Ultra Shallow Seismic Reflection in Depth: Examples from 3D and 2D ultra shallow surveys with application to joint Seismic and GPR imaging.

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Summary

High-resolution shallow-seismic images are wavelet dependent. The ability to obtain 300Hz and 800Hz high-resolution ultra shallow subsurface images has been well demonstrated (Bachrach and Nur, 1998a,b,c). However, since the final results of shallow seismic reflection surveys are typically presented as stacked time sections, we do not often address the issue of absolute locations of the stratigraphic units in depth. This problem is even more severe when comparing GPR time sections to seismic time sections.

The ability to directly compare GPR and seismic surveys (directly in the sense of imaging the same structure) is based on the ability to generate same wavelength images. The same wavelengths will average the same scales in the subsurface. For example, 1m wavelength will be back-scattered from the same subsurface heterogeneities and there will be no need to address averaging of small-scale heterogeneities. However, the seismic velocities tend to span a wider range than GPR velocities, and the seismic wavelength scales with the velocity, given a fixed central frequency. For example, the velocity increases from few hundred m/s in the unsaturated zone to more then 1500m/s below the water table, whereas the GPR velocity decreases only by a factor of about 2.5 (say from 0.15m/ns to 0.06m/ns) across this interface. This fact causes difficulties in the interpretation of time domain seismic images and specifically in the comparison of such data to GPR time domain data.

A recent 3D ultra shallow seismic experiment allowed us to obtain a 3D earth-cube with exceptional S/N ratio. This 3D data set allows us demonstrates the wavelength dependency of shallow seismic resolution. We use this example to interpret the relation between seismic and GPR images using synthetic and field examples.

“Perfect” Example: 3D Ultra Shallow Seismic Reflection

Figure 1 present the results of an ultra shallow 3D seismic experiment conducted in Moss Landing Beach in December, 1997. Details on the acquisition parameters and processing can be found in Rickett and Bachrach, 1998. The data quality is exceptionally good and the details in the shallow sand are revealed with a wavelet of central frequency, 300Hz . The nominal bin size is 0.1×0.1m Fig. 1C shows the filtered supergather with all offsets present in the seismic experiment.

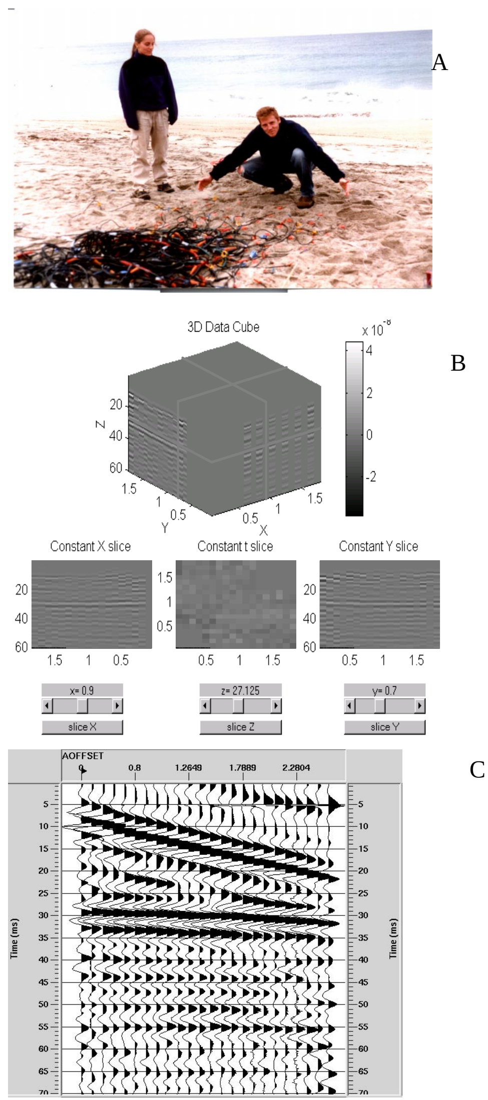

Figure 1: A. 2D geophone array: 8 rows of geophones 0.2m apart. B. Seismic time-cube. C. Supergather of all offsets binned into 0.1cm traces. This is a raw supergather after 300Hz filtering.

The water table reflection is the prominent reflection at 30ms. Note that there are other reflections above (~20ms) and below (~45ms) the water table. The 3D NMO stacked data cube presents structure both below and above the water table. The flatness of the layers in this section allows us to depth convert the data without migration, based on the well defined NMO velocity and water saturated sediment velocity (Bachrach and Nur, 1998c).

Note that when depth converting the seismic cube, the events are stretched in depth. The 30ms water table reflection is mapped to a depth of 3m, wheras the 40ms reflection mapped to depth of 8m. Morever, the 300Hz wavlength which is (in the dry sand with velocity of 220m/s) 0.7m is scaled with depth to become 5.3m at 40ms. These results are summarized in Figure 2. This simple exersize demonstrates the bias in a time section when the velocity changes are large (as in this case: water table in unconsolidated sediments).

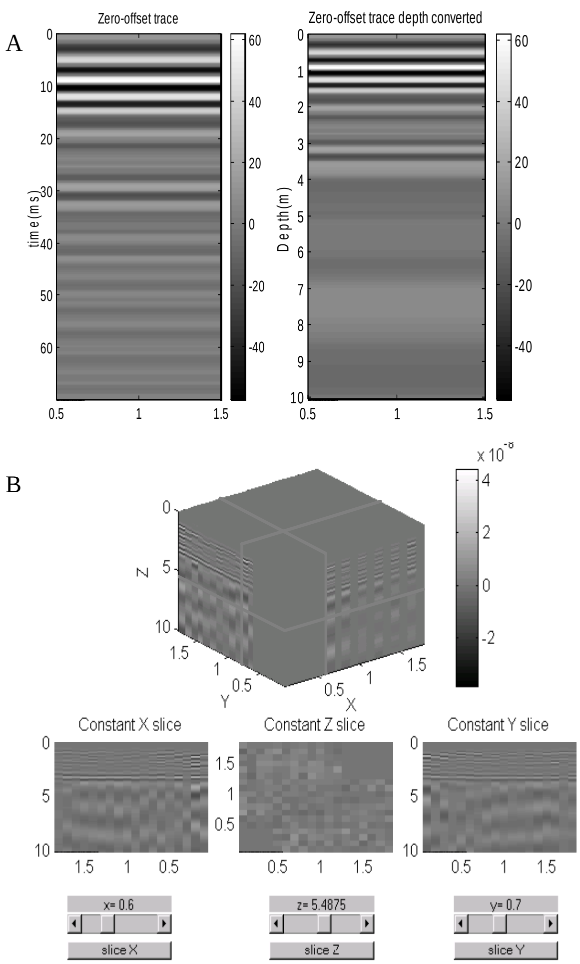

Figure 2: Depth converted seismic data A. Left zero offset trace from the supergather in Figure 1, Right: depth converted zero offset trace (the first 10m); B. 3D Earth cube in depth derived from the velocity function.

Application to Joint GPR and Shallow Seismic Imaging:

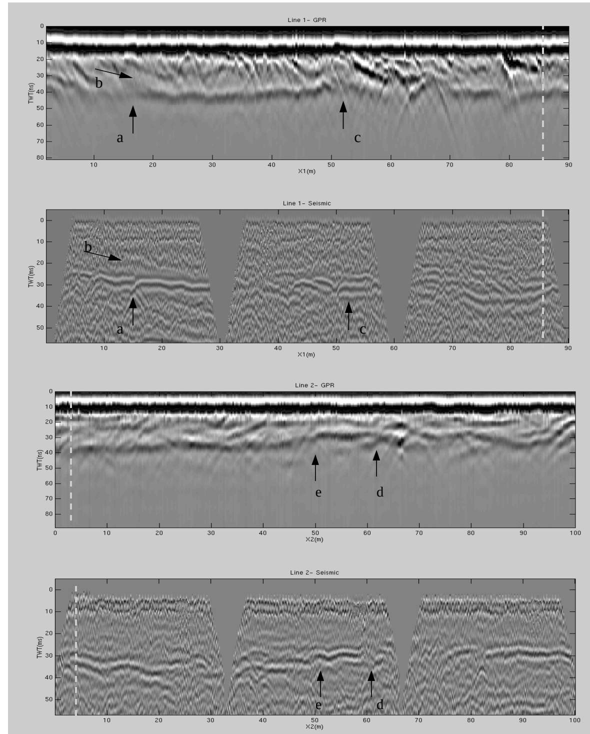

Figure 3. Unmigrated CDP stack section and GPR common offset 100MHz section. From line 1 and 2. Events a,b,c,d,e are identified to be in the same location in both sections.

Bachrach and Nur (1998a) showed a joint GPR and seismic experiment over a river point-bar. The CDP stacked seismic data and the GPR common offset gather are both shown in figure 3. The GPR reflection ends at the water table due to its salinity while the seismic section images stratigraphic details both below and above the water table. Again, as in the previous example, since the saturated velocity is about 1600m/s and the stacking velocity for the water table reflection is 240m/s the wavelength increases by a factor greater than 6. The GPR wavelength in the water is actually smaller then the wavelengths in the dry sand because the electromagnetic velocity in saturated sand is lower (the unsaturated/saturated EM velocity ratio is about 2.5). Thus, the ***ONLY*** place where we can directly compare the seismic image to the GPR image is the zone where the wavelengths are similar. Otherwise, we have to address not only the changes in the electrical properties verses the acoustic properties of the subsurface, but also the nature of the subsurface reflection in terms of the average properties of the subsurface. This is demonstrated in the synthetic model shown in figure 4. The synthetic seismograms show how the layer above the water table is well resolved in both seismic and GPR while the layers below the water table are not resolved seismically due to the increase in wavelength. Great care is needed in the comparison of such seismic and GPR data.

This example illustrates the difficulty in understanding the relationship between the geometric features on a GPR section and a seismic section. Any attempt to use GPR and seismic together must address the upscaling/downscaling of the wavelength in the medium. Note also that this example also shows that given the same wavelength a direct relationship between the GPR and the seismic image can be obtained. A better relationship between the GPR and the seismic image is shown in the time migrated section presented in figure 5. The position of the reflectors and the scale are of the same order. Although the migrated section is of lower quality (more noisy and contaminated from the migration "smiles"), the dips in the GPR and seismic images and point diffractors are properly positioned and a good interpretation of the events can be made.

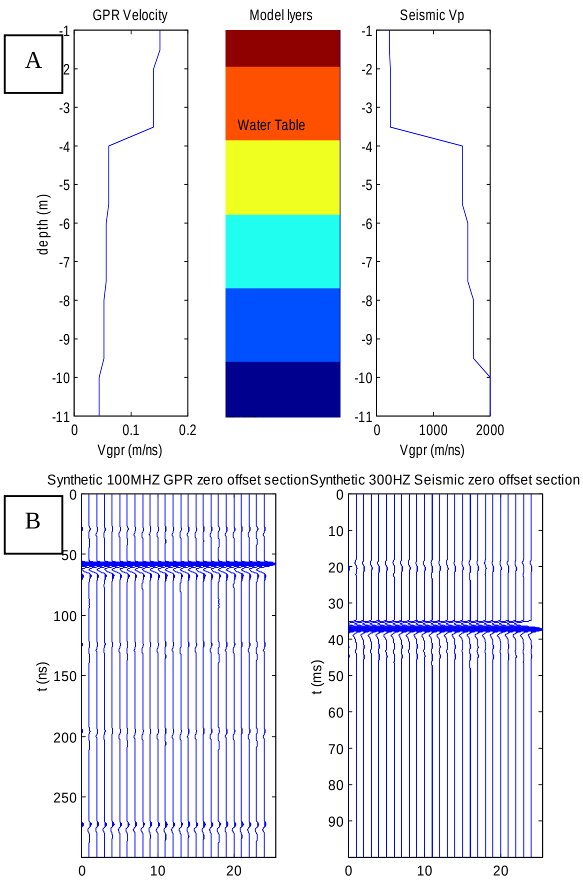

Figure 4: A: six layers with model for synthetic seismogram with the corresponding seismic and GPR velocities. The model represent sand unit whith a water table at depth of 4m. B: 300Hz seismic zero offset synthetic seismogram and 100MHz zero offset synthetic GPR radarogram over the model layers. Note that the model present

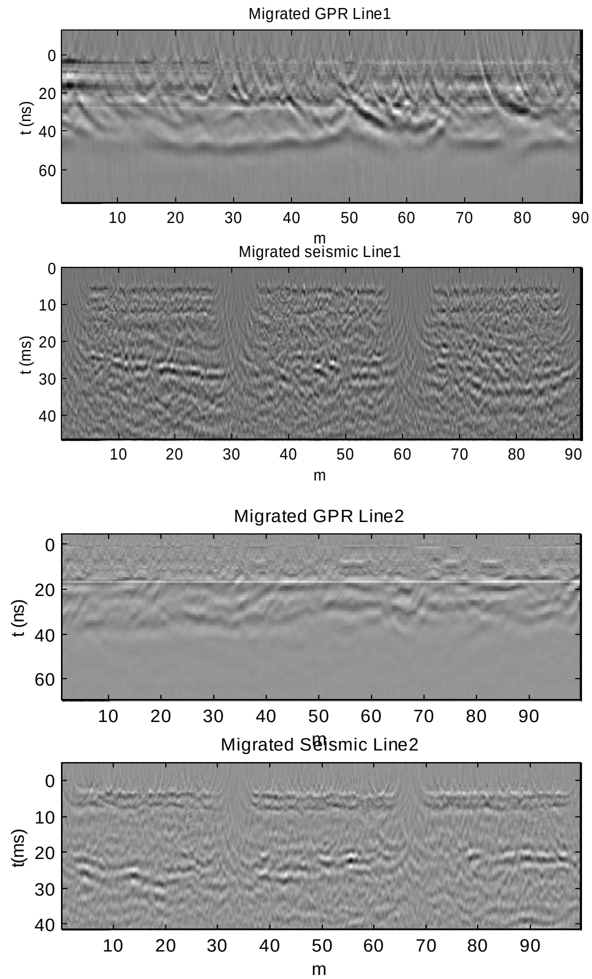

Figure 5: Time migrated section for line 1 and 2 in figure 3. The migration (FK with constant velocity) was applied to compare the events seen in the time section above the water table. The prominent reflection in the seismic data is the water table, some evidence for structure are seen in the seismic and the GPR data. Wavlength are about the same order (~0.8m). Processing of the GPR section included airwave removel, dewawing and migration. Note the dipping events in line 1 are restored. Note also tha the

Summary

We show how ultra shallow seismic can provide a good 3D subsurface image. However, given the constant central frequency, the resolution scale with the velocity of the medium. In the case of high velocity contrast, "high-resolution" time sections can be misleading. This problem is even more evident when comparing the GPR and the seismic image. Since EM velocities and seismic velocities change differently, the seismic and GPR resolution will change differently within different geological units. Thus a valid structural analysis can be done only when the wavelengths are of the same order.

Acknowledgements

We thank Schlumberger-Doll Research for supporting some of the fieldwork. We thank Dr. W. Murphy, Mr. A Reischer, Dr. N. Drinkwater and Dr. W. B. Ward for valuable discussions and assistance. We also thank Ranie Lynds for valuable field assistance and Dr. Mike Knoll for valuable discussion the last SEG meeting. The Stanford Rock Physics Project and a fellowship grant from Michae L. Haider and Cecil H. and Ida M. Green have supported this work.

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