Converted-wave processing in a complex area: near surface and imaging challenges

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ABSTRACT

Converted waves (C-waves) could have a more extended application if some processing challenges were overcome. This study focuses on such issues like the near surface heterogeneity and the complex geological structure, and their effect on C-wave imaging. This work is inspired by a zone with such characteristics from Colombia.

For analysis purposes, this study separates the near surface and the depth imaging issues. Thus, the near surface is studied with real data using tomography, and depth reflectors imaging is investigated in a synthetic model without near surface problems. Only preliminary analyses have been carried out in the last topic.

S-wave velocity models of the near surface from surface seismic and from uphole data agree, in their main features. However, the uphole shows slower velocities in the very shallow part, which appears more reliable. Synthetic data generated reasonable good images with conventional methods. More complicated models will be investigated in the future, focused on velocity analysis and filtering methods.

INTRODUCTION

Converted wave (C-wave) processing methods have made noticeable progress (e. g. Harrison, 1992, Thomsen, 1999) that have enabled their successful application in the industry (e. g. Stewart, et al., 2003). High quality information has been obtained, especially in marine data (OBC/OBS). However, there are some processing challenges that are yet to be overcome to have a more extended application to more complex areas on land.

Multicomponent seismic data from Colombia motivated the study presented here, since the data was acquired at a valley with topographical elevations and in the presence of geological structures. A 2-D 3-C surface seismic line provides the processing data, and an uphole survey provided data related to the near surface. Previous processing of these 2-D data set has shown the challenges presented to conventional converted wave processing methods (Mason, 2013), such as statics correction and velocity analysis..

Near surface challenges have been identified early in S-wave exploration methods,.They are caused by the heterogeneity of the near surface and the corresponding low velocity of S-waves. Besides that, the trajectory of converted waves is complicated and not symmetrical, making it harder to stack events even for the most simple case. This is the imaging challenge, which depends on the geological structures.

In order to study these issues of   converted waves processing, in this work the near surface and the depth imaging issues are analyzed separately, each one with a different approach. Thus, to study the near surface, tomography methods on the uphole and surface data are investigated, and for the depth imaging methods a synthetic model without near surface problems was created.

FIELD DATA

The data was acquired in a location of the Middle Magdalena Valley basin of Colombia. The specific location corresponds to the valley of a small river, illustrated by Figure 1. There are alluvial sediments (Q) close to the river, and Tertiary outcrops (T) in the hills nearby. A 9 km 2D 3C seismic line, approximately in a north-easterly direction, was acquired there, identified by a dotted line in the Figure. Two uphole surveys, identified by numbers in Fig. 1, were acquired at this location on shallow boreholes to study the near surface. Only uphole 1 was used in this work.

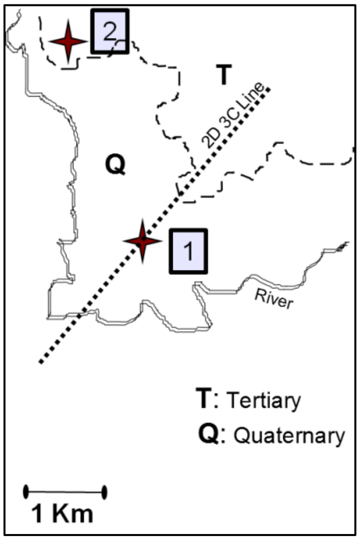

FIG. 1. Field layout and setting. Location of a seismic line, shown by the dotted line, and two uphole surveys, shown by numbers . Uphole 1 and the 2D 3C seismic line were used for this analysis.

The 2D seismic line sources were separated from each other by 40m, and the receivers by 10 m from each other. The energy sources were dynamite charges of 2.7 kg buried 10 m below the earth's surface. The receivers were digital multicomponent accelerometers, with the radial component in the inline direction. One example of the data obtained is shown in Figure 2, the horizontal component is given in Figure 2a, and the vertical component in Figure 2b. Notice the content of strong low velocity events in the noise cone of the horizontal component: these events were interpreted as S-wave refractions, and were used for the S-wave velocity analysis. Analogous events have been identified previously by other investigations, e. g. Dufour (1996) and Zuleta (2010).

The boreholes had a maximum depth of 60 m from the surface. There were 23 sources of energy inside, separated by 2.5 m from each other, between 5 and 60 m depth. Small dynamite charges of 150 g were used as explosive sources, interspersed with caps. The receivers were accelerometers of the same type used for the surface data, separated by 5 m from each other with a maximum offset of 100m. Figure 3 shows examples of the data obtained for the horizontal component and for five source depths: 55, 45, 30, 20 and 10 m. Notice the strong event, identified as direct S-waves generated by the source (see Guevara et al., 2011). This event was picked to obtain the near surface velocity model.

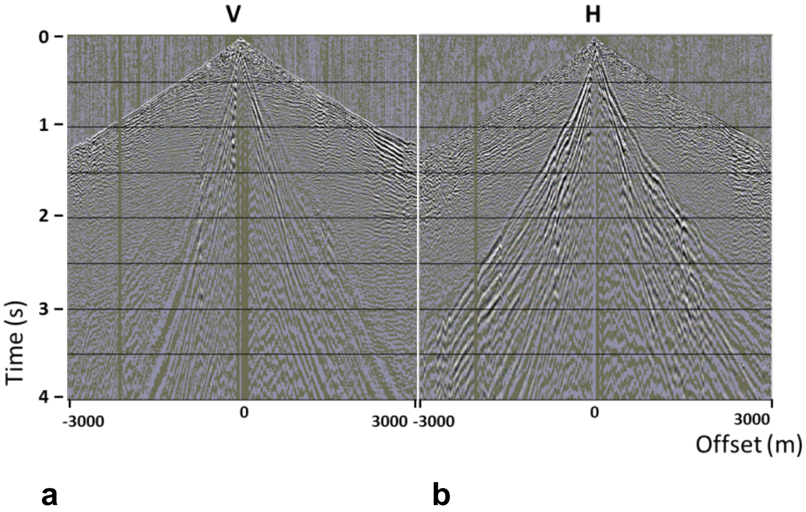

FIG.2. Examples of shot gathers in the 2D Line. (a) Vertical component,(b) Horizontal component. Notice the strong event in the low velocity cone of the horizontal component, identified as an S-wave refraction.

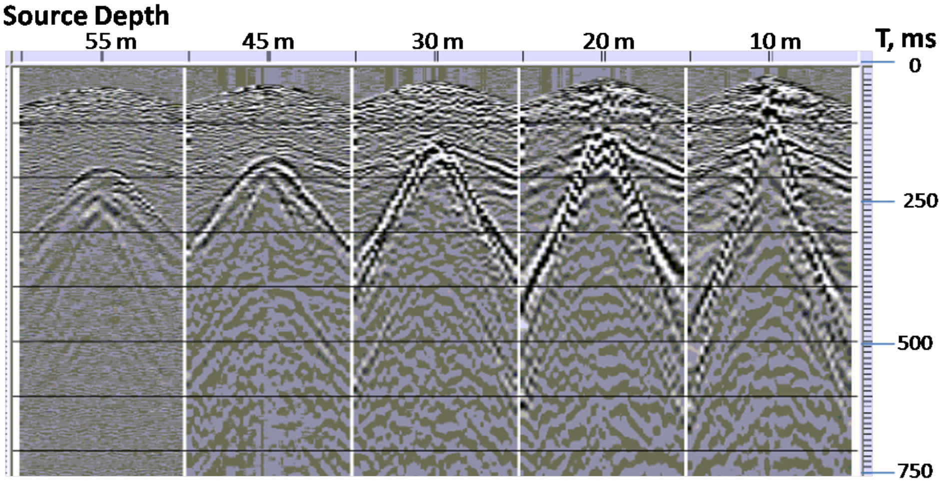

FIG. 3. Examples of horizontal component shot gathers from the uphole, for five shots at different depths. Notice the strong event, identified as an S-wave generated by the source.

ANALYSIS OF THE NEAR SURFACE

The near surface S-wave velocity model can provide key information for the statics correction and for advanced migration methods. The near surface velocity field of S-waves can be quite complex and hard to obtain with surface methods, and often contains a certain amount of uncertainty. Shallow borehole data can provide additional constraints to obtain a more reliable model.

In previous work (e. g. Guevara et al., 2011), an S-wave velocity model was obtained using zero offset arrival times from a borehole study. This result is extended here to the same data, picking all the arrivals and using tomography. The resulting model is local, valid only for a short distance. Besides, we account with the 2D 3C seismic line data, which provide refraction events, thus with tomography it is possible to obtain a widespread velocity model.

Figure 4 illustrates the picking of events on data from the 2D seismic line (Fig. 4a) and from the uphole data (Fig 4b). The model resulting from tomography of the uphole data is illustrated in Fig. 5, with depth referred to the land surface and with a maximum offset of 50 m. Vertical and horizontal scales are proportional. The model resulting from tomography of the 2D line refractions is shown in Fig. 6a, with the surface shown by a black line. For analysis purposes a squeezed version of the uphole velocity model of Fig. 5 is shown in Fig. 6b. Besides that, the location and depth of the borehole where the uphole data were acquired is shown by vertical red lines on the profile in Fig. 6a. The velocity scale colors are the same in both Fig. 6a and 6b. Notice that the resultant velocities agree, except for one important difference: the shallower velocity from the uphole, between 0 and 15 m, is slower, about 150 m/s, compared to the velocity of Fig. 6a which is about 250 m/s.

An explanation of this difference is the sampling of the surface data: there is a receiver every 10 m, and a wave with a frequency of 20 Hz and a velocity of 150 m/s would have a wavelength of 7.5 m, which requires 3.75 m sampling to avoid aliasing of the refracted events, and the receivers are separated by 10 m in the surface data.

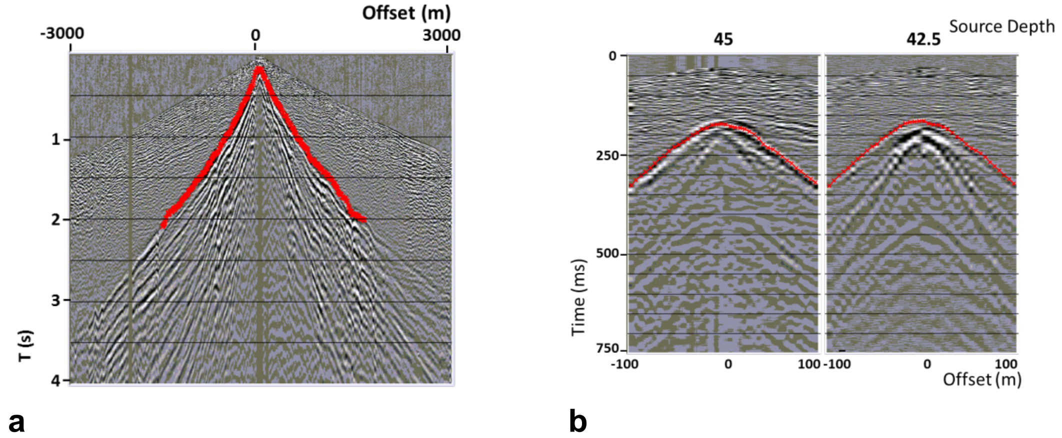

FIG. 4. Examples of picking near-surface S-wave events. (a) Refractions of a shot in the 2D Line. (b) Direct S-wave arrivals generated by explosive sources of two shots in the uphole.

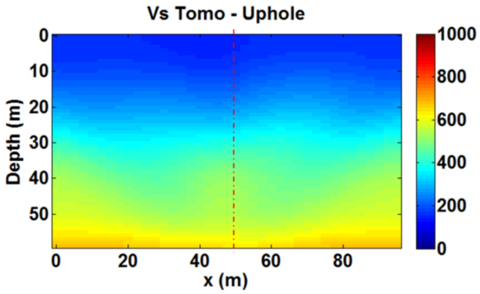

FIG. 5. Velocity of S-waves in the near surface obtained using tomography on the S-waves picked in the uphole data.

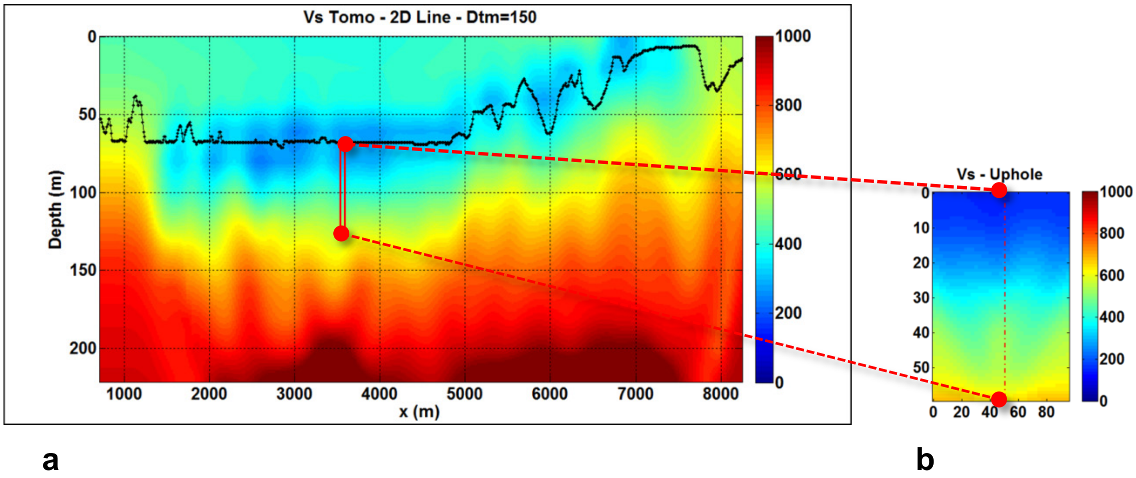

FIG. 6 . Near surface S-wave velocity after tomography of the 2D line, compared with the uphole result. (a) S-wave velocity from tomography of refracted arrivals of the 2-D line. The black line indicates the surface topography. (b) For comparison, a squeezed version of Fig. 5 (V_S from the uphole tomography). Notice slower velocities in the shallower uphole data.

DEPTH IMAGING

A model inspired by the real data was generated to study imaging issues for converted waves in this area. Velasquez (2012) provides information about the geological characteristics of this setting. Fig. 7a illustrates the S-wave velocity, and Fig. 7b shows the velocity profiles for P and S waves at location 3300 m of the *x*-coordinate axis. It can be noticed that there is no surface heterogeneity in the model. As a first approach, the model is as simple as possible.

A 2D elastic finite difference method was used for modeling. It is 4th order in space, and 2nd order in a time staggered grid algorithm. A zero phase 20 Hz Ricker wavelet was used as a source of energy.

A conventional converted wave processing flow was applied to the horizontal component, with elevation statics, and including reversal of negative offset traces and asymptotic binning, using ProMAX software. Harrison (1992) describes details of this methodology. A converted wave stack that uses the Common Conversion Point (CCP) method is presented in Fig. 8. This method assumes horizontal layers, and is described by Tessmer and Behle (1988). No noise filtering was applied before this stack, Diffractions and apparent artifacts shown for the stack are probably caused mostly by unfiltered coherent events. As for the velocity, an RMS velocity was obtained from the geological model. Other methods to obtain this velocity will be tested.

Finally, an example of the application of prestack Depth Migration is shown in Fig. 9. It was applied CREWES Matlab tools such as the migration code *pspi_shot*. .A velocity field based on the true velocity model (Fig. 7) was used for this migration. No filtering was applied to the original data. Consequently, coherent noise and artifacts are also apparent in this result. However, reflectors at the expected depth can be observed, supporting the robustness of the method.

These are preliminary results to test two extreme steps in the processing flow. Ideally, prestack migration in depth would be the most appropriate, since it does not require any assumption about the geometry as most of the basic methods do, but it is more attached to the physical properties. In a real case, this velocity field is unknown, so techniques to find it are required, which has been identified as perhaps the most critical step. Methods like EOM (Equivalent Offset Migration) will be investigated with this purpose (e. g. Guirigay and Bancroft, 2012).

The basic steps of stacking in time are fundamental, and a basis for any further processing. It is proposed to explore these steps with increasing resemblance to the real data. and with increasing accuracy of the processing methods.

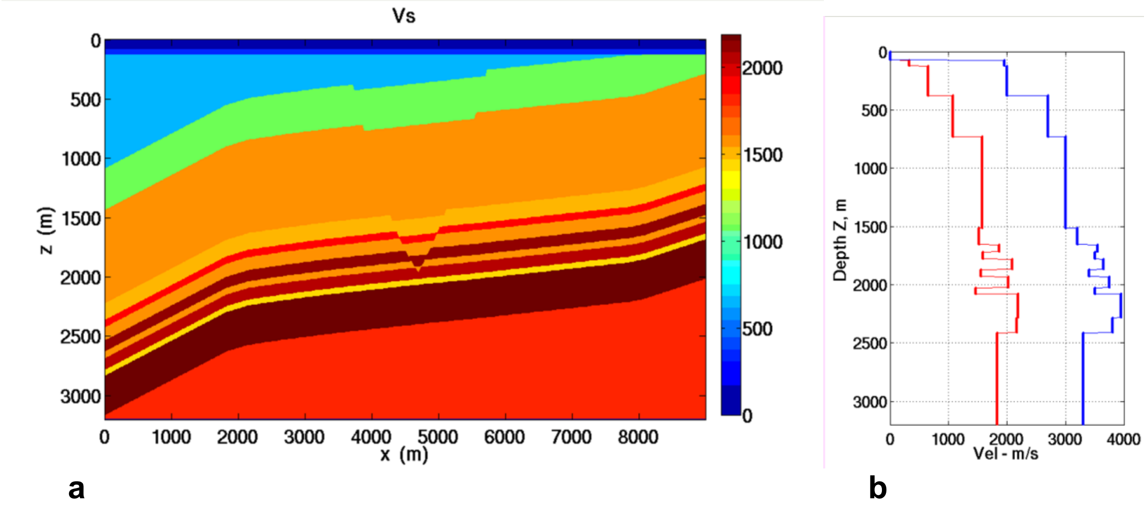

Fig. 7. Geological model to study the imaging issues. (a) The *Vs* field. (b) Velocity profiles *Vp* (blue) and *Vs* (red) at x=3300 m.

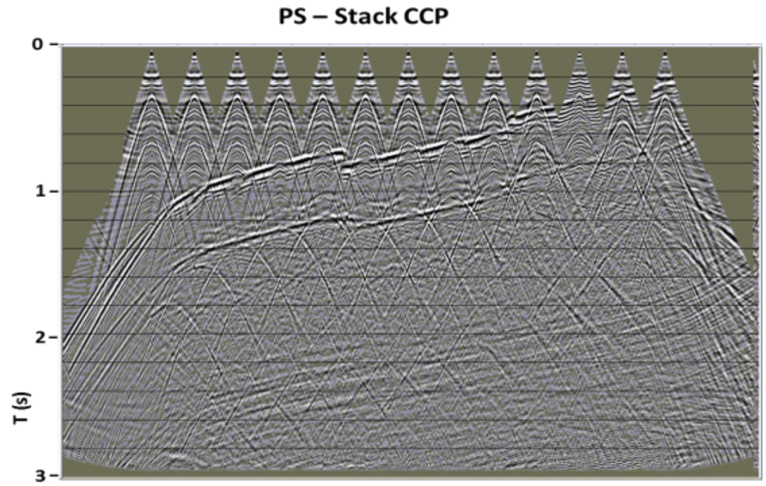

Fig. 8. Stack of the synthetic c-wave, using the CCP approach.

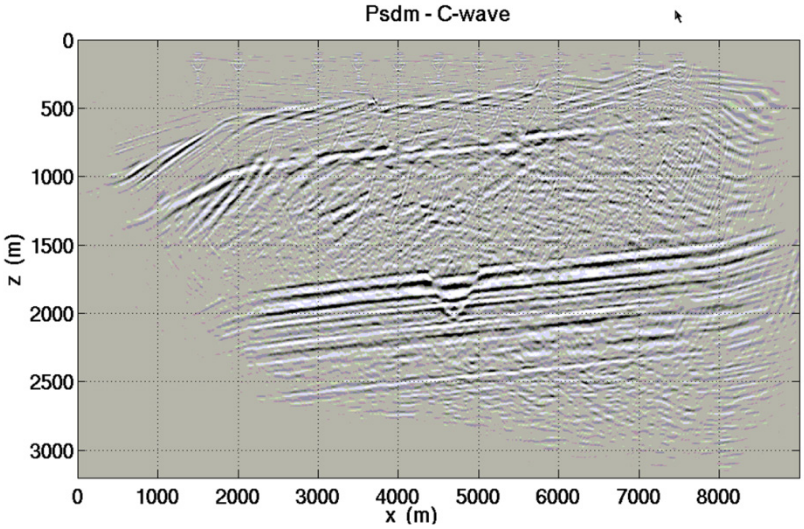

FIG. 9 . Prestack migrated section of the converted wave, synthetic data

CONCLUSIONS

S-wave near-surface velocity models were obtained from surface and uphole data using tomography The resulting models from the surface and uphole data corroborate each other.

However, the velocity model from the uphole survey shows slower velocity at the shallower part than the one obtained from the 2D data. It could be an extended property of the near surface. It is probably not possible to detect these slower velocities using data from a 2D line. This can be critical for S-wave propagation in the near-surface and also when calculating receiver static corrections for the converted wave data.

Tomography is shown to be an appropriate method in this case. It allowed obtaining the information of the uphole data, and shows quite reasonable results on the surface 2D line.

The stack of synthetic data appears reasonably good, despite the simple method used, and the missing filtering, as much as the PreSDM applied. However this result is related to a known velocity model and the missing near surface heterogeneity of the model. Velocity analysis using EOM will be tested on these data. Increasingly realistic models will be investigated in the future.

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