Borehole-Radar Methods: Tools for Characterization of Fractured Rock

Introduction

Locating and characterizing bedrock fractures and lithologic changes is an important component of studies of ground-water supply and contamination in fractured-rock aquifers. Borehole-radar reflection methods provide information on the location, orientation, and lateral extent of fracture zones that intersect the borehole, and can identify fractures in the rock surrounding the borehole that are not penetrated by drilling. Cross-hole radar logging provides cross-sectional maps of the electromagnetic properties of bedrock between boreholes that can identify fracture zones and lithologic changes and can also be used to monitor tracer tests.

Borehole-radar logs can be integrated with results of surface-geophysical surveys and other borehole-geophysical logs, such as acoustic or optical televiewer and flowmeter, to distinguish transmissive fractures from lithologic variations or closed fractures. Integrated interpretation procedures provide results that can be used to develop conceptual and numerical models, design monitoring and sampling programs, and monitor implementation of contamination remediation measures, such as blast-fracturing.

Theory of Operation

Borehole-radar methods use the reflection and transmission of radar-frequency electromagnetic (EM) waves to detect variations in subsurface properties. Borehole radar waves have frequencies of about 10 to 1,000 megahertz (MHz), with corresponding wavelengths in earth materials of meters to centimeters.

The principles of borehole-radar reflection logging are similar to those of surface-radar profiling, except that the antennas are connected together and lowered as a single unit down the open or polyvinyl chloride-cased borehole (fig. 1). A radar pulse is transmitted into the bedrock surrounding the borehole. The transmitted pulse moves away from the borehole until it encounters material with different electromagnetic properties, such as a fracture zone, change in rock-type, or void. At this location, some of the energy in the radar pulse is reflected back towards the receiver, and some of it is transmitted further into the rock (fig. 1). A radar reflection profile along the borehole is created by taking a radar scan at each position as the antennas are moved in 0.1 to 1.0 meter (m) steps up or down the borehole. The typical reflection patterns observed in radar reflection profiles from planar and point reflectors are shown in figure 1.

Radar-reflection logging can be conducted with omni-directional or directional receiving antennas. Omni-directional antennas are useful for rapidly identifying the location, dip, and lateral continuity of fracture zones, but directional antennas are required to determine

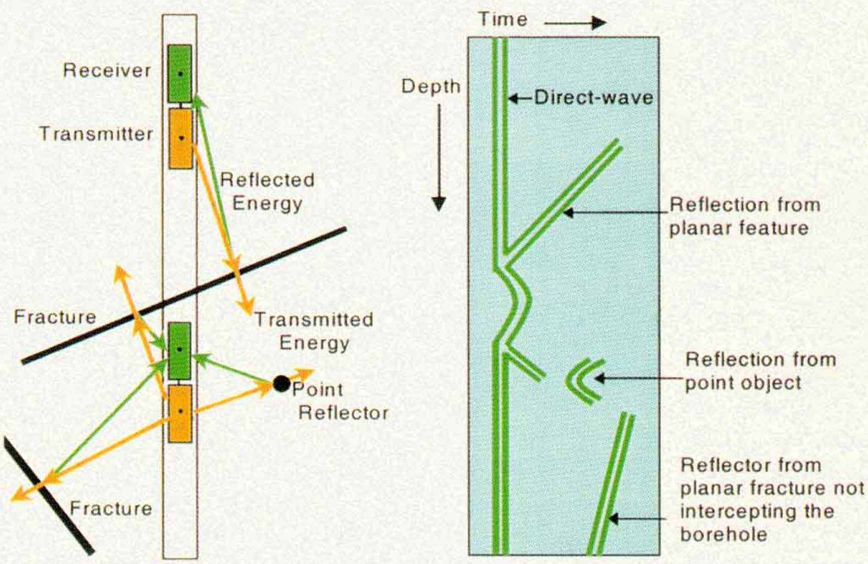

Figure 1. Orientation of transmitter and receiver in a single borehole and the resultant radar record from a fracture and a point reflector.