contemporaneous formation measurements, drilling operations create an environment that is generally hostile to electronic instrumentation and sensor operations.

When the position information for the logging instrument includes both depth and orientation, the log can take the form of a two-dimensional "image" of the borehole wall. Imaging enables analysts to study the fine-scale structure of the penetrated formations, including stratifications, fractures, dip angles, rock texture, vugs, and other features and anomalies. Most imaging tools are wireline logging tools, though at least some LWD imaging tools have been proposed. See, e.g., U.S. Patent 6,600,321 (Evans); U.S. Patent 7,098,664 (Bittar); U.S. Patent 7,272,504 (Akimov); U.S. Patent 6,678,616 (Winkler). There do not appear to be any logging while drilling tools that can provide a sonic density image log.

SUMMARY

According to an aspect of the present invention, there is provided a logging while drilling tool that comprises: a drill collar having at least one acoustic transmitter and at least one acoustic receiver to make azimuthally-sensitive measurements of formation P-wave and S-wave velocity or slowness values; and processing circuitry coupled to the at least one receiver, wherein the processing circuitry determines formation density based at least in part on measured P-wave and S-wave velocities or slowness values.

According to another aspect of the present invention, there is provided a logging method that comprises: rotating a logging-while-drilling tool as it moves along a borehole; detecting acoustic waves propagating along a wall of the borehole using at least two receivers; processing signals from the receivers to measure formation density values; and associating the formation density values with the tool's position and orientation.

BRIEF DESCRIPTION OF THE DRAWINGS

An understanding of the disclosed embodiments can be obtained when the following detailed description is considered in conjunction with the drawings, in which:

Fig. 1 is an illustrative view of a logging-while-drilling (LWD) environment;

Fig. 2 is an illustrative borehole wall image;

Fig. 3 is a cross-sectional view of an illustrative LWD imaging tool;

Fig. 4 is a side view of an illustrative embodiment of an LWD imaging tool;

Fig. 5 shows the propagation of an acoustic wave in the borehole wall;

Fig. 6 shows illustrative receive waveforms;

Fig. 7 is a side view of an alternative embodiment of an LWD imaging tool;

Fig. 8 is a functional block diagram of illustrative tool electronics;

Fig. 9 is a flowchart of an illustrative sonic density imaging method; and

Fig. 10 is a block diagram of an illustrative computer system.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description thereof are