Chapter 5

ACOUSTIC LOGGING: THE COMPLETE WAVEFORM AND ITS INTERPRETATION

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SUMMARY

The waveform generated in acoustic logging contains significantly more information than the traditional compressional interval travel time measurement. Four components of the wavetrain, viz. shear and compressional lateral waves, the Stoneley and pseudo-Rayleigh waves, are discussed. A description of experimental studies of the acoustic wavetrain in homogeneous and inhomogeneous scale models is given followed by analytical results pertaining to each of the four component waves. The analytical results are presented in three parts: First, individual results for the pseudo-Rayleigh and Stoneley waves are discussed. Secondly, full waveform studies are presented which are based on numerical integration schemes. Finally, the results of branch cut integration techniques applied to the shear and compressional lateral waves are given. The lateral wave impulse responses and the responses to a realistic source function are presented for a variety of borehole parameters. It is also shown that the shear arrival should be viewed as a composite of both the shear and pseudo-Rayleigh signals.
1. INTRODUCTION

Continuous well logging measurements fall into three technique groups: electrical, nuclear and acoustic (or sonic). When non-continuous, i.e. point by point, devices such as the formation tester or core sampler are considered, a fourth, purely mechanical category is added.

Most wireline logging measurements are aimed at the goal of formation evaluation, a term which refers to the determination of lithology, geometry of structure (porosity and microstructure), pore fluid identification, density, permeability and mechanical properties. Among the important exceptions is the cement bond log, an acoustic measurement for evaluating the quality of the cement bond achieved in cased holes. In almost all cases, formation evaluation objectives cannot be achieved unambiguously without using two or more logging techniques. Even when all relevant logs are available, several formation properties cannot be directly determined. In particular, some key parameters such as formation permeability and mechanical strength can be inferred but not deduced with existing wireline logging technology.

Acoustic logging is unique in that it is the only continuous logging measurement which is directly sensitive to some of the mechanical properties of formation rock. Thus, when the formation density is known, from the gamma–gamma log, acoustic wave interval transit time measurements provide a means for determining the elastic moduli of the rock. While the traditional application of the acoustic log is for porosity determination, it has received increasing attention in recent years for its potential in several other applications including mechanical property determination.

In conventional open hole acoustic logging a single measurement is made as a function of depth in a borehole, viz. the compressional wave transit time in the formation over a fixed spatial interval, typically 1 ft. In conjunction with the appropriate additional logging data, this measurement can be applied, with varying degrees of validity, to porosity determination, lithology identification and seismic correlation. As we shall see, however, this one measurement is not sufficient to generate substantive information about the elastic moduli or other mechanical properties of the formation, an important but elusive set of parameters. To make further progress, more detailed evaluation of the full acoustic waveform is required, which includes a determination of the shear wave velocity in the formation.

It has been known for some time that the conventional acoustic