ACOUSTIC RADIAL PROFILING FOR OPTIMIZATION OF WIRELINE FORMATION TESTER OPERATIONS: CASE STUDIES FROM CLASTIC RESERVOIRS OF INDIA

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ABSTRACT

Clastic formations are the main reservoir rocks in Indian oil and gas fields. Drilling practices and mud invasion may cause extensive near wellbore formation damage, which can alter the near wellbore formation properties and thus affect the efficiency of formation tester measurements.

We showcase two case studies. The first case reveals how the acoustic radial profiling results assisted in assessing the reason behind the dry tests acquired by a wireline formation tester and the loss of rig time; the second case demonstrates how wireline formation testing operations were optimized using the acoustic radial profiling results and thus saving rig time. In this case, the identification of optimal depths for wireline formation tester acquisition was the main challenge. The objective was to optimize the operations of wireline formation tester efficiently by use of the acoustic radial profiling information.

The first case study was in a shallow water exploration well in the Western Offshore basin of India. This well has several potentially hydrocarbon bearing zones. A dynamic tester operation was planned for both sampling and pressure tests based only on standard open-hole logs. Unfortunately, most of the points were unsuccessful. Later, acoustic radial scanning results were analyzed using monopole radial profiling information. It was found that most of the dry test points were at depths with high formation damage. However, the few successful pretest depths were devoid of any damage.

In the second case from an ultra-deepwater well, acoustic radial profiling analysis was used to optimize the wireline formation tester operations by avoiding zones with formation damage, minimizing dry tests and saving rig time.

These two cases proved that acoustic radial profiling results can optimize dynamic tester measurements by avoiding altered/damaged zones; thus, reducing the number of dry tests and saving rig time.

INTRODUCTION

Clastic hydrocarbon reservoirs are predominantly present in the Northern part of Western Offshore basin in Tapti - Daman fields and also in Miocene formations in offshore Krishna- Godavari (KG) basin. The study has been carried out for a shallow water exploratory well from Western offshore basin of India and for a deepwater well in Offshore KG basin.

The purpose of this paper is to showcase an effective methodology to optimize the acquisition of wireline formation tester measurements by avoiding the zones of alteration and damage. This helps in identifying the accurate depths with negligible skin for effective sampling and pressure tests.

Formation damage does not necessarily mean that samples cannot be acquired, but sampling in these zones may have an increased risk of tool plugging or sticking. To minimize these risks, sampling from zones with minimal or no damage should be attempted first *(Valero, 2006).*

METHODOLOGY

Principle

Acoustic radial profiling is based on the velocity differences at various receiver station points in the new generation borehole acoustic tool, which has multiple monopole transmitters. One monopole transmitter is located at the bottom part of the tool and far away from the receiver section, which is called as monopole far transmitter. However, there are two other monopole transmitters located near the receiver section, named as monopole lower and monopole upper. Apart from these monopole transmitters, there are two dipole transmitters namely XD and YD which generate flexural waves in two orthogonal directions in order to measure formation shear slowness (fig. 1).

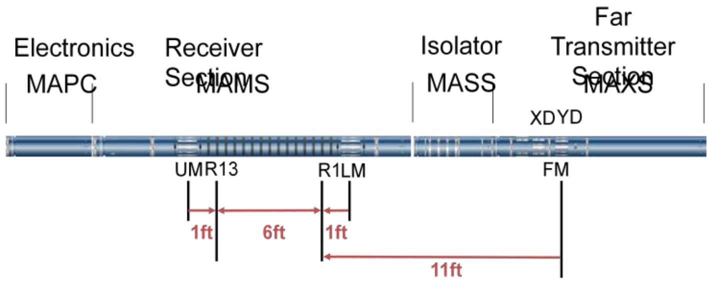

Fig 1. New generation Sonic tool configuration (Copyright © Schlumberger; *Courtesy: Schlumberger Oilfield Review, 2006)*

Monopole Radial Profiling

Monopole radial profiling is based on the arrival time detection of compressional waves at different receiver stations of the borehole acoustic tool. Radial penetration of the acoustic waves depends on the distance between transmitter and receiver spacing. This reflects that compressional wave arrivals recorded at the first receiver position (nearest to lower and far transmitters) characterize the velocity of the formation near the wellbore, whereas the waves received at the top most receiver characterize the velocity of the deeper and undisturbed zone of the formation (fig. 2).

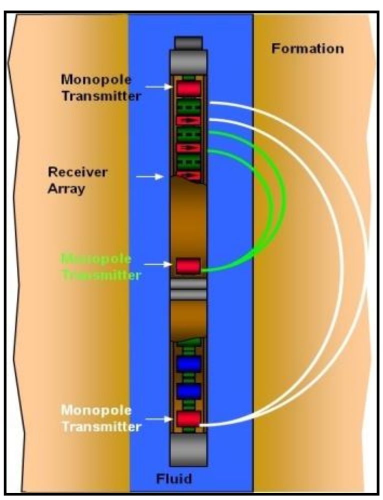

Fig 2. New generation sonic tool T-R spacing (Copyright © Schlumberger; *Courtesy: Schlumberger Oilfield Review, 2006)*

In addition to this obvious advantage of multiple monopole transmitters in the new generation sonic tool, radial profiling could be achieved by a robust and automatic inversion scheme that provides a two dimensional image of the formation compressional slowness. This inversion scheme is based on ray tracing method that estimates a 2D (axial and radial) image of the formation compressional slowness. The inversion scheme translates the estimated transit time to the slowness variation around the wellbore (fig. 3). The method inverts for a varying profile when the slowness decreases monotonically with radial distance in the formation *(Valero, 2006).*

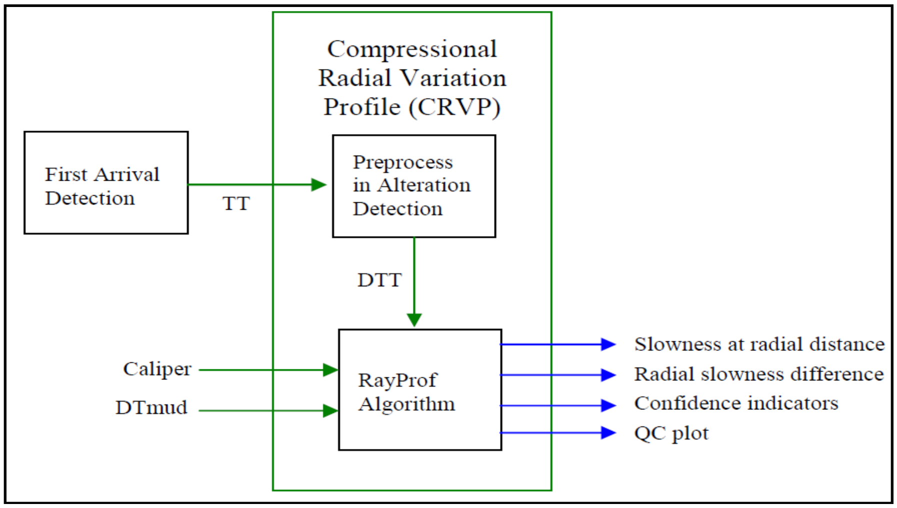

Fig 3. Compressional Radial Profiling schema

The variation in compressional slowness of the formation radially away from the wellbore is used for generating the monopole acoustic radial profiling. This result can provide critical information about the presence and severity of the formation alteration, which can be used effectively to optimize the wireline formation tester operations (fig. 4).

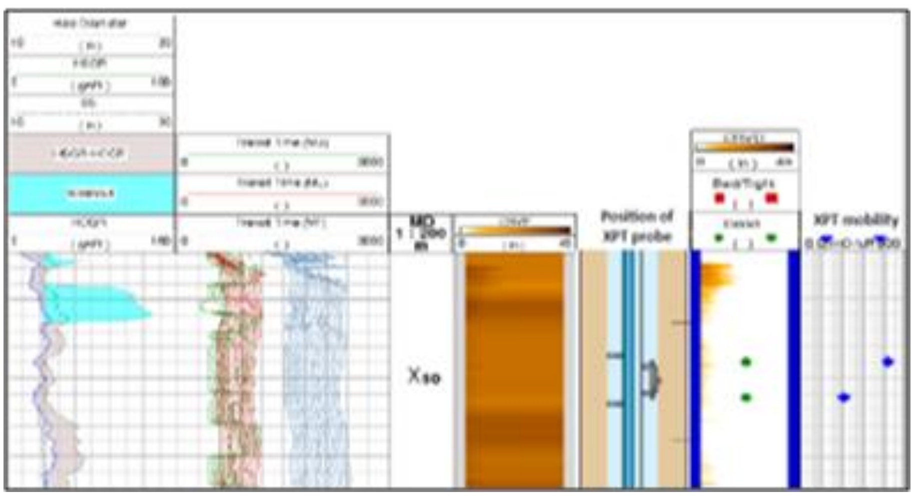

Fig 4. Optimization principle of formation tester measurements using acoustic radial profiling

Dipole Radial Profiling

The shear velocity responds to the solid framework of the rock and is almost insensitive to fluid effects. From the rock mechanics perspective, it is very helpful to evaluate the shear velocity in both the far field, as well as, the near wellbore to determine changes caused by drilling induced stresses (fig. 5).

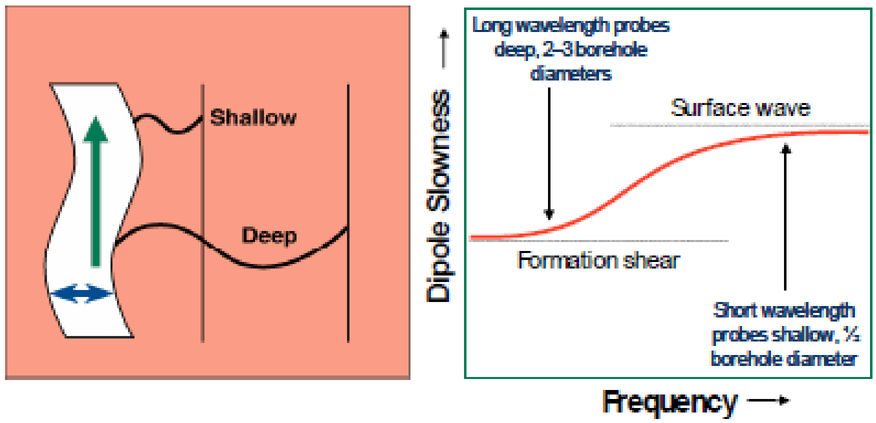

Fig 5. Dipole radial profiling principle ***(Jiang et al., 2008)***

Dipole radial profiling is based on the computation of difference between the dispersion curve extracted from the dipole data and the dispersion curve corresponding to an isotropic and homogeneous medium. This difference and its variation versus frequency is then inverted into a slowness response versus depth into the formation *(Jiang ,2008).*

Basics of Wireline Formation Testing (WFT)

One of the most important applications of Wireline Formation Tester tools is to perform "pretest" measurements in order to measure formation pressure and mobility. During a pretest the formation pressure is measured at a given depth by a WFT designed to make contact with the formation by placing a pressure transducer in contact with it. A probe connects to a pressure transducer, which is part of the tool, is surrounded by a packer. The mud cake around the localized area is usually cleaned. The formation is thus exposed to a chamber which is common with the pressure transducer, and this chamber is manipulated by the tool to cause the pressure in the space to decrease (Fig.4) to a pressure well below that of the formation to be tested (this phase is called the drawdown). This reduced pressure further cleans the mud cake from the isolated portion of the borehole wall. After the chamber is filled with formation fluid during the applied drawdown, then the pressure rises during the buildup phase. At equilibrium the pressure transducer connected to the chamber indicates the formation pressure. This procedure is repeated at different depths within the formation to acquire the reservoir pressure survey.
However, the dynamics of the drawdown and particularly the buildup pressure responses reflect the formation permeability in the vicinity of the wellbore. During the pretest, the formation fluid is withdrawn through the WFT probe into the pretest chambers. This generates a localized flow in the formation whose pattern is essentially spherical in character. Hence, the analysis of the dynamic pressure response of the pretest is based on the theory of spherical flow of a slightly compressible fluid in a homogeneous medium. This drawdown pressure depends on the effective permeability of the formation to the flowing fluid which is usually mud filtrate from the invaded zone. The time required for build-up is essentially a function of the formation permeability of the uninvaded formation to the mobile phase of the formation fluid. Thus, formation permeability from the pretest can be obtained from analysis of both the drawdown and the buildup periods.

Drawdown Mobility Equation:

As a consequence of the spherical nature of the fluid flow, which implies that most of the fluid movement takes place in a small volume immediately surrounding the probe, steady-state conditions are usually obtained very quickly during the drawdown period and the mobility (ratio of permeability, K to viscosity, μ) is given as follows:

$$\frac{K}{\mu} = \mathrm{Pr}obeConst.\frac{q}{\Delta p}$$

Drawdown mobility is also calculated by the following expression, which uses the area enclosed by the pressure-time curve during the drawdown and pretest sequence and the total volume (V) drawn during the drawdown period.

$$\frac{K}{\mu} \approx \Omega_S \frac{V}{4r_p} \frac{1}{\int_0^{t_\delta} \Delta p(\tau) d\tau}$$

where, Δp is the pressure drop, rp is the probe radius, ΩS is a constant, τ is pretest time and q is the flow rate *(Ghosh et al., 2009).*

Workflow

The schematic shown in fig. 6 explains the procedure adopted in our study of the sonic waveform analysis for evaluation of compressional and shear radial profiling. Monopole and Dipole waveforms were acquired using a new generation acoustic tool (*Valero et al., 2006*), which has three monopole and two dipole transmitters. The sonic data processing involved extraction of compressional and shear slowness values and their radial variation away from the borehole, thus providing a radial slowness/ velocity profile. This information was utilized for optimum planning and depth selection for formation tester measurements. Monopole radial profiling was carried out using a RayProf algorithm; Backus-Gilbert (B-G) inversion technique was used for dipole radial profiling evaluation.

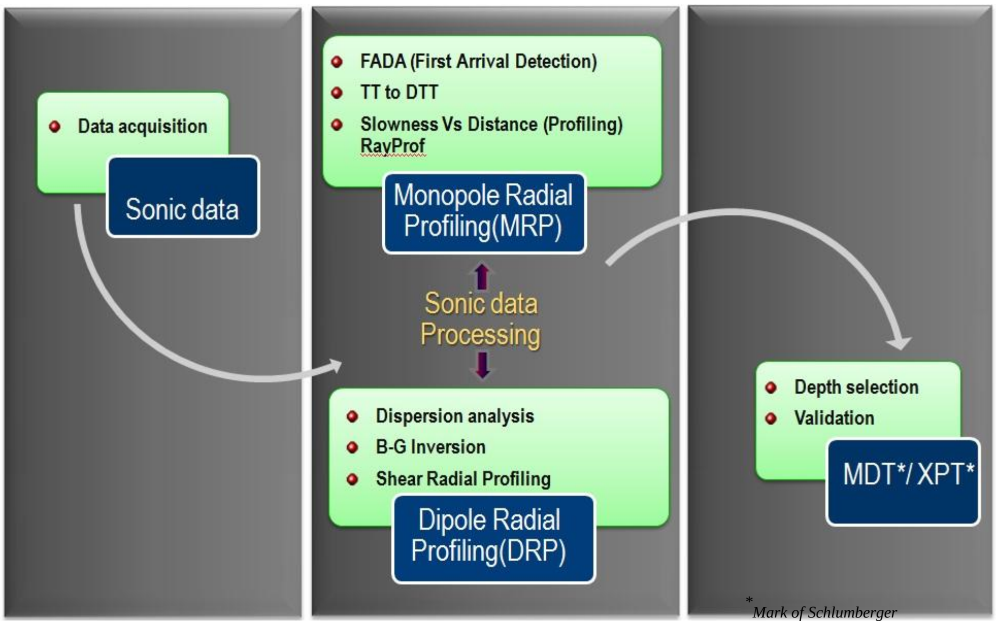

Fig 6. Workflow of the present study

RESULTS

Case A:

The first case study (case A) is from a shallow-water exploratory well drilled in the Daman area of Western Offshore Basin, India. The well was drilled with oil-based mud and through a clastic sequence with varied lithologies like Siltstone, Sandstone and Shale. Wireline formation tester pre-test points were selected based on basic open-hole log responses (gamma-ray, resistivity, neutron and density log signatures). Most of the pretest points were dry and inconclusive. Monopole and Dipole acoustic radial profiling evaluation was carried out; it was found that most of the unsuccessful pretest points were against zones with higher formation damage/alteration, as shown in fig. 7.

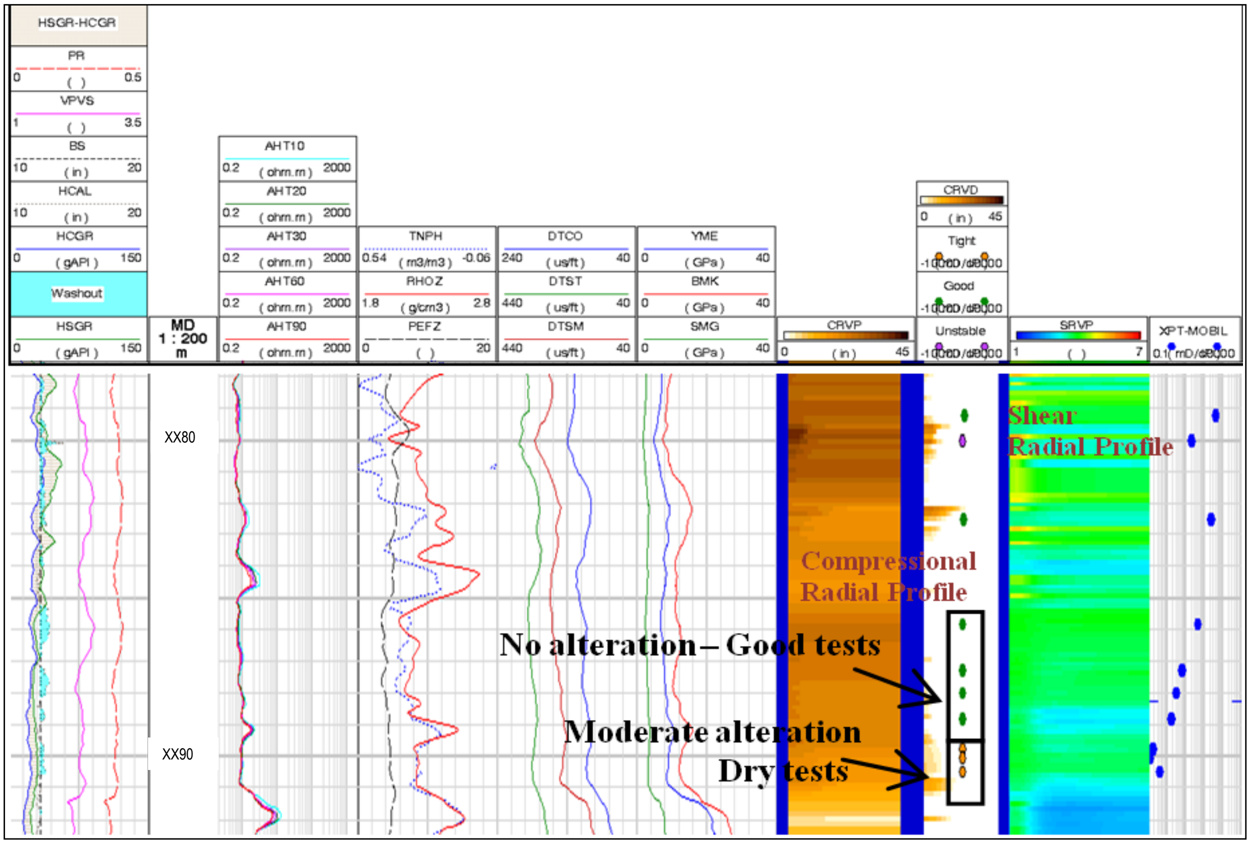

Fig 7. Integrated results of Monopole and Dipole radial profiling evaluation showing zones of formation alteration and formation tester measurement points.

Case B:

The second case (case B) showcases how the acoustic radial profiling helped in optimizing the wireline formation tester measurements. The well was drilled through Miocene clastic sequences in ultra-deepwater setup. This well was also drilled using oil-based mud. Wireline pre-test depth points were selected based on acoustic radial profile information by avoiding altered and damaged zones. The success rate of good pretest measurements could be significantly improved, as shown in fig. 8.

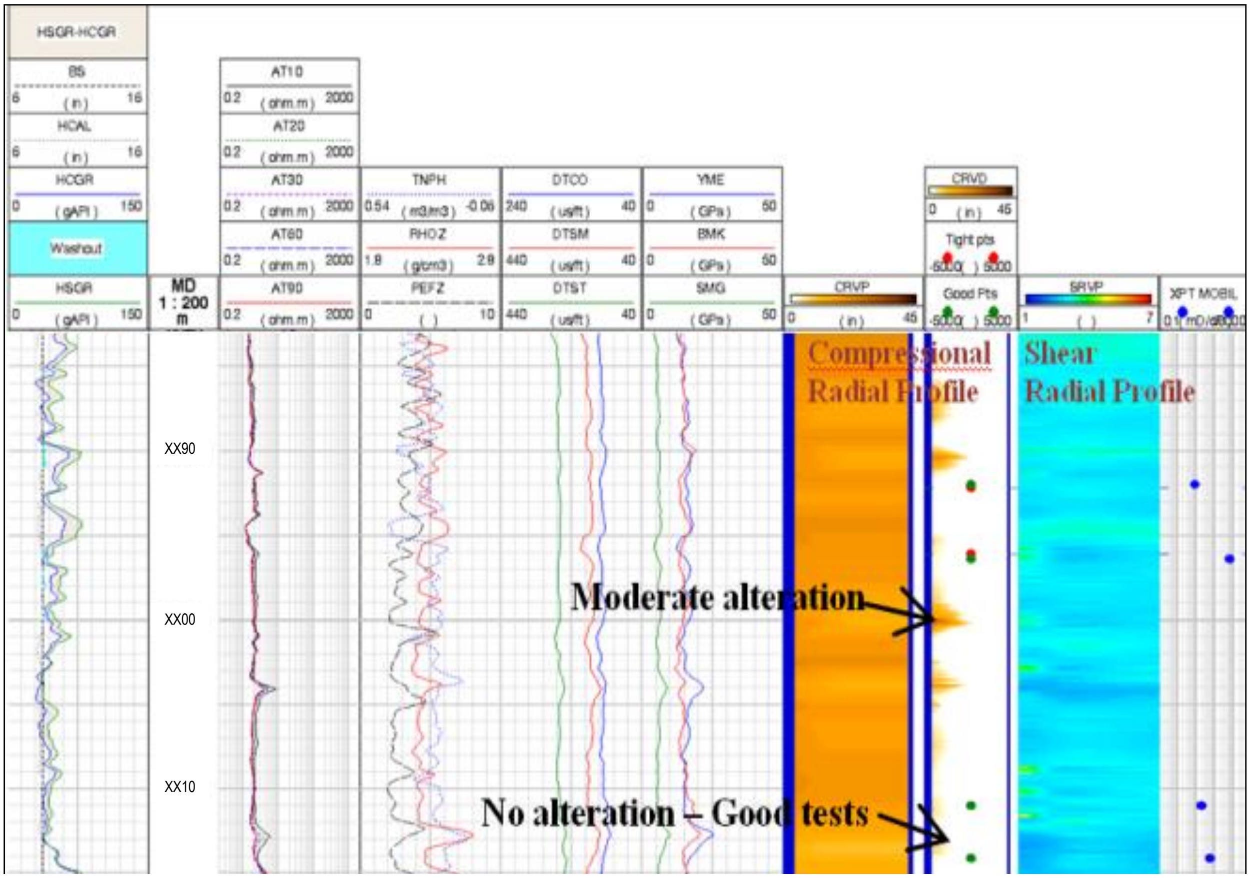

Fig 8. Integrated results of Monopole and Dipole radial profiling showing zones of formation alteration and formation tester measurements (Good tests) against zones of no alteration/ damage.

DISCUSSION AND CONCLUSIONS

The usefulness of acoustic radial profiling has been proved through two case studies in the present paper. In the first well, wireline formation tester acquisition points were selected based on standard open-hole logs only. In this case study, most of the wireline formation tester measurements were not successful, either due to lost seal or tight. Acoustic radial profiling results proved that against those unsuccessful points, there was near wellbore formation damage as indicated by the difference in near and far field wellbore slowness. The pretest depths which had no changes in shear slowness away from the wellbore were successful. However, intervals with near well-bore softening probably caused by mechanical or mobility damage are prone to seal failures or might lead to a tight pre-test point. In the second well drilled in ultra deepwater, acoustic radial profiling was carried out prior to the wireline formation tester acquisition, and based on the radial profiling results, optimal depths were selected for pre-test and sampling operations. Acquisition was successful with desired data and thus saving rig time.

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