High resolution seismic reflection – constraints and pitfalls in groundwater exploration

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Abstract: High resolution seismic profiling can be successfully applied to aquifer delineation. Constraints are introduced by the methodology itself, and by the complexity of near surface geology. Target specific workflows, and the inclusion of borehole and geological data is the key to reasonable subsurface images.

Key words: shallow seismic reflection, ground water, aquifer detection

Introduction

Seismic methods are the most common exploration and reservoir management tools in the hydrocarbon industry. They have developed rapidly in recent years, hence in high-resolution seismic reflection, resolving layers that are only a few metres thick are standard. In practice, however, the high-resolution seismic technique is complex and requires much more than a simple scaling-down of normal seismic methods for correct deployment. Many specific difficulties arise when detecting shallow layers, for example due to equipment limitations or the inhomogeneity of near surface geology.

Data acquisition and processing

In terms of data acquisition, high-resolution seismics requires denser sampling than normal seismics, both in terms of time and space (more geophones per distance unit). Purely scaling down the acquisition geometry is inadequate, because the frequency bandwidth of the recorded data does not scale-up in the same proportion. It was recognised very early that it is essential to use well coupled high-frequency receivers (Hoover & O'Brien, 1980) and high-frequency seismic sources (Evison, 1952). The latter usually produce lower energy, which limits the penetration depth. Every enhancement increases expenses, and thus a cost-effective compromise must be selected according to each individual case.
Processing steps that are effective for petroleum-industry data are not able to solve specific details when applied to shallow seismic data sets. Such recordings usually suffer from surface and guided waves that arrive at the same time as the reflection signal. In most cases a reliable image below travel-times of 50 ms can only be produced if reflections can be iden-

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tified on filtered shot- or CDP-gathers (STEEPLES & MILLER, 1998). In some cases, executing only basic processing steps is sufficient.

In the example shown in Figure 1, data processing included a progressive but careful first break mute and airwave mute. Only short wavelength static corrections were applied. After spiking deconvolution, the moveout correction was based on a velocity model derived from refraction analysis and transit time measures on bedrock samples.

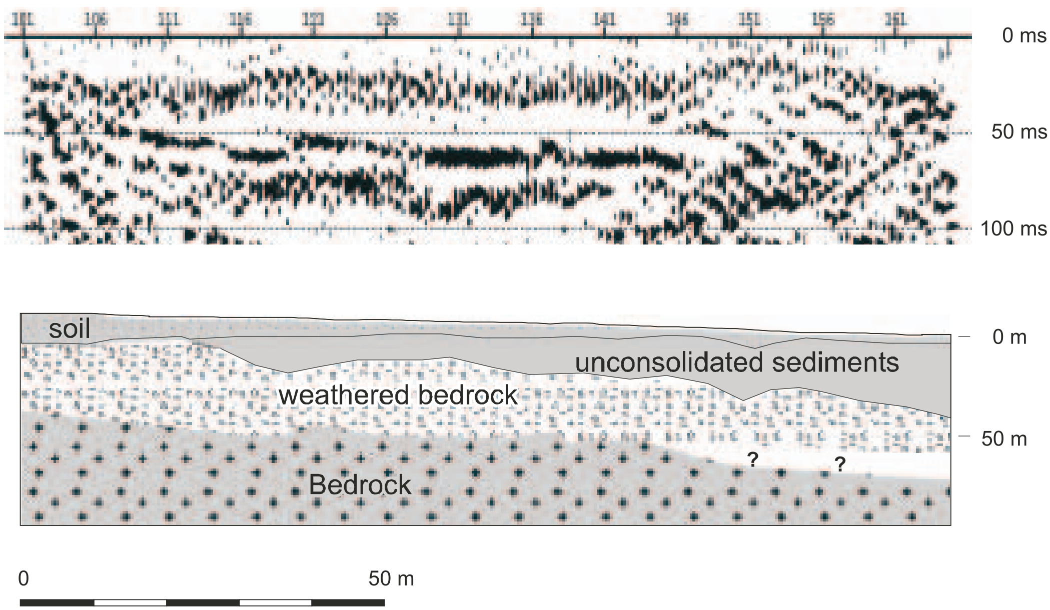

Figure 1. Metamorphic bedrock covered by weathered rocks and low velocity cover-sediments. Top layers were resolved by refraction analysis, bedrock topography was interpreted from the reflection seismic section shown above.

High-resolution data are extremely sensitive to the near surface composition of the earth. Thus innovative static correction techniques must be applied to correct for travel-time errors caused by variations within the weathering layer. The overall data processing strategy aims to optimise the resolution of the final dataset, by increasing the spectral bandwidth (YILMAZ, 1987). One of the keys is to repeatedly deconvolute the data. Improvement is limited in areas where thick soil or gravel severely damp high-frequencies in the recordings. Structural interpretation is best performed on migrated sections. This is because dipping reflectors are then properly positioned, and diffraction patterns are shifted to their spatial point of origin. For very shallow seismic data, generally below 100 m, migration produces only minor changes. This was discovered by BLACK ET AL., (1994) since fewer continuous gently dipping reflectors and low velocities mainly occur.

Interpretation

The hydrogeologist typically expects a geological model and the prediction of whether a distinct layer is an aquifer or not. Unfortunately, for petrophysical reasons, seismic data cannot directly indicate water bearing zones. An experienced interpreter can apply up-to-date techniques to high-resolution seismic data and:

- resolve faults that displace any aquifer
- discriminate between the upper and lower boundary of an aquifer
- identify specific seismic patterns for facies analysis
- interpret unconformities for Sequence Stratigraphy

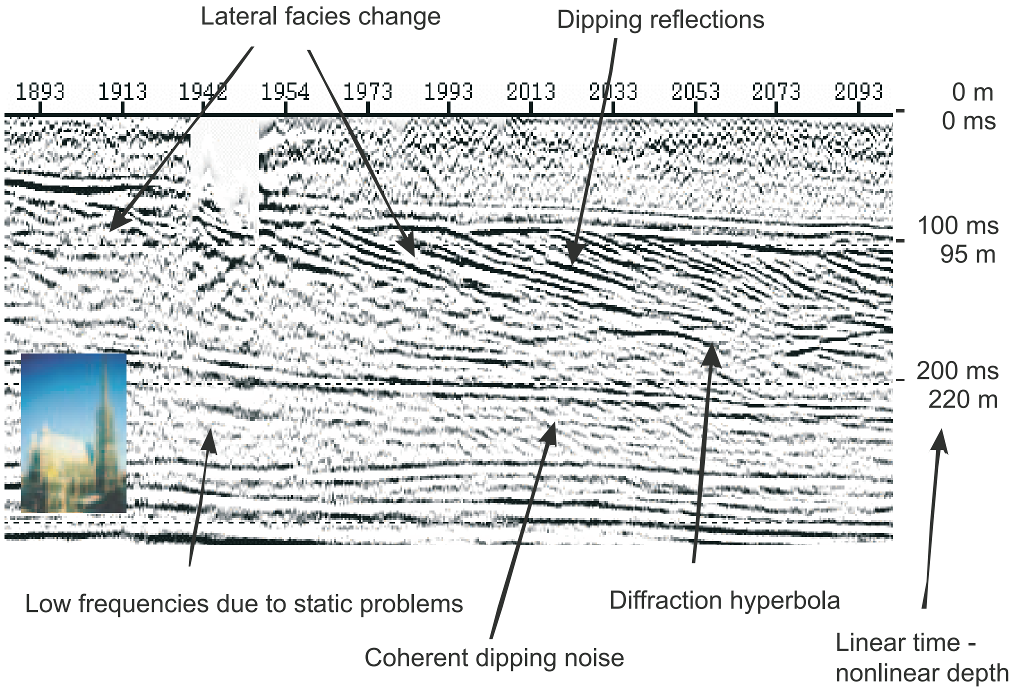

Figure 2. High resolution unmigrated seismic section showing deltaic deposits indicated by dipping reflections. The delta starts at the left end of the section and thickens to about 50 m at the right. The top of these sediments was interpreted as a potential aquifer. Numerous artifacts that could mislead the interpretation process are indicated. The Vienna Stephansdom (136 m high) is shown to scale.

Precise interpretation must take into account that seismic sections are images containing distortions, rather than a precise picture of the subsurface. If only non-migrated data is available, diffractions or artefacts like "bow tie structures" or reflectors positioned incorrectly due to dipping (Figure 2) may be present. Seismic sections have time as their vertical axis. Conversion into true depth can be done if the speed of sound through the layers is known. These data are seldom available, therefore depth must be considered approximate. A seismic reflector does not always represent a change in the sediment type, but may only be a change in the physical character of the soil such as grain size, porosity, density, or hardness. In areas of complex geology not only one single subsurface model fits the seismic data thus interpretation is more like an art than science.

CONCLUSIONS

Despite several complexities seismic reflection is the only method that provides continuous information about structure and facies in the underground. However, the hydrological community has not yet taken full advantage of seismic methods. Finally, expensive seismic surveying is usually much cheaper than a dry well.

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