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## Crosswell Electromagnetic Tomography in Haradh Field: Modeling to Measurements

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### Abstract

Crosswell electromagnetic (X-well EM) resistivity is emerging as an intriguing technology for reservoir surveillance. It provides a cross-sectional resistivity image between two wells and has the potential to provide fluid distribution at an inter-well scale. It can be used for identifying bypassed hydrocarbons, monitoring macroscopic sweep efficiency, planning infill drilling, and improving effectiveness of reservoir simulation. It can be deployed for one-time or time-lapse surveys.

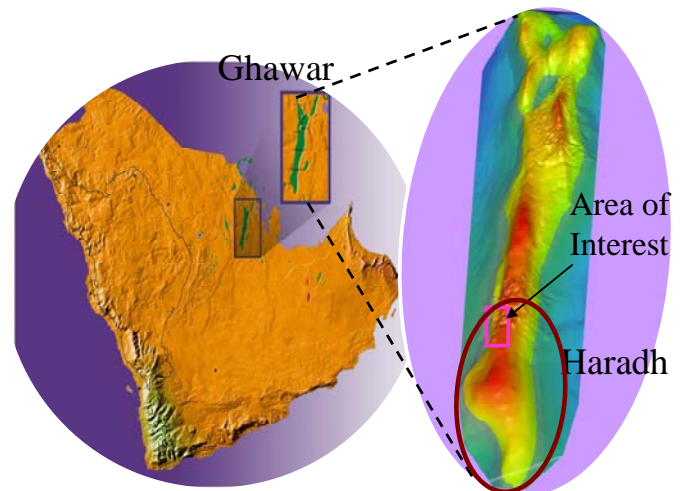
A crosswell EM technology trial project is being conducted in an Upper Jurassic carbonate reservoir, at the Ghawar Field in Saudi Arabia, to monitor the movement of injected water flood front and map the fluid distribution. The project site is in Ghawar's southern region, Haradh Field, and consists of three wells in the oil-water contact zone where peripheral injection water may have produced an uneven flood-front distribution.

Significant drilling and well deepening were required prior to the deployment of tools in the three-well triangle. In fact, one new well was drilled and two other wells were deepened by more than 200 m, so that good volumetric coverage could be obtained at the oil-water contact zone. Extensive logs, core and formation tests were also acquired to provide deterministic saturation profiles at the near wellbore region. Formation evaluation in the project area indicates that one of the wells was fully swept while a second well, some 400 m away, was not.

In July 2007, crosswell EM surveys were acquired across the three Haradh wells. In spite of the large well separations, the acquired EM data had good quality, and good stations repeatability. Preliminary processing has revealed a structure consistent with the background structure but a clear image of the oil-water contact is yet to be made.

### Introduction

The Haradh Field is in the southernmost part of the greater Ghawar Field – the largest single oil field in the world (**Figure-1**). Arab-D is a 100-m thick, highly prolific, upper Jurassic reservoir comprising a carbonate sequence of grainstones, packstones, and wackestones<sup>1</sup>. The original sedimentary textures have been altered in many places by leaching, recrystallization, cementation, dolomitization, and fracturing, which have caused a variety of pore types<sup>2</sup> to coexist in Arab-D. Flood-front movement can be uneven in some parts of the reservoir. Reservoir porosity ranges from less than 10% at the base to over 30% at the top while permeability ranges from few millidarcies to more than one Darcy.



**Figure-1: Arabian Peninsula and Ghawar Field. The area of interest lies in the southwestern flank of Ghawar, within Haradh.**

The Arab-D reservoir in Ghawar has historically been operated at relatively low depletion rates. Flank water injection is being carried out to maintain pressure and to improve sweep efficiency in this reservoir. With current inter-well spacing, about 1 km, determining fluid distribution behind the flood front is a key challenge to maximizing recovery from this reservoir.

Traditional reservoir fluid monitoring techniques, e.g. pulsed-neutron logs (PNL) and resistivity logs, have investigation depths ranging from few inches, for PNL logs, to about 3 m for the deepest resistivity logs<sup>3</sup>. Therefore, they cannot be used effectively for flood-front monitoring at the inter-well scale.