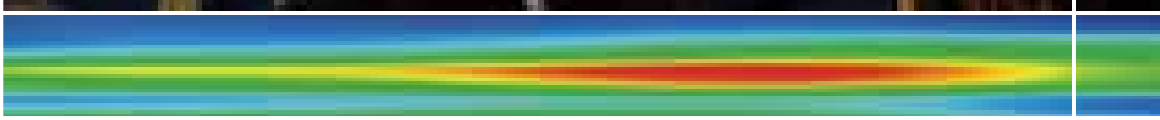
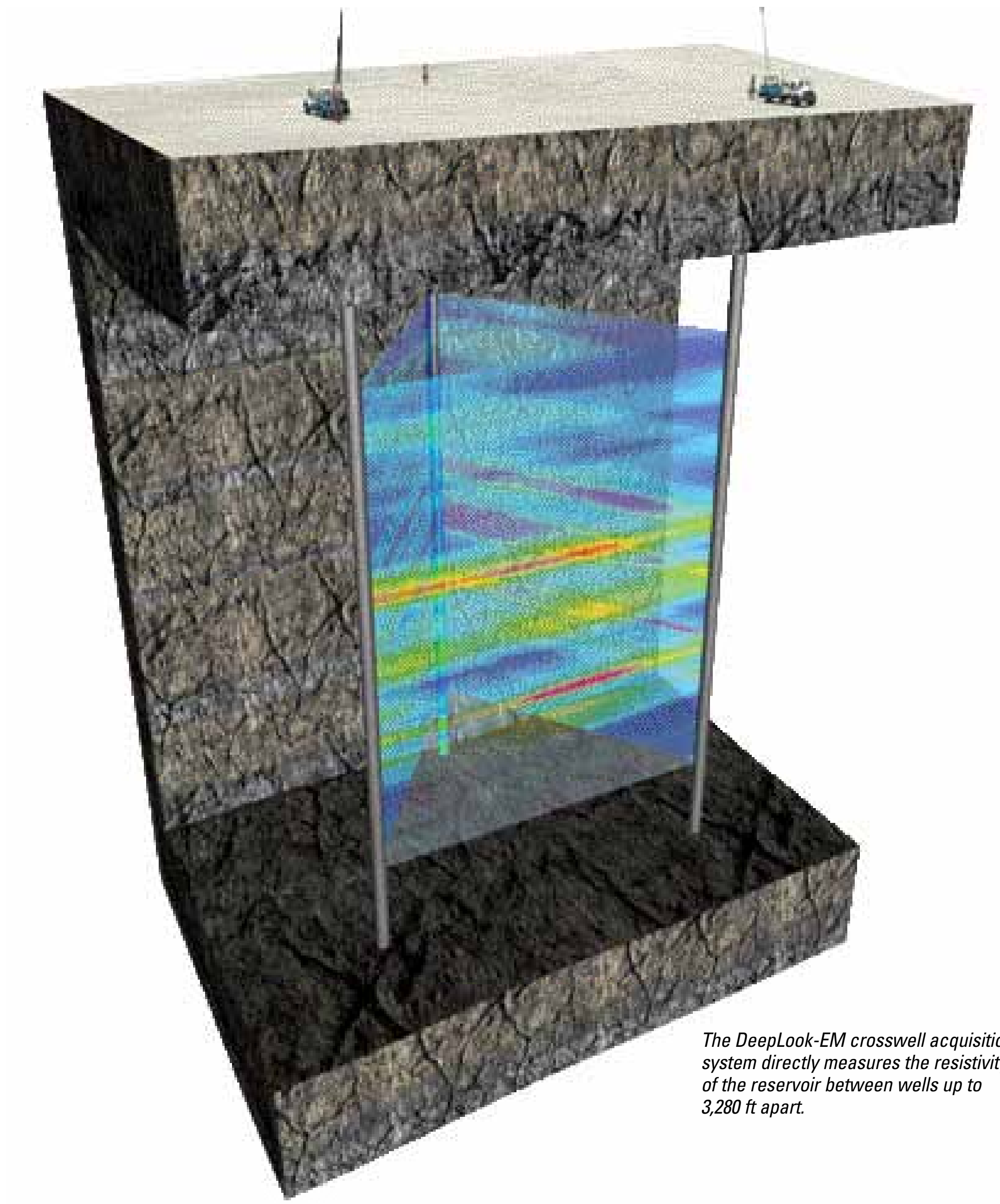
Schlumberger



DeepLook-EM

Enhanced crosswell reservoir monitoring system

Reservoir-scale resistivity images help you understand fluid distribution and predict movement for successful reservoir management.



The DeepLook-EM crosswell acquisition system directly measures the resistivity of the reservoir between wells up to 3,280 ft apart.

Until now, logging has measured only within the borehole and near-well environment. The DeepLook-EM* enhanced cross-well reservoir monitoring system expands the scale investigated by resistivity logging to give you the big picture for monitoring fluid distribution and movement on a reservoir scale.

Building on two decades of research by a consortium of industry, academia, and US Department of Energy scientists, Schlumberger advances in technology, processing, and inversion techniques make it possible to directly measure the resistivity distribution between wells. Variations in resistivity reflect changes in porosity (subsidence), saturation (waterflooding, bypassed pay), and temperature (steam flooding).

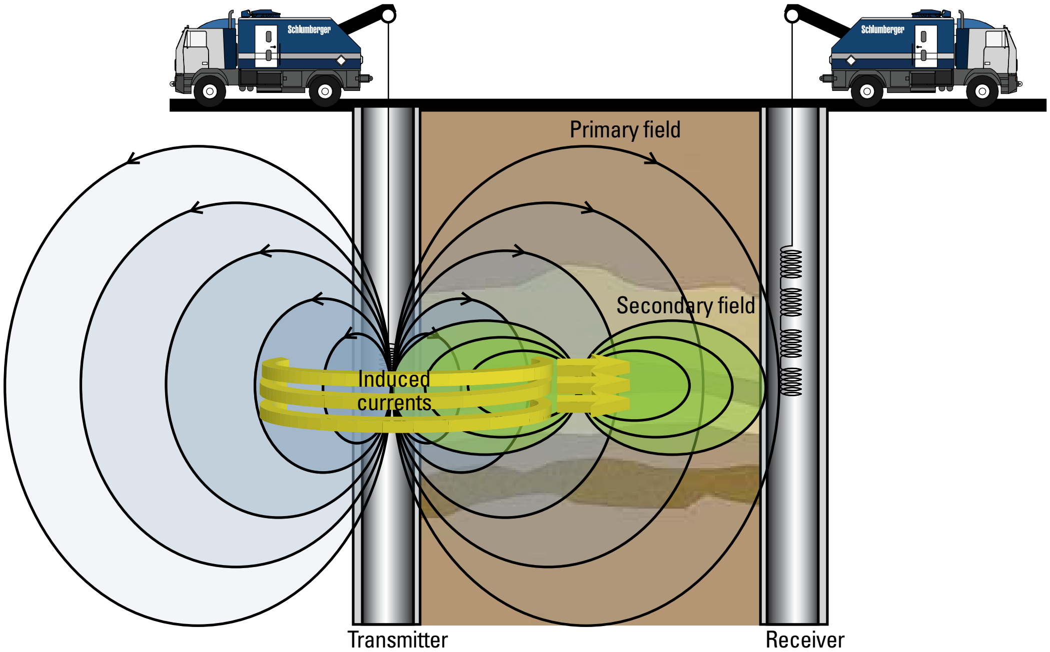
Looking Deep

The DeepLook-EM acquisition system consists of a transmitter tool deployed in one well and a receiver tool deployed in a second well, with the two wells located up to 3,280 ft [1,000 m] apart, depending on formation and resistivity contrasts. A Global Positioning System is used for synchronized communication of the tools, which are conveyed on standard wireline equipment.

The interval logged, including positions above, below, and within the zone of interest, is at least the length of the well spacing. Typically DeepLook-EM station spacing is 2% to 5% of the well spacing.

The 32.4-ft [9.88-m] transmitter antenna is a vertical-axis magnetically permeable core wrapped with several hundred turns of wire and driven to broadcast a continuous sinusoidal signal at frequencies from 5 Hz to 1 kHz. The frequency selection depends upon the borehole environment (for example, chromium casing or open hole), well separation, and formation resistivity. Lower frequencies are required for the receiver in steel well casing, larger well separation, and low formation resistivity.

The transmitter has a magnetic moment that is more than 100,000 times stronger than the source in a conventional single-well induction logging system. The interwell distance depends on the condition of the wells and is determined through modeling and simulation.



Both the primary magnetic field generated by the transmitter and the secondary magnetic fields resulting from the induced currents are measured by the four receiver sensors.

The transmitter signal induces electrical currents to flow in the formation between the wells. The currents, in turn, induce a secondary magnetic field related to the electrical resistivity of the rock where they are flowing. At the receiver borehole, induction coil receivers detect the magnetic field generated by the transmitter (primary field) as well as the magnetic field from the induced currents (secondary field). The receiver tool comprises an array of four receiver coils, which reduces logging time by simultaneously recording the signals.

For each receiver station, the transmitter in the other well is moved between the depths of interest while continuously broadcasting. To reduce noise, the incoming signals are averaged several hundred times per station. Depending on the amount of averaging and frequency of operation, the transmitter logging speed ranges from 2,000 to 5,000 ft/h [600 to 1,520 m/h]. Once a complete transmitter traverse, or profile, is collected for a receiver position, the receiver tool is repositioned and the process repeated.

Logging is conducted at the location of the moving transmitter. The operation is controlled through the logging surface station and a laptop computer and requires a wireline field unit and mast or crane at each of the two wells.

Deeper Understanding

Inversion of the DeepLook-EM data to generate interwell resistivity images follows a rigorous workflow that integrates existing reservoir information. The field data are compiled using Petrel* seismic-to-simulation software to create a field model of possible fluid movement scenarios. Simulation based on the scenarios then ensures that the appropriate measurement sensitivity is applied.

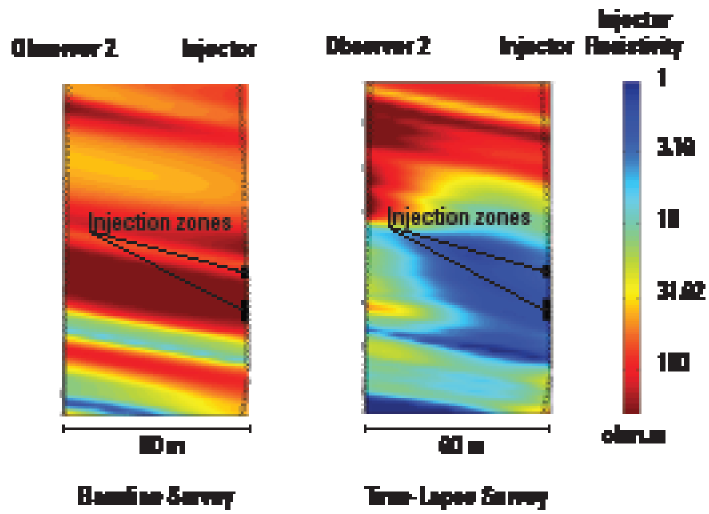
Following the DeepLook-EM survey, the interwell resistivity distributions are exported back to the field model for data integration and interpretation to provide critical insight for fluid tracking of water and steam, bypassed pay detection, and reservoir characterization.

Case Studies

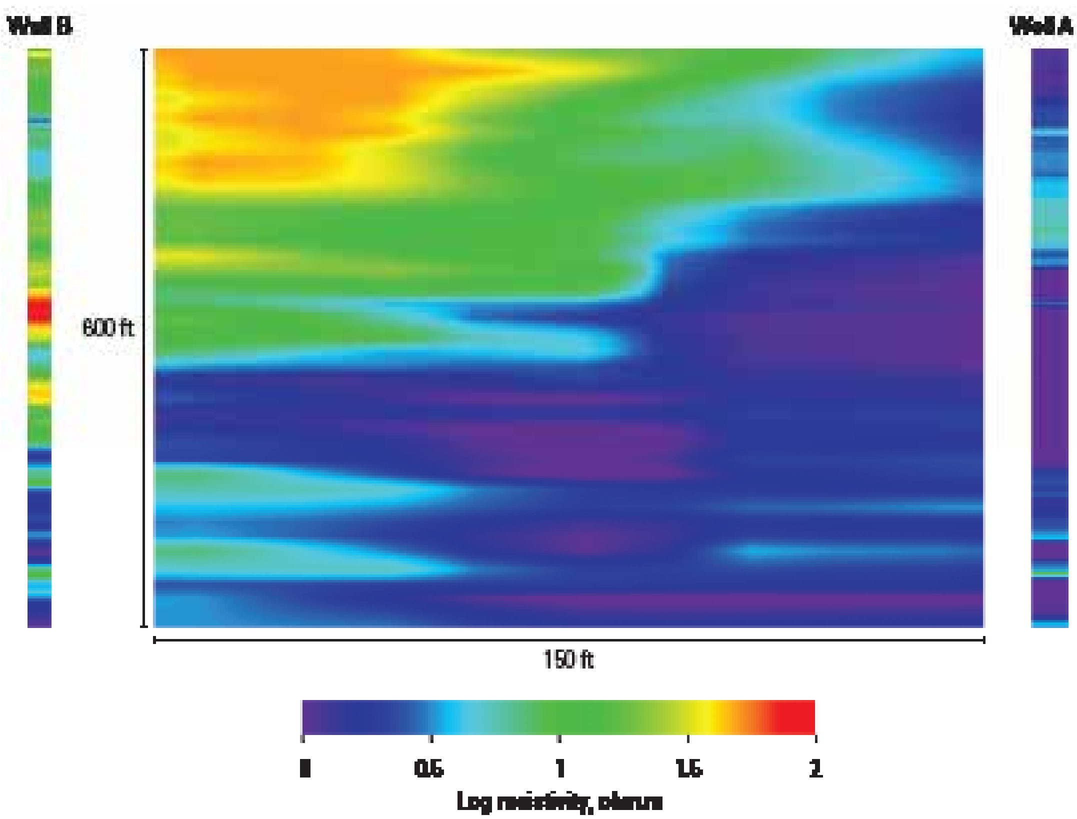
Monitoring interwell fluid front to optimize injection

Petroleum Development Oman (PDO) needed to monitor water-flood conformance in an Oman field with a high fracture density and thief zones. Fluid distribution could only be guessed at because conventional methods of measuring fluid movement relied on interwell interpolation of wellbore-scale data.

Wireline resistivity measurements from before injection were used to construct a baseline model to which DeepLook-EM time-lapse survey data were interpolated. Although the DeepLook-EM images indicate successful movement of a large volume of swept water, which is consistent with the injection and production volumes, they also suggest areas of remaining oil, and the injection strategy and infill drilling can be tailored to extract the previously unknown bypassed pay.



The DeepLook-EM images after water injection confirm that large volumes of water are swept within and outside of the injection interval.



The DeepLook-EM resistivity profile between observation Wells B and A in the steamflooded San Joaquin field images an abrupt boundary midway, where the resistivity changes from 2 ohm.m in the depleted zone to more than 50 ohm.m.

Tracking cyclic steam injection

The complex, steeply dipping geology and variety of reservoirs complicated determining the affected volume around each cyclic steam injector in a field in the San Joaquin Valley, California, USA. Because the DeepLook-EM system directly measures resistivity, which is sensitive to changes in fluid saturation and temperature, it is the ideal technique for tracking distribution of the injected steam volumes and the resulting swept zone.

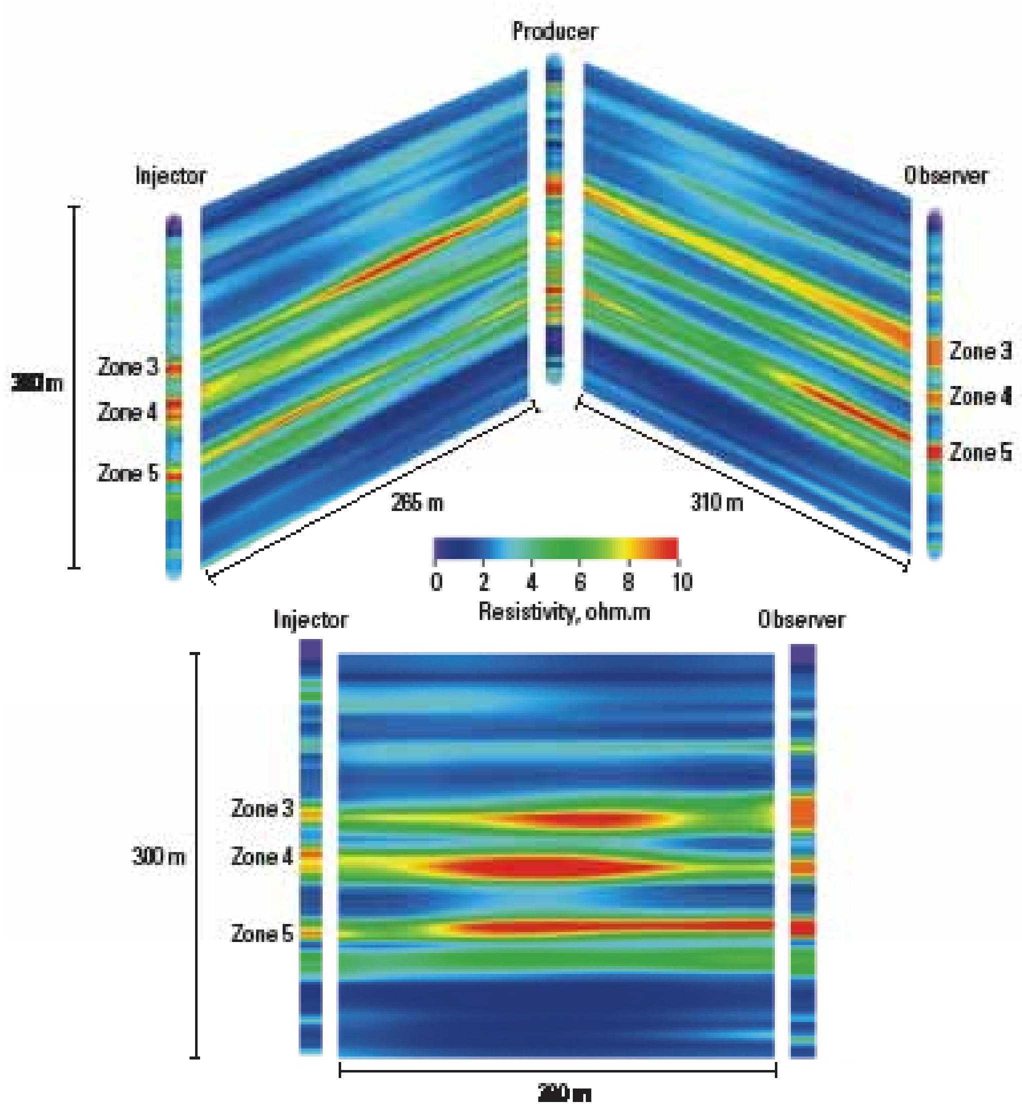
In the resistivity profile, the abrupt boundary midway between Wells A and B marks a resistivity change from 2 ohm.m to more than 50 ohm.m over a short interval. The blue colors denoting lower resistivity identify the depleted zone resulting from the replacement of oil by formation water and steam condensate, which matches the log in Well A. The orange and red colors are characteristic of unswept oil sands. From this accurate boundary placement, the operator could appropriately position the steam-saturated volume in the section for optimizing extraction.

Finding bypassed pay in complex channel sands

China Petroleum & Chemical (Sinopec Corp.) wanted to better understand the configuration of reservoir sands in Gudao field in central China. The reservoirs are in both discrete channels and continuous deltaic sheets, but numerous faults prevent straightforward interpretation between wells.

DeepLook-EM reservoir-scale resistivity surveys confirmed the continuity of the three producing zones between the wells and imaged thickness variations related to compaction. With this information Sinopec Corp. can optimize flood sweep efficiency, which is indicated by decreased resistivity where injected water has replaced hydrocarbon.

Significant bypassed reserves revealed by the higher resistivity section on the DeepLook-EM images were confirmed by correlation to the resistivity log of a subsequently drilled offset well to the survey area.



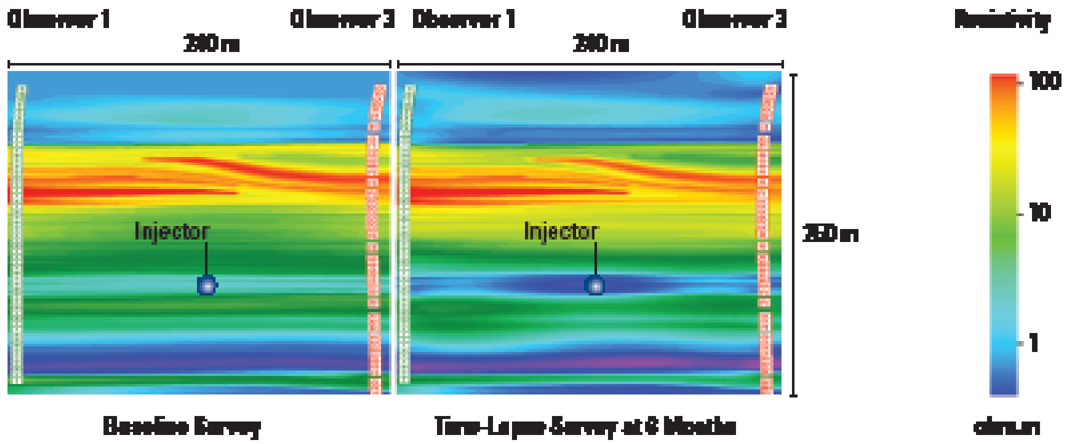
DeepLook-EM crosswell resistivity images between three wells in Gudao field show consistent, continuous producing zones, with the higher resistivity in Zone 5 indicating bypassed oil.

Case Studies

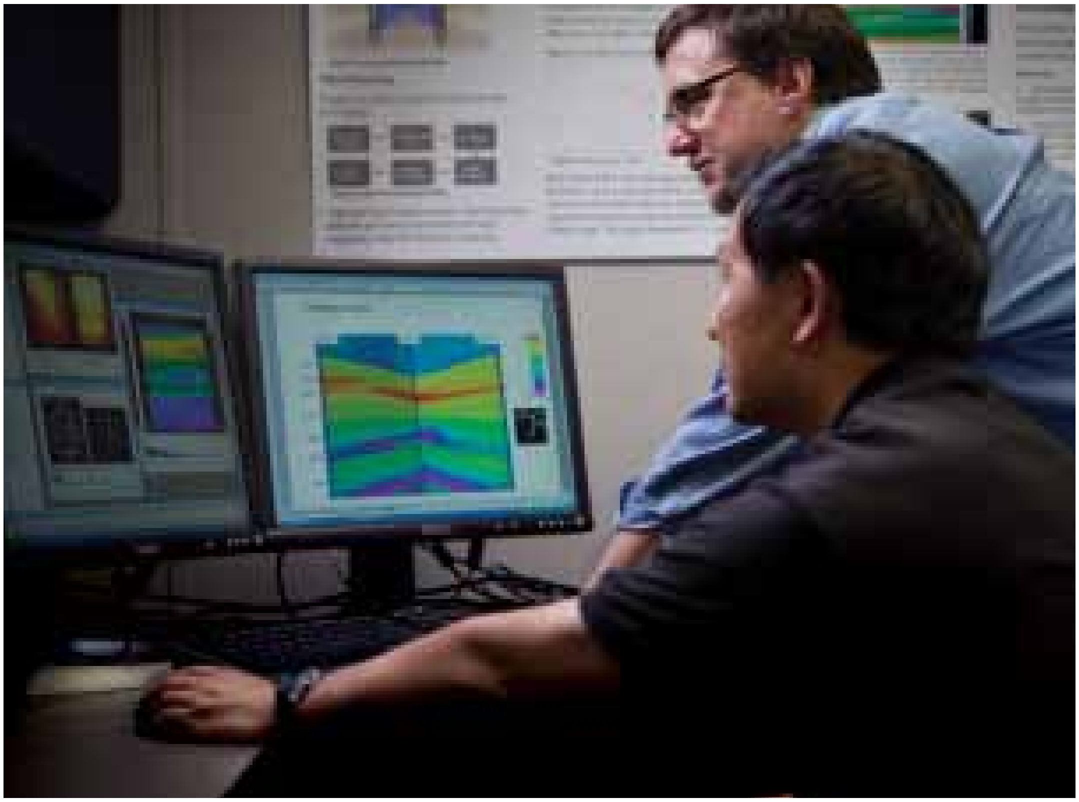
Confirming water sweep dimensions

A prolific UAE field operated by Abu Dhabi Company for Onshore Oil Operations (ADCO) was experiencing uneven sweep. But lateral coverage with conventional logs and the vertical resolution of subsurface seismic survey were insufficient for monitoring interwell fluid flow and led to unanswered questions in the stochastic flow simulation.

DeepLook-EM time-lapse resistivity surveys indicate successful waterflooding from the injector well to the observer well, confirmed by RST* reservoir saturation tool measurements. Surveys at 6-month intervals are planned to verify the continuing direction and coverage of water movement. From the between-well imaging, ADCO can fine-tune injection management to avoid both water override and bypass.



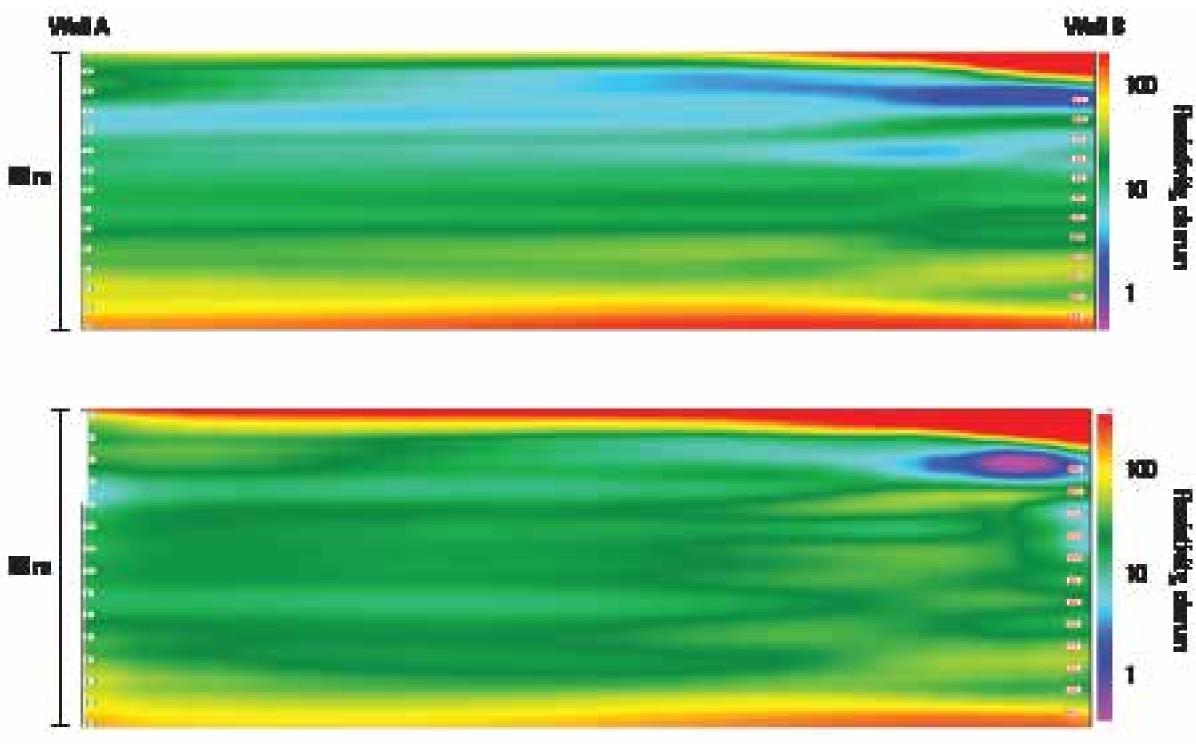
Time-lapse DeepLook-EM crosswell resistivity surveys at a 6-month interval show a large water sweep preferentially from east to west between Wells 1 and 3.



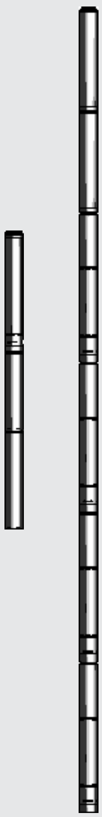
Revealing waterflood distribution

For 30 years, Saudi Aramco has been continuously pumping seawater into peripheral water injectors to maintain pressure in a giant oil field. However, the distribution of the injected water is not fully known because of reservoir complexity. Conventional resistivity measurements indicate that two producing wells had watered out, but the resistivity distribution between the wells was unknown.

Crosswell DeepLook-EM measurements were collected between the two producing wells 2,772 ft [845 m] apart on the west flank of the reservoir. The DeepLook EM survey revealed variable sweep efficiency, potentially leaving hydrocarbons in place.



In the top panel, the baseline model inferred from conventional resistivity logs indicates that the reservoir between the wells has watered out, with conductive injected fluid (blue) sweeping the reservoir. The inverted DeepLook-EM resistivity survey in the bottom panel indicates otherwise, with a higher resistivity range (green to yellow) in the same, high-porosity section of the reservoir.



DeepLook-EM Interwell Distances

Transmitter Well	Receiver Well	Well spacing, ft [m]
Open hole	Open hole	3,280 [1,000]
Open hole	Steel casing	1,640 [500]
Open hole	Chromium casing	2,953 [900]
Chromium casing	Chromium casing	1,312 [400]
Chromium casing	Steel casing	984 [300]

Specifications

	DeepLook-EM Transmitter	DeepLook-EM Receiver
Temperature rating, degC [degF]	150 [302]	150 [302]
Pressure rating, MPa [psi]	138 [20,000]	103 [15,000]
Well size—min., cm [in]		
Open hole	11.5 [4.5]	6.5 [2.5]
Cased hole	11.5 [4.5]	6.5 [2.5]
Well size—max., cm [in]		
Open hole	No limit	No limit
Cased hole	35 [13.75]	No limit
Outside diameter, cm [in]	8.5 [3.375]	5.5 [2.125]
Length, m [ft]	9.88 [32.4]	Four receivers: 22.5 [73.8]
Mud type or weight limitations	No fluid restrictions	No fluid restrictions
Well deviation	0°–20°	0°–20°
Frequency range, Hz	5–1,000	5–1,000

www.slb.com/deeplook

Schlumberger