A recent horizontal drilling campaign in western China has broken drilling performance records while using the industry’s first high build rate, rotary steerable system (RSS) with custom integrated bits to target very thin, ultra-deep oil reservoirs.

In recent years, technological breakthroughs in downhole tools, bits and integrated systems have dramatically enhanced operators’ ability to drill, land and steer complex wellbores in increasingly challenging environments. In early 2013, for example, PetroChina began drilling horizontal wells in a mature oil field in western China, using a hybrid rotary steerable system (RSS) capable of achieving higher build rates than conventional tools. Despite very thin, hard target reservoirs and high structural uncertainties, all three ultra-deep wells drilled with this new technology achieved their objectives while breaking existing performance records. As a result, PetroChina is reducing total runs per well, boosting rates of penetration (ROP), extending footage per run, minimizing nonproductive time (NPT) and costs, and increasing reservoir exposure.

**HADE OIL FIELD CHALLENGES**

Tarim Oilfield Company (TOC), a subsidiary of PetroChina Company Ltd, is engaged in prospecting, developing, and producing oil and gas from fields in the Tarim basin, one of the most prolific hydrocarbon producing regions in China. Located in the Xinjiang province of western China (Fig. 1), the basin is among the world’s most challenging areas to conduct exploration and development activities. Much of this remote basin is a vast desert, surrounded by high mountains. Hade (or Hadexun) oil field is one of four major producing fields in the northern Tarim basin, characterized by deep or ultra-deep reservoirs, with relatively high pressures and temperatures, moderate porosities and permeabilities, and low viscosities.

Hade was the first large-scale marine sandstone field in China with proved reserves in excess of 100 MMtoe. Discovered in 1998 and originally developed with vertical wells, Hade has been producing from Carboniferous reservoirs since August 2000. PetroChina’s strategic objective for the field is to increase production to 30 MMtoe/year by the end of 2014. To maximize productivity, TOC began drilling horizontal wells several years ago. Today, there are more than 50 horizontal wells in the field.
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Fig. 1. The Tarim basin, one of the country’s most prolific producing areas, is in the Xinjiang province of western China. PetroChina aims to increase production to 30 MMtoe by year-end 2014.

Hade field is a low-relief structure, with a complex tectonic and depositional history resulting in subtle stratigraphic-anticlinal trapping and a complicated oil/water interface in places. Oil reservoirs include the main Donghe Sand member, and two thin sand layers located within the Middle Mudstone formation, at burial depths of more than 5,000 m, TVD. These thin target sands—the subject of this case study—consist of fine, tightly cemented clastics of volcanic and metamorphic origin, exhibiting rock strengths up to 15,000 psi.

In the center of the field, where reservoir thickness is greater, geological uncertainties are lower, and the geosteering challenge is not as complex, TOC relies on local directional drilling partners. However, the company generally turns to international drilling contractors to deliver horizontal wellbores at the boundaries of the field, where uncertainties are high and the target reservoir is only 1-3 m, TVD, in thickness, and sometimes even thinner. The hard, abrasive sandstone causes considerable shock and vibration, and a high rate of tool failures while drilling and steering the 8½-in horizontal section using conventional RSS technology. Due both to rig constraints—such as sub-optimal rotating speed—and RSS dogleg limitations, it proved difficult, and in some cases impossible, for drillers to achieve the required directional well profiles.

The high rate of equipment failures had two additional consequences. First, it led to significant non-productive time (NPT), partly because it was necessary to pull out of hole frequently to change tools. Three to five runs were often necessary to drill the build-up section, and outcomes remained unpredictable. Second, given the number of tool failures and the complex logistical situation, some international contractors lacked the local infrastructure or advanced drilling technology necessary, either to sustain or to improve performance in this extremely challenging environment.

When TOC began planning another horizontal drilling campaign at the edge of the structure in late 2012, Schlumberger, which has had full operational support infrastructure in the region for years, offered to bring a unique integrated solution to Hade field’s tough drilling and geosteering challenge. The objective was to maximize reservoir contact in the 8½-in lateral section, while mitigating risks and minimizing total drilling time and costs.

HYBRID RSS WITH CUSTOM BITS

For the 2013 drilling program, which began in January, the Schlumberger PowerDrive Archer high build rate RSS technology was chosen to target thin, hard sandstone reservoirs. This unique RSS, first commercialized in 2011, represents a breakthrough in steering control. It is the industry’s first truly hybrid RSS, integrating proven components from push-the-bit and point-the-bit systems.

In a conventional push-the-bit RSS, external pads push against the borehole wall, forcing the bit in the desired direction. On the other hand, a conventional point-the-bit RSS uses an internal bent to misalign the tool, relative to the borehole axis. Combining elements of these two systems, the new RSS provides higher dogleg capability and directional control than either tool alone, Fig. 2. All external components rotate fully with the drillstring. In steering mode, its electronic control unit holds a rotary valve geostationary, diverting a small percent of mud flow to a set of internal pads, which push on the inside of a stabilizer sleeve instead of the borehole wall. The sleeve is hinged on a universal joint, which pivots and points the bit in the desired direction. The degree of deflection can be controlled mechanically, and held electronically in a constant direction, as long as necessary, to achieve the objective.

In a variety of challenging formations, this hybrid RSS delivers high build rates, previously possible only with traditional downhole motors, along with smoother, less tortuous boreholes characteristic of a fully rotating RSS. As a result, it can punch through hard stringers while maintaining full directional control. It also can drill deeper before kick-off and build angles faster than a conventional RSS, maximizing reservoir exposure along the lateral and increasing potential production. In addition, by moving the logging-while-drilling (LWD) gamma ray tool about 18 ft closer to the bit than the previous RSS, the system provides a much earlier indication of contact with reservoir boundaries.

As with a hybrid steering system rotating through hard formations and higher doglegs, specialized bits and fatigue management are necessary to ensure reliability and optimum drilling performance. The high build rate RSS is part of an “en-
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**Fig. 3.** The IDEAS integrated drillbit design platform simulates bit behavior in the context of the entire drilling system— including the RSS, BHA and drillstring—optimizing performance and durability for specific applications and fields.

An engineered drilling system consisting of a custom PDC drill bit from Smith Bits, drill string, and bottomhole assembly (BHA). Using the Smith Bits IDEAS integrated drillbit design platform (Fig. 3), engineers simulate and optimize custom bit behavior as part of the entire system, using a range of operating parameters specific to the well, formation and field.

Finite element analysis and detailed strain-based fatigue studies predict the run life of all components for specific drilling applications. A fatigue management system can track the actual build rate in real time and compare it with the predrill fatigue model, further reducing risks and extending BHA life. As a result, it is possible to drill much longer sections, at higher ROP, in a single run.

**ECONOMIC VALUE / NEW RECORDS**

Since first deployment of the hybrid RSS and integrated drillbit technology in January 2013, PetroChina Tarim Oilfield Company has finished drilling three horizontal wells targeting thin oil reservoirs at the edge of Hade field. The new tool has proven capable of achieving the required build rate despite the hard formation, while reducing shock and vibration and minimizing tool failures. After kicking off deeper than offset wells and landing in the reservoir about 50 m sooner, the 8½-in sections of these wells have been successfully geosteered in sands as thin as 0.3 m, TVD.

Application of this unique technology in Hade oil field has yielded a number of economically valuable benefits. Because the high build rate RSS is roughly half the length of a conventional RSS, and simpler to support and maintain onsite, the system has eliminated the logistical complexities and delays of shipping replacement tools or parts from elsewhere in China.

The high build rate RSS, combined with custom drill bits in an integrated BHA, can drill in a single run what previously required three to five runs with conventional technology—a 67%-to-80% improvement. These advanced drilling technologies have improved the average ROP in the 8½-in section from 2.65 m/hr in previous wells to 4.65 m/hr—a 75% acceleration. Additionally, the average footage in the 8½-in section has been extended from 236 m/run in previous wells to 503 m/run (Fig. 4)—a full 113% improvement.

Drilling performance enhancements have saved PetroChina substantial rig time and costs. Time-depth curves for the three wells drilled, using the new RSS, indicate a total reduction of 25 days compared with offset wells, saving roughly eight days per well, Fig. 5. In the process, the company has set both field and world records. Achieving an ROP as high as 5.83 m/hr, one well set a new field record. Drilling as much as 620 m in a single run, another well set a new footage record. Finally, drilling at 5,048 m, TVD, one well broke the existing world record for the deepest run using this new technology in the field.

Schlumberger expects to drill additional wells for TOC this year, using the same hybrid RSS and integrated drillbit system. In the past, due to dogleg limitations, TOC drilling engineers planned well trajectories to land in these thin target reservoirs about 450 m from the surface location. With the new tool’s high-build-rate capability, horizontal wells are now being planned to land at least 100 m closer to the surface location. Each well is expected to increase reservoir exposure by roughly 100 m. All of the planned wells should add more than 1,900 m of reservoir exposure to the overall drilling campaign—the equivalent of drilling at least one extra well, without incurring the additional...
risk, time, or cost—using this engineered drilling system to optimize horizontal drilling performance.

**CHALLENGING APPLICATIONS**

Since its introduction in 2011, the high build rate RSS has proven effective at overcoming tough drilling challenges in a number of environments worldwide. In western China, the first application has been for thin, abrasive, ultra-deep oil reservoirs at the outer edges of a complex structure, with high uncertainties and associated risks. Elsewhere, drilling engineers have found applications in deepwater wells with unconsolidated sands, unconventional shale plays seeking maximum reservoir contact, and other fields in which high build rates and reliable directional control are critical to success. China, itself, has substantial unconventional shale resources, which may benefit from the technical capabilities of this advanced geosteering solution in the future.

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