TAKING SAMPLES THROUGH CASING

ABC® Analysis Behind Casing services make formation evaluation behind casing a viable option. Applications range from assessing bypassed hydrocarbon zones and evaluating flood efficiency to time-lapse monitoring. ABC services are particularly useful in wells where openhole logs cannot be run owing to difficult formation and well conditions or to operational problems. Innovative cased hole tools provide measurements for determining porosity, resistivity, lithology, shale content, and fluid saturations along the wellbore; and obtain formation pressure data and fluid samples.

The CHDT® Cased Hole Dynamics Tester tool, which is part of the ABC suite, can drill a hole through casing and into the formation to test a zone. It then plugs the hole and enables engineers to isolate the formation from the wellbore after testing. This sealing capability means operators can resume production without costly casing or cement repairs.

In this article, Bao Wei, Sherif Farag,Sameer Joshi, Wang Helin, and Yang Yong examine various techniques for cased hole analysis and their value for well and field management.
Conventional testing and sampling through casing are performed either by well or surface testing via perforated intervals or by perforating the casing to test a zone isolated between two rubber packing elements, usually before setting the production tubing. The latter method then requires a cement squeeze to restore the casing integrity. This article focuses on a new system that can drill up to six precise sampling tunnels through casing on each downhole logging trip, acquire multiple formation pressures, take representative formation-fluid samples, and restore casing pressure integrity by plugging the drilled holes.

Borehole casings and cement have important oilfield functions such as keeping the drilled hole secure and stable and preventing the crossflow of fluids between different zones. However, once the casing is in place, it prevents further access to any part of the rock sequence other than the perforated zones. Consequently, operating companies often have to perform any necessary logging and testing before the hole is cased. Tools such as the MDT® Modular Formation Dynamics Tester can be run in open hole to measure pressures, take samples, and conduct pressure-transient tests at intervals before the hole is cased. However, sometimes drilling challenges, wellbore stability issues, and even weather conditions may result in cancelled or suboptimal openhole testing programs.

There are several reasons why engineers may wish to access a formation once a hole has been cased. For example, during the initial drilling of a well some thinner pay zones might have been disregarded for formation evaluation because the main objective was to reach a larger oil or gas accumulation at a greater depth. At the time of drilling, those thin zones might have been classified as uneconomic or have been unrecognized. Sometimes, new surveys within an existing oil or gas field can reveal a greater potential for exploitation. Samples taken from behind the casings of existing wells may then help engineers to evaluate the pressures and fluid contents of formations to identify bypassed hydrocarbons and thus decide where best to drill new wells.

**Behind the casing**

There are several tools for gathering information about the state of a formation behind the casing. These include the CHDT® Cased Hole Formation Resitivity tool, the DSI® Dipole Shear Sonic Imager, the RST® Reservoir Saturation Tool, and the CHFP® Cased Hole Formation Density tool. While each of these technologies can help engineers to assess what is behind the metal casing, they all rely on remote sensing and can only measure the static properties of the formation through casing. None offers direct measurement of formation pressure or sampling of formation fluids.

Until recently, the only way to recover samples from behind casing required a shaped explosive charge to blast a hole through the casing and the cement to reach the formation. The RFT® Repeat Formation Tester, which was introduced during the 1980s, can make two perforation shots on each trip and can fill two fluid sample chambers, but it then has to be brought back to the surface for the perforated holes in the casing to be repaired.

Unfortunately, the tool has several limitations. The diameter of the hole and the depth of penetration cannot be predicted, so the resulting measurements can be difficult to interpret. The explosion can damage the seal between the tool and the casing and make pressure testing and sampling impossible. The cement and the formation may be damaged, and the resulting irregularity on the inside of the casing can impede other operations in the well. To repair the holes, the RFT tool must be pulled out and the casing maded good by squeezing cement into the perforated section.

**A new tool**

The limitations of the RFT tool led to the development of the CHDT tool, a behind-casing pressure and sampling tool. The tool was built at the Schlumberger Houston Product Center in association with the Gas Technology Institute, Des Plaines, USA. The CHDT tool can drill through casing and cement, conduct pretests to measure pressures and mobilities in the formation; take representative fluid samples; and use a range of analytical techniques to measure fluid properties in real time (Fig. 1). It then plugs the hole and can be moved into drill and test up to five more holes in the same logging run.

In its simplest configuration, the CHDT tool consists of a stack of three modules about 9-m long and 4” in diameter. The probe module at the bottom contains the drilling and plugging assemblies and the pressure gauges. The drill control module is in the middle and the power cartridge module is at the top. An optional sample container module may be included. This configuration brings the total length of the tool to around 12 m. In this form, the toolstring is suitable for casings of 5½" to 9½” in diameter, but extendable to 13½” in casing.

In hole sizes equal to or greater than 7 in, the CHDT tool is fully combinable with all the modules of the MDT tool (these were previously deployable only in open hole). These include the downhole pump and the OFA® Optical Fluid Analyzer. All the modules are connected by a common flowline, which enables samples of formation fluid to pass between them on their way from the formation to the sample chambers. The CHDT tool is lowered to the point of interest in the well, where it is held in place by two anchor shoes that extend from the probe module and press against the casing.

A circular gasket or packer around the drilling probe makes a pressure seal between the probe and the casing. Once a good seal between the packer and the casing has been confirmed, a flexible drill shaft cuts through the casing and the cement and into the formation behind them.

The drill bit has a diameter of 0.28 in and can extend laterally up to 15 cm from the inner wall of the casing. From time to time during drilling, debris from the hole is pulled back into the tool in bit-cleaning cycles to keep the drilling tunnel clean and avoid bit sticking. A pressure pretest may be performed at any point to test the seals or to determine the mobility of the formation through the drilled hole.

When the probe has made contact with the formation, the engineers can perform a variety of tests. The formation pressure can be measured, fluid mobility can be determined, and fluid samples taken and analyzed in real time or stored in a sample container for examination at surface.

**Tests and pretests**

Until recently, testing the fluid content of formations behind casing could be a slow and complicated process. The most difficult challenges included making a secure seal against the formation for pressure testing and extracting representative formation fluids. One of the CHDT tool’s most useful features is the pretest function. The probe module contains a pretest chamber that may, at any time, be used to produce a measured volume of up to 100 cm³ of fluid from the formation into the tool. This pretest chamber consists of a piston that can be retracted inside a cylinder, like a medical syringe.

**The CHDT tool can drill through casing and cement; conduct pretests; take representative fluid samples; and use a range of analytical techniques. It then plugs the hole and can be moved on to drill and test up to five more holes in the same logging run.**
If the tool is properly sealed against the casing, retracting the pretest piston by a small amount before drilling will reduce the pressure sharply, because there should be no fluid flow into the cylinder. This pressure should then remain almost constant or rise very slowly if there is a good seal. Such tests are used to check the integrity of the seal between the probe and the casing wall; the condition of the cement outside the casing; and the seal integrity of the plug when the drilled hole is plugged at the end of the operation.

When the probe is in contact with the formation, a pretest can be used to measure the dynamic properties of the rock-fluid system. The pressure-time curve reveals vital information about the flow properties of the formation. The drilling process can have additional advantages because the tunnel created bypasses the damaged zone near the wellbore and connects the tool to the virgin formation. A typical pressure pretest is shown in Fig. 2.

Sampling for retrieval or real-time analysis

Once the probe has made contact with the formation and the pretests are complete, engineers can start to collect samples. A pump produces fluid from the formation through the probe module and passes it through a variety of fluid analyzers and, if desired, into the sample-unit module where it can be stored in 1-galUS containers, which are supplied as standard with the CHDT tool. If the MDT multisample module is attached, then the samples can be collected in six 450-cm³ PVT bottles or six 250-cm³ single-phase bottles. Larger sample chambers can also be used (up to 6 galUS) if required.

However, the CHDT tool can also test samples in situ and report the results in real time. For example, if the LFA* Live Fluid Analyzer for MDT tool is included in the toolstring, the formation fluid can be passed through a gas detector and a 10-channel optical spectrometer that distinguishes between water, oil, and gas. The LFA tool is used to assess sample contamination in real time and can also provide the gas/oil ratio (GOR) of the single-phase formation fluid. It is usually necessary to optimize the pump rate to ensure that the fluid is representative of the formation rather than the area immediately outside the casing and behind the cement, which is typically contaminated with drilling fluids.

Using the LFA module, engineers can analyze and gather fluid data while the tool is set across several zones along the wellbore. The CFA* Composition Fluid Analyzer gives the formation fluid composition in terms of methane, C2-C5 compounds, and C6+ compounds as the fluids are pumped. Its fluorescence detector helps to identify retrograde condensate gases in real time by detecting dew precipitation in the gas phase. The CHDT tool is pretested while still in cement. Once the pretests are complete, engineers can start to collect samples. A pump produces fluid from the formation through the probe module and passes it through a variety of fluid analyzers and, if desired, into the sample-unit module where it can be stored in 1-galUS containers, which are supplied as standard with the CHDT tool. If the MDT multisample module is attached, then the samples can be collected in six 450-cm³ PVT bottles or six 250-cm³ single-phase bottles. Larger sample chambers can also be used (up to 6 galUS) if required.

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Plugging the gap

Once testing and sampling operations are complete, the CHDT tool inserts a corrosion-resistant Monel® alloy plug into the drilled hole. The plug can withstand differential pressures between wellbore and formation of up to 70 MPa (in both directions), and it protrudes no more than 0.8 mm from the inner casing wall. After plugging, a final pressure test ensures that the plug makes a secure seal before the tool is unset and the probe is moved to the next drilling position.

A risk assessment is normally performed at the planning stage to determine the most appropriate remedy if the plugging should fail. The hole can be sealed by a conventional cement squeeze operation once the CHDT tool has been withdrawn, but some operators prefer to leave any hole open.

Fluid analysis in Indonesia

Sembalung field is in the Tarakan basin in the northeast of Kalimantan, Indonesia [Fig. 3]. Production from the field started in 1977; peak oil output was 1,900 m³/d. The field is in a geologically complex setting with more than 30 different sand units of variable thicknesses. Most of the oil production comes from zones 24D to 28 in the upper-middle Miocene Tabul formation.

Equatorial Energy acquired the asset in 1998. The company later redeveloped the field and identified a previously unrecognized southward extension with untapped reservoirs.

The field has recently been acquired by PT Medco Energi Internasional. Between November 2002 and June 2003, engineers used the CHDT tool in 7 existing wells to drill 71 test holes and then to determine the fluid mobilities and perform fluid analyses. The test on one of the seven holes bored in Well SBK-41 is a typical example (Fig. 4). For this hole, the pressure was measured in the probe module over the course of about 40 min. The tool was lowered to the drilling position at a depth of 1,179 m, and the hydrostatic pressure in the well was measured as 10.3 MPa. Anchor shoes then pushed the probe module against the inner wall of the casing to make a seal. The first pretest drew a small volume of fluid and the pressure dropped. The pressure was then monitored to check the seal between the probe and casing. Drilling then cut through the casing and into the cement.

Once the hole reached the cement, drilling was halted for another pretest. The gradual rise in pressure indicated that the cement was in good condition. As the drill passed through the cement and into the formation, the pressure rose rapidly and then stabilized at around 8.4 MPa, which was the formation pressure. A third pretest then measured the mobility of the formation fluid. In this example, 21.5 cm³ of fluid was produced, and the pressure gradually rose again as fluid from the formation flowed into the probe. A mobility of 122.1 mD·cm/s was calculated from these test results.

When pumping the fluid from the formation into the wellbore began, the pressure dropped and stabilized while flow continued for about 15 min. The formation fluid passed.
through the probe module and into the LFA module. A typical LFA log from this phase for an oil-bearing formation is shown in Fig. 5. A similar log for a formation containing gas is shown in Fig. 6. In the test described, it was decided not to plug the drilled hole, so the seal was broken and the pressure returned to the hydrostatic pressure in the well.

The complex geology of the Sembakung field has resulted in commingled production from multiple zones in most wells. Before the CHDT survey, faulting and lithological variations across the field made it impossible for engineers to predict whether a layer that was depleted in one well was necessarily depleted elsewhere. The 71 zones tested in 7 wells helped the production team to map the complex interconnectivity of the oil-producing zones and led to an improved understanding of pressure depletion across the field. The tests also helped in mapping oil and gas accumulations and bypassed zones and provided useful information for planning future production wells for the field.

Six of the seven wells tested were found to be oil bearing in the zones investigated and are now in production. The seventh well, Well SBK-39, was known to be structurally higher than the others. It was suspected that the formations that acted as reservoirs elsewhere in the field might be above the gas/oil contact in this well. The CHDT tool confirmed that the formations were gas bearing, and Well SBK-39 has since been shut in.

A survey to characterize the many distinct formations in Sembakung field would have been extremely challenging using conventional techniques. The CHDT tool’s ability to sample up to six drill holes on each trip and to measure pressures and mobilities, and identify fluids in real time helped to make the work feasible.

**Rapid testing operation guides well-completion strategy**

Discovered in 1937, the Gunung Kemala oil field is in South Sumatra, Indonesia (Fig. 7). Pertamina currently operates the field, and most of the production comes from wells that are less than 2,000-m deep. In 2002, Pertamina drilled a new,
deeper well, Well GNK-X1, and conducted drillstem tests (DST) at depths of between 2,400 and 2,440 m. These tests revealed potential oil and gas zones.

Two more wells were drilled to establish the extent of the field—Well GNK-X4 reached a depth of 3,450 m in October 2003 and Well GNK-X3 was drilled to 2,802 m in December 2003. Both these deeper wells yielded many possible pay zones, far too many to be explored by DSTs. Consequently, Pertamina deployed the CHDT tool to study three promising zones in each well. The tool was used to measure formation pressures and to take hydrogenation samples.

The tests were carried out in April 2004 after the holes had been cased. An extended pressure buildup test followed the pumpout period that was conducted at each sampling point in these wells. This test enabled fluid mobility and formation permeability to be computed. The hole was then plugged and a successful pressure test was then conducted (Fig. 8). This pressure test was similar to that shown in Fig. 4, though it was performed over a much longer period.

A sample LFA log, recorded at a depth of 1,890 m in Well GNK-X3, is shown in Fig. 9. The pumped fluid is seen to be a mixture of oil and water. Well GNK-X3 was sampled at three points. The uppermost point produced oil and water at a pressure of 15 MPa and a permeability of 720 mD. The lowest point produced water and volatile oil or condensate at 29 MPa with a permeability of 8 mD. The hole at an intermediate depth produced only water. The large differences in pressure and permeability between the two producing zones led Pertamina to develop a dual-completion approach for this well.

A similar sequence was carried out using the CHDT tool on Well GNK-X4; gas condensate and water were discovered in the uppermost formation and gas in the two lower zones. Pertamina carried out a surface pressure buildup test on the top zone at a later date; this lasted more than 40 h without attaining stabilized flow. However, a downhole pressure buildup test on the well using the CHDT tool was completed in a few hours to provide fluid and permeability information.

Pertamina has used the results from the CHDT tests to develop its well completion strategies for the Gunung Kemala field. In the Sembakung and Gunung Kemala fields, CHDT campaigns were able to gather data faster than traditional methods.

Pertamina was able to test each zone in 3 to 4 h with the CHDT tool, although a CHDT tool cannot perform all the functions of a full-scale DST. For example, the CHDT tool cannot achieve flow rates similar to those used in production tests and the recovered samples may be smaller than those acquired from a DST. However, by testing several points in a thick section, fluid complexities may be revealed vertically; DSTs can reveal much deeper lateral complexities.

Figure 7: Gunung Kemala field in South Sumatra.

Figure 8: Pressure test in Gunung Kemala field on Well GNK-X3. The seal pressure test was followed by a rise in pressure as the drill entered the formation. The position of the drill is shown by the black trace. The drill was withdrawn three times for pressure tests. The pumpout cycles were paused while two PVT fluid samples were taken for later analysis.
Open and shut casing

The CHDF tool provides information for optimizing recompletion plans, planning for enhanced oil or incomplete log data, assessing secondary pay zones, and evaluating the economic potential of older wells. The ability to restore the pressure integrity of the casing after a drilling and sampling operation is a major step forward for testing technology. This will be invaluable to operators throughout the Middle East and Asia as they seek to optimize well and reservoir performance and to eliminate the costs associated with traditional through-casing operations.

Analysis behind casing

The ability to measure formation resistivity behind casing has been a major goal for the oil industry since the 1930s. The measurement theory was developed at almost the same time as the first openhole resistivity tools, and it may have seemed relatively easy to develop a suitable measurement tool. In practice, however, the very small magnitude of the currents involved prevented engineers from completing this task for more than 60 years.

Today, ABC services help operators to perform state-of-the-art formation-evaluation measurement, particularly in older wells. They also offer a way to acquire high-quality data in wells where the openhole logging conditions were difficult. The results from cased hole logs can be directly compared with the openhole equivalents so that field operators can conduct reliable and cost-effective time-lapse analyses of their reservoir formations. The ability to run an advanced logging suite in a cased hole also helps to reduce the risks associated with the acquisition of oilfield assets.

Today, reservoir properties such as resistivity, bulk density, and formation pressure are being measured behind casing. The latest formation-evaluation technologies provide cost-effective data and information for:

- finding bypassed or additional pay in older wells
- monitoring saturation, depletion, and reservoir pressure
- avoiding openhole logging in development wells
- managing wells with high-drilling risks by logging after setting casing
- gathering additional information to complement openhole and while-drilling logs.

ABC data acquisition techniques can be applied in wells of any age to improve reserves estimates and productivity. The advanced technologies available to analyze formations behind steel casing include formation resistivity measurements that can calculate the saturation more than 3 m from the wellbore—a significant improvement over the 23-cm range typical with the standard pulsed-neutron approach.

Formation evaluation behind casing

Effective formation evaluation behind casing depends on a range of factors, including a clear understanding of the condition of the casing and the cement in the well. In most situations, a cement-evaluation log will reveal any anomalies in the cement sheath that might affect the performance of through-casing formation-evaluation tools. The most effective cement evaluation will draw on data from two tools: the USI* UltraSonic Imager and the CBT* Cement Bond Tool. Both wellbore diameter and completion configuration influence the selection of logging tools.

Expert log interpreters can incorporate completion details such as wellbore geometry, tubulars, inclination angle, and well-log data into production estimates and recommendations for perforation or stimulation treatments. These recommendations rely on a detailed understanding of formation properties such as porosity, lithology, and fluid saturation. Such data are derived from density, gamma ray, neutron, resistivity, sonic, and spectroscopy logs. Engineers can also use fluid-mobility data from cased hole testers to complement petrophysical analyses.

ABC services offer a range of applications; for example, engineers can use the CHFR tool, which applies innovative technologies for deep-reading resistivity measurements beyond steel casing, to evaluate saturation. This tool and the CHFR-Plus* Cased Hole Formation Resistivity tools operate in similar ways by introducing a current into the casing. A voltage drop occurs as a small amount of the current escapes into the formation. The voltage drop is proportional to the formation conductivity and enables calculation of formation resistivity.

Since its introduction in 2000, the CHFR tool has been applied around the world for evaluation of bypassed pay, reevaluation of old fields, reservoir and saturation monitoring, and primary evaluation of wellbores that were cased before formation evaluation was complete. The CHFR-Plus tool, which was introduced in 2002, offers similar measurement capabilities, but at twice the speed of the CHFR tool through a new measurement technique. Cased hole resistivity tools operate at speeds up to 61 m/h and provide resistivity measurements deeper into the formation than their openhole equivalents (Fig. 10).

Saturation and porosity determination in cased wells

Carbon/oxygen (C/O) logging can be used to determine saturation in cased wells and can provide data for reservoirs that contain fresh water and those containing waters of unknown salinity; for example, in zones where there is ongoing water injection and the salinity of the injected water differs from that of the original water in place. Repeated saturation measurements made using the CHFR tool and the RSTPro* Reservoir Saturation Tool are key elements of time-lapse monitoring for reservoir management.

To complement saturation analyses, the CHFP* Cased Hole Formation Porosity tool measures formation porosity and sigma values. This tool has a Minirion* pulsed neutron generator that eliminates the need for a chemical source. Borehole shielding and focusing enable petrophysicists to perform environmental corrections.

The DSI tool provides accurate measurements of formation compressional transit times to establish porosity and as a gas indicator. The tool also measures shear slowness, which is key for evaluating mechanical properties such as wellbore or perforation stability, predicting hydraulic fracture height, or sanding analysis. Data from the DSI tool can also be used to determine stress anisotropy, which is a key component for oriented fracturing. The data also contributes to geophysical interpretations using synthetic seismograms, vertical seismic profiles, and amplitude variation with offset analyses. Fully combinable with other cased hole logging tools, the DSI device operates at logging speeds up to 1,100 m/h. Before running the tool, it is crucial to evaluate the cement integrity because a high-quality cement sheath improves the quality of the data.
Cased hole formation evaluation

In openhole log interpretation, neutron and density logs can be combined to estimate a total porosity measurement or a crosplot porosity, which is less sensitive to lithology and formation fluid effects than either measurement on its own. For reliable cased hole formation evaluation, the same technique can be employed using CHFD logs.

The CHFD tool works by compensating for casing and cement effects to derive formation density values using a three-detector density tool. The concept of measuring density through casing is not new, but log analysts were faced with a significant problem—small changes in casing thickness caused large errors in the estimates of formation density. The method was also sensitive to variations in cement quality.

For a successful cased hole density measurement, the log analyst must have information that enables corrections to be made for variations in casing thickness and in cement quality.

This requires the combination of three different detectors with differing sensitivities to casing, cement, and formation (Fig. 11). The shortest-spacing, or backscatter (BS), detector is sensitive to the casing thickness, the short-spacing (SS) detector has more sensitivity to casing and cement, and the long-spacing (LS) detector has more sensitivity to the formation density.

A comparison of the cased hole density (black), and openhole density (red) in 9\(\frac{5}{8}\)-in casing indicates the importance of the three-sensor system (Fig. 12). In the left-hand track, the density is computed using a three-detector density tool, while in the right-hand track only the SS and LS detectors were used. Above the casing collar, where the casing thickness had changed slightly, the match between openhole and cased hole data was better when three detectors were used.

Figure 11: The three-detector system provides the information about casing variations, cement quality, and formation properties that analysts require to correct their cased hole density measurements.

Figure 12: For cased hole surveys, the three-detector system provides a much better match to openhole density data than can be achieved using a two-sensor system.

ABC services in China

For several years, engineers have used thermal-neutron-decay time measurements to evaluate the formations behind well casings. Recently, new technologies have been developed that improve the industry’s ability to investigate the conditions behind the metal casing. These tools can provide cased hole resistivity, geochemical, and epithermal neutron logging.

Locating an oil-bearing sandstone

Analysis behind casing has been successfully applied to oil fields in China and has proved particularly useful in situations where openhole logging could not be conducted. In one well, for example, the field operator had recorded logging-while-drilling (LWD) resistivity and gamma ray logs with the intention of logging the openhole section on wireline at a later date. However, poor hole conditions higher in the well prevented the wireline tools from reaching and logging the series of clean, high-resistivity zones that had been identified with the LWD logs (Fig. 13). To overcome this issue, the operator decided to examine these promising zones after the well had been cased.

Figure 13: Analysis behind casing allowed the field operator to make a detailed analysis of clean, high-resistivity zones that could not be logged using wireline methods in openhole conditions.

Figure 14: Through-casing logs identified one of the zones as a significant oil-bearing sandstone.
The mud logs had indicated limestone and sandstone in the rock sequence, and there were oil shows, which made it important for the operator to test these zones. However, without porosity and lithology logs it was very difficult to evaluate the potential reservoir zones in this well.

Once the casing had been run, engineers logged these vital zones through the casing using a combination of CHFD, CHFP, DSI, and ECS* Elemental Capture Spectroscopy tools (Fig. 14). The zone at about X83 m was found to be an oil-bearing sandstone. The uncalibrated K-lambda estimate of producibility made from the lithology suggested that the zone would flow hydrocarbon fluids. After perforation, this zone produced oil at a rate of approximately 19 m³/d during well testing.

Cased hole, open hole

In another example from China, the operator decided to evaluate the quality of data from cased hole and openhole logging using resistivity, DSI, CHFP, CHFD, and ECS tools. These logging tools were run in both openhole and cased hole conditions in a new well. The casing was 7 in, 32 kg/m. The repeatability of the logs over the main zones and the quality of the cased hole measurements can be clearly seen in Fig. 15.

- **CHFP tool**: The results from the CHFP tool (track 3) showed excellent repeatability for the neutron porosity measurements between the openhole and cased hole data. Note the quality of the CHFP log at X,190 m where the cement quality was particularly bad.

- **CHFD tool**: The repeatability of the density log (track 3) was not as good as that from the CHFP tool. This was caused by the relatively heavy casing. However, the quality was sufficient for formation evaluation. Shale effects on the density neutron data were clearly identifiable, and a good cross-plot porosity could be computed.

- **Sigma logs**: Unfortunately, the cement quality was not good enough to obtain compressional sonic data through casing (track 4), but the dipole shear sonic data was excellent.

- **Sigma logs**: The CHFP tool (track 5) also generates a sigma measurement, and the openhole and cased hole sigma repeatability was excellent. Sigma measurements are often used to indicate the presence of clay or gas.

- **ECS lithology**: ECS logging (tracks 6 and 7) was slower in the cased hole than in the open hole, so the vertical resolution of the ECS log was better in the cased hole. The clay volume repeated very well in both openhole and cased hole data. The minor differences in the carbonate content were caused by the patchy nature of the cement, which made it difficult to make a fixed cement correction (calcium correction).

- **USI tool**: A good-quality cement map is essential to all ABC logs (track 8). The average cement quality, in terms of acoustic impedance, is also shown on this track. In this case, the cement was very unevenly distributed and of generally poor quality. In older wells, casing thickness data from the USI tool is essential for ABC log interpretation, because small changes in casing thickness, will have a large impact on the logs.

The future of analysis behind casing

As exploration and production companies focus increasingly on their mature fields, formation evaluation behind casing is set to become a vital process for production optimization.

ABC services, including interpretation support, enable operating companies to acquire and interpret data and then make informed decisions about areas such as sidetrack drilling, offset drilling, well intervention, and well or field monitoring. ABC services make it possible for E&P companies to obtain well logs in situations that previously would have impeded or prevented data acquisition.

In adverse wellbore conditions, such as wells with borehole-stability problems, operators now run casing and then conduct logging operations afterwards using the ABC services. For mature and/or depleted fields, operators may use these services to evaluate potential pay behind the casing rather than drill a new well to acquire data. Producing wells and fields are easily monitored using ABC tools. In many situations, planning these operations can minimize rig-time costs. The only obstacles to successful data acquisition with these tools are probably well accessibility and the condition of the casing, the cement, and the well-completion hardware.