Resistivity, Imaging-While-Drilling Tool Helps Well Placement in Chinese Tight Reservoirs

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Two case studies describe the use of a new resistivity and imaging-while-drilling tool that was used to improve well placement in the Sichuan Basin of central China—a drilling environment presenting high levels of geological uncertainty. The first case involved the technology’s application in a very thin tight dolomite gas reservoir, and the second case involved the first commercial development well in the region to target a carbonate oil reservoir. In addition to assisting well placement, the technology enabled valuable information about the natural fracture network to be obtained to support the completions design.

Background

The Sichuan Basin holds the biggest gas reserves in China and is the country’s leading gas production region. The basin rests in a major compressional tectonic area, highly compressed and characterized by thrust-faulted anticlines. Modern exploration and production started in the 1950s. Most of the gas and modest quantities of oil are produced from fractured carbonate and low-permeability sandstone reservoirs.

PetroChina Southwest Oil & Gas Company (SWOGC)—one of the biggest subsidiaries of PetroChina—operates in the basin. It has more than 100 exploration and development concessions in the region, covering a total of 180,000 km². Natural gas reserves in place are 842.2 billion m³, with estimated recoverable reserves of 320 billion m³.

During the early phases of exploration and development, wells were drilled vertically. Horizontal wells were introduced during the 1990s to enhance production from tight reservoir plays, which include limestone, dolomite, and tight sands. Logging-while-drilling (LWD) applications used for formation evaluation and well placement typically included propagation resistivity, density/porosity measurements, and real-time density image logging.

Today, after more than 20 years of production, most of the thickest tight gas reservoirs have been intensively developed. Since 2011, PetroChina SWOGC has increasingly targeted ever thinner tight gas formations using long horizontal drilling combined with multistage hydraulic fracturing. However, several subsurface challenges needed to be overcome for these efforts to succeed, particularly because of the extensive faults and fractures in the reservoir rock.

To meet these challenges, and enhance reservoir understanding, the company has deployed advanced LWD real-time acquisition and transmission technology providing high-resolution electrical borehole images, azimuthal gamma ray, and multidepth formation resistivity measurements.

The New Tool

The new LWD capability deployed in these case studies provides high-resolution resistivity and borehole images around the full circumference of the borehole in conductive mud environments. The MicroScope high-resolution resistivity and imaging-while-drilling technology uses a 4¾-in. tool in 5⅞-in. to 6½-in. hole sizes that measures azimuthally focused laterolog resistivity at multiple depths of investigation. Also measured are azimuthal gamma ray and mud resistivity. Formation resistivity measurements, high-resolution borehole images, and azimuthal gamma ray data are transmitted uphole in real time, facilitating proactive well placement decisions.

This technology is suitable for use in diverse and challenging environments, including unconventional shale plays, and carbonate and clastic reservoirs. It enables enhanced formation evaluation, optimal placement of horizontal wells, and identification of fractures and faults for optimization of completion design.

A multidisciplinary team of oilfield operator and service company experts provided support for the resistivity measurement and imaging-while-drilling technology and the well placement and completion operations. Based in an interactive drilling operations support center of PetroChina SWOGC in Sichuan, a well placement team interpreted the real-time LWD data and guided the geosteering operations. After drilling, specialists from the service company interpreted the natural fracture network, modeled the reservoir structure, and recommended how the well could be optimally segmented during completions.

Case Study: Thin Dolomite Gas Reservoir

Making use of the new LWD capability, PetroChina SWOGC drilled a long horizontal well in a dolomite gas reservoir, where the target zone was predicted to be between 1 m and 2 m thick. The major challenges were to stay in the producing zone and identify fractures to help optimize...
completions. As it was a major compressional tectonic area, reverse/thrust faults and high structural dip uncertainty were expected. In addition, the reservoir was likely to exhibit significant lateral changes in thickness and petrophysical properties. The nearest offset well was more than 3 km away—too far to be useful as a means of reducing drilling uncertainty in an area characterized by rapid lateral structural and stratigraphic change.

The LWD technology provided a high-resolution resistivity image that clearly identified and defined the formation dips, faults, and fractures along the horizontal section. Even with the local structural undulations, variations in target zone thickness, and lateral property changes along the horizontal section, these images helped the operator to optimize geosteering as the well was drilled (Fig. 1). The 1095-m horizontal section was drilled with 91% in zone—exceeding the minimum requirement of 80%—and with good trip gas readings throughout the section.

The well was completed in one run in a total of 151 drilling hours. The initial gas production of 120,000 m³/d exceeded the operator’s production goal by 33%, compared with similar previous wells. The technology also provided valuable information about natural fractures (Fig. 1) that aided the design of hydraulic fracturing stages for completion optimization. In particular, it enabled the well to be segmented into zones of high- and low-density natural fracturing. The success of this well has enhanced the potential of thin tight gas/reservoir development in the basin. Several wells have now been planned in different target zones.

Fig. 1—High-resolution LWD resistivity imaging enabled accurate and optimal placement of the trajectory within the thin dolomite gas reservoir, despite the presence of high structural dip uncertainties and stratigraphic variations. Geological features, including fractures and bed boundaries, are clearly identified and defined along the horizontal section.

Fig. 2—The well was successfully placed within the sweet spot of the carbonate oil reservoir, despite the faults and dip variations along the horizontal section.
**Case Study: Tight Carbonate Oil Reservoir**

Modest oil reserves have been discovered concurrently with gas development in an area of the basin. PetroChina SWOGC used the resistivity and imaging-while-drilling tool to drill the first commercial oil well in the carbonate reservoir. A long horizontal well was planned in a reservoir bounded by two complex major faults. The formation was predicted to be 5 m to 7 m thick; however, the well was expected to encounter minor faults. To be successful, the company needed to identify the formation dips, faults, and fractures along the section being drilled. There were no nearby control wells to study to reduce the uncertainty.

During drilling, the high-resolution borehole images—combined with other key measurements from the tool—facilitated proactive geosteering decisions (Fig. 2). In one instance, the technology identified a fault on the west side of the well and made an azimuthal adjustment to shift the trajectory eastward to avoid exiting the formation at the fault. A total of 810 m was drilled in the horizontal section, 100% in zone with good oil shows throughout. The well was completed in a single run with a total of 265 circulating hours and 155 drilling hours. Identification and analysis of fractures along the horizontal section provided valuable information to optimize completion and hydraulic fracture staging design.

**Conclusion**

PetroChina SWOGC has used the resistivity and imaging-while-drilling tool to further oil and gas development in the Sichuan Basin and is applying it in more thin tight gas and carbonate oil reservoirs. The technology has also been applied recently in a thick tight sandstone gas reservoir to enhance production by steering a horizontal wellbore into the most highly fractured areas of the reservoir. JPT