Review and Comparison of Three Different Gas Shale Interpretation Approaches

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This paper was prepared for presentation at the SPWLA 53rd Annual Logging Symposium held in Cartagena, Colombia, June 16-20, 2012.

ABSTRACT

This paper reviews and compares three recently published approaches for simplicity, validity and parameter sensitivity. The first two approaches are based on deterministic models; the third approach uses a response equation technique in which models are defined by means of tool response equations and interpretation constraint equations. The first approach assumes that the weight fraction total organic carbon (TOC) is available from an external source, the rock grain density is known, and total water saturation is constant. This enables the use of a single equation based upon the bulk density log to solve for total porosity from which the gas filled porosity can be obtained with the assumption of constant water saturation. The second approach assumes that the formation consists of two constituents: porous mineral matrix and porous kerogen. It makes use of the fact that in gas shale, kerogen generally contains oil-wet porosity, so that constant kerogen porosity, completely gas saturated, is imposed. The volumes of porous mineral matrix, porous mineral kerogen, and porous mineral porosity can be obtained by using the sonic and density logs with an assumed known rock grain density and assuming the porous mineral matrix gas saturation is a constant. The assumption of constant porous mineral gas saturation can be relaxed by iteratively using the resistivity log to update the assumed value of the hydrocarbon saturation.

This paper shows that Methods 1 and 2 can be replicated by using a response equation based statistical optimization technique. This technique requires some simple constraints, such as constant kerogen porosity or constant gas saturation. Moreover, the constant saturation assumptions can be easily removed, and it is possible to calibrate to core grain density and gas filled porosity with or without wireline geochemical data, TOC, or x-ray diffraction (XRD) mineral data.

The results of all three approaches are presented for a Haynesville gas shale well. The explicit models of Methods 1 and 2 are tested for consistency with core data. Although Method 2 suggests using TOC to establish a correlation with pyrite to obtain an improved prediction of grain density, this paper demonstrates that geochemical logs generally provide a more robust prediction of pyrite because they measure sulfur directly.

INTRODUCTION

This paper compares three shale gas interpretation response equation based "inverse methods." The methods differ in the number of equations (logging tool measurements) and the number of unknowns. When there are as many equations as unknowns, frequently the system of equations and unknowns is called deterministic and generally an exact solution can be obtained. The solution is exact in the sense that the solution exactly reconstructs each of the response equations to agree precisely with the corresponding logging tool measurement. When there are more equations than unknowns, the best solution is generally one that minimizes the error between the actual and reconstructed logs. Freedman et al. (2011) notes more generally that conventional inverse methods used in the industry today typically involve the constrained minimization of a weighted sum of squared deviations between a set of measurements and a set of equations. The equations are either empirically or theoretically derived and relate reservoir properties to be predicted (e.g., porosity, saturation, and clay volume) to measurements (e.g., resistivity, nuclear, and acoustical). Constraints are imposed, such as 0 <= porosity (v/v) <= maximum porosity. The goal of the interpreter is to determine physically meaningful values for all parameters used to describe the response equations, such as hydrocarbon fluid density or grain density, so