How to evaluate orientation data, quality control

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Core orientation data are crucial in many types of geologic or reservoir engineering studies.

Given the lengthy list of potential problems, however, how much faith should one put in the results?

In areas where many cores have been oriented from one or more wells, results from a new well can be compared with previous orientation data. Rose diagrams of fracture directions, sediment transport directions or directional permeabilities are particularly useful for this purpose.

Dip and strike of bedding planes can be compared to the well's dipmeter log. These comparisons are usually done long after the core has been cut and it may prove impossible to trace and rectify suspected errors.

The problem is much the same for the first cores in an area where no prior data base is available.

What techniques are available to improve one's confidence in orientation results even in areas where no comparison with surrounding wells is possible? As is often the case in oil and gas operations, development of quality control standards offers the best opportunity of ensuring consistency and quality of results. Orientation service companies have their own quality controls but it is both possible and desirable for an operator to improve and check those standards.

Multishot quality control. A suggested list of quality controls for multishot orientation is shown in Table 3. The quality control steps prior to going in the hole require the close cooperation of operator, coring service and orienting service personnel.

The distance between survey points should be determined such that it does not jeopardize the drilling operation. Survey spacing should not exceed 5 ft if orientation quality is to be maintained.

Downhole, the suggested procedures improve the possibility of having "tie-in" points between the reference groove on the core and the multishot orientation data. After retrieval of the core, a check of the punch marks will reveal if any tightening or loosening has occurred. Even very small punch mark offsets must be noted and measured in order to evaluate orientation results properly.

Careful assembly and marking of the core upon recovery is critical to multishot orienting as much as it is to paleomagnetic orienting. The same procedures are used in either case.

The core should be carefully assembled into continuous intervals, which are defined as a length of core where each piece can be accurately fitted to the next. Continuous intervals are bounded by breaks such as rubble zones, spin off points, the tops and

Fig. 6

Reference groove offset

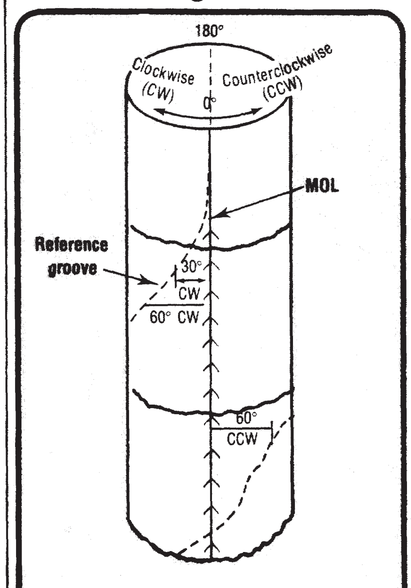
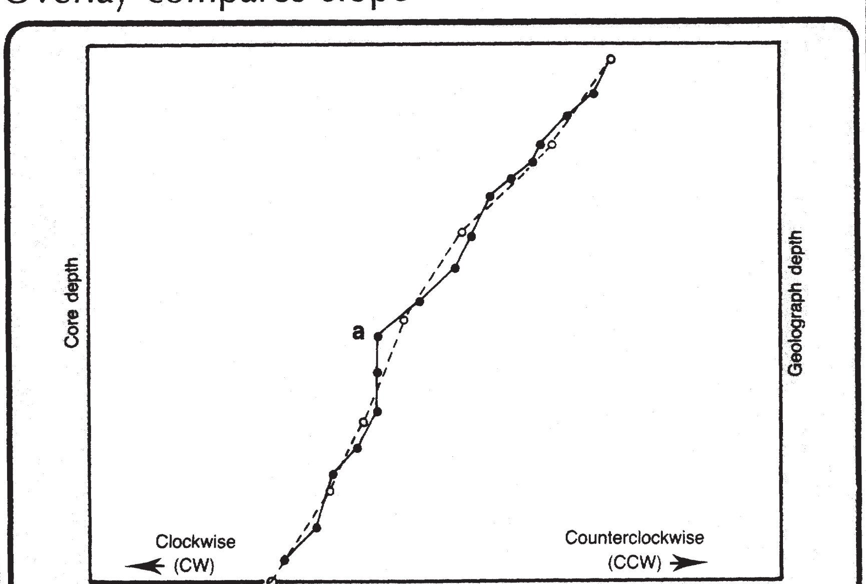


Illustration of conventions for measuring MOL/reference groove deviation. Measurements of deviation should be made every 1-2 ft. Looking downhole with the MOL at twelve o'clock, angles are measured to the right (clockwise) or the the left (counterclockwise) to a maximum of 180°. OGJ

Fig. 7

Overlay compares slope



Plots of the multishot data and core data should overly closely. Some variability is expected such as point "a" since the measurement interval on the core will usually be tighter than the interval between multishot survey points. OGJ

Table 3

Quality control checklist

MULTISHOT TECHNIQUE

Prior to going in hole:
1. Determine the number of feet between surveys.
2. Specify tandem cameras.
3. Double check instrument make up.
4. Be sure tool is aligned on the principal scribe knife.
5. Double check lug/reference groove offset.
6. Use chisel or punch to set "matched" marks across each threaded joint.

While in the hole:
1. Take a survey 0.5-1.0 ft below top of cored interval.
2. Take a survey immediately above any connection point.
3. Take a survey 0.5-1.0 ft below any connection point.
4. Take a survey at the base of the core, prior to breaking off to trip out.

When the orientation tool and core barrel are retrieved:
1. Check punch marks at all joints and remeasure amount of offset.
2. Carefully fit core together, mark straight line(s) (MOL) parallel to the axis of core.
3. Correlate core to Geolograph depths noting particularly indication of the top and bottom of the run and any connection points. Mark correlated depths on core.
4. Note breaks in core continuity caused by rubble zones, spin offs, connections. Record tops and bottoms of continuous intervals.
5. Measure angular offset between lines parallel to core axis (MOL) and reference groove at one to two foot intervals.
6. Ask for separate interpretation sheets for the primary and backup cameras. If possible, have them read independently by different orienting engineers.

In the office:
1. Plot up multishot data and MOL/reference groove measurements from the core and overlay
2. Be sure multishot orientation data are accurately transcribed on any inhouse records and heading of MOL is accurately determined.

PALEOMAGNETIC TECHNIQUE

Prior to going in hole: No special procedures required. Scribe shoe is recommended but not mandatory.

While in the hole: No special procedures required.

When the orientation tool and core barrel are retrieved:
1. Carefully fit core together, mark line(s) (MOL) parallel to the axis of core.
2. Note breaks in core continuity caused by rubble zones, spin offs, connections. Record tops and bottoms of continuous intervals.

In the office:
Be sure paleomagnetic orientation data are accurately transcribed on any inhouse records and heading of MOL is accurately determined.

Table 4

Strengths and weaknesses

Application/value	MULTI-SHOT	PALEO-MAGNETIC
Deviated hole	F-P	G-F*
High angle deviated hole	F-P	G-F*
High latitude drilling site	F-P	F-P
High temperature hole	P	G
Coarse grained sediments	G	F-P
Rubble zones	P	P
Limited core continuity	P	F
Partial core recovery	P	G
Unconsolidated sediments	P	G†
Archived core	no	E
Visual core inspection	no	E
Core samples required	no	yes
Cased hole	P	G
Optional interval selection	F	E
Resolving anomalous points	P	F
Real time data	E	P
Onsite personnel	yes	no
Equipment failure	yes	no
Risk to hole	yes	no
Rig time	yes	no

E = excellent
G = good
F = fair
P = poor

* May be poor to north
† If not disturbed

bottoms of runs, and usually connection points. Using a straight edge, one or more lines parallel to the core axis must be marked the length of the core.

In the authors' experience, a right angle piece of aluminum, approximately 1 in. on a side and 18 in. to 3 ft long makes an excellent tool for this purpose.

A point at which a drillstring connection was made can generally be identified on the core by striations, grooves, and other surface markings which will exist on either side of a break. In some cases, the core will fit together across the break but there will be obvious offset in the scribe lines.

Identified connection points on the core must be carefully correlated to the equivalent drilling depth prior to marking the depths on the core. The positions of connection points as well as the top and bottom of the core must be considered when marking core footages in order to ensure the accuracy of depth correlations. After marking depths on the core it is then possible to record the beginning and ending depths for each continuous interval.

The angular offset between the master orientation line (MOL) and the reference groove should be measured and recorded every 1-2 ft over the length of each continuous interval (Fig. 6). A variety of circular protractors, rulers, or graphic displays can be adapted to make the necessary measurements.

Although circular protractors are more accurate, they are not as readily available. The most useful technique for identifying and correcting multishot errors is a plotting and overlay procedure using both the multishot records and the measurements taken directly from the core.

The multishot reference groove data are plotted on a graph. The true azimuth in degrees is plotted along the horizontal axis, and surface-recorded depth along the vertical axis. On a separate sheet the recorded measurements taken from the core are plotted on the same scale.

Ideally, the slope of the reference groove line should be similar for both sets of data. When the plots are overlaid, the lines should track each other closely (Fig. 7).

Overlays are useful for spotting both subtle and major problems in multishot data. Fig. 8 illustrates some types of problems which can be discovered using the overlay technique.

Identifying a problem, however, is less than half the battle in most cases. Some errors, such as the core/surface depth correlation error shown in Fig. 8, are relatively simple to correct. Core depths are high relative to the comparable Geolograph depth. Uncorrected, data over most of this interval would be measurably off.

The barrel tightening problem requires calculation of the cumulative error present in the multishot data at numerous points throughout the interval. The calculation is straight-forward only if the tightening is systematically cumulative.

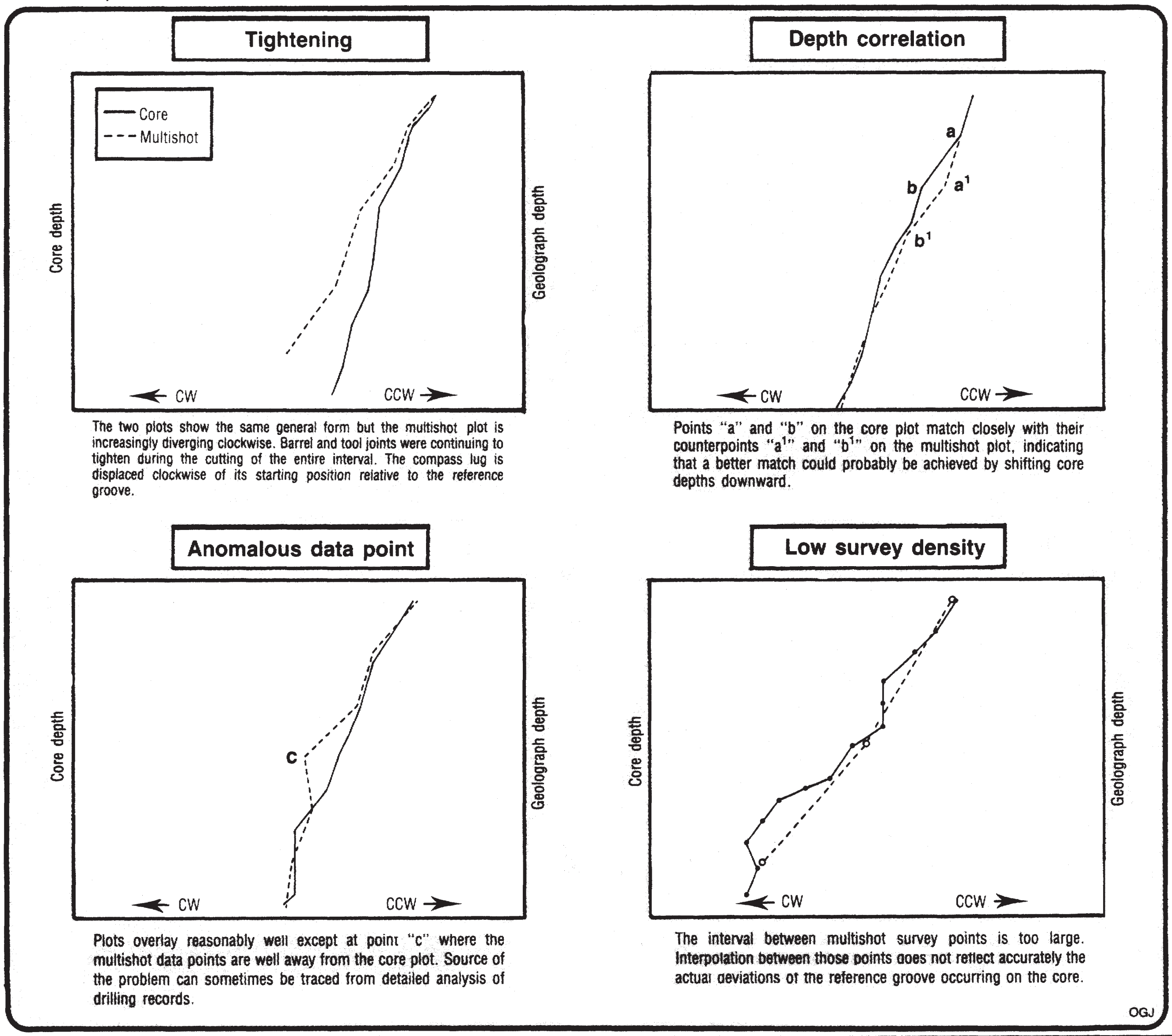
Some problems identified by an overlay may require extensive reference to complete records of the coring operation. One bad data point could stem from a short duration reduction in penetration rate or it could represent an anomalous point for which there is no obvious explanation. Although the overlay technique will indicate the presence of a problem, correction or explanation may not always be possible.

The overlay technique can be used to evaluate the magnitude of depth correlation errors and several types of multishot problems which are not constant over the length of the run. It cannot, however, detect error where every survey point is off by a constant amount, whether 1° or 180°. Thus, the emphasized importance of quality control, double checking equipment and measurements before and after running in the hole.

Transcription of records in a remote office offers some of the same opportunities for introducing errors as at the wellsite. Quality control must include sufficient checks to minimize this po-

Fig. 8

Overlays reveal problems



Tightening: The two plots show the same general form but the multishot plot is increasingly diverging clockwise. Barrel and tool joints were continuing to tighten during the cutting of the entire interval. The compass lug is displaced clockwise of its starting position relative to the reference groove.

Depth correlation: Points "a" and "b" on the core plot match closely with their counterpoints "a[1]" and "b[1]" on the multishot plot, indicating that a better match could probably be achieved by shifting core depths downward.

Anomalous data point: Plots overlay reasonably well except at point "c" where the multishot data points are well away from the core plot. Source of the problem can sometimes be traced from detailed analysis of drilling records.

Low survey density: The interval between multishot survey points is too large. Interpolation between those points does not reflect accurately the actual deviations of the reference groove occurring on the core.

tential in circumstances that may be far removed in both time and location from the original cutting of the core.

Paleomagnetic quality control. While paleomagnetic orientation requires no downhole blind procedures, the accuracy of the technique can still be affected by human factors similar to those encountered when using multishot. The procedures for marking and core handling are the same, and avoiding errors at this stage greatly increases accuracy. Paleomagnetic orientation tends to benefit from the fact that sampling and measurements are carried out under less adverse conditions. Equipment calibration and redundant measurement procedures reduce the chances for error.

Given that sources of human error are minimized, paleomagnetic orientation accuracy is largely dependent on the magnetization of the rock itself. The natural remanent magnetization of the rock consists of the composite (vector sum) of magnetizations that may be acquired through sedimentary, thermal, or chemical means.

Distinct paleomagnetic directions are recorded by many discrete grains, thus the measured vector is an average of these many individual directions. If the individual grain directions are very uniform, the grouping of the plug sample directions from a continuous interval of core will be good, and orientation accuracy will be enhanced (Fig. 9).

If the alignment of the many individual grains is highly variable, then accuracy will be diminished. In practice there are several magnetic components, commonly having different directions, contained in any one sample. These additional components are secondary magnetizations that have been recorded in the rock by chemical or thermal events generally occurring long after deposition.

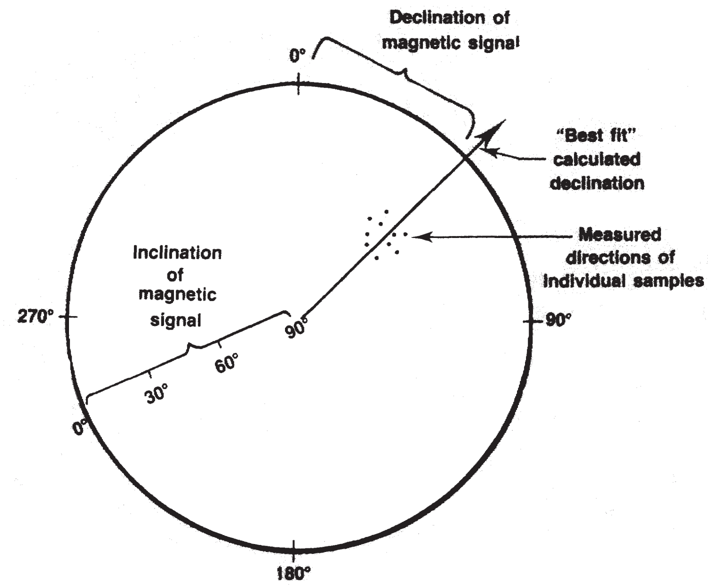
The different components can be separated in the laboratory using a variety of progressive demagnetization techniques. Different magnetizations are destroyed at somewhat different rates, usually obeying the "last in, first out" principle. Therefore, individual magnetizations are more precisely calculated from the vector subtracted over several demagnetization steps.

The subtracted vectors generally show much tighter groupings than do the directly observed resultant vectors.

Paleomagnetic measurements are amenable to sophisticated vector analysis techniques which enhance the orientation accuracy. These vector analysis techniques also provide sta-

Fig. 9

Stereonet plot



Simplified stereonet plot of magnetization directions in core coordinates of samples from a continuous interval with calculated "best fit" declination for core interval.

OGJ

tistical confidence limits that can be used to estimate the accuracy of the core orientation for each continuous interval.

Orientation accuracy. A review of multishot results covering 14 wells throughout the world showed significant errors (greater than 20°) or total equipment failure in 19 out of 40 cores. The types of errors and failures ran the gamut of errors discussed above.

Three runs recovered no useful data as a result of camera or scribe shoe failure.

Eight runs were systematically in error from 100-180° due to human errors in the shop, at the wellsite, and in the core processing facility.

Two runs revealed barrel tightening problems with an observed maximum error of 80°.

Other errors were attributed to single anomalous survey points or were of unknown origin.

Apart from the mechanical failures which were obvious at the wellsite, the other errors were discovered by comparison with previously established directional data from surrounding wells, and in reviewing the data using techniques discussed above. While quality control at every stage of a multishot orientation operation can significantly improve reliability and accuracy, the very nature of the multishot orientation limits the degree of improvement possible. The downhole equipment, multiple operations, and diverse personnel involved from beginning to end will always leave the technique vulnerable to error.

While orientation errors of 180 degrees are possible, under the best of circumstances multishot accuracy can be $\pm 5°$ but is more typically $\pm$ 10-15°.

The accuracy of paleomagnetic core orientation can be affected by such factors as steepness of the paleomagnetic signal, number of available samples, and lithology. Accuracies of $\pm 5°$ are possible and accuracies of $\pm 10°$ are common using the current technology.

With experience in an area and a formation, the amount of orientation error can usually be estimated in advance of coring. In circumstances where the signal inclination is very steep, the technique may not be applicable. But a review of projects to date found that no lithology or location, including the North Sea and North Slope of Alaska, yielded demonstrable orientation errors greater than 40°.

Table 4 provides a comparison of the strengths and weaknesses of multishot and paleomagnetic orientation techniques.

Orientation costs. Multishot core orientation costs are directly related to variables such as remoteness of drilling location, coring depth, hole conditions, service company involved, and equipment specifications.

Paleomagnetic core orientation costs vary depending on working location for plug collection, the quality and continuity of core to be plugged, the rock type, and the orientation accuracy desired.

The cost of either orientation technique can show tremendous variation from job to job as a result of these factors. Although a direct cost comparison is difficult, an analysis of the service company costs of 10 representative wells showed that the average service cost for the multishot was approximately $20/ft of core oriented less than for paleomagnetic orientation.

The costs for multishot orientation ranged from $50 to approximately $200/ft of oriented core for stateside wellsites. Paleomagnetic orientation costs range from $60 to approximately $190/ft oriented.

A truer comparison of orientation costs must factor in the tangible cost of rig time associated with running a downhole survey. A minimum of 1-3 hr rig time is needed for a typical multishot survey.

If intangible costs (due to problems such as jammed core or stuck pipe) are incurred as a result of the orientation survey, these costs must also be considered. Average costs for the two techniques are comparable when tangible rig costs are included. Undiscovered errors in data reported further increase the cost per foot of core accurately oriented.

Results and value. The paleomagnetic plug sampling technique and the multishot camera technique are the main alternative procedures currently available for orienting cores.

In most ways the paleomagnetic technique is simpler than the multishot technique since fewer people and less rig equipment and time are involved. For these reasons the potential for uncorrectable error in orientation is also reduced. Paleomagnetic orientation is more difficult if several components of magnetization are present in each plug sample. This difficulty can be resolved with proper interpretation techniques. Paleomagnetic orientation accuracy tends to be more amenable to verification and internal checks. Since the orientation is based on a magnetic property of the rock, additional verification is possible as long as the core can be resampled. It may also be possible to verify the paleomagnetic results, if necessary, by sampling adjacent cores or even surface outcrops.

Paleomagnetic core orientation is not subject to a wide variety of operational difficulties that can compromise multishot data. High bottom hole temperatures work to the advantage of the paleomagnetic technique. Poor recovery will not affect paleomagnetic orientation accuracy if the rock recovered is at least competent enough to assemble a continuous interval.

Both orientation techniques fall

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short of being the total answer to all orientation problems in all circumstances. Rubble that cannot be fitted together to form a cylinder cannot be oriented by either technique. High latitudes are potentially troublesome for both techniques, and poor core handling and marking procedures are always a cause for concern.

Core orientation data can sometimes be derived from dipmeter and televiewer records. In cases where this is possible, more direct methods of orientation are unnecessary.

All drilling operations involve considerable expense and risk. Downhole, each special procedure increases the risk of sticking pipe, hole collapse or blowout. Although core orientation data may be valuable to the geologists and engineers engaged in reservoir studies, concern for losing a well can be the overriding consideration. Complete understanding of the procedures involved in core orientation and very close attention to quality control during every stage of an orienting operation can do much to alleviate the concerns regarding the quality of the results. Removing the orienting operation from the downhole environment, as is the case with the paleomagnetic technique, eliminates additional concerns related to hole risk and expenses associated with rig time and operations.

Reducing risks and associated costs while improving orientation reliability permits application in situations where the benefits of orienting core were formerly considered to be marginal.

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