An operator developing a heavy oil field wanted to significantly ramp up production with an enhanced oil recovery (EOR) program. The preferred EOR method began with cyclic steam injection into thin reservoir layers. The operator identified time-lapse vertical seismic profile (VSP) as a key technology to monitor the way in which the injected steam spread.

Working with Baker Hughes, a GE company (BHGE), a study was made of the plan’s feasibility and how to tailor survey methods to match specific geological and geophysical conditions. Following extensive 3D modeling, detailed plans were generated for acquiring a 3D-VSP survey.

Goals included shooting a repeatable baseline survey for time-lapse study purposes, acquiring high-resolution data so that individual thin reservoirs could be imaged, and characterizing reservoir properties and estimating the steam chamber size after a 30-day steam injection cycle.

The plans called for high levels of source positioning accuracy and consistency to ensure effective use of future time-lapse repeat surveys. Providing the necessary vertical resolution required achieving the highest frequency data possible. Therefore an innovative approach with 75 closely-spaced downhole receivers was designed.

These data quality targets were all successfully delivered during the field operation using several advanced techniques, which also maximized shooting efficiency and minimized survey time. These techniques included the BHGE AutoSweep™ source-driven VSP system and real-time kinematics (RTK) high-precision source position measurement. These solutions provided the required source consistency and accuracy while ensuring the survey was shot efficiently in an area with congested surface conditions.

Data processing generated a seismic image volume with frequencies up to 130Hz which is 30% higher than previous VSP or seismic data. Amplitude anomalies due to steam replacing the oil in the reservoirs were clearly evident around the well that had been injected. This was as predicted based on the pre-

**Challenges**
- Congested survey area with numerous surface obstructions and obstacles
- Obtain higher resolution data than had previously been acquired in the area

**Results**
- Obtained high-resolution steam chamber images in thin, vertically stacked reservoirs
- Validated 3D-VSP techniques for use in reservoir surveillance
- Provided data to locate infill producer and injector wells to optimize production
- Acquired base line survey for time lapse comparison
project rock physics modeling. However, the shape and direction of steam flow was not exactly as expected.

Further processing of this seismic information when combined with log data allowed small-scale changes in acoustic impedance to be studied so that detailed interpretation and mapping of individual channel and facies could be made. Examining this data provided an explanation for the pathways and steam flow observed in the seismic volume.

Understanding the reservoirs, barriers, and effectiveness of the steam flood helps optimize an EOR program. It will also help determine where infill and producer wells need to be drilled and how to operate them to achieve maximum production.

Steam chamber image around injection well (red) as imaged using data derived from a 3D-VSP with receivers in the adjacent well (green)