Multicomponent Receivers for P-wave Seismic over Rough Topography: Motivation and Results

John M. Behr, Dominion Exploration Canada Ltd., Calgary, Canada

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Abstract

Rough topography creates many challenges for seismic acquisition, processing, and interpretation. The rapidly changing elevations can increase shooting expense, degrade signal to noise ratios, create imaging problems, and obscure structural complexity. Multicomponent (3C) receivers may potentially improve this situation.

This paper outlines the motivation and techniques for using multicomponent receivers in rough topography. Most of the improvements are expected to effect the P-wave reflection data. To evaluate multicomponent receivers, a Canadian Foothills line was recorded with both standard vertical coiled geophone arrays and 3C MEMS receivers. The coiled geophone data was processed with parameters identical to the vertical channel of the 3C receivers. Comparisons of these P-wave sections show a slight improvement from the use of these single point MEMS receivers. Initial converted wave sections show the expected lower resolution. Techniques that improve the P-wave seismic using the multicomponent data, including polarization filtering and emergence angle corrections, are explored.

Why Use Multicomponent over Rough Topography?

Most multicomponent acquisition is conducted because of interest in the converted-wave seismic section. Converted waves can give an interpreter insight into rock properties and can sometimes even produce a better structural image. Converted-wave seismic generally suffers from lower resolution, and in areas with rough topography surface complexities will exacerbate this problem. However, using multicomponent receivers presents many advantages for P-wave reflection seismic in these areas.

Intra-array statics are a major concern in rough topography. Over an receiver array length, significant changes in elevation or near surface velocities can degrade the high frequency component of a receiver array (Figure 1). For this reason, it has become common in the Foothills to "pod" geophone arrays over a few meters. Unfortunately the advantages of a geophone array are lost by podding, and near surface variations can further compromise the response. A typical multicomponent receiver station has a single sensor, and a single sensor completely removes the intra-array static problem.

One advantage of geophone arrays is their wavenumber rejection of surface waves, like groundroll or airblasts. Rapidly varying surface geology and rough topography makes array design difficult, and podding geophones makes an ineffective array. However, by recording the full particle motion at the receiver, one can separate the linearly polarized P-wave events from the circularly polarized surface waves. Polarization filtering is still an area of active research (Jin and Ronen, 2005). This type of filtering is not possible with standard vertical geophones.

In flat topography, a horizontal, low velocity layer usually refracts upgoing waves to a near vertical direction. In rough topography, this low velocity layer is no longer horizontal. Vertically travelling P-wave reflections impinging on a non-horizonatal low velocity layer will always be refracted to a non-vertical emergence angle (Figure 2). Vertical geophones only record the cosine of the emergent P-wave energy. Multicomponent geophones will record all of this energy. If the P-wave's angle of emergence can be determined for a receiver location, the non-vertical energy can be rotated to the vertical component. This receiver calibration could potentially add significant energy to a P-wave reflection section.

Some Foothills areas suffer from poor signal to noise ratios due to carbonate karsting near the surface. This can set up multi-pathing and distructive interference of the data. By recording full particle motion, possiblities for detecting and filtering this scattered energy are created. This could have a considerable impact on Foothills seismic.

Many other techniques for rough topography are possible when using multicomponent geophones. It has been suggested that information about out-of-plane events can be extracted from polarization infromation (Stewart and Marchisio, 1991). Better near surface velocity models might be determined by looking at first break P/S mode conversions (Din and Morozov, 2004). Strong converted energy may be detected from steeply dipping subsurface events. The converted wave data may prove useful for fracture detection, anisotropy analysis, AVO, and imaging. None of these benefits or techniques can be used with geophones that only record the vertical component of particle motion.

Potential Problems

There are risks in using these receivers. Using new methods can sometimes introduce deployment problems in the field. Multicomponent sensors have to be carefully orientated and planted, and trained jughounds should be employed. This may create cost overruns. Another risk is data quality. A signal to noise decrease could occur because of multiplicity reduction; there will no longer be the stacking effect of a geophone array. Also, with no redundant geophones at a station, a single poor receiver plant could have a large impact on the final stack. Noise reduction, both from ambient noise cancelation and from array effects on surface waves, will be reduced, and this could pose a problem, especially in the windy environment of the Foothills.

Presently, the cost of the multicomponent MEMS receivers is higher than traditional coiled geophones; this will probably be the case until the manufacturers can recoup their development costs. However, for the heliportable operations common in areas of rough topography, these single station receivers can save costs by their lighter weight, and by the fact that without arrays, fewer geophones need to be transported and planted. Eventually, 3C MEMS recording should cost less than conventional arrays for Foothills acquisition.

The Foothills Test Line: a Side-by-Side Comparison

In order to compare multicomponent seismic with conventional vertical geophones, a joint venture seismic shoot was undertaken by Devon Canada and Dominion Exploration Canada in September 2004. The 17 km 2D line was shot over deeply incised valleys with over 400m of topography. Previous shooting had shown this to be an area of exceptionally good data quality for the Foothills. The completely heliportable dynamite sources had a 100m spacing. Six vertical coiled geophones deployed over 25m arrays were planted with a 25m station spacing, with podding of the array carried out where there were steep elevations. The Sercel DSU MEMS multicomponent receivers were planted with a 12.5 m spacing next to them. The two separate receiver lines were recorded into the same Sercel 408XL system. The spacing of the MEMS was reduced to help account for the loss of redundancy. Few operational problems were encountered during acquisition. There were 721 MEMS receivers and 361 of the coiled geophone arrays for a maximum offset of 4500m.

Initially, the data was processed at Veritas by two separate processors, one with the coiled geophone and one with the MEMS data, in order to give a “blind” comparison of the receiver differences. Only the tilt corrected vertical component was used for the multicomponent processing P-wave result. Comparisons were made after completion of pre-stack time migrations. Large differences were seen, with the vertical component MEMS data looking better than the coiled geophone. However, subsequent processing of the coiled geophone line with the same velocities and statics produced very similar sections, with subtle improvements from the multicomponent receivers (Figure 3).

Polarization Filtering Results

An adaptive polarization filter was attempted to try to improve the data quality of the multicomponent seismic. The technique used was developed by Meersman and Kendall (2005) and uses a sliding design window with a complex SVD. Non migrated results show an effective removal of the surface waves and almost no change of the reflections (Figure 4). Migrated results show a slight improvement in data quality over the unfiltered vertical-component section. The largest improvement was seen on the shot records.

Because of near surface complications, expectations for a good converted wave section were low. However, many of the 3C techniques that improve the P-wave data will also impact the converted wave. The converted wave data showed few coherent reflections at the primary zone of interest, although reflection strength did seem to increase on the steeper events. The shallower events did image, and polarization filtering was able to improve the section considerably.

Emergence Angle Calculation Results

The P-wave does not necessarily emerge vertically in areas with rough topography. Some areas in this test survey have slopes in excess of 60 degrees. If a low velocity layer lies parallel to this, only half the P-wave energy will be recorded on the vertical component. However, there is no good reason to believe that this layer is well behaved and exactly mimics changes in elevations. Where there are rocky outcrops, it may not even be present. Therefore, the emergence angle must be determined independantly of the elevation profile. One technique is to extract the emergent angle of the first break energy. The first break energy should be pure P-wave energy, and not contaminated by the complexities of the later shear arrivals. Hodograms from our dataset show the linear first break energy arriving with an non-vertical angle (Figure 5). The energy is not polarized in the radial direction, and this may be due to the LVL sloping out-of-plane to the line. The emergence angle can be extracted, and shown to be highly correlated to receiver station and poorly correlated with offset and shot station (Figure 6). The angles down the line vary from 0° to over 65°, with some correlation to the elevation gradient. Subsequent rotations and calibrations with the angles will hopefully produce improvements on the P-wave and converted wave processing.

Conclusions

Areas with rough topography are difficult areas for acquisition, processing, imaging and interpretation. With little added expense, multicomponent receivers may help alleviate these issues. Results show that in this one area of the Foothills, multicomponent receivers can produce results at least as good as typical coiled vertical geophones, and sometimes better. Polarization filtering was shown to be an effective surface-wave attenuation technique. Emergence angles from the Foothills are strongly related to receiver position, and calibration with this angle could be used to increase the P-wave energy available to process. Many other techniques have yet to be tried. With the currently available results and great future potential, multicomponent receivers may be the best choice for acquiring seismic over rough topography.

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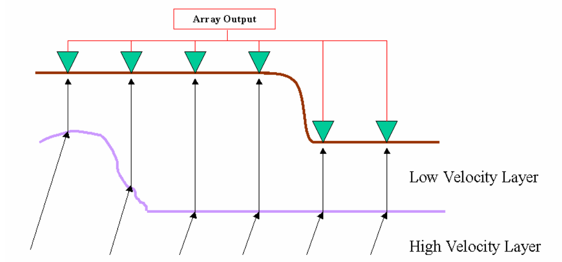


Figure 1: Intra-array statics can be created by elevation changes or sub-surface LVL changes. The steep slopes and variable sub-surface of the Foothills can create significant high frequency loss over a geophone array.

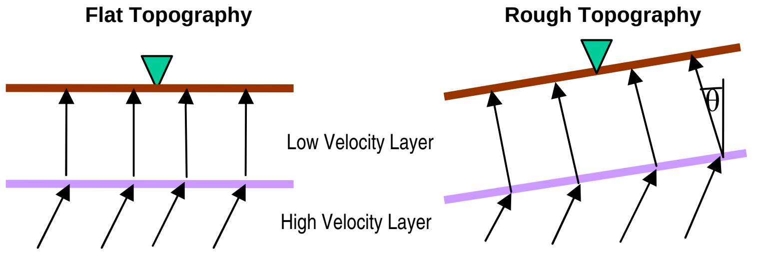
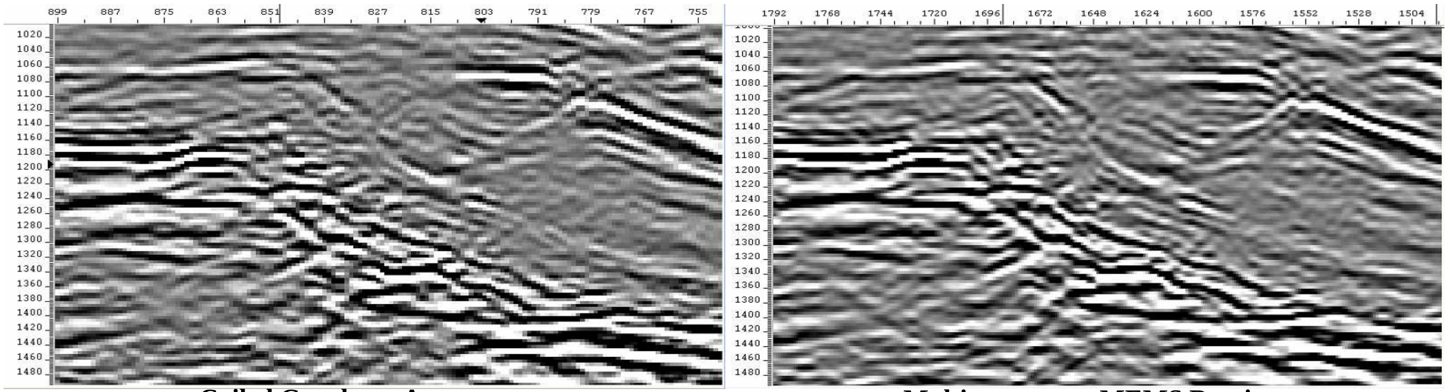
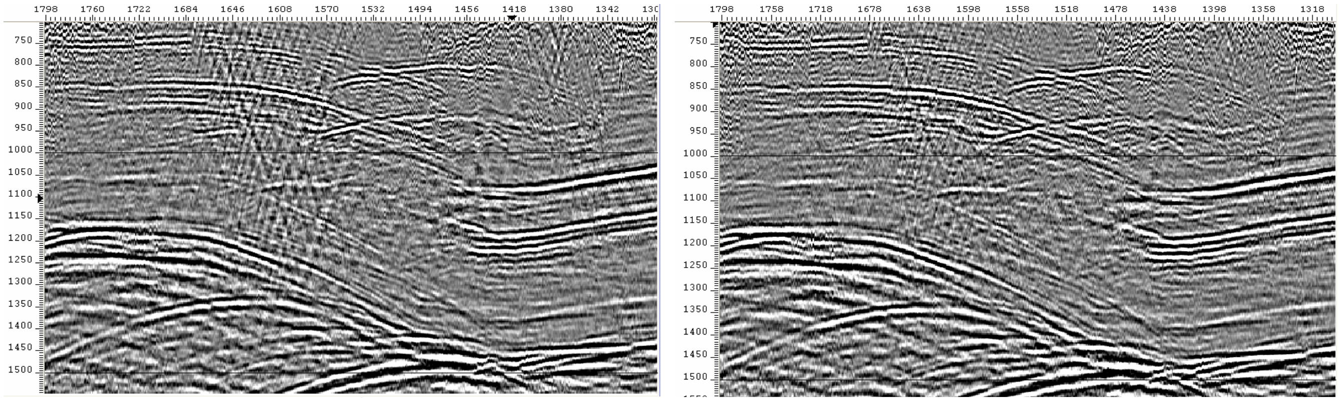


Figure 2: A flat low velocity layer will refract upgoing P-waves to a near vertical orientation. In rough topography, the upgoing wave will be refracted away from vertical. Vertical geophones will only be able to record the cosine of the emergent angle energy.



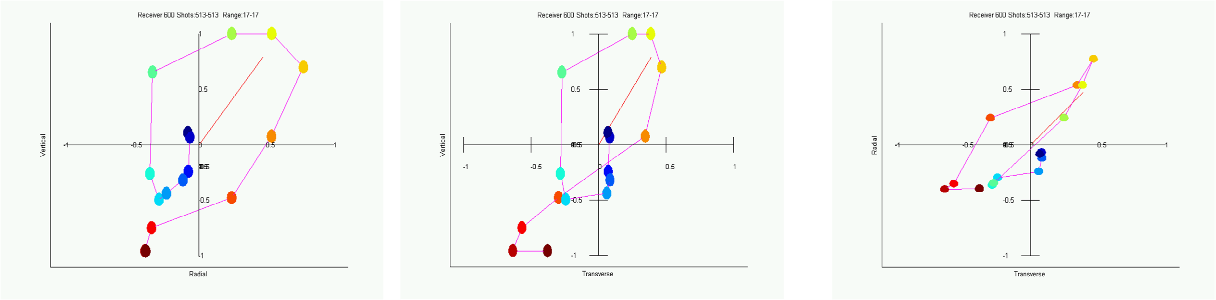
Coiled Geophone Array **Multicomponent MEMS Receivers**

Figure 3: A side-by-side comparison of vertical coiled geophone array and multicomponent MEMS acquisition from a Foothills line produce similar results, with the slightly better continuity on the multicomponent section. Both seismic lines have the same surface consistent statics, velocities, and are pre-stack time migrated.



P-Wave Stack Before Filter **P-Wave Stack After Polarization Filter**

Figure 4: Polarization filtering reduces groundroll but does not effect the reflections on a stack of the P-wave multicomponent data.



Vertical vs. Radial **Vertical vs. Transverse** **Radial vs. Transverse**

Figure 5: Hodograms from the first break of a single trace over the Foothills line. This receiver was in an area with about a 60° dip. The red vector is the calculated directional vector for the emergence angle of the first break energy. It is over 40° from vertical and oriented almost 45° from the radial direction. This is a typical hodogram over rough topography for this survey.

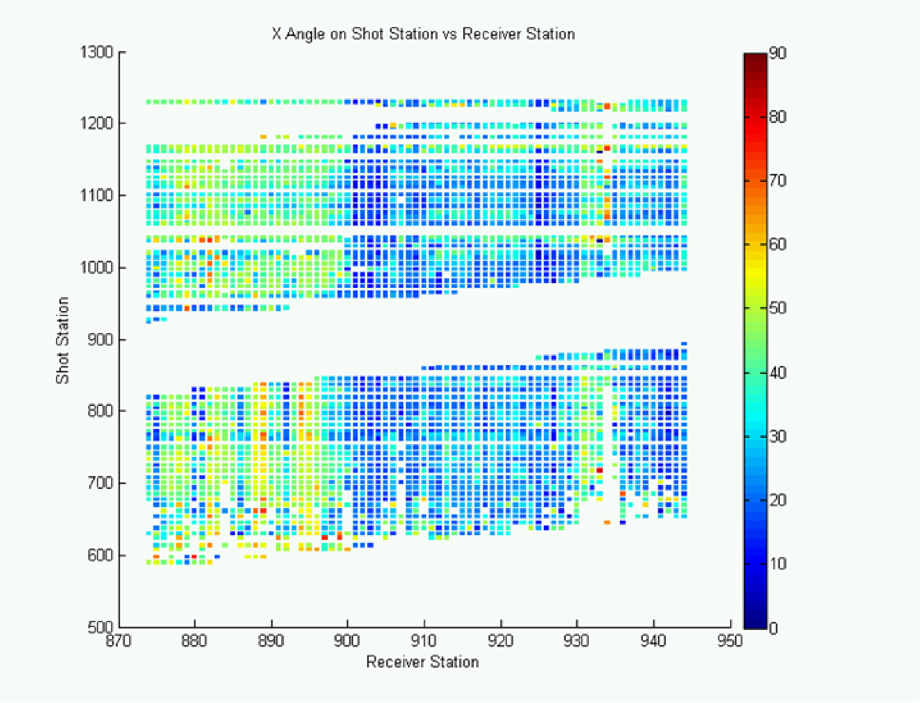


Figure 6: This diagram shows the calculated angle of emergence from the first breaks over a small portion of the Foothills line. The vertical banding shows that the angle is well correlated with receiver station, and poorly correlated with offset and shot station. Vertical bands between receivers 875 and 898, and between receivers 930 and 935 show angles of emergence in the range of 45° to 65°.