SPE 110623

# Borehole Effects and Correction in OBM With Dip and Anisotropy for Triaxial Induction Tools

P. Wu, SPE, H. Wang, SPE, G. Minerbo, SPE, D. Homan, SPE, T. Barber, SPE, and M. Frey, SPE, Schlumberger



This paper was prepared for presentation at the 2007 SPE Annual Technical Conference and Exhibition held in Anaheim, California, U.S.A., 11–14 November 2007.



## Abstract

The latest advance in resistivity logging is the multi-spacing triaxial induction tool. In addition to the conventional induction logs, a triaxial induction tool provides added capability to measure formation anisotropy (horizontal and vertical resistivities), relative dip, and azimuthal angles over a wide range of logging conditions. The anisotropy measurement is very important in low-resistivity pay analysis, while the dip and azimuth measurements have many important geophysical and geological applications.

However, due to the physics of the triaxial induction measurements, the borehole effects are significant even for oil-base mud (OBM) conditions. These borehole effects must be corrected in order to obtain accurate measurements of the formation properties. Through extensive modeling studies, we learned that borehole effects depend on many parameters, including hole diameter, tool eccentric distance and azimuth, mud resistivity, formation horizontal and vertical resistivities, formation relative dip, and azimuth angles. Removing the borehole effects is a very difficult and complicated three dimensional (3D) electromagnetic inversion problem, which involves many free parameters.

We have developed an inversion algorithm for OBM filled boreholes that robustly solves for horizontal and vertical resistivities, relative dip and azimuth, tool eccentric distance and azimuth. The model for the inversion is an eccentric tool in a borehole through an anisotropic formation with a dip angle. These inverted parameters can then be used to derive the borehole correction for the triaxial measurements. We demonstrate the algorithm through theoretical examples and field logs. The algorithm is very efficient and fast enough to be implemented as real-time well site answer product.

Throughout this paper * designates a Mark of Schlumberger.

## Introduction

Induction logging has progressed a long way from its infancy[1] of using a few simple axial coils to the latest multi-spacing triaxial induction tool.[2,3,4] By *triaxial* we mean that the basic array consists of three orthogonal, collocated transmitters, and three orthogonal, collocated receivers and bucking coils (**Fig. 1**). A pioneering study[5] of formation anisotropy and induction logging suggested that with fully triaxial tensor measurements, one can solve for the formation parameters of horizontal and vertical resistivites ($R_h$, $R_v$), dip, and azimuth in an anisotropic formation with arbitrary dip angle.

However, the presence of a borehole introduces significant amount of borehole effect to the measurements in both water-base muds (WBM) and OBM. For WBM, the borehole effects are so large that a special multielectrode tool design[6,7] is employed to reduce the borehole effect to a manageable level. The residual borehole effect is then handled by an algorithm[4] similar to that of standard array induction tools

Early in the field tests of the multiarray triaxial induction tool in deviated wells, however, it was discovered that the borehole effect, especially in OBM, is also a function of the relative dip and azimuth of the formation anisotropy. The size of the effect is larger for the short arrays, and less for the long arrays. Left uncorrected, the effect reduces the usability of the short arrays to accurately measure formation properties. Understanding and correcting the residual borehole effects for all spacings are essential for using all the arrays for 2D and 3D inversion and imaging algorithms.[4,8,9]

First we will present some modeling results showing the effects of the OBM filled borehole to the triaxial induction measurements.

Second, we will show an inversion algorithm that solves for $R_h$, $R_v$, formation relative dip and azimuth angles, as well as the tool eccentricity distance and azimuth based on a model of a eccentric tool in a borehole filled with OBM through an anisotropic formation with a dip angle. The inverted parameters are used to compute the contributions to the measured conductivity tensor due to the borehole. These borehole contributions are subtracted from the raw measurements to obtain the borehole corrected results. We demonstrate the borehole inversion results through theoretical examples and field triaxial data sets.

## Modeling of Borehole Effects in OBM

A finite element (FEM) method program is used to model the responses of the triaxial induction tool. The tool consists of