P-Wave Enhancement in Rough Terrain using Multicomponent Seismic Data: Catatumbo, Colombia

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Summary

The sensitivity of 3C sensors to the vector properties of the signal may improve P-wave information in rough terrain. In this work, data processing taking into account the topography illustrates this point. Multicomponent data, from a mildly rough topography and folding geology setting in the Northern Andes in Colombia, was used in this study. The seismic data were acquired with 3C sensors oriented vertically. From ray trace modeling taking into account the low velocity layer, waves should arrive almost normal to the surface. Consequently the rotation of the radial and vertical data into a direction normal to the topography would better separate P- and S-waves. Assuming this hypothesis, P-wave data was estimated using both the vertical and horizontal components and compared with using the vertical alone. Improvement can be observed in the P-wave stacked section after this mode separation, which suggests that this procedure can be better than the usual identification of P- wave with the vertical component.

Introduction

Since many less complex locations have been thoroughly explored, petroleum exploration in complex areas is increasing. In spite of much effort in that direction, the seismic images obtained there are frequently unsatisfactory. However the multicomponent method has been applied to structurally simple geological settings, and its potential for obtaining information from more complex zones has not been explored widely.

Multicomponent exploration to improve P-wave data in complex areas has been subject of recent publications, e. g. Behr (2005), and Ronen *et al.* (2005). Also new and promising acquisition instruments and techniques have been developed (e. g. Gibson et al., 2005) and processing methods have been proposed, that consider specific properties of multicomponent data. These developments present the opportunity to exploit the well-known potential information content of converted waves (e.g. PS-waves) for describing structural and lithological properties in more complex settings (e. g. Stewart and Marchisio, 1991; Margrave *et al.*, 2001).

An experiment with the vector detection of the incident P-wave is presented in this work, applied to a case study of the Northern Andes in Colombia. In the multicomponent method usually the vertical component is assumed to be equivalent to P-waves, and the horizontal radial component is assumed to correspond to the converted PS-waves. However, these assumptions are not necessarily true. P-waves may not be limited to the vertical component, since the waves may not arrive normal to the surface, as in the case of a high-velocity near surface, or the sensors may not be normal to the surface, as in rough terrain. The later case is investigated here.

Methodology

The data used was acquired in the Catatumbo Area, a Northern Andean setting in Colombia. The geology includes shales and sandstone from the Tertiary and shales, sandstone and limestone, from the Cretaceous. Prospective reservoirs are in permeable sandstones, and also in fractured limestones. Structures include folding and faulting from moderate to severe. There are some hills in this area, which stand out about 400 m over the alluvial valleys, and usually correspond to outcrops of older rocks.

A multicomponent survey, using MEMS technology sensors (Gibson et al. 2005) and dynamite as the source of energy, was acquired in this area. The acquisition design included a symmetrical split-spread with 800 locations per shot, 15 m between receivers and 60 m between sources. The nominal fold was 100. A 10 Km seismic line of this survey was selected for this experiment.

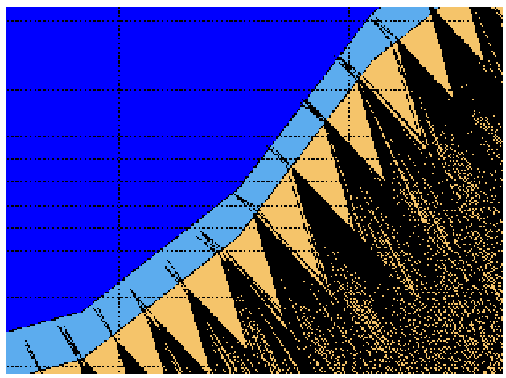

Figure 1. Ray tracing in a rough terrain with a low velocity near surface layer.

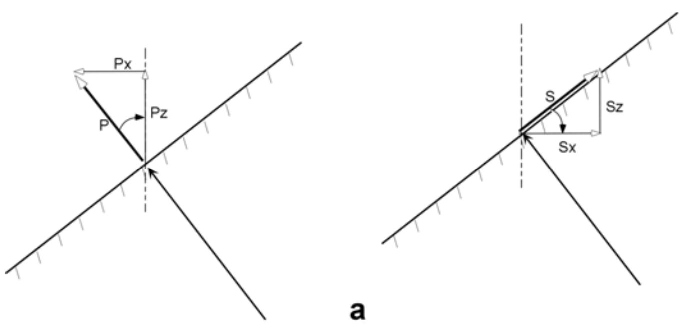

Figure 2. Angle of incidence and components in dip terrain (a) P-wave (b) S-wave

Figures 1 and 2 illustrate the rationale of this experiment. Figure 1 shows ray-trace modeling from the steeper Llanos basin foothills in Colombia, with a low-velocity near-surface weathering layer. Most raypaths arrive almost normal to the surface. Under this assumption, Figure 2 shows the two components of P-waves (2a) and S-waves (2b), which depend on the slope of the terrain. Only the vertical component of the two waves would be recorded with the conventional 1-C seismic acquisition, then it wouldn't be possible to separate them. With the multicomponent data, we have the two components of the vector and can separate the two wave modes.

Figure 3 illustrates the topography and the near surface geology (aspect ratio one-to-one), corresponding to the seismic data selected. A hill about 400 m high can be observed at the right hand side. Figure 4 illustrates the slopes in degrees, calculated from the topographical information. These slopes are the information required for wave mode separation assuming wave incidence normal to the surface. Most of the slopes are under 20 degrees, with some flat sections. Close to the hill can be identified slopes around 20 degrees and more.

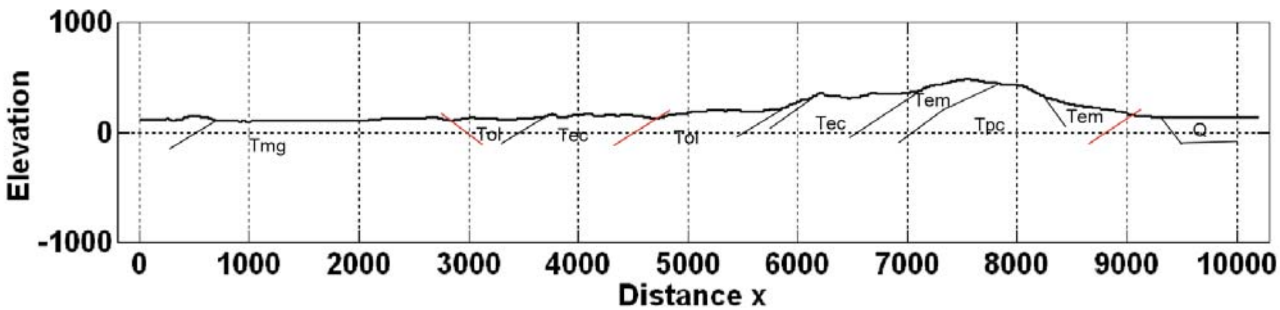

Figure 3. Section that shows the surface geology and the topography at a one-to-one scale.

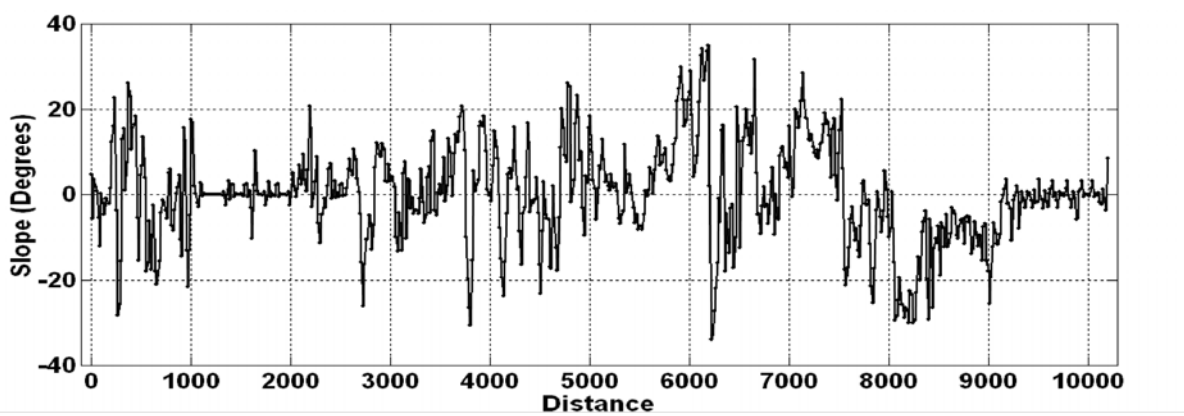

Figure 4. Slope in degrees calculated from the topography.

Results and Discussion

A processing flow oriented to obtain stack sections was applied to this data. It included radial filtering, to attenuate coherent noise, and nonstationay Gabor deconvolution, for amplitude correction and spectral whitening (Margrave et al., 2002; Henley, 2003). After that, rotated resultants of the vertical and radial components, corresponding to the P-wave, were calculated and added together. In this way two stack sections were obtained, one with simple processing and the other one with the same processing plus the addition of the two rotated components.

Figure 5 shows enlarged portions of the near surface of the resulting stacks, corresponding to the distances 4500 to 6000 in Figures 3 and 4. (The CDP 4800 in Figure 5 corresponds approximately to the distance 5500 in the previous Figures.). Some enhancement, indicated by the oval, can be observed. The receiver locations corresponding to this zone, can correspond to closer distances (around 4000 to 7000 m), which includes steep slopes as can be observed in Figure 4.

Information from nearby upholes indicate perhaps thinner than expected low velocity near surface layers, which could imply significant non-normal incidence to the surface. Behr (2005) suggested this hypothesis after hodogram analysis in rough terrain. However the results are meaningful, showing that normal incidence is probably a better assumption than vertical incidence at least in this case. The method can be the object of more extended testing, since it depends on the characteristics of the near surface, which can be quite variable. In the case of non-normal incidence, the free surface effect (e. g. Kähler and Meissner, 1983) should be considered.

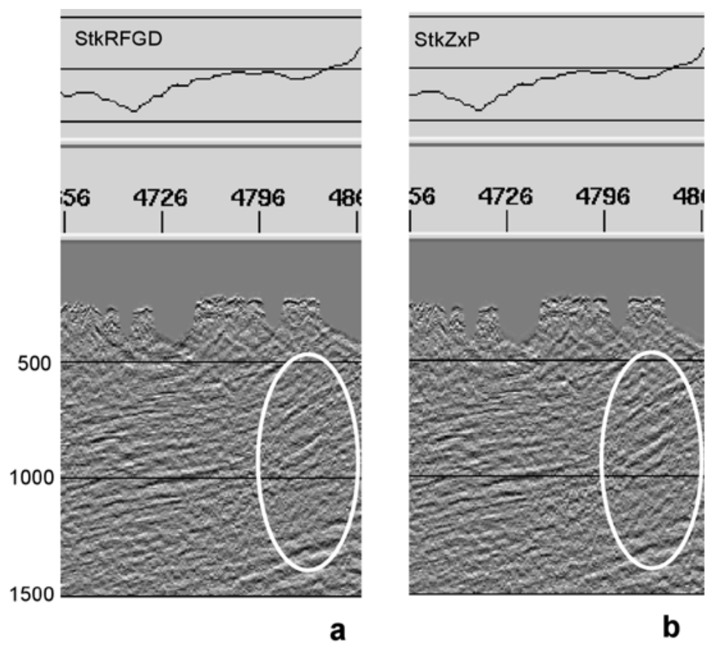

Figure 5. P-wave stacked sections using (a) vertical component only and (b) vertical and horzontal components with rotations defined by the slope of the topography.

Conclusions

The multicomponent seismic method allows consideration of the orientation of the incident P-wave vector to the surface, so it should be possible to detect an improved P-wave signal. Our results suggest that it is possible to obtain an enhanced P-wave section in a steep topographic zone by assuming normal incidence to the surface, and separating P- and S- waves accordingly.

Wave arrival at the recording surface can be more complicated than the simple model proposed here if the incidence is not normal, since it depends on the near surface wavespeeds. Given more information about the near-surface layer, a better approximation, taking into account non-normal incidence and considering the free surface effect, might contribute to better results.

Acknowledgements

The authors thanks Ecopetrol (Colombia) who encouraged this work and allowed publishing the results, and to the CREWES Project sponsors for their support to this research.

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