FIELD TEST RESULTS OF A NEW-GENERATION LARGE-BORE ROTARY CORING TOOL

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ABSTRACT

Wireline sidewall cores have a well-established role in the formation evaluation program in providing key rock properties. While they provide a subset of the exhaustive information obtainable from continuous core, for reasons of operational efficiency they are often deemed to be the most practical option.

Although the ability to perform routine core analysis (RCAL) measurements on sidewall core samples improved significantly with the introduction of the first rotary sidewall coring tools in the 1980s, significant limitations remain related to the relatively small size of the sample. Among other challenges, measurement uncertainty is higher compared with core plugs, and in heterogeneous formations the smaller volume of rock is expected to be intrinsically less representative of bulk reservoir properties. Many special core analysis (SCAL) and rock mechanics methods are not considered to give valid results or cannot be performed owing to insufficient volume of core material.

To address the given challenges and improve the range of tests that can be accurately performed on sidewall cores, we introduce a new wireline rotary sidewall coring tool that acquires samples slightly larger than standard laboratory core plugs, 1.5 in in diameter by 3 in in length. Every aspect of the new coring system has been engineered to enable easy and reliable wellsite operation with real-time intelligent drilling control and efficient recovery in a broad range of lithologies. An innovative system of core handling and core preservation techniques ensures the recovery, traceability, and integrity of each core from the moment it is cut downhole until delivery to the laboratory.

We review the results of six months of field testing in both soft and hard formation types (shale, sandstone, and carbonate) with respect to core recovery, core quality, and the resulting possibilities for core analysis. We provide a laboratory perspective on the expected efficacy of common measurements carried out on the new sidewall cores compared with those from standard rotary sidewall cores, and find that for most analyses we should expect low uncertainty similar to core plugs cut from whole core.

A case study from North America is presented, illustrating an optimized process for unconventional reservoir analysis that begins with careful selection of sidewall coring points based on log interpretation and the operator’s analysis requirements. During core acquisition, the usefulness of novel tool features for downhole core assurance is demonstrated, and it is shown that the full range of analyses required may be carried out on the new large, high-quality sidewall core, where previously several sidewall cores would have been required. The end result is that an extended reservoir interval could be successfully characterized from a single sidewall coring descent, where previously at least three sidewall coring descents or multiple stands of whole core would have been required.

INTRODUCTION

The use and usefulness of wireline sidewall cores as a formation evaluation tool have grown significantly since the introduction of the industry’s first percussion sidewall coring tool in 1936. The possibility of taking formation samples using a wireline tool offered the industry for the first time several attractive operational advantages. First, it was operationally efficient; a sidewall coring descent could be completed in just a few hours. Second, sidewall core samples could be taken in a single descent from widespread depth stations over an extended open hole interval, whereas a conventional coring run was typically targeting a continuous interval of 30, 60, or 90 ft. Third, because...
the wireline coring tool was positioned downhole based on correlation to SP or gamma ray logs, there was very precise control over the depth of each sample.

Such cores were obviously not a replacement for whole conventional cores in all respects however. Due to the explosive force propelling the bullet into the formation, the samples recovered often suffered mechanical damage. This typically led to overestimation of porosity and underestimation of permeability (Webster, 1959). Despite efforts to optimize the design of the bullets, recovery is less than perfect, especially in hard formations in which the bullets cause excessive shattering or fail to penetrate.

Percussion sidewall cores are commonly 0.69 to 0.88 in in diameter and 0.6 to 1.2 in long, depending on bullet selection, penetration, and core breakage point. (Schlumberger, 2010) Even in the event of undamaged samples, the small amount of material is limiting for most types of analysis that might be carried out on conventional cores.

The quality of sidewall cores and the resulting analysis possibilities improved greatly with the introduction of the first wireline-conveyed rotary sidewall coring tools in the 1980s. Typically in rotary sidewall coring operations the entire tool is anchored in a static position once it is deemed that the tool is positioned at the correct depth and a diamond coring bit cores into the side of the borehole. Once at maximum extension the bit and motor assembly is canted vertically to snap off the rock sample and retract the sample into the tool. Then a piston moves the sample from the bit into a storage module such that another sample may be taken using the same bit.

The rotary technique essentially eliminated the hard lithology limit and made it possible to obtain samples with little or no mechanical damage in the majority of lithologies. It also significantly increased the size of the sidewall core samples, to 0.92 in in diameter and up to 2 in long. Corelab (East, 2001) have noted the increased usefulness of these rotary sidewall cores for routine core analysis (RCAL) measurements, as well as “fair” results for a number of special core analysis (SCAL) measurements for which percussion cores are judged entirely unsuitable.

Despite the improvements brought by this generation of rotary sidewall coring tools, several challenges remain. These tools generally provide a “core length indication” during the coring process, which indicates how far the bit travelled into the formation during coring, but does not guarantee if, or how much, core has been recovered.

Not until the wireline tool has been brought to surface, the equipment rigged down, and the cores downloaded is the actual core recovery known and the sample sizes determined with certainty.

It has been our collected experience that recovery in soft lithologies, especially those less than 600 psi unconfined compressive strength is especially challenging for these tools. This is attributed to a number of causes, including shearing of the formation and washout during drilling or crushing of the sample during downhole handling.

Limitations remain with respect to the size of the rotary sidewall core, which is approximately four times smaller, by volume, than a typical 1.5-in core plug cut from a whole core. The analysis of either conventional cores or rotary sidewall cores is traditionally a give and take with regard to the various measurements that may be undertaken. The limiting factor for producing these analyses is the amount of rock sample that the lab has to use. There are many applications for cores but each analysis performed usually means that another analysis cannot be unless enough sample has been delivered to the lab.

Variability in sidewall core length and recovery therefore provide challenges in the planning of a coring program because there is no assurance of being able to perform the analysis until after tools have come back to surface. Operators must wait until the cores are downloaded and measured at surface or they must factor into their coring program local knowledge of average length and recovery to add a safety factor to the number of cores attempted to recover their necessary sample set.

If an operator waits to measure the cores and then decides on a second coring run, there is still no guarantee that the additional coring run will recover the cores. In the case where the operator proactively anticipates poor rotary coring recovery in the local environment, much time can still be wasted preemptively taking additional cores that are eventually found to be redundant upon returning to surface.

A NEW-GENERATION ROTARY SIDEWALL CORING TOOL

In 2004, we launched a project in response to these issues to engineer a new coring tool, starting from a completely blank slate. A simple alternative that was also considered was to modify an existing coring tool with a larger bit. While obviously faster to implement, this proposal did not address any of the issues other
than the large core, and so was excluded. Seven years later, we are in the field test phase with a new-generation sidewall coring tool that offers significant innovation on multiple fronts.

Fig. 1  The new-generation rotary coring tool, showing the extended bit (left) and hydraulic arms for anchoring the tool (right).

The new rotary sidewall coring tool is deployed using wireline cable (fig. 1). An individual tool is capable of taking 50 sidewall cores, 1.5 in in diameter by 3 in long, in a single descent in a well. The new tool presently does not have a commercial name but is referred to as new-generation rotary coring tool. The principal specifications of the prototype tool are in table 1.

<table>
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<th>Physical Specifications</th>
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<td>Lithology Soft Limit</td>
<td>100-psi UCS</td>
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Table 1  New-generation rotary coring tool specifications.

Several novel features improve the efficiency and efficacy of the overall sidewall coring operation, beginning with digital telemetry compatibility, which facilitates combinability with most wireline logging tools. Thus it is feasible, for example, to run a formation imaging tool in the same descent to precisely locate cores or to run an inclinometer to measure azimuthal orientation.

Telemetry compatibility enables transmitting more data uphole during operations than the coring tools of the previous generation, and the new-generation tool can be more effectively controlled with software commands from surface. This enables real-time feedback and advanced control of drilling parameters: torque, weight-on-bit, and rate of penetration are accurately measured and transmitted uphole. They can be regulated on-the-fly either manually or by an automatic optimization algorithm.

During coring, the tool uses advanced static-sleeve technology to cut cores in a wide range of target lithologies from granite to 100-psi unconfined compressive strength (UCS) unconsolidated sandstone. The non-rotating sleeve minimizes sample exposure to shear forces to help avoid failure or washout of soft formation samples.

In addition to the usual bit penetration measurement, each of the 50 cores is directly measured for length as it is shifted from the static sleeve to the storage magazine. This provides a positive real-time confirmation that the core was recovered, as well as an accurate indication of core size.

Storage of cores in the magazine has also been greatly improved compared with previous tools, which store all cores in a common tube and rely on gravity to drop markers between the cores. In the new tool, each core is placed in an individual storage canister as it is shifted out of the static sleeve (fig. 2). The canister provides mechanical support and in addition slows the entrance of borehole fluids to the rock sample as additional cores are taken or the tool is pulled back to surface.
At surface a variety of handling options are possible according to the operator’s preferred procedure. Most commonly, the canisters are downloaded from the magazine and placed directly in airtight bottles, thus eliminating the risk of handling the cores at the wellsite. Alternatively, the cores may be removed for special packaging or preservation techniques carried out by laboratory personnel. Yet another option is to ship the entire magazine to the core lab.

**ANALYSIS POSSIBILITIES**

A generality that often holds true in core analysis is the more material, the better. In heterogeneous carbonates or thinly laminated heterolithic formations, a larger sample will closer approach representative elementary volume. Even in homogeneous rocks there is a benefit in that volumetric measurements inherently carry lower uncertainty percentages as the volume of the sample increases. As more of the new-generation 1.5-in × 3.0-in sidewall cores are delivered to core analysis companies, many interesting applications for rotary sidewall cores are coming to light. We elaborate further on some of these applications below based on our preferred methods.

**Tight Rock Analysis (TRA)**

The measurement and integration of reservoir and completion quality parameters are critical for the understanding of unconventional reservoirs. The number one challenge is dealing with the extreme variability of these resources. These resources are characterized by extremely low permeabilities and porosities in which the matrix is the dominant feature. They require special lab techniques that are often destructive to the sample.

The key to analysis is to have an appropriate sample mass that is representative of the rock type that is being sampled. Conventional core is the best method for obtaining that representative sample because the sample mass can be obtained from a single depth point. As an alternative, rotary sidewall samples have been used. Until recently the use of rotary sidewalls for analysis has required that multiple samples be obtained in the same lithology unit. This leads to potential compromises in the accuracy of analysis:

- The required amount of mass is not obtained. We find that as mass is reduced the accuracy of the measurements is affected. Or in the least the workflow is affected.

- The material gathered from multiple samples must be combined. This material comes from samples that are typically spaced over a 2-ft interval, potentially smearing or hiding heterogeneous characteristics.

In our preferred method, the total weight and bulk density are determined for each sample, then the sample is crushed and sieved. A fresh, sieved sample is then weighed and the partial grain volume (grain volume plus interstitial fluid volume) of each sample is determined by the Boyle’s law technique to measure the gas-filled pore space. The pressure decay during this measurement is used to determine permeability to gas. Total and effective porosity and fluid saturations are determined via the retort method (API, 1998).

This method requires 120 to 150 g of bulk sample. The large-format cores delivered by the new sidewall coring tool eliminate the issue of sample mass and the amount of material delivered provides the same accuracy in reservoir quality measurements as conventional core.

While the sample mass obtained with the 1.5-in sidewall cores will allow for equivalent reservoir quality measurements to be made, we must be aware that measurements based on sidewall samples are obtained at discreet depths over the length of the borehole. This means that some information that can only be obtained at the continuous whole-core scale will be missed.

**3D Geomechanics**

The laminated nature of shales requires knowledge of mechanical anisotropy to properly evaluate stimulation requirements and ensure long-term production. Layered media have mechanical properties that are, in general, different along the directions of each of the
axes. The properties in the plane of the bedding will be different from those in the perpendicular direction. Such materials are called transverse isotropic. Their mechanical behavior is characterized by five independent parameters:

1. Young’s modulus (stiffness or resistance to compression) normal to the plane of the bedding,
2. Young’s modulus in the plane of the bedding,
3. Poisson’s ratio (when a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression; Poisson’s ratio is a measure of this effect) normal to the plane of the bedding,
4. Poisson’s ratio in the plane of the bedding,
5. Shear modulus (a measure of the rock’s response to shearing deformations) normal to the plane of the bedding.

Sidewall core samples are normally taken in vertical wells and are horizontally oriented. The size of traditional rotary sidewalls does not allow oriented measurements to determine vertical to horizontal anisotropic characteristics.

The large-format sidewall core allows for a robust mechanical testing program that requires taking oriented samples from the 1.5-in-diameter sidewall core. These samples are oriented parallel, perpendicular, and at 45 deg to the bedding planes as shown in figure 3. In determining the applicability of these measurements we need to recognize that they are appropriate in a shale in consideration of the small grain sizes in most shales.

Implications for the Analysis of Sidewall Cores from Conventional Reservoirs

In addition to the obvious benefits of recovering undamaged samples in unconsolidated formations, the principal improvements in conventional core analysis made possible by the large-format sidewall cores relate to increased measurement precision resulting from the increased core volume.

As an example, any type of analysis relying on core bulk volume measured using the caliper method will benefit significantly from the larger sample size. Assuming uncertainty of ±0.015 mm for sample length and ±0.004 mm for core diameter (API, 1998), a simple mathematical exercise determines uncertainty of ±1.4% for a 0.92-in × 2.0-in sample compared with ±0.8% for the new 1.5-in × 3.0-in sample. This would be most applicable for vuggy carbonates, or possibly for unconsolidated formations if the pore volume cannot be directly measured. In such cases, the errors correspond directly to porosity units.

Any type of direct fluid volume measurement will benefit greatly from the increased core size. Extreme errors of up to ±50% have been noted in the literature when the sample size is small or when total fluid volume (i.e., porosity) is low (API, 1999). In this case, the analysis of low-porosity formations will benefit the most from the increased sample size. The reduction in uncertainty will be directly proportional to the sample size, effectively fourfold.

We thus suggest that by acquiring a sidewall core sample equal in size to a typical laboratory core plug, we have reduced measurement uncertainty to the same level for most types of analysis. However, it is
important to bear in mind that we may not always be measuring the same thing; while it is certainly possible to acquire conventional cores with minimal flooding, it remains an inherent limitation of sidewall coring that the samples are normally taken from the flushed zone of the formation. Consequently fluid saturation, as well as any SCAL method using fresh-state samples, may give different results when performed on a sidewall core, whatever the size of the sample.

Sidewalls are dependent on log-scale heterogeneity, which is not a true depiction of the actual heterogeneity. More can be done with continuous whole core through further analyses such as lithological and depositional descriptions, fracture analysis, and large-sample testing. While large-format sidewall cores come very close to providing the same laboratory analysis capabilities as whole core, the goals of the program must be clearly understood for a proper determination of coring methodology.

CASE STUDY—USA

An operator drilled an exploration well to assess sand and shale targets in the Permian Basin. Required measurements from core included porosity (total, effective, and gas-filled), fluid saturations, permeability, mineralogy, and petrology, as well as geochemical analysis for total organic carbon (TOC) and rock evaluation from 21 zones. A main objective of the coring program was to integrate the results with the log interpretation.

The core points were spread over a 1200-ft interval as illustrated in figure 4. Considering the operator's objective, and also that the cores were picked after running the logs, conventional coring would not have been a practical option for this well. At least six conventional coring runs would have been required to cover all of the zones.

Table 2 lists the ideal sample masses for the planned reservoir quality analyses as per laboratory requirements. Performing all of these methods ideally requires 200 grams of material for robust results. Any amount less will increase the uncertainty associated with the analysis.
Variability in core length and recovery are common issues with rotary cores so when trying to ensure enough rock sample is acquired for a full analysis it is important to consider the density of the formation along with the core volume. Table 3 demonstrates this relationship for a representative value of bulk density.

Table 3 states sample mass as a variable of core length for standard sidewall coring technologies and the new large-format coring system. To achieve 100% of the coring program objectives using standard technology, at least 4 cores would be required for each zone of interest. Given 21 requested zones, the resulting coring program would require taking a minimum of 84 cores assuming 100% recovery of full-length cores. This would equate to two descents with a standard rotary coring tool.

Taking full advantage of the increased size of the new large-format core as well as the unique downhole core-assurance features of the tool, the program was achieved in a single descent. The 21-core program required 26 stations to complete, out of which four stations indicated that no core had been recovered while one station indicated a short core (table 4). In each case, the field engineer was immediately aware of subpar core recovery, and immediately repositioned the tool within 1 ft of the originally requested depth, successfully acquiring five replacement cores.

Table 4 Summary of operational results for the USA case study job. The core measuring 2.32 in was identified downhole.

At surface, the cores were kept inside their individual canisters upon downloading from the storage magazine. The canisters were wrapped in cling wrap and put inside sealed jars, which were in turn put into a specially insulated core transport case and shipped to the core lab (fig. 5).

![Fig. 5 A specialized case with jars used for core transportation to the laboratory.](image-url)
During lab analysis it was found that three cores were cracked upon arrival. Fortunately, the individual canisters holding the cores kept the pieces together and allowed for confident grouping prior to lab analysis so that no material was lost.

In general, the cores were found to be in excellent condition and of adequate size for testing. The accuracy of the downhole length measurement was clearly demonstrated, as seen in the core photographs in figures 6–9. No anomalies were noted that would have precluded a robust measurement in any of the planned analyses.

As of this writing, geochemical and petrographic analyses were still in progress. Analysis of porosity, permeability, and fluids was performed according to plan using the TRA techniques previously described. Permeability was measured using the pressure-decay technique for the majority of the samples, however, eight samples with larger grain size were measured using the pulse-decay method. The results were delivered to the operator, who commented that flushing of the samples with mud filtrate appeared to be low compared with his usual experience with sidewall cores.

The operator was highly satisfied with the sidewall coring operation and the laboratory results, and plans to continue use of the new coring tool in future wells.

CONCLUSIONS

The new-generation rotary sidewall coring tool represents for the industry a major advance in sidewall coring, both operationally and as an important and reliable source of reservoir information.

During field testing it has been demonstrated that the tool is capable of reliably drilling and recovering cores 1.5 in in diameter and up to 3.0 in in length, with an average recovery length of approximately 2.75 in, representing four times the volume of standard rotary sidewall cores.

The increased core volume is opening a world of new possibilities in core analysis by increasing the laboratory’s flexibility in the overall workflow and the use of destructive testing methods. The larger sample size has also effectively increased the precision of laboratory measurements to the same level the industry is accustomed to when measuring plugs taken from conventional core. It is noted that while large-format sidewall cores come very close to providing the same laboratory analysis capabilities as whole core, the goals of the program must be clearly understood for a proper determination of coring methodology.

During field testing, unique new tool features relating to the measurement, handling, and preservation of core samples also proved their value. In particular, the downhole measurement of core length proved extremely effective, ensuring that 100% of the needed cores were recovered in a single descent with enough material available for all planned testing. We envision that this capability will revolutionize the way that sidewall coring programs are planned and executed in the future. Using the downhole measurement of core length, operators will know immediately if they have enough sample mass and volume for the required analysis program and can confidently make real-time decisions on further coring attempts.
Fig. 6  Four of the recovered sidewall cores from the case study well.

Fig. 7  Six of the recovered sidewall cores from the case study well.

Fig. 8  Six of the recovered sidewall cores from the case study well.

Fig. 9  Six of the recovered sidewall cores from the case study well. The 2.32-in core was recovered in two pieces inside the canister.
REFERENCES


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