PETROPHYSICAL SIGNIFICANCE OF ORIENTED SIDEWALL CORES FOR IMPROVED RESERVOIR CHARACTERIZATION

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Abstract The advent of drilled sidewall cores has made it possible to obtain much more information than was previously available from percussion sidewall cores. Directional equipment on the coring tool enables the azimuth and deviation of the bit to be recorded for each core. Inspection of the core in the laboratory, in most cases, provides information to determine the top of the core as well as the formation versus borehole ends. These parameters make it possible to completely orient the drilled sidewall core with respect to the horizon and geographic north.

Directional rock fabric studies (which require well oriented samples), such as AMS (anisotropy of magnetic susceptibility) in conjunction with dense core sampling, dipmeter data and CAST images have been successfully completed. Marked core tops enable the petrographer to obtain valuable information from sparsely sampled intervals or formations. When sampling is adequate, sedimentologic studies in formations are possible from oriented, drilled, sidewall cores. The orientation of laminations and features such as graded bedding have been established and compared to detailed dipmeter data. Directional permeability, migration of fines and skin damage studies have been made on samples drilled from the borehole wall and depth correlated to well logs with a gamma ray.

INTRODUCTION

The acquisition of cores greatly increases our understanding of the geology of an area. Core data may also increase our understanding of a specific reservoir. Oriented core may not be needed when investigating reservoir characteristics such as bulk mineralogy or core porosity. However, when it becomes important to look for a change in a characteristic such as rock texture, fabric, permeability, porosity or mineralogy, then samples of known directional orientation are essential.

Ideally, oriented whole core would be preferred for detailed sedimentologic and petrophysical studies. Unfortunately it is not always possible to obtain whole core over a particular interval. By positioning the coring tool with the open hole gamma ray, intervals of particular interest can be sampled. Rotary-drilled sidewall cores have proven to be viable alternatives to whole core, especially where sampling is dense and it is possible to orient the cores. Oriented drilled sidewall cores find their niche when trying to understand formation heterogeneity and where changes in the characteristics being investigated are resolvable over a one-inch plug. Directional characteristics such as permeability, textures, magnetic fabric and skin damage have been successfully studied using oriented drilled sidewall cores.

The studies or methods included here are preliminary attempts to investigate particular problems. The merit of some of these studies may be questionable and will, no doubt, require further study to determine their validity and usefulness. However, the main objective is to illustrate and emphasize the possibilities for sedimentologic and petrophysical studies using oriented drilled sidewall cores.

ORIENTATION OF CORE

There are two categories of orientation which can be determined for various core types: orientation with respect to magnetic north and physical orientation with respect to the borehole axis.

Orientation With Respect to Magnetic North

Orientation with respect to magnetic north is a somewhat tricky prospect. Electronic survey instruments are available to provide orientation for conventional diamond core. A great deal of careful planning and execution are required in order to obtain reliable survey results which can be used to orient the core (Henry, 1990).

Direct measurement of magnetic north is not yet commercially available for rotary drilled sidewall cores, although it has been accomplished on an experimental basis. One interesting method uses the borehole televiewer's directionally-oriented acoustic image of the borehole wall to "see" core holes in relation to the surrounding rock, thus orienting the corresponding cores. Still, it is not always feasible to obtain borehole televiewer data on all wells in which sidewall cores are collected.

Physical Orientation

For sidewall cores, physical orientation consists of determining the top of the core with respect to the borehole axis, and which end of the core was the borehole end as opposed to the formation end. Finding tops on whole core and plugs removed from the whole core should not generally pose a serious problem since the core comes out of the well with deepest depths at the bottom of the core barrel. In a deviated borehole, knowledge of the borehole inclination is required to orient the core with the horizon.

Establishing tops of sidewall cores, both percussion and rotary-drilled, is often feasible, but requires direct knowledge of the equipment and procedures for taking the cores. To obtain orientation data for percussion cores, it is necessary to be at the well site when the cores and core barrel are brought to the surface. Sometimes it is possible to estimate the top of the core from its position in the core cutter and

FIGURE 1. Percussion sidewall core. Scale in centimeters.

the connecting cables (Schumacher, 1990 personal communication).

Often, percussion cores are recovered from unconsolidated to poorly consolidated formations. When the percussion core is NOT inspected and marked at the well site and carefully transported to the lab it can end up looking like the core in Figure 1. This core is a poor to uncemented sandstone which was shipped in a glass bottle. During transportation, the core bumped around inside the bottle, completely altering the original shape, and thus destroyed any surface artifacts which might have existed.

It is possible to orient rotary-drilled sidewall cores with respect to top and with respect to the formation and borehole ends from physical features present on the core (see Figure 2). The diamond bit creates tool marks or artifacts on the cylindrical surface of the core which indicate the top of the core. To understand the significance of the artifacts, it is essential to understand how the service company's equipment works. In the case of the HLS coring tool, a groove is often incised on the top of the formation end of the core during the process of breaking the core free from the formation. The freshly broken surface indicates the formation end of the core. The borehole end generally is fairly smooth; borehole curvature is usually obvious on this end.

Before trimming or further tests to the core, the top and the formation ends should to marked with indelible ink. As seen in Figure 2, a line along the core axis marks the top of the core. Arrows drawn along this line point away from the borehole toward the formation. Thus when the ends of the core are trimmed and the incised groove is removed, it is still apparent which is the formation end and which is the borehole end.

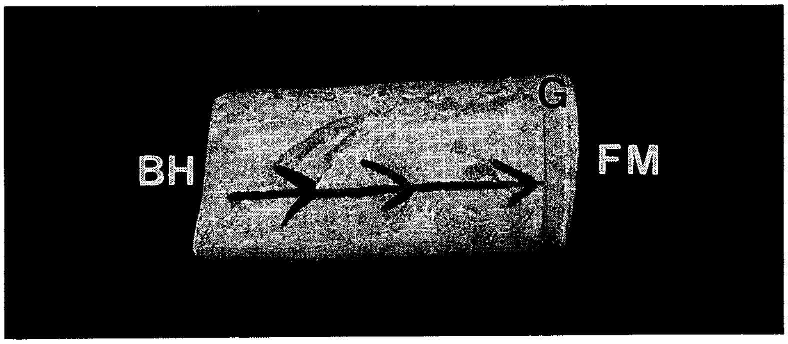

FIGURE 2. Rotary-drilled sidewall core. The borehole end (BH), formation end (FM), groove cut by the diamond drill bit (G) and line marking the top of the core are shown.

APPLICATIONS FOR ORIENTED ROTARY SIDEWALL CORES

AMS Study

Anisotropy of magnetic susceptibility (AMS) theory, methods of measurement and application have been described by several authors (Bhathal, 1979; Hrouda, 1982; Schieber *et al.*, 1988). AMS is the magnetic fabric of rocks (Hrouda, 1982) and studies have shown AMS to be related to paleocurrent orientation (Bhathal, 1971; Ellwood *et al.*, 1979; Taira *et al.*, 1979; Hrouda, 1982; and Schieber *et al.*, 1988).

In a study by Knode *et al.* (1990) thirty sidewall cores from two test wells (#1 and #2 of this study) at the HLS facility in Fort Worth, Texas were drilled with the rotary coring tool and AMS was measured for each core. These cores were oriented both by the "tool mark" and "televiewer" methods since complete, three-dimensional orientation was necessary to obtain meaningful AMS results. A borehole televiewer (HLS Circumferential Acoustic Scanning Tool [CAST^{TM}]) was run over the interval of interest both before and after the cores were drilled. It was possible to "see" the core holes on the televiewer image and thus orient them with respect to magnetic north. Each interval was logged with a six-electrode dipmeter to detect possible bedding features. Table 1 summarizes the results of the AMS study compared to computed dips derived from the six-electrode dipmeter passes.

This study was conducted in a Cretaceous sandstone with slightly variable lithologic character; the unit in one well contained an abundance of thin shale stringers, while the unit in the other well contained a shale-free sandstone. The AMS strike and dip direction results compare favorably in one well, yet differ by 90° in the other well, possibly reflecting a change in depositional environment. More study is needed to understand the exact nature of the differences. The results of this study illustrate the value of oriented borehole samples in sedimentologic studies.

TABLE 1. Summary of Dip Magnitude and Direction.

	Well #1	*Well #2*
AMS Foliation Plane		
Dip Magnitude	4.2°	5.8°
Dip Direction	226.2°	315.9°
Six Electrode Dipmeter		
Dip Magnitude	5-10°	5-15°
Dip Direction	225-240°	225-240°

After Knode *et al.* (1990)

Oriented Thin Sections

Thin sections are routinely made from all types of core. Generally mineralogy, porosity types, diagenetic features and other items of interest can be determined from thin sections even through they are of an unknown orientation. The ability to orient the top of the thin section with respect to the borehole axis can provide additional valuable information about the directional (vertical as well as horizontal) changes in rock fabric and texture. In addition to the traditional thin section orientation perpendicular to the axis of the core, it is possible to make longitudinally oriented thin sections to observe changes from the borehole to the formation end of the core.

Many cores and companion thin sections with unknown orientation have been inspected. In most of the cases the samples have been massively bedded or the scale of features are too large to be resolved by a sidewall core; thus orientation would probably not provide additional information. However, where fabric, structural or textural features are present, the lack of orientation renders these features interesting, but not useful, to interpretation. Where sampling is sufficiently dense, information derived from oriented cores can provide valuable insight into sedimentary processes.

Figure 3 is a photomicrograph of an oriented thin section. Knowledge of the orientation allows for the following textural and structural elements to be established: the sandstone overlies the illite-rich layer; loading of the sand has caused flame structures (f) to develop; and there is development of a burrow (b), filled with illite-rich sediment, with an opening upward (not seen on this photomicrograph).

Directional Permeability

Permeability of standard sidewall cores is routinely measured along the long (or horizontal) axis of the core. Core orientation is not required for this analysis. If

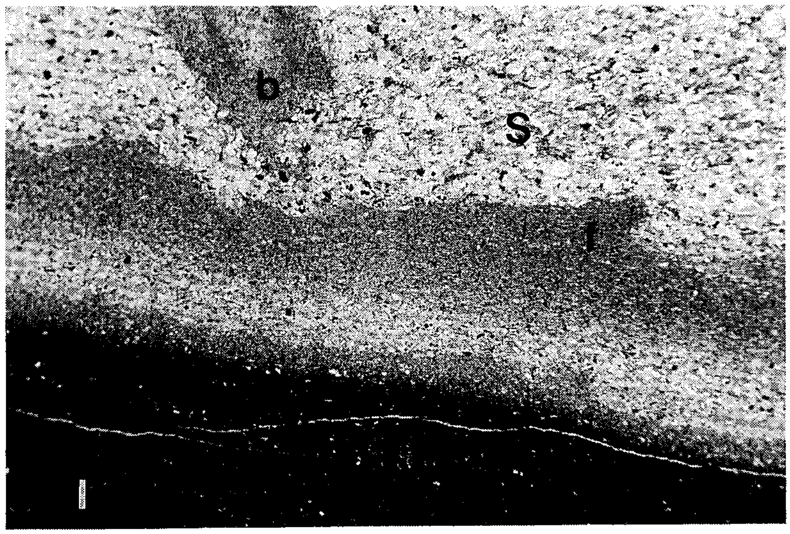

FIGURE 3. Boundary between illite-rich layer (I) and the overlying fine grained sandstone (S). The photomicrograph is oriented so that up is toward the top of the page. Plane light, 32X.

direction-specific analysis is desired, then all the directional parameters need to be known. By using horizontal or vertical plugs removed from conventional whole core, the top of the plug is easily established. Unfortunately, it is not always possible to obtain whole core for all intervals of interest and rotary or percussion sidewall cores may be all that are available.

Preliminary experiments have been conducted in the HLS Petrophysics Lab on the feasibility of using drilled sidewall cores for directional permeability studies. By testing plugs cut in different directions from a single block of a known lithology (in this case, Berea Sandstone) it was determined that it is feasible to measure directional (vertical) permeabilities greater than 0.1 millidarcy from a drilled sidewall core using a screen technique similar to that used for larger plugs (API RP 40, 1960). This technique is of little use unless the top of the core is known.

Changes in Permeability Along the Long Axis of the Core

A nine-well study was conducted on a Devonian, fine to very coarse grained, well cemented sandstone to determine if permeability was being reduced by fine dust generated by air drilling. These wells were initially air drilled, then the holes were loaded with salt mud to facilitate coring. The client was interested in the effect of air drilling on permeability in the near-borehole region. Rotary sidewall cores were drilled and recovered every foot in the pay sand in each of the nine wells.

When the cores arrived into the laboratory, the formation ends were established and the appropriate markings were drawn on the cores. A minimum of sample was trimmed away from both ends to prepare the cores for cleaning and further analyses. X-ray diffraction analysis revealed that no fluid sensitive clay minerals were present in the samples. After the initial permeability was measured, all material except one-half inch of core at the formation end (see Figure 2) was trimmed away and the samples (formation end only) were placed in an ultrasonic bath to remove any fines caused by the second trimming. After drying the samples were retested. Table 2 summarizes the number of cores which showed a change permeability for each well.

TABLE 2. Summary of permeability changes.

Well	*Cores showing Increase In Permeability*	*Cores Showing Decrease In Permeability*	*Cores Showing No Change In Permeability*	*Total Number Cores*
1	19	5	1	25
2	22	2	0	24
3	25	0	0	25
4	12	5	0	17
5	16	5	0	21
6	21	0	0	21
7	20	0	0	20
8	14	5	0	19
9	18	5	0	23

Of 195 cores tested in this manner, 86% showed an increase in permeability, 14% showed a decrease and 1 sample (0.5%) showed no change. This indicated a possibility that the overall permeability was being influenced by the borehole end of the core. Table 3 summarizes the range of increase and decrease seen in each well. In some cases, such as well #6, the huge range increase reflects an increase in one sample from approximately 1 millidarcy to approximately 500 millidarcies. In most cases the increases were much more modest.

A number of factors could have contributed to the overall improved permeabilities in the remnant from the formation end. Only one end of the core was tested after the second trimming. The fact that the samples were shortened, thereby decreasing the length traveled by the flowing gas, may explain the increase. The ultrasonic cleaning process could be responsible. Additional, in-depth studies are required to determine the nature of the changes in these cores.

Skin Damage

Skin damage in a borehole results from chemical or physical change by drilling, completion or injection fluids. Often the only way to assess this damage is to take sidewall cores and observe the changes that take place in a horizontal direction away from the borehole. For this purpose it is essential to discriminate between the borehole and formation ends of the core. Oriented thin sections, chemical tests, SEM and a variety of other tests can be used to determine any changes that may have occurred.

One particular study was conducted where toxic waste had been injected into disposal wells for a long period of time. By establishing the borehole end of the core, a thick (2-3 millimeter) mineral buildup on the borehole wall was detected. Oriented thin sections were made of several of the cores, but the results were inconclusive regarding any alteration caused by the toxic waste.

TABLE 3. Range of percent change in permeabilities.

Well	*Range % Increase*	*Range % Decrease*
1	0.2-57.0	6.4-13.8
2	0.3-937.0	4.2-11.7
3	2.6-170.5	-
4	4.1-181.7	3.1-34.1
5	5.6-745.4	3.4-16.9
6	8.57-49000	-
7	0.5-152.5	-
8	4.9-374.7	0.3-28.8
9	2.8-92.7	0.6-11.2

The relatively short length of the drilled sidewall core (generally less than 2 inches) limits this method to near-borehole effects. If long range planning were possible where fluids were to be injected, a set of cores recovered prior to injection would provide a good control mechanism for future, post-injection comparisons.

CONCLUSIONS

Where whole core has not, or cannot be obtained, drilled sidewall cores have proven to be a viable alternative. By noting artifacts created by the drilling process, it becomes possible to orient drilled sidewall cores in the borehole perspective. It is also possible to magnetically orient drilled sidewall cores (and perhaps percussion cores) using an imaging device such as the borehole televiewer to visually locate the core holes.

Drilled sidewall cores can contribute to improved reservoir characterization as well as an understanding of formation heterogeneity when the tops and ends of individual cores can be recognized. Oriented rotary-drilled sidewall cores have been used successfully for an AMS study to determine magnetic fabric; to orient thin sections for petrography where changes in mineralogy, fabric, textures and porosity are of interest; and to determine directional permeability (i.e. vertical permeability in a horizontal core). Preliminary studies to investigate both permeability variations along the core axis and skin damage have been conducted. Additional work is needed to determine the validity and usefulness of these methods.

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