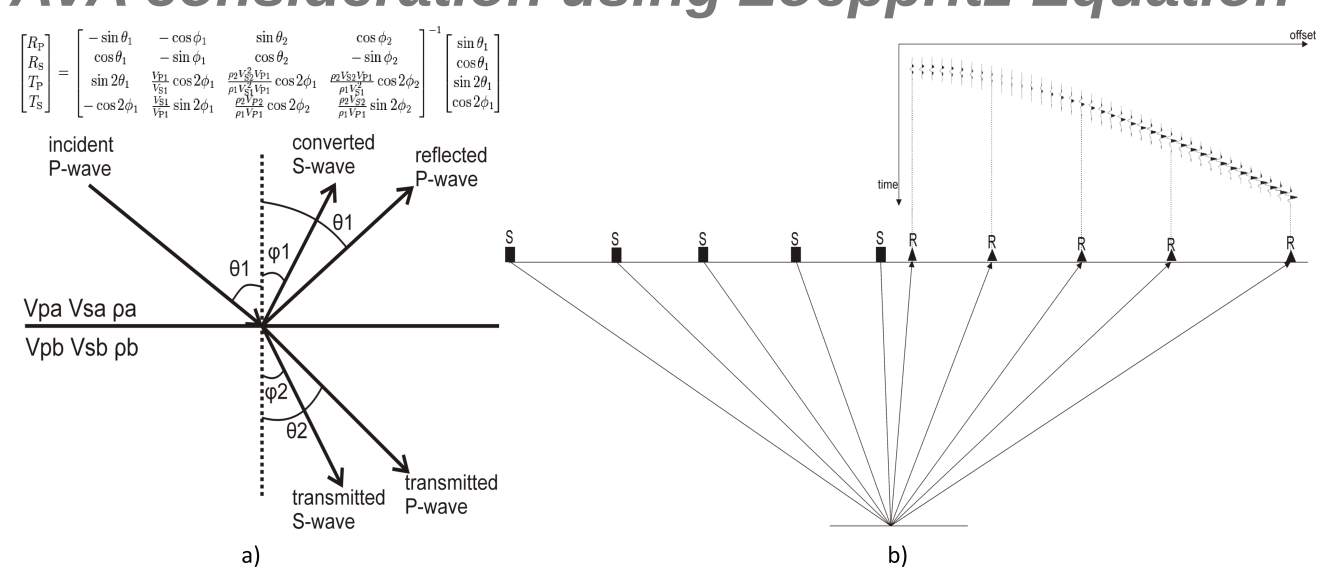
(**Fig. 2** Statistics of borehole velocity and density measurements. a) velocity and density borehole measurements of Athabasca sandstone below 300m depth b) velocity and density borehole measurements of the basement rock) (Mwenifumbo, 2004)

S-wave velocity was not measured in any boreholes in McArthur River area, but can be estimated from VSP surveys. The data below the unconformity is limited because less than three boreholes in the study area penetrated into the basement rock.

Note: P-wave velocity contrast can be small, so imaging of unconformity could fail over low-impedance area.

Sensitivity analysis

AVA consideration using Zoeppritz Equation

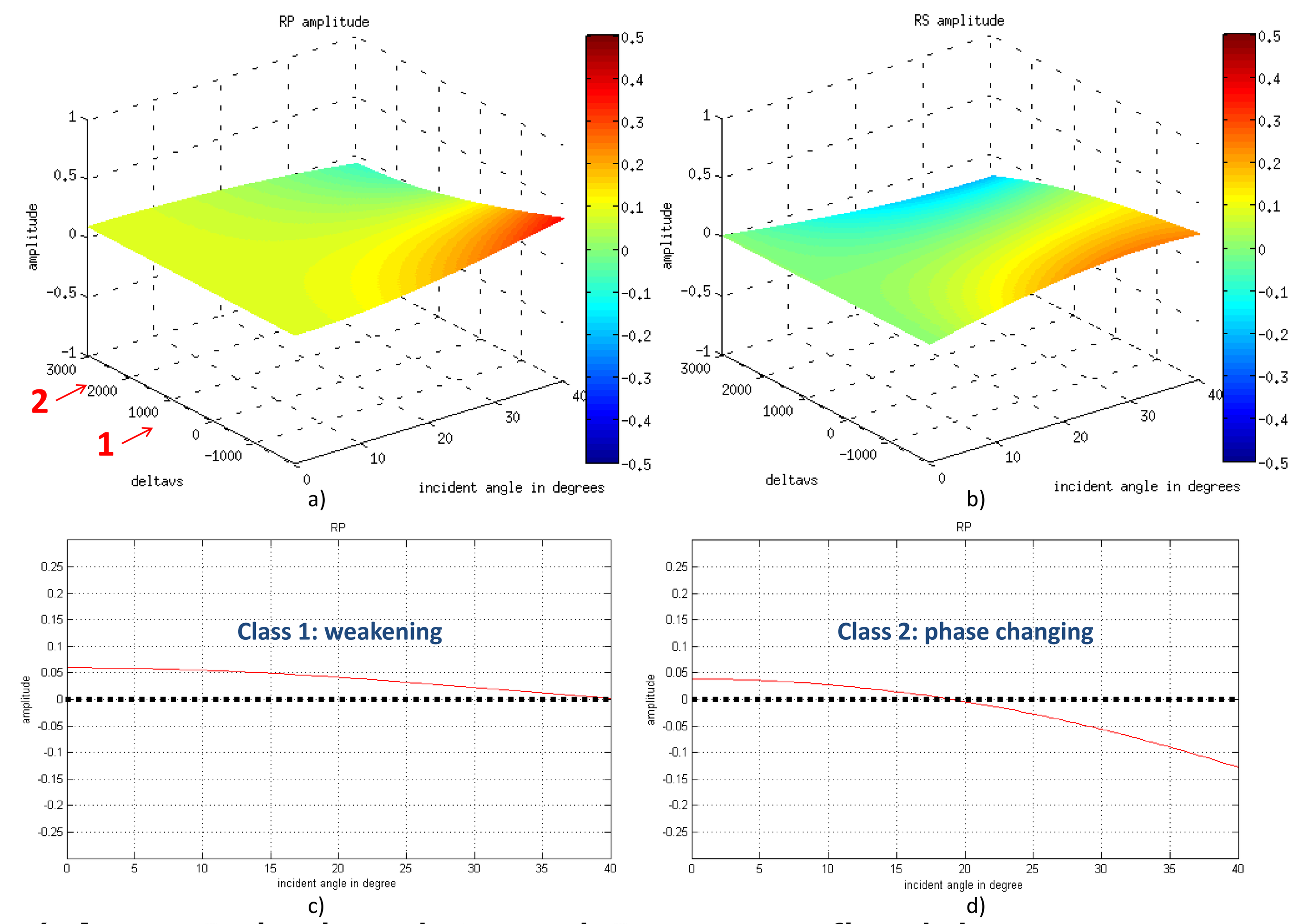


(**Fig. 3** Illustration of AVA. a) Incident P-wave products and their reflectivity given by Zoeppritz equation. b) Source-receiver geometry of a CMP gather.)

AVA response can be predict by Zoeppritz equation for both converted S-waves and reflected P-waves based on a plane wavefront assumption which is commonly used for exploration of deep targets (greater than 1km).

Note: Stacking traces (a conventional reflected P-wave processing step) in figure b) will cause suppression of the signal.

Calculation of AVA response using Zoeppritz equation (figure 4) indicates prominent decreasing of P-wave reflectivity with increasing incident angle. On the other hand, converted S-wave reflectivity tends to show brightening amplitudes.



(**Fig. 4** Calculated P- and S-wave reflectivity versus incident angle using Zoeppritz equation. a) and b) AVA response changes with S-wave velocity contrast. c) and d) AVA response class 1 and 2 as arrowed in a).

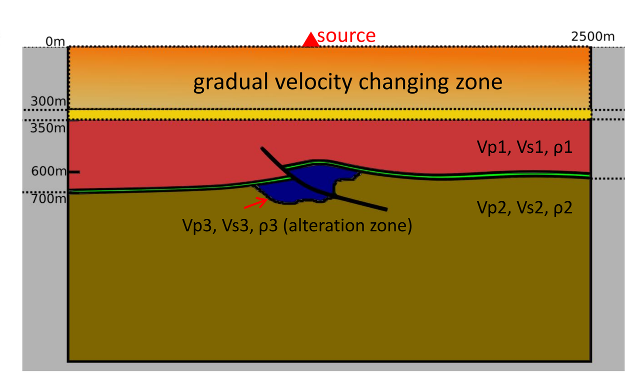
Reflected P-wave weakens at far offset near class 1. With high S-wave velocity contrast (more than 2000 m/s near class 2), P-wave changes phase.

Changing of S-wave velocity contrast affects both reflected P-wave and converted S-wave AVA properties. A phase changing of reflected P-wave can result in weakening of signal during CDP stacking process. S-wave reflectivity is close to zero at near offset, and depends on S-wave velocity contrast at far offset.

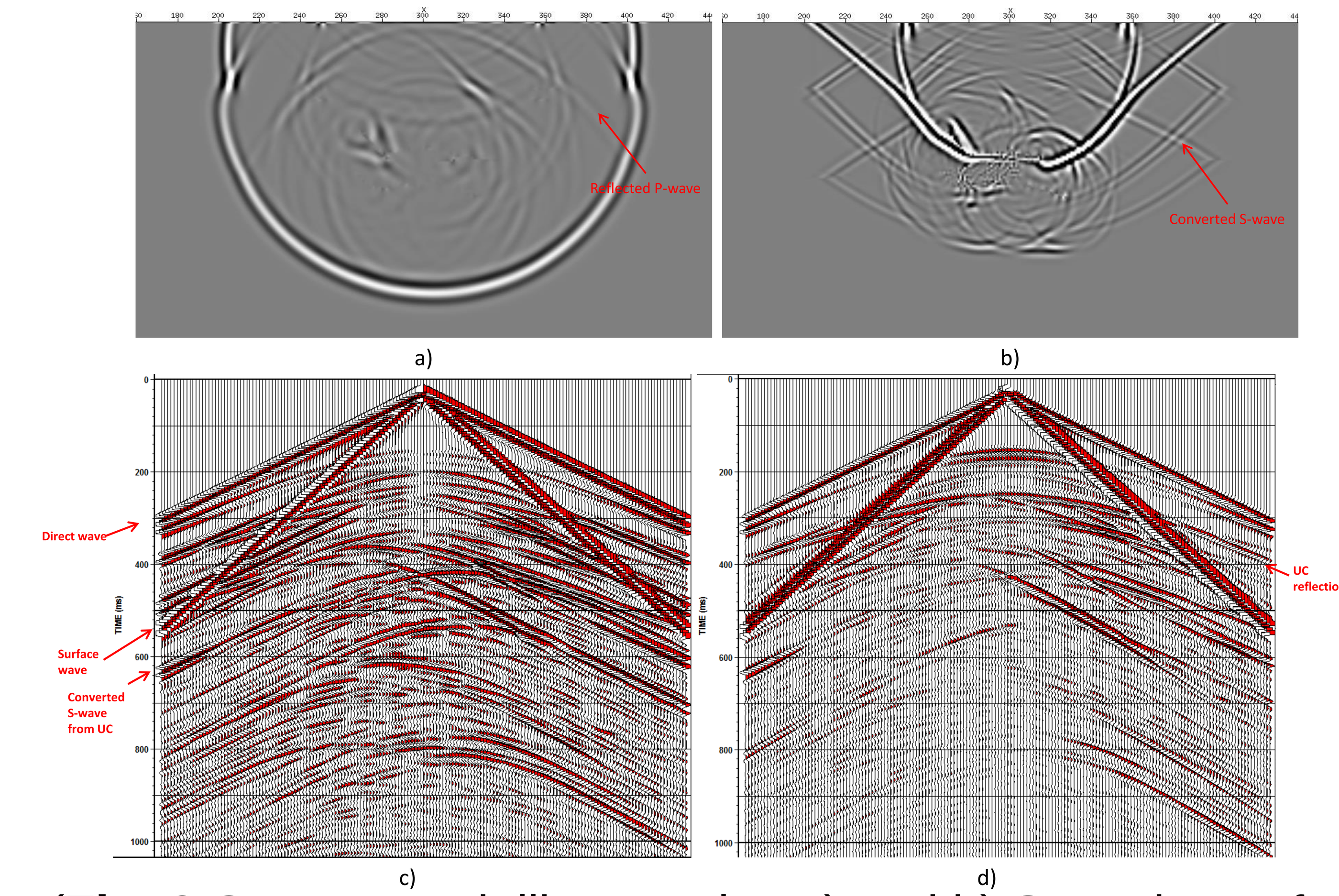
Elastic wave modelling

Simulating the wavefront

However, for a shallow reflector, the Zoeppritz equation based on a planar wavefront assumption is not sufficient to predict amplitudes of P- and S-waves correctly. Spherical wavefront can be calculated by 2D full elastic forward modelling. The produced synthetic seismic record contains P-, S-wave and surface waves.



(**Fig. 5** A sketch of geologic model considering multiple scenarios in Athabasca basin, modified from Bolen, 2002)



(**Fig. 6** Current modelling results. a) and b) Snapshots of P- and S-wave wavefield at 250ms c) and d) Horizontal and vertical components of above modelling)

Snapshots show amplitudes on the wavefront of P-wave reflection from the unconformity is not as consistent as that of S-wave.

Converted S-waves have little interference with surface waves on the synthetic shot record compared with reflected P-waves.

Repeating the modelling with different source location will produce full elastic synthetic CMP gather for analyzing of amplitude attributes of the unconformity.

Outlook

Enhance the image with S-wave information

The study evaluates the imaging potential of converted S-waves, and will be applied in the processing of multicomponent 2D, 3D and VSP data in Athabasca Basin.

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