Conclusion

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This book provides a state of the art overview of borehole seismic methods and acoustic logging methods, for application in geotechnology and civil engineering fields, and also presents examples of data acquisition and analysis from the oil sector that are transposable if required with the necessary realism to near surface studies (in the fields of geotechnology, hydrogeology and seismic hazards).

Indeed, **Chapter 1** details the methodology of acquisition and analysis for routine measurements in geotechnology to establish shear velocity (Vs) logs. These measurements can be downhole, uphole and crosshole. The added value compared to the ASTM standards is to provide recommendations for the acquisition methodology (calibration procedures for the geophysical measurement chain, tools for trajectory or inclination measurements, and impact of downhole tube waves) and for processing (carrying out a two phase analysis to avoid artifacts related to real paths or refracted waves) and also for combining useful methods (possibility of controlling cementation, possibility of using two boreholes in crosshole analysis, provided that

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this is combined with downhole acquisition). For a deep survey where an uncased borehole can be used, PSSL should undoubtedly be recommended. The measurement can be supplemented with full waveform acoustic logging (Sonic FWF) to improve vertical resolution with Stoneley modes. However, it remains preferable to have a data surplus in the first meters, with a downhole or crosshole, because this section is usually cased, outside of the water table, and an invasion of the formation by a sealant, which would distort PSSL measurement, cannot be excluded.

Chapter 2 shows that it is possible to acquire a near-surface VSP (between 0 and 100 m), using the same means as for a downhole. After processing, the benefit of VSP is that it provides a seismic trace without multiples that is directly comparable to a surface seismic section in the vicinity of the borehole. It is important to note that the lateral investigation can be increased by offsetting the source relative to the borehole. This technique is called Offset Vertical Seismic Profiling (OVSP). The image obtained after processing is thus a single-fold seismic section. Finally, a Seismic Walkaway is a series of offset VSPs, with the surface source situated at several locations corresponding to successively increasing offsets with respect to the borehole. Therefore, the image obtained after processing is a section with a low degree of multiple-fold coverage. In addition, a VSP provides an image of the geological formations below the borehole.

Chapter 3 illustrates that acoustic logging recordings with a conventional monopole probe can be used to obtain not only a P-wave velocity log, but also imaging in the well vicinity with decimetric to metric scale lateral investigation for refracted modes. In addition, the analysis of the reflected and diffracted modes with multi-transmitter and multi-receiver tools makes it possible to extend the investigative power of acoustic logging and to make a micro-seismic survey of the well. The response of the Stoneley wave is strongly related to the state of continuity of the borehole wall. The attenuation of Stoneley waves (decrease of amplitude and frequency) is used to characterize the fissured medium. In addition, wave conversion phenomena are observed at the boundaries of the fractured zones. These phenomena are very pronounced on the Stoneley waves, especially in the presence of open fractures.

When the shear velocity of the formation is lower than the P velocity of the borehole fluid it cannot be measured with a conventional monopole tool. It is then necessary to implement a dipole-type acoustic tool equipped with polarized transmitters and receivers. Such tools generate polarized compression waves perpendicular to the borehole axis. These compression waves create flexural modes at the well wall that generate pseudo-shear waves in the formation that propagate parallel to the well axis. The flexural wave travels at the S-wave velocity and is therefore the most reliable logging method for estimating a shear velocity log. An adaptation is available for the geotechnical field, namely PS suspension logging (PSSL) which involves a flexible tool.

Using a near-surface dataset (3D seismic, VSP and full waveform acoustic logging), **Chapter 4** illustrates: the principle of depth conversion of surface seismic methods using VSP data, the influence of the cementation on acoustic measurements, the principle of calibration of the formation velocity measurements obtained by acoustic logging with those provided by the VSP, as well as the principle of time conversion of acoustic data and the calculation of synthetic seismograms.

Chapter 5 presents an innovative example of the application of borehole seismic methods and logging techniques. The example describes the contribution of seismic and acoustic methods to the characterization of karstic formations. For this purpose, it appears that a 3D seismic block can be used in hydrogeology to build a 3D model of karstic aquifers. VSP data characterize karst levels in two ways. Firstly through the conversion of P-waves to Stoneley waves at the top of the most porous levels, and secondly through the analysis of ambient noise which is at its maximum at the level of the water producing layers. Finally, full waveform acoustic logging also enables the characterization of karstic formations, but on a different scale. At the level of a karstic body, we observe a strong attenuation of the refracted P-wave and a distortion of the acoustic signal. The analysis of the acoustic waves recorded simultaneously on the two receivers of a monopole acoustic tool can be implemented to calculate a Singular Value Decomposition (SVD) of the logs, which makes it possible to define acoustic attributes. The attribute, called the Noise/Signal detector, is the product of three normalized terms (velocity coefficients (CV), amplitude coefficient (CA), correlation coefficient (CCor). In karstic zones, a rise in these three coefficients was observed, therefore the analysis of ambient noise (seismic and acoustic) and the conversion of body waves into Stoneley waves can be used to detect and quantify flow circulation, while a 3D seismic block can be used to build a 3D model of karstic aquifers. We can therefore conclude that 3D seismic surveys, full waveform acoustic logging and VSP enable the characterization of karstic formations at different scales.