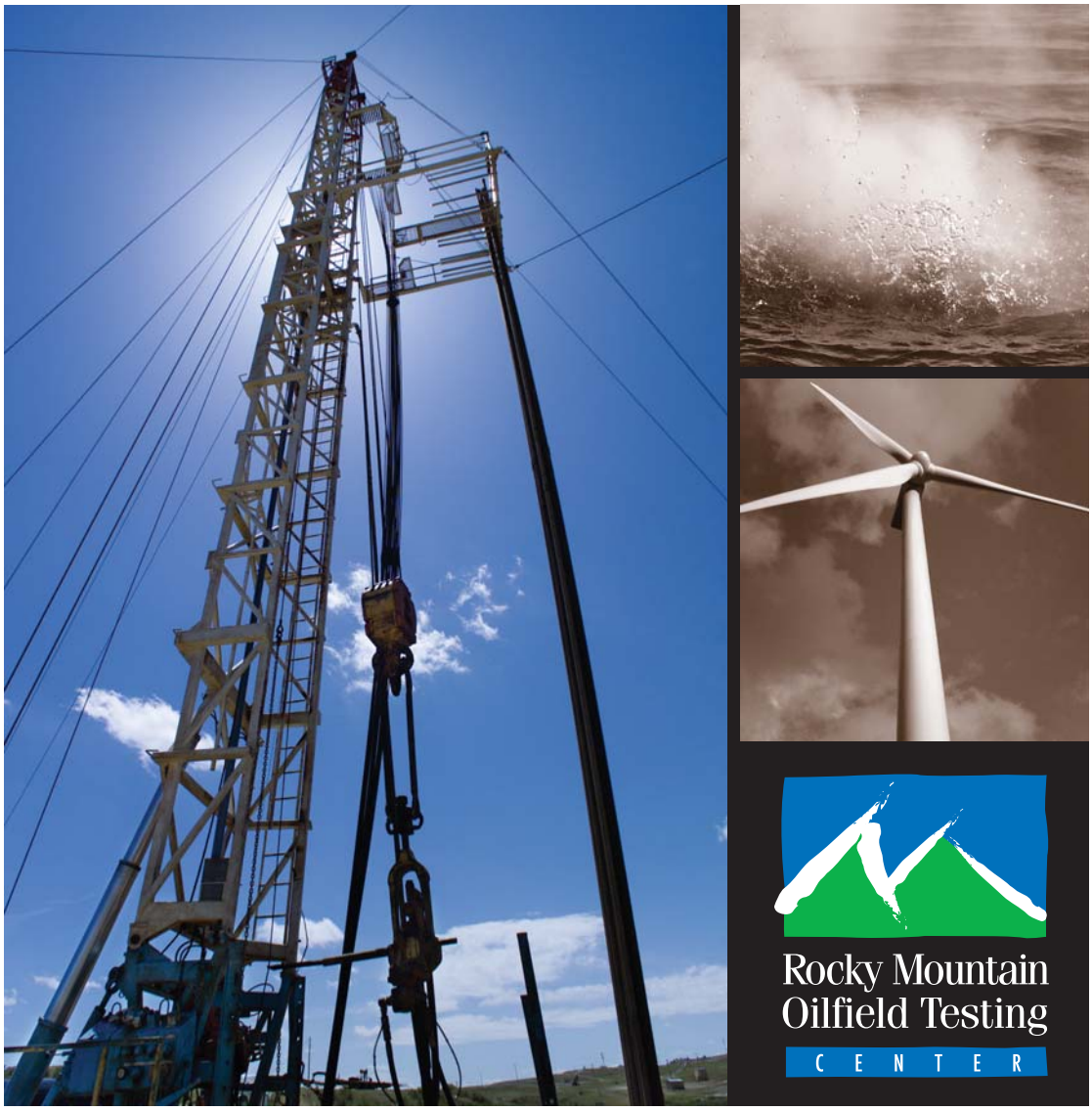

Technology International Inc.: Seismic While Drilling Project

Naval Petroleum Reserve No. 3, Teapot Dome Field, Wyoming

Final Report for the period of June 11-14, 2008
Completed February 2009

U.S. DEPARTMENT OF ENERGY

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Rocky Mountain Oilfield Testing CENTER

U.S. DEPARTMENT OF ENERGY

CRADA 2008-107 (DOE-RMOTC-71053)

Technology International Inc.: Seismic While Drilling Project

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ABSTRACT

Technology International Inc. and the Rocky Mountain Oilfield Testing Center (RMOTC) jointly tested a prototype tool that generated low-frequency seismic sources at the drill bit in a downhole environment. This test was performed in June 2008 and occurred at the RMOTC field site utilizing the RMOTC Rig No. 1, a full-service drilling rig. The prototype tool was deployed downhole on drill pipe and consisted of two high-frequency sparkers that can generate a low-frequency seismic pulse. The sparkers could be set to fire in both an orthogonal (horizontal) or axial direction in relation to the tool position. The sparkers were activated once the mud flow reached a rate of over 300 gpm. Visual inspections of the sparkers revealed that they fired as designed. Two seismic lines were laid out on the surface to detect the seismic pulses generated by the sparkers. Several tests were run at different depths to test the sparkers in both the horizontal and axial modes. The noise generated by the rig made it difficult to detect the seismic pulses at the surface, but post processing of the seismic data revealed that the sources were detected. The mud circulating equipment generated consistent frequencies of 3.3 and 6.6. When the sparkers were fired downhole, the surface seismic recording equipment was able to detect a 5.3 Hz signal that was generated by the 2 Hz seismic pulse modulated by the 3.3 Hz noise of the drill rig.

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INTRODUCTION

Technology International Inc. (TII) of Kingwood, Texas, entered into a Cooperative Research and Development Agreement (CRADA 2008-107) with the Rocky Mountain Oilfield Testing Center (RMOTC) to test a prototype seismic while drilling (SWD) tool. The tool consisted of an 8-inch special drill collar outfitted with a bull head containing special sparkers in the axial and the horizontal positions. The sparker source system was powered by a turbine generator and controlled by a downhole processor. The turbine generator consumed minimal hydraulic energy, allowing the SWD system to run consecutively with all conventional drillstring components without consuming the available downhole hydraulic energy required to achieve optimum drilling rates.

The primary purpose of the project was to field test the SWD tool in a wellbore with real-world conditions to verify tool functionality outside of the laboratory environment in which it was designed and built. The tool was designed to engage the downhole sparkers once the flow of drilling mud reached a rate of 300 gallons per minute (gpm). In order to verify that the tool sparkers were functioning correctly, two 2D seismic lines were laid out on the surface so that the center points of each line were positioned directly above the bottomhole location of the wellbore being used for tool deployment. The two lines crossed each other at an orthogonal angle and were each 0.5 miles in length. The seismic signals generated by the tool were monitored in real time using full-wave digital VectorSeisTM accelerometers and sophisticated seismic recording equipment developed by ION Geophysical.

BACKGROUND

Vibrations caused during drilling activities have been studied for many years to see if they could be used as a viable source for seismic monitoring operations. The monitoring of these vibrations has been termed seismic while drilling (SWD). The information collected from SWD has been useful in a variety of applications including: understanding the nature of the formation being drilled, determining the precise bit position during drilling operations, monitoring bit wear on multi-cone bits, and determining an accurate travel time for seismic waves propagating from the known bit depth to surface recorders, which is useful in pre- and post-processing of seismic data for time to depth data conversion. Drill bit SWD provides the geophysicists and drillers with valuable information to optimize drilling efficiency and to help steer the bit to the planned drilling target with the ability to predict pore pressure ahead of the bit and verify reservoir models in real time. Older generation multi-cone roller bits have proven useful in generating the vibrations necessary for SWD to be possible. Newer polycrystalline diamond compact (PDC) bits, however, have proven to be more difficult. The downhole vibrations generated by PDC bits typically are not sufficient for SWD monitoring.

One of the largest obstacles to overcome in using PDC drill bits for SWD is the ability to generate a seismic source that is of a low enough frequency to transmit through the rock from the depth of the bit to the surface. All possible borehole pulsed sources, including hydraulically driven devices, sparkers, explosives, etc., produce high frequencies. This is counter to the need for long-distance transmission through rock. TII designed a prototype SWD tool that contains high-frequency sparkers that can produce a low frequency source when fired downhole. These sparkers are capable of generating selectable mid-band frequencies in the range of 1 to 20 Hz. This low-frequency source has the potential to provide real-time imaging in deep (15,000 feet or more), high-temperature (150 degrees C), and high-pressure wells.

The sparkers are used to create a gas bubble. This bubble forms when an underwater high-energy spark impulse occurs. The bubble expands outward until the pressure inside the bubble reaches ambient pressure. At this point, the bubble collapses. This process produces two high-energy pressure pulses, one at the initial impulse, and one upon bubble collapse. The initial testing of the sparker acoustic source was performed in a laboratory sample rock environment. These tests were conducted by suspending the electrical spark device in an 8.5-inch hole bored into the center of a 16-inch diameter, by 40-inch long, cylindrical sample of White Sierra

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Figure 1. Laboratory test environment showing cylindrical granite rock chamber used for analyzing the electrical sparker devices.

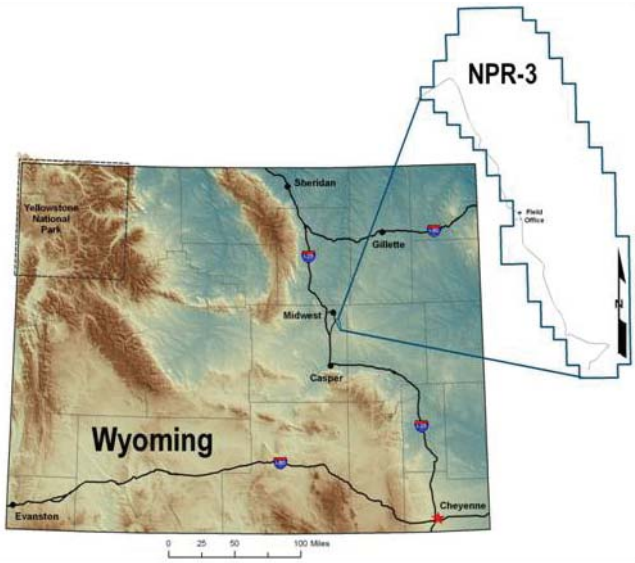

Figure 2. Map showing location of RMOTC field site.

Granite (Figure 1). During the first series of tests, the performances of various high frequency sparker configurations were measured. These tests demonstrated that the sparker energy was in agreement with both a calibrated hydrophone suspended in water and the values measured with vertical and horizontal accelerometers affixed to the outside of the rock cylinder. The initial laboratory tests showed that the sparker performed as theory predicted and the model was validated.

RMOTC TESTING

Technology International Inc. contracted with RMOTC to field test its SWD tool in a downhole environment. This test utilized the RMOTC Drilling Rig No. 1 which was situated at the north end of the Teapot Dome Oilfield within the Naval Petroleum Reserve No. 3 (NPR-3) located in east central Wyoming (Figure 2). The test was planned to immediately follow a scheduled cleanout of the 45-4-X-21 well. This well had been drilled during the previous summer and had been left open since drilling operations suspended in August 2007. Due to bad hole conditions and the need to set a cement plug over the Tensleep interval, the hole needed to be cleaned out to bottom (5,664 feet measured depth). The cleanout began on June 10, 2008, and took longer than expected. On June 12, 2008, the bit had only reached a depth of 4,311 feet. At this point, the drilling operations ceased and the rig was readied for the upcoming Seismic While Drilling test with TII.

Personnel from TII began arriving on site at RMOTC on June 12, 2008. Prior to their arrival, a group from ION Geophysical Corporation and Paragon Geophysical Services began laying out two lines of geophones and the associated recording and processing equipment. The lines were laid out orthogonal to each other with the center point of each line positioned on the surface above the bottomhole location of the 45-4-X-21 well, approximately 500 feet west of the well-head location. Each of the two lines employed 48 receiver stations with 55 feet between each station (Figure 3).

On June 13, 2008, the testing phase of the project began. The tool was raised up on the rig floor (Figure 4) and attached to the 4.5-inch X-H drill pipe using a crossover bit sub. The bottomhole assembly consisted of two joints of 7-inch drill collars and six joints of spiral 6-inch drill collars along with the crossover bit sub. The prototype tool was 26 feet long with an 8-inch outer diameter. The vertical sparker on the SWD tool (Figure 5) was actuated and the toolstring was tripped down the wellbore to a depth just below the casing shoe.

The testing program consisted of a series of individual tests conducted on the downhole seismic pulsing device at different depths in the borehole. For each test, the

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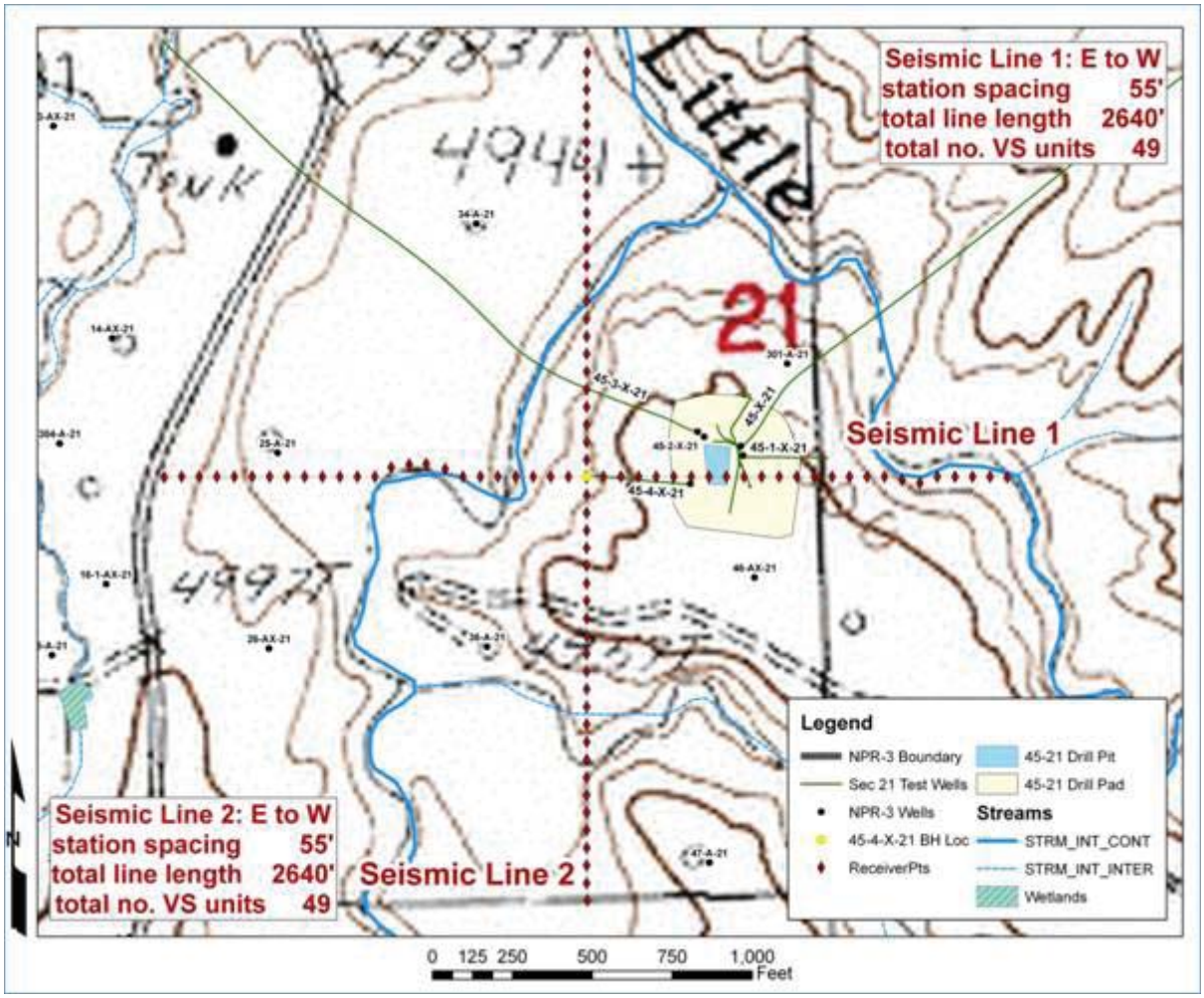

Figure 3. Map showing seismic layout across the 45-21 drill pad.

tool was positioned at a known depth. Once the tool was in position, mud circulation was rapidly increased from approximately 200 gpm up to 350 gpm. The increased flow rates activated the seismic pulser. The test partner used a hand-held radio to inform the seismic crew in the recording trailer when to start and stop acquiring the seismic data generated from the SWD tool. The seismic data was recorded in SEGY format and then reformatted for use in ION proprietary processing software. The seismic field engineers had the ability to view and filter the data for real-time viewing and field processing. Once the data was recorded, the flow rates were dropped back to under 300 gpm and the individual test was completed. The tool was then repositioned to a new depth and the process was repeated.

The first test was run at a depth of 580 feet, just below the casing shoe. The initial analysis of the seismic records did not detect the pulses generated by the downhole tool over the noise generated by the drill rig engine, pumps, generators, and other surface equipment. This allowed for some uncertainty as to whether the tool sparkers had actually fired or not. After not seeing a response on the seismic records, tests were run to verify that the seismic recording data was picking up signals. These tests included banging the kelly pipe attached to the drillstring and also on the conductor casing of the wellhead with a large sledgehammer to see if the recording equipment could pick up the high-frequency ringing. These surface tests were not conclusive due to the fact that the seismic recording equipment was more than 100 feet away from the drill rig and that the high-frequency seismic waves from the hammer did not propagate very far through the

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Figure 4. Prototype SWD tool being lifted onto the drill rig in preparation of being run down the hole.

Figure 5. Base of the prototype SWD tool showing the covered vertical sparker in the center of the tool.

ground before being attenuated.

Despite not knowing if the sparkers were working or not, the decision was made to continue the downhole testing and record the data with the hope that post-processing of the data would be able to detect the pulses. Following testing, the drill pipe was tripped out of the hole and the SWD tool was inspected on the rig floor. A visual inspection of the vertical sparker showed that the pulsing device was working correctly as planned. At this point it was getting late in the day and operations were shut down until the next day.

The next morning, the sparker configuration was changed so that the direction of the seismic pulses was fired in a horizontal direction rather than vertically. Another series of tests were run to record the noise generated by the surface equipment including the mud pumps, the generators, and the rig itself. This data was collected so that the background noise could be post-processed out of the seismic data to the extent possible. One of the preliminary discoveries of the test was that the high-frequency surface noise completely overwhelmed any signal that was generated by the downhole source tool during preliminary seismic acquisition. After this discovery, changes were made to the seismic recording devices and the lower frequency wavebands were amplified in an attempt to filter out the high-frequency noise generated by the surface equipment during acquisition.

The tools were again lowered downhole via drill pipe and were tested at known depths. Once this was done, a small but distinct low-frequency anomaly appeared on the seismic records that appeared to correlate to times that the horizontal component of the downhole tool was actuated. Following the tests, the tools were tripped out of the hole, washed down, and visually inspected. Again it was clear that the horizontal sparker had fired as planned. The tools were laid down and operations were ceased for the project at RMOTC.

DATA ANALYSIS

Following field testing at RMOTC, the recorded seismic data was taken back to ION Geophysical for data processing. After the data was processed it was noted that the rig environment created many sources of background noise. Records for the background noise tests showed that when pumping mud at 350 gpm, two consistent frequency spikes were generated at 3.3 Hz and 6.6 Hz (Figure 6a). The frequency range of the seismic pulsers was programmed to generate a low frequency of 2.0 Hz, since that was below the expected bandwidth range of the background noise. After processing the seismic data, it became apparent that the seismic records showed that no coherent energy was recorded below 3 Hz. This

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6a 6b

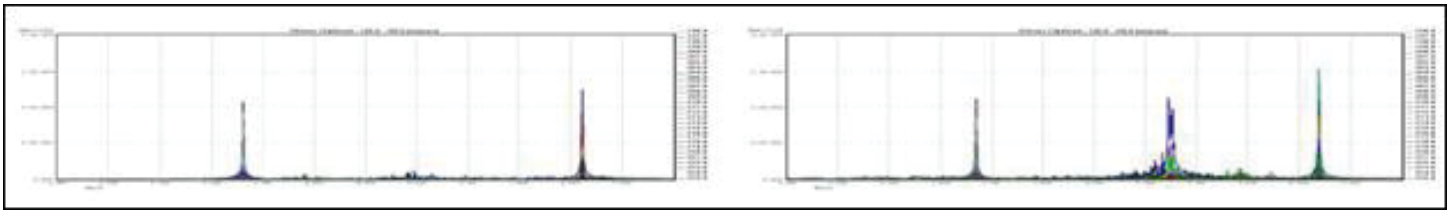

Figure 6. 6a. Noise generated by the mud pumps at a flow rate of 350 gpm created spikes at 3.3 Hz and 6.6 Hz. 6b. A third spike was generated when the sparkers were fired at 5.3 Hz.

was due to the fact that the seismic sensors and recording equipment were designed to dampen all signals below 3 Hz. Therefore it was not possible to see the 2 Hz signal. However, it was discovered that the 2 Hz signal modulated with the 3.3 Hz mud flow signal created a combined signal 5.3 Hz, as shown in Figure 6b.

FUTURE RESEARCH OPPORTUNITIES

The data analysis showed that a higher frequency signal of around 4 Hz is needed for the seismic acquisition equipment to be able to capture the generated seismic source. While the tool is in drilling mode, the energy generated by the low frequency sparker would normally have to compete with all of the coherent noise energy generated at the rig site while the pumps are running and drill string rotating. The capacitors in the SWD tool are capable of storing the high voltage electricity generated by the tool while the mud is flowing. Therefore, the sparkers can be programmed to use the stored energy to generate a 4 Hz seismic signal every 20 seconds with the pumps turned off. This 4 Hz signal, generated without the noise from the pumps, should be distinct and capable of being detected and recorded by the seismic recorders. The data could then be processed and stacked to generate the necessary seismic image of the subsurface.

There may be other useful applications of the TII SWD tool. The additional energy generated by the sparkers may increase the rate of penetration of the drill bit when utilized while in drilling mode. There may also be an application in using this tool as a means of cleaning production wells by repairing formation skin damage resulting from scale and paraffin buildup.

CONCLUSIONS

Technology International, Inc proved that their downhole sparker functioned properly as it was designed when tested in a downhole environment at the Rocky Mountain Oilfield Testing Center. The tool generated the necessary low-frequency seismic source necessary to transmit the seismic energy from deep underground up to the surface in both the vertical and horizontal modes. The Seismic records acquired during testing were able to record the events associated with firing the sparkers. Post processing of the data indicated that although the seismic equipment could not directly record the low-frequency 2 Hz source, it was able to detect an indirect 5.3 Hz signal that coupled with the constant 3.3 Hz signal frequency generated by the mud circulating equipment from the drill rig and the 2.0 Hz signal generated by the sparkers. The data collected during the test has proved to be extremely valuable for TII to continue research and development of drill bit SWD technology. Future testing will be necessary to demonstrate that the technology can be used to increase drill bit penetration rates as well as prove useful for mitigating skin damage in well bores.

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