ACCURACY AND RELIABILITY OF ELECTRONIC INSTRUMENT CORE ORIENTATION SURVEYS

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ABSTRACT

Comparison of electronic instrument core orientation survey results with direct core measurements and paleomagnetic core orientation data for a west Texas well shows that the accuracy of electronic surveys can be seriously reduced by operator error, drilling induced vibration and tool torque. An example from a south Texas well demonstrates the need for careful tool setup and alignment at the well site.

Guidelines for proper tool setup, core handling and data analysis to minimize these problems include the following: (1) Use a multiplexer in the survey tool that scans rapidly, at least 30 cycles per second, and be sure all electrical connections are tight. (2) Center the tool with properly sized rubber finger or straight, rotating spring stabilizers and scratch a mark across each threaded connection to show if any of the joints loosen or tighten during coring. (3) Before coring, record a measurement with the tool stationary in the hole to obtain a reliable vertical reference for subsequent magnetometer measurements during coring. (4) Accurately correlate time with depth during coring by recording, at about two minute intervals, the time, measured with a stop-watch, and the corresponding geolograph depth. (5) After coring, assemble the core into physically continuous intervals, record interval depths and mark each interval with a straight reference line. Measure the angle between this line and the survey reference groove and compare this value with the angle predicted by the survey. (6) Compare the original, complete tool data with the final, edited report.

Paleomagnetics can be used to check the electronic survey and may be required to obtain accurate orientation data if much vibration is encountered during coring.

INTRODUCTION

Fully oriented diamond cores are increasingly important in modern exploration and reservoir development programs, which commonly require detailed information about directional properties of potential reservoir rocks. An accurate knowledge of fracture trends and regional stress fields, for example, is valuable for planning enhanced recovery projects such as water flooding, CO2 or Nitrogen injection, and is essential for modern horizontal well drilling programs.

Traditionally, most cores have been oriented using a down-hole, "multishot " survey instrument, which makes a photographic record of a compass mounted in the tool. Unfortunately, this technique may increase the risk and expense of a coring program because drilling and circulation must be stopped at regular intervals to obtain clear photographs. Error rates as high as 50% or more have been reported (Brindley, 1988).

In the past few years, however, new digital equipment has become available that permits continuous recording of core orientation readings without stopping. This Electronic Survey Instrument ("E.S.I.") technique promises to reduce the cost and risk of down-hole core orientation while significantly increasing accuracy and reliability (Brindley, 1988). As with any new technology, however, there are some serious pitfalls that must be avoided when the technique is used routinely at the well-site.

This paper discusses the theory and practice of E.S.I. core orientation and proposes quality control procedures to enhance the accuracy and reliability of the technique. The need for careful quality control is demonstrated by a case study of a commercial E.S.I. core orientation survey run on a well in west Texas. An example from a south Texas well demonstrates the need for careful tool setup and alignment at the well site.

ELECTRONIC SURVEY INSTRUMENT CORE ORIENTATION

Modern well site core orientation tools (Figure 1) are based on measurement-while-drilling (MWD) systems that provide measurements of directional drilling tool orientation (toolface updates) during drilling (Brindley, 1988). The instruments are self-contained, battery powered units that use triaxial accelerometers and magnetometers to measure the direction of the earth's gravity and magnetic fields at preset intervals during drilling. This information for each measurement station or "shot point" is stored in electronic memory during drilling and is downloaded to a small, personal computer when the tool is retrieved upon completion of the survey run. The computer is then used to calculate the orientation of the tool at each measurement station based on the recorded gravity and magnetic data. This information provides the compass bearing of a "reference" groove cut in the side of the core by a knife located just above the core catcher in the bottom of the core barrel (Rowley, et al, 1971).

To conserve battery power, the tool does not operate continuously. The operator can program the instrument to turn on initially after a delay of up to about nine hours to avoid a needless drain on the batteries while the tool is tripping into the hole. When the instrument turns on after this initial delay, it powers up, delays briefly to allow the electronics to stabilize and then reads and records each accelerometer and magnetometer axis in succession. The tool then powers down until the next measurement is taken (Tensor, Inc., 1988).

The measurement interval is set at the surface by the operator based on the expected penetration rate and length of core to be oriented. Ideally, several shots per foot are taken to obtain a high density data set that can be used to accurately correlate with depth any breaks that occur in the core. A longer sample interval may be required, however, when drilling rates are slow, to conserve battery power and to avoid running out of memory storage, which currently can hold about 1000 individual shots (Tensor, Inc., 1988).

QUALITY CONTROL PROCEDURES

In principle, the well site core orientation system seems fairly simple and straight-forward. A computer uses accelerometer and magnetometer measurements recorded by the tool to calculate the orientation of the survey tool. This information is then used to orient the core.

In practice, however, there are numerous complications. These include problems with tool setup and alignment, down-hole data acquisition, data analysis, data editing and core handling.

Tool Setup and Alignment

Reference Scribe Angle: Down-hole core orientation surveys typically use a survey instrument placed inside a non-magnetic drill collar just above the core barrel (Figure 2). Stabilizers center the instrument in the drill collar. The tool is connected via a series of spacers to a rod attached to the inner tube of the core barrel. The survey instrument orients a reference scribe knife located just above the core catcher at the bottom of the core barrel. The scribe knife cuts a groove in the core, and the survey provides the compass orientation of the groove. Thus, the angle between the survey instrument at the top of the core barrel and the scribe knife at the bottom must be accurately determined to obtain a reliable core orientation survey.

Some core barrel designs allow this angle to be measured and recorded in the shop when the core barrel is assembled. The position of the reference scribe knife at the bottom of the core barrel is marked on a threaded connector at the end of the thin rod by sighting along the length of the core barrel and marking the connector with a cold chisel. The angle between this mark and the orientation lug on the orientation tool is then measured after the tool and spacers are assembled (Rowley, et al, 1971).

For other core barrels, the angle is measured at the well site with the survey tool and core assembly hanging vertically in the derrick (Figure 3). A circular protractor with a movable arm is attached to the bottom of the inner sleeve of the core barrel as it hangs in the derrick. The zero mark on the protractor is aligned with the reference scribe knife. A telescope attached to this arm is then used to sight vertically along the core barrel to align the movable protractor arm with a metal rod or "flag" that marks the orientation of the survey tool at the top of the core barrel. A cross-hair in the telescope eyepiece is used to make the alignment precise.

In principle, this well site procedure appears very simple and straight-forward. In practice, the procedure is far from simple, requiring meticulous care at every step. For example, at night, on a wet, muddy rig floor with the core barrel swaying in the wind, the odds of a problem arising are relatively high.

A good quality telescopic sight with adjustable cross-hairs should be used on the telescopic protractor alignment tool (Figure 3). It is important to be sure that the vertical cross-hair of the telescope is parallel to a radius of the inner core barrel when the alignment tool is attached to the core barrel. This may be done by laying out the inner core barrel on a rack and marking the high side at each end using a welder's level (Figure 4). Fasten the alignment tool to one end of the core barrel and align the telescope with the high side mark. Place the welders level on the high side mark at the other end of the pipe such that the level bubble rod is vertical. Rotate the cross-hair reticle on the telescope until the vertical cross-hair is parallel to the vertical level bubble rod and tighten the set screw to lock in the cross-hair reticle orientation.

Be sure the survey engineer understands that the angle between the survey tool and the scribe knife is properly determined by rotating the alignment tool protractor arm until the survey tool flag is parallel to the vertical cross-hair (Figure 5). If the core barrel is bent slightly, the flag will not overlay the vertical cross-hair. The angle determined, however, remains valid so long as the flag is parallel to the cross-hair.

Determining the angle between the survey instrument and the reference scribe knife has been emphasized because this measurement is critical. An error will affect the entire survey and is extremely difficult to detect.

Tool Torque: Torques encountered during coring can be very high, twisting the orientation tool and core barrel assembly causing joints to loosen or tighten during coring. The result may be serious errors in the orientation survey or even physical damage to the survey tool itself. The numerous connections required to make up the orientation tool and spacer assembly must be carefully tightened by wrench so that they will not slip during drilling. If these connections either tighten or loosen, the survey will be inaccurate because the angle has changed between the survey instrument and the reference knife.

Scribe Knives: Another alignment problem that can arise involves the scribe knife shoe that cuts the reference groove in the side of the core (Figure 2). This shoe is normally fitted with three scribe knife blades. One blade scribes the reference groove used to orient the core while the other two help stabilize the core and scribe two "support" grooves in the core (Rowley, et al, 1971). Ideally, the three knives are set up so that the reference knife is closer to one of the support knives than it is to the other (Figure 6). Although scribe shoes with this asymmetric knife configuration are not always readily available, they should be used if at all possible because the asymmetric pattern of grooves they cut in the core allows rapid, unequivocal identification of the reference groove and unequivocal determination of top direction in individual core pieces.

Unfortunately, the presence of support knives in the orienting shoe occasionally results in a very serious, systematic error that is difficult to detect unless some independent orientation data are available. The error occurs when the orienting toolface of the survey instrument is mistakenly aligned with one of the support knives rather than with the reference knife. This is a serious mistake that is not uncommon and that can cause systematic errors of 120 degrees or more (Bleakly, et al, 1985).

Down-Hole Data Acquisition

Vibration during coring is a serious problem for E.S.I. core orientation that can potentially result in total loss of data or acquisition of data that are spurious or inaccurate. Vibration related problems include physical tool damage, intermittent loss of power, and abnormal functioning of survey tool sensors.

The modern down-hole survey tool is a sensitive, solid-state, electronic instrument that must be carefully designed to operate in the rugged down-hole environment encountered during coring operations. Because the tools were originally designed for MWD (Brindley, 1988), there have been problems with tool failure due to mechanical stress when the tools were used under the more rugged conditions encountered when drilling cores. Some tools are now available (see Brindley, 1988) that have been strengthened for use in orienting drill core. The modifications, which include filling the tool with a cushioning material to insulate its electronic circuit boards from mechanical shock and strapping down key electrical components to the circuit boards to keep them from vibrating loose, have reduced but have not eliminated failures due to the mechanical stress of coring.

Intermittent loss of power is another vibration related problem that affects E.S.I. core orientation. The problem appears to be caused by electrical contacts vibrating loose within the battery pack during coring. This can result in total loss of data if the memory resets or in the acquisition of spurious or erratic data because the electronics do not have time to stabilize properly before a measurement is taken.

Perhaps the most serious negative affect of vibration is that it degrades the performance of the sensors in the electronic survey tool. For example, vibration obviously interferes with the normal operation of the accelerometer used by the tool to determine a vertical reference based on the acceleration of gravity. Vibration can result in highly erratic accelerometer readings because it produces rapidly changing accelerations in many different directions.

Similarly, vibration can also degrade magnetometer readings from the survey tool, but in a way that is not so obvious (Figure 7). To take a reading from the magnetometer, the tool scans the three axes of the magnetometer in succession and then combines the readings to give a complete measurement of the total magnetic field. In combining the measurements from the three axes, the tool assumes that the axes are orthogonal. If the tool is vibrating rapidly, however, the orientation of the magnetometer axes may change during the time required for the tool to read each separate axis. Effectively, the magnetometer axes are then no longer orthogonal. Thus, a spurious magnetic direction is calculated when the data from the three axes are combined.

Data Analysis

Data from the electronic survey instrument may be analyzed in a number of ways to orient drill core, the method used being determined by variable drilling conditions such as angle of hole deviation, latitude of the well site, magnetic interference in the hole and intensity of mechanical stress and vibration encountered during coring. Selection of the correct data analysis method is absolutely essential to reliably orient drill core. For most coring situations, operators select one of three analysis options. The following is a summary of the three most commonly used analysis techniques (Tensor, Inc., 1988).

1) **Inclined Hole, Moderate Tool Vibration:** For highly inclined holes with moderate to low vibration during coring, the hole deviation is measured with the tool at rest before and after the survey. The accelerometer measurements, recorded at each shot point while coring is in progress, are then used to determine the high side of the core. The survey report lists the angle between the high side of the core and the reference groove at each shot point. It is usually left to the customer to calculate the azimuth of the reference groove by adding this reported angle to the azimuth of the hole deviation determined from the stationary shots that were taken before and after the survey.

2) **Nearly Vertical Hole, Low Tool Vibration:** For holes that are nearly vertical and for which vibration of the tool during coring is low, the inclination of the tool may be determined for each shot using data recorded by the accelerometer during drilling. The vertical reference is established by the accelerometer. The corresponding magnetometer reading is used to determine the compass orientation of the tool.

3) **High Tool Vibration:** For holes where tool vibration is high, the above techniques give erratic results because the accelerometer measurements recorded while coring is in progress are inaccurate. Under these circumstances the best procedure is to record an accelerometer measurement with the tool stationary, prior to the start of coring. This measurement is then used to determine the vertical reference for the tool for all subsequent shots taken while the core is being cut. The accelerometer data taken while coring is in progress are ignored, and the core is oriented by combining the stationary accelerometer data with magnetometer data acquired during drilling.

Data Editing

Regardless of the analysis technique used, the well site survey instrument produces much more data than is normally reported to the customer in the final report. A typical final report lists an orientation reading on a one foot spacing. The initial tool readout usually lists several readings per foot (compare Figures 11 and 12, Tables 2 & 3).

To determine which shots to include in a survey final report, the operator must first determine the depth at which each shot is taken. This is normally done by starting a stop watch when the tool is turned on and then comparing at regular intervals the time on the stop watch with the drilling depth shown on the geolograph. If the data are reasonably consistent from shot to shot, the shot selected is simply the one closest to the depth increment shown in the final report.

If the data vary considerably from shot to shot, however, as is often the case where tool vibration is high, the operator must select the "best" values to include in the report based on tool parameters such as reported hole deviation angle, total acceleration of gravity, total magnetic field strength and general "smoothness" of the data from point to point in the final report (see Table 3). The shot points selected for use in the final report are ideally those for which the above parameters most nearly match the values expected at the latitude and longitude of the survey site. This indicates that the accelerometer measurements have not been affected by random tool vibration, and the magnetometer measurements have not been biased by metallic "junk" in the hole.

Unfortunately, there may be enough variation in the quality control parameters from shot to shot to make selection of the "best" shot point somewhat subjective. In this situation, some survey engineers may tend to select shot points to minimize the apparent variation in direction from point to point in the final survey report. Thus, it is not uncommon for an E.S.I. core orientation report to be somewhat subjective, showing much less apparent variation than was present in the original data. The customer should always check for this possibility by comparing a copy of the initial, unedited probe data with the final, edited report.

Core Handling

No matter how good a down-hole survey is, the ultimate value of the survey depends on how the core is handled and marked after it is cut. A core is not oriented simply because a survey has been taken. A considerable amount of work must be done with the core itself, preferably <u>before</u> sampling or handling the core for any other purpose. All too often the cost of an orientation survey is totally wasted because early sampling and handling fails to take into account the critical needs of the orientation survey.

Core Layout and Marking: As soon as possible after an oriented core is taken it should be laid out, and the pieces carefully fitted together into continuous intervals of core separated by breaks in the core's continuity, such as spin-offs and rubble zones (Figure 8). The top and bottom of each continuous interval of core should be carefully recorded so that the original continuity of the core can be reconstructed after pieces of the core are removed for other studies, such as whole core analysis.

Once the core is laid out and fitted into continuous intervals, a straight line should be marked down the length of the core with a chalk line or a straight-edged piece of angle aluminum (Figure 8). This line should be placed carefully and made permanent with a marking pen or grease pencil because it will serve as a "Master Orientation Line" or "MOL" (see Van Alstine and Gillett, 1982). The orientation survey data are used to determine the compass orientation of the MOL. The orientations of directional features present in the cores, such as fractures or sedimentary structures, are measured relative to this line.

The straight MOL is useful because the reference groove scribed by the orienting core barrel is seldom straight and may even spiral around the core like a "barber pole." Thus, orienting features relative to the reference groove can be tedious.

Depth Control and Survey Quality Check: More importantly, marking an MOL on each continuous interval of core provides a means to check on the quality of the orientation survey and to compensate for certain errors that sometimes occur (see Bleakly, et al, 1985). This can be done by measuring and recording the angular deviation between the MOL and the survey reference groove at regular intervals. The observed deviation as a function of depth can then be compared to the expected deviation calculated from the orientation survey report. Any significant discrepancy indicates that there is a problem with the orientation survey for the depth interval over which the discrepancy occurs.

A common source of error is a depth shift between the core and the orientation survey. This can be checked by shifting a plot of expected deviation with depth up or down relative to a plot of the observed deviation with depth (Figure 9). If the two curves match after a reasonable shift in depth, this shift can then be applied to correct survey depths to match core depths (see Bleakly, et al, 1985).

Even after a depth shift has been applied, a more subtle problem is commonly observed in orientation survey data. The observed and expected angular deviations between the MOL and the reference groove commonly match in the upper portions of a continuous interval and then begin to drift apart toward the base of the continuous interval. Thus the orientation survey data become increasingly inaccurate toward the base of the continuous core interval, with a bias in direction that is usually clockwise, looking down the core.

This error suggests that the survey tool and spacer assembly has experienced a torque during coring that has caused it to twist progressively as coring proceeded. This twist changed the angle between the orientation tool and the scribe knife producing the observed systematic error in the orientation survey. Partial compensation for the error can be achieved by calculating the average angular bias per foot and subtracting it from the orientation survey results. The problem can be minimized by using survey data for the top of a continuous interval of core to obtain the compass orientation of the MOL for the entire interval. This avoids the less accurate survey data from lower in the interval.

ERROR ANALYSIS

The accuracy of E.S.I. core orientation is difficult to evaluate routinely because it depends on a number of factors, including drilling conditions and procedures and tool setup and handling, which tend to be poorly constrained and are seldom well documented. Mistakes in tool setup, for example, can cause systematic errors as large as 180° that are extremely difficult to detect after the survey is taken.

The minimum error under ideal conditions, however, can be estimated with some accuracy. Nelson, et al (1987) have determined that, under ideal conditions, the accuracy of the original down-hole orienting technique, which uses photographs of a multishot survey tool compass (Rowley, et al, 1981), is about ±11°. Brindley (1988) states that the accuracy of the newer, E.S.I. technique, is about 2.5° better than the multishot technique. Thus, the accuracy of E.S.I. core orientation under ideal conditions should be about ±8.5°.

Conditions on a drill rig are seldom ideal, however. Nelson (1987) estimates that the accuracy of down-hole core orientation techniques is about ±10°, provided certain conditions are met:

1) The reference grooves should be clearly cut and should run straight down the length of the core. If the grooves spiral around the core, small errors in depth could cause large errors in orientation.
2) Orientation data are most reliable for continuous intervals of core that are at least 6 to 10 feet thick because inaccurate depths due to rubble zones or missing intervals can cause serious orientation errors.
3) The initial probe data should show relatively little variation between shots, and the azimuth of the reference groove in the final report should either remain constant or increase gradually with depth over each continuous interval of core.

4) As a function of depth, the angle measured directly on the core between the reference groove and the MOL should agree with the angle calculated from the orientation survey. If the angles do not agree after a small amount of depth shifting, the orientation survey is inaccurate and should not be used.

Even when these criteria are met by a survey, it is important to recognize that there may still be serious, systematic errors. For example, if the angle between the orienting instrument toolface and the reference scribe knife is recorded incorrectly or changes during drilling, an entire survey may be inaccurate by a large amount even though the tool itself functioned perfectly and all the data are internally consistent. It is, therefore, highly desirable to check the orientation survey by orienting part of the core using an independent technique such as paleomagnetics, or, if the rocks are well bedded, by comparison with a high-quality dip meter survey.

CASE STUDY #1

South Fault Block Unit 4-62 Well, West Texas

Phillips South Fault Block Unit ("SFBU") 4-62 well in west Texas provides an informative case study of E.S.I. core orientation under severe conditions. In the Fall of 1988, eight fully oriented diamond cores were cut, recovering about 160 feet of highly fractured Ellenburger Formation.

Drilling was difficult. Blowouts and lost circulation resulted in long down-hole times. Foam had to be used instead of mud to minimize lost circulation. Without the damping effect of mud in the hole, drilling induced vibration was severe.

Under such adverse conditions it is not surprising that problems were encountered with the E.S.I. core orientation survey. The problems were not unique, however, and may also occur under more normal drilling conditions.

Problems Encountered

Multiple E.S.I. core orientation reports were issued for each of the first three oriented cores drilled from the SFBU 4-62 well. Orientation values for the same core differed between reports by as much as 170^{o}.

Two E.S.I. reports were issued for the first oriented core (core #1 in the drilling program). The first report indicated that the reference groove scribed in the core by the orienting core barrel zig-zagged down the core, spiraling over 20^{o} per foot in some intervals (see Table 1, Figure 10). Direct observations on the core, however, showed that the reference groove was actually relatively straight. The second report

(Table 1, Figure 10) was in much better agreement with direct observations except for an apparent clockwise bias (looking down the core) of 5 to 10°, increasing gradually with depth.

Similarly, the initial E.S.I. report (see Table 2, Figure 11) for the second oriented core (core #5 in the drilling program) indicated that the reference groove spiraled over 100° per foot. Direct observation of the core, however, showed that the groove was actually straight. A second E.S.I. report was generated with similar results. Finally, a third E.S.I. report issued that indicated a straight reference groove as actually observed on the core.

At this point in the coring program systematic sampling for paleomagnetic core orientation was begun because the E.S.I. results were clearly questionable. The orientations reported in the initial E.S.I. report (Figure 13) for the third oriented core (core #9 in the drilling program) indicated a relatively straight reference groove, as observed on the core, but differed by over 144° from the orientations determined using paleomagnetics. The fact that a discrepancy existed was reported to the service company, but the actual value of the paleomagnetic orientation was withheld. After reanalyzing the data for a few days, the service company released a revised report matching the paleomagnetic orientation within 5° (see Table 4, Figure 13).

Rigorous quality control quidelines applied to subsequent cores greatly improved the accuracy and reliability of the E.S.I results. Only one E.S.I. report was generated for each of the subsequent cores. E.S.I. data for these cores generally agree with the paleomagnetic results (Table 4).

Some orientation data was lost for several cores, however, because down-hole time was excessively long causing the batteries to run down. Also, the tool occasionally generated spurious data when the power supply became low or intermittent.

Overall, three types of problems were encountered with the down-hole core orientation surveys for the SFBU 4-62 well - problems related to excessive vibration during coring, inaccurate correlation of time with depth, and equipment failures.

Problems Related to Excessive Vibration

Incorrect data analysis option: The first hint of trouble with the SFBU 4-62 down-hole core orientation survey came when the survey engineer issued two reports for the first oriented core, with orientations differing up to 33° for the same depth (see Table 1, Figure 1).

The problem apparently arose because the data analysis method normally used by the service company (company A in this report) failed to adequately compensate for extremely high tool vibration. The survey company used commercially available software for data analysis. This software provided several different options for calculating the final orientation results. The analysis option chosen to generate the first report used survey tool accelerometer readings that were recorded at each shot point while coring was in progress to determine the vertical reference for each magnetometer measurement. Unfortunately, the nearly random accelerations caused by extreme tool vibration produced extremely erratic vertical reference measurements and, therefore, correspondingly erratic core orientation results.

The data analysis option chosen for the second report gave more consistent orientations. This option used a single reading recorded while the tool was stationary in the hole prior to coring to determine a vertical reference that was used for the entire core.

Subjective Data Editing: The two E.S.I. core orientation reports issued initially for the second oriented core from the SFBU 4-62 well were nearly identical (Table 2, Figure 11) even though one report used the first data analysis option discussed above, and the other report used the second option. Direct observation of the core, however, showed that the reference groove was straight whereas the E.S.I. reports indicated that the groove should have spiralled by at least 170° down the length of the core. At this point the survey engineer reexamined the data and issued a third E.S.I. report indicating that the reference groove was straight, in agreement with the direct observations (Table 2, Figure 11).

This inconsistency between E.S.I. reports apparently resulted from subjective editing of initial E.S.I. probe data by the survey engineer. As is normal for E.S.I. core orientation, the survey tool was set by the operator to take several readings per foot and then edited to produce a final report listing only one reading per foot. Ideally, the readings taken closest to the one foot spacing would have been reported, and the other readings used by the operator to verify proper tool operation and time to depth correlation. Apparently, tool vibration was so severe, however, that the parameters used for editing, such as the measured acceleration of gravity (GTotal), total magnetic field intensity (HTotal) and inclination of the measured magnetic field direction (Dip), tended to vary erratically in this survey, making editing difficult (see Table 3, Figure 12). Thus, a great deal of operator judgment was required to select the readings that were included in the final reports.

Subjective data editing poses a potentially serious problem for E.S.I. core orientation quality control because there is a natural tendency for operators to select readings that minimize the apparent variation in orientation readings from foot to foot as listed in the final report. For example, comparison of Tables 2 and 3 shows that the initial data for continuous interval #1 of core #5 vary up to 173° between readings whereas the reported results vary a maximum of only 12°, and the editing parameters do not allow the unequivocal selection of one data reading over another for many of the shots. Thus, the final report fails to reveal the actual variability in the data and gives the customer a false sense of security in the accuracy of the results.

To minimize this problem on subsequent cores, a complete listing of the initial E.S.I probe data was obtained and used to independently check the quality of the E.S.I. core orientation reports. Although it was not always possible to improve on the editing done by experienced E.S.I. operators, examination of the complete data listing at least gave a better sense of the data accuracy than the edited final report. Also, highly questionable parts of the survey became readily apparent.

Although orientation survey companies do not routinely provide the customer a complete listing of the data output from the survey tool, it appears highly desirable for the customer to insist on receiving a copy along with the final report. In addition, a complete listing should be obtained of the final orientations for each shot point calculated using the "magnetic only toolface" option for data reduction, which applies one vertical reference reading to all measurements. Without these complete listings, it is virtually impossible for the customer to quality control an E.S.I. core orientation survey.

Incorrect Time-Depth Correlation: Both E.S.I. and paleomagnetic techniques were used on the third oriented core, and the E.S.I. data were found to differ from the paleomagnetic results by 144° (Table 4, figure 13). Survey engineers eventually determined that the E.S.I. orientation was incorrect. Time had been incorrectly correlated with depth so that the wrong shot points were used to orient the core. Thus the originally reported orientations were totally incorrect. After time was properly correlated with depth, so that the correct shot points were used, the down hole survey orientation matched the paleomagnetic orientation within 5° (Table 4).

Apparently this problem arose because the survey engineer relied in part on the geolograph clock at the drill rig, which failed to keep accurate time. The start and finish of the survey were recorded using an accurate stop watch, but the engineer failed to record corresponding stop watch time and geolograph depth readings at regular intervals throughout the coring operation, relying instead on the inaccurate geolograph record of time and depth.

Equipment Failures: Extreme vibration during coring, long down-hole times due to drilling difficulties and operator error handling the survey tool all contributed to equipment failures affecting the quality of E.S.I. core orientation for the SFBU 4-62 well.

Vibration during coring apparently caused sporadic separation of electrical contacts in the survey tool's battery pack resulting in intermittent loss of power during some coring runs. This produced either total loss of data because the memory reset or spurious data because the electronics in the tool had insufficient time to stabilize following a power loss.

Long delays on several coring runs due to drilling difficulties caused problems for the E.S.I survey because the survey tool batteries were nearly exhausted before coring began. As the charge on the batteries ran low, the tool either started producing spurious data or shut down and gave no results.

One case of operator error setting up and handling the survey tool was observed on the SFBU well. The error seriously intensified problems with vibration for the second oriented core (see Figures 11 & 12). In this case the operator failed to tie the survey tool to the air hoist cable at several places along its length prior to lifting the tool onto the drill platform. As a result, one of the rotating spring stabilizers used to center the tool within the drill collar was bent. This caused the tool to move with an eccentric, off-axis motion during coring, which produced increased vibration and highly erratic data.

<u>Summary of Problems Encountered</u>

In summary, problems with the E.S.I. core orientation survey for Phillips SFBU 4-62 well include the following:

1) Multiple E.S.I. core orientation reports were issued for each of three cores. Orientation values listed for the same core differed up to 170° between reports.
2) High tool vibration made the initial E.S.I. probe data highly erratic. As a result, the final orientation survey reports were highly subjective, including only the "best" readings, apparently selected in part to minimize apparent scatter in the data.
3) One core was misoriented by about 137° because time was incorrectly correlated to shot point depth.
4) The Long down-hole times required for several cores caused either acquisition of spurious data or total loss of data because the survey tool batteries ran down.
5) Inaccurate data were obtained for one core due to excessive vibration caused by a survey tool stabilizer that was bent when the tool was improperly lifted to the drill platform.

Service Company Comparison

Most of the SFBU 4-62 well down-hole core orienting was done by one contractor (company A). A second contractor (company B), however, was used for the final three cores. Thus, the performance of two slightly different E.S.I. tools and analytical techniques can be compared.

The survey tools used by both company A and company B were quite similar in basic design. Both were based on measurement-while-drilling (MWD) systems that provide measurements of directional drilling tool orientation (toolface updates) during drilling. Company A used the same tool for both MWD and core orienting operations. Company B used a slightly modified tool for core orientation.

The primary difference between the tools used by the two service companies was that the tool used by company B had been strengthened to hold up better under the increased vibration encountered during coring. Also the multiplexer in the tool scanned the accelerometer and magnetometer sensors 32 times per second, faster than the multiplexer in the tool used by company A, which scanned the sensors about 11 times per second. In addition, a proprietary design was used for the accelerometer in the tool used by company B whereas the tool used by company A contained a commercially available accelerometer.

The initial probe readings recorded at each shot point by company B were generally less erratic than those recorded by company A (compare Tables 3 & 5, Figures 12 & 15). The final reported orientation values, however, varied up to 15° even though the reference groove was nearly straight (Table 5, Figure 14), suggesting that vibration was still a problem.

Both service companies experienced power supply problems due to abnormally long down-hole times caused by drilling problems. The response of the tools to low power supply, however, was different. The tool used by company A gave erroneous results when the charge on the batteries ran low. The tool used by company B shut down and gave no results.

As a result of these differences, the tool used by company B may be somewhat more reliable than the tool used by company A and could give slightly better results in high vibration environments such as were encountered on the SFBU well. Based on the SFBU results, however, the difference in tool performance does not appear to be great. The care and experience of the engineer who runs the survey and interprets the results is far more important than minor differences in tool design. Also, this was not a truly accurate comparison of tool performance and analysis techniques because the survey by company B was done in less fractured rock that drilled more smoothly than was the case for the survey by company A.

Perhaps the most significant difference between the surveys run by the two service companies was the method used for data analysis and interpretation. Company A used a commercially available computer software package to arm their probe and analyze the data. This software provided several different analysis options providing great flexibility for optimizing the analysis to handle a wide range of drilling conditions. Company B, in contrast, had relatively few options available for computer analysis of survey data in the field.

Paleomagnetic Core Orientation

Paleomagnetic core orientation proved to be invaluable in sorting out the problems encountered with E.S.I. core orientation for the SFBU 4-62 well. The paleomagnetic technique successfully oriented all but one of the intervals cored and was used exclusively for fracture analysis and directional strain release studies requiring oriented cores (see Table 4). Although the final, corrected E.S.I. reports for each core agreed within ±15° with the paleomagnetic survey, some of the most serious errors in the E.S.I. survey might have been missed without the paleomagnetic core orientation data.

CASE STUDY #2

Ward C #11 Well, South Texas

Some core barrel designs allow the angle between the survey instrument at the top of the core barrel and the scribe knife at the bottom to be measured in the shop when the core barrel is assembled. For others, however, the angle is measured at the well site with the survey tool and core barrel assembly hanging vertically in the derrick (Figure 3). The latter method was used to align the survey tool and core barrel assembly for the Phillips Ward C #11 well in south Texas, which was cored during the spring of 1990.

Problem: In principle, the well site alignment procedure appears simple and straight forward. In practice, under the less than ideal conditions commonly encountered at the well site, the odds of a problem arising are relatively high. Such was the case with the Ward C #11 well. The following is a summary of the problems that arose:

1) The eyepiece and elbow assembly of the alignment tool telescope fitted loosely in the telescope tube. Jiggling the assembly slightly changed the angle measured with the instrument by as much as 20°. The telescope was new and did not appear to have been damaged so this problem apparently related to instrument design and manufacturing.

2) The inner core barrel was slightly bent, a situation that is very common and virtually impossible to avoid. As a result, the survey engineer found it difficult to properly align the telescope cross hair with the flag (see Figure 5). At one point, the engineer thought alignment had been achieved, but a visual sight along the core barrel without the telescope showed that the alignment was off by a least 20°.

3) It appeared that the cross-hair reticle was not properly calibrated in the eyepiece so that the angle measured with the device would have been inaccurate even if the correct procedure for a bent core barrel had been followed.

Solution: This problem was solved by using better equipment and a simple, well site calibration technique.

1) A good quality telescopic rifle sight, with cross-hair adjustments, was used to replace the telescope originally supplied with the telescopic protractor alignment instrument.

2) The rifle sight cross-hair was aligned by laying the inner core barrel horizontally on a rack at the well-site and marking the high side at both ends with a welder's level (Figure 4). The alignment tool was then clamped to one end of the core barrel and the protractor arm rotated to align the telescope with the high-side mark. The welder's level was placed on the high side mark at the other end of the core barrel so that the level bubble rod was vertical. The cross hair reticle was then rotated until the vertical cross-hair was parallel to the vertical level bubble rod and the set screw tightened to lock in the adjustment (Figure 4).

3) The proper procedure for sighting on the alignment flag with a bent core barrel is to rotate the alignment tool protractor arm so that the flag is aligned parallel to the vertical cross-hair of the telescope. By aligning parallel to the flag, and assuming the vertical cross-hair has been calibrated to the axis of the core barrel, a correct orientation is achieved in spite of any bend in the core barrel (Figure 5). The originally observed error was caused by rotating the protractor arm so that the flag passed through the center of the cross-hair. This placed the flag at an angle to the vertical cross-hair.

The accuracy of the new telescopic alignment system was checked by comparing the telescopically measured angle between the survey tool and scribe knife with the angle determined directly by using a plumb bob and tape measure to measure the offset across connections between marks scratched on each piece of the core barrel assembly. The results agreed to within about ±1° verifying the accuracy of the new alignment system.

SUMMARY OF RECOMMENDED QUALITY CONTROL PROCEDURES

1) If possible, determine the angle between the survey tool and the reference scribe knife in the shop when the core barrel is assembled. If this is not possible, use a telescopic protractor alignment tool with a good quality rifle or pistol type telescopic sight to measure the angle with the core barrel hanging in the derrick (an elbow bend added to the eyepiece is desirable for safety so that the operator does not have to stand directly under the core barrel). Be sure to check the alignment of the telescope cross-hair. The vertical cross-hair should be parallel to a radius of the inner core barrel when the alignment tool is attached to the core barrel.

2) Be sure the survey engineer understands that the angle between the survey tool and the scribe knife is properly determined by rotating the alignment tool protractor arm until the survey tool flag is parallel to the vertical cross-hair. If the core barrel is slightly bent, the flag will not overlay the vertical cross-hair. The angle determined, however, will be valid so long as the flag is parallel to the cross-hair.

3) One or two stationary readings should be taken before and after coring and at each connection point to provide an accurate check on time-depth correlation, to obtain accurate hole deviation, regional gravity and regional magnetic parameters for survey quality control, and to establish a reliable vertical reference for the survey tool magnetometer. Vertical reference data obtained while coring is in progress may be unreliable due to tool vibration.

4) Insist that the final core orientation report include a copy of the original shot-point data unloaded from the tool. Compare the data with the actual core. If the reference groove on the core is relatively straight or spirals smoothly with depth while the shot point data for the same depth interval jump around, then the quality of the survey is suspect.

5) The geolograph clock on the drill rig may be inaccurate. Avoid incorrect correlation of shot points with depth by insisting that the survey engineer keeps track of time with a stop-watch, independently from the geolograph clock. At about two to four minute intervals, the engineer should record stopwatch time and corresponding geolograph depth. The time of any significant drilling breaks or changes in pump pressure should also be recorded. The final report should contain a copy of this record.

6) Use either rubber finger or rotating spring stabilizers to center the survey tool within the non-magnetic drill collar. If rubber fingers are used, be sure they are long enough to minimize tool vibration but short enough not to twist the assembly by binding inside the drill collar. If rotating springs are used, the survey tool should be tied to the air hoist line at several points before lifting it onto the drilling platform to avoid bending the stabilizers at the rotating joints. A bent rotating spring stabilizer can induce an eccentric motion in the

tool resulting in erratic readings. Avoid using rubber fin stabilizers, which may increase the possibility that the survey tool assembly will torque or twist during drilling and thereby bias the orientation results.

7) If available, request solid or poured battery packs to power the down-hole survey tool rather than stacks of individual cells. Vibration produced by drilling can break the contact between individual cells causing intermittent loss of power. Spurious data can be generated before the tool electronics stabilize after each power break.

8) Check that both the direction and magnitude of the magnetic declination correction have been calculated correctly.

9) Mark a scratch across each joint in the survey tool assembly after it has been made up and tightened. Examine the scratches after coring to determine if any of the joints have loosened or tightened. The results of this examination should be included in the final report.

10) Core should be laid out, continuous intervals recorded and a straight Master Orientation Line (MOL) drawn along the length of the core before any sampling is done. Measure and record the angle between the MOL and the survey reference groove on the core at regular intervals. Compare the angles directly observed with those calculated from the orientation survey. If the results do not agree, depth shift the survey data until a match is achieved. If no agreement can be obtained by a reasonable amount of depth shifting, the survey is probably inaccurate.

11) Some paleomagnetic orientation should be done routinely to check against systematic E.S.I. errors that are otherwise difficult to detect. Such errors can occur, for example, when the angle between the reference scribe and the survey tool is recorded incorrectly. Paleomagnetic core orientation may be used independently or as a backup if problems are encountered with an E.S.I. core orientation survey.

TABLE #1

SFBU 4-62 WELL
Core #1

E.S.I. Core Orientation Final Report
(Company A)

Measured Depth	Shot	Reference Groove 1st Report	Reference Groove 2nd Report	Reference Groove Observed on Core*
7760	468	344.3	344.3	344
7761	485	345.1	344.7	346
7762	500	352.2	350.4	348
7763	520	2.8	352.7	350
7764	539	0.4	354.0	352
7765	557	6.1	358.3	354
7766	572	334.9	359.7	355
7767	586	3.8	359.9	358
7768	603	15.4	3.3	0
7769	624	40.4	7.2	1
7770	639	354.0	9.2	3
7771	655	41.2	11.8	7
7772	671	29.6	12.6	9
7773	692	46.2	16.6	11
7774	710	51.7	18.8	12
7775	722	27.7	18.7	14
7776	740	32.8	29.4	17
7777	755	38.7	25.5	20
7778	773	59.9	30.1	26
7787	912	45.2	40.2	
7788	931	36.9	48.0	
7789	953	50.2	50.8	
7790	972	52.1	51.8	

* Orientation of the reference groove as measured directly on the core relative to the compass bearing of the first electronic survey instrument orientation measurement at the top of a continuous interval of core.

TABLE #2

SFBU 4-62 WELL
Core #5

E.S.I. Core Orientation Final Report
(Company A)

	Measured Depth	Shot	Reference Groove 1st Report	Shot	Reference Groove 2nd Report	Shot	Reference Groove 3rd Report	Observed on Core**	
	7817	483	141.9	483	141.9	483	141.9	142 |	
	7818	497	134.0	497	134.0	497	134.0	146 |	
	7819	509	142.8	509	144.3	509	144.3	155 |	Interval
A>	7820	529	329.6	529	332.5	523*	158.9	150 |	#1
B>	7821	551	339.0	551	341.2	541*	158.8	152 |	
	7822	566	117.1	566	119.7	564*	158.8	156 |	
C>	7823	581	325.9	581	328.4	577*	137.9	156 |	
	7824	595	338.6	595	341.3	590*	11.3	11 |	
	7825	606	309.0	606	311.5	604*	300.4	12 |	Interval
	7826	620	258.1	620	260.3	620	260.3	19 |	#2
	7827	639	307.8	639	311.4	639	311.4	7 |	
	7828	657	334.6	657	336.0	656	272.9		
	7829	666	6.5	666	8.7	670*	277.3		
	7836	-	-	-	-	760*	144.2		

* Note that shot point differs from earlier reports.

** Orientation of the reference groove as measured directly on the core relative to the compass bearing of the first electronic survey instrument orientation measurement at the top of a continuous interval of core.

TABLE #3

SFBU 4-62 WELL
Core #5

E.S.I. Initial Probe Data*
(Company A)

	Reference Shot	Time	Groove*	GTotal[1]	HTotal[2]	Dip[3]
	519	13:38:00	161.3	1007	104002	36.2
	520	13:39:00	68.6	1000	106817	35.5
	521	13:40:00	338.6	1005	90557	14.4
	522	13:41:00	207.0	993	79938	39.2
A3>	523	13:42:00	158.9	1000	106744	35.3
	524	13:43:00	158.7	1001	97696	27.1
	525	13:44:00	68.6	1017	94677	22.9
	526	13:45:00	108.3	992	59824	44.9
	527	13:46:00	68.6	1001	96495	25.2
	528	13:47:00	158.6	999	88711	10.4
A1,A2>	529	13:48:00	331.8	1001	68310	63.5
	530	13:49:00	338.0	988	63065	77.9
	531	13:50:00	68.5	913	99340	28.3
	532	13:51:00	68.6	1001	101008	30.1
	533	13:52:00	175.4	1003	35213	26.6
	534	13:53:00	179.3	1001	88422	40.3
	535	13:54:00	26.4	1007	69397	26.7
	536	13:55:00	338.7	1001	87880	-5.4

* To compare with Table #2, the value for each shot has been converted from direct instrument reading to reference scribe orientation by adding 9.14^{o} for magnetic declination, 102.4^{o} for the angle between the instrument toolface and the reference scribe, and 2.15^{o} for approximate hole deviation compensation.

[1]G Total is the measured acceleration of gravity at each shot point.

[2]H Total is the measured geomagnetic field intensity at each shot point.

[3]Dip is the measured inclination of the geomagnetic field at each shot point.

TABLE #4

SFBU 4-62 WELL
PALEOMAGNETIC CORE ORIENTATION

INTERVAL* (FT.)	E.S.I. SURVEY M.O.L.	PALEOMAGNETIC* M.O.L.	A95*, PB*
7760.0-7790.0	360	352	7, 12
7817.0-7823.0	"350"	"336"	31, 2
7824.0-7827.0	122	-	unstable
7854.0-7858.0	(A)167, (B)316	311	10, 9
7861.5-7862.5	210	213	12, 7
7863.8-7865.0	"211"	"252"	14, 4
8071.8-8080.0	156	153	10, 5
8089.0-8098.0	171	164	10, 1
8191.5-8205.3	120	122	6, 5
8370.5-8374.6	355	360	5, 1

DEFINITIONS*

INTERVAL: Continuous length of core consisting of core pieces that fit together without breaks.

M.O.L.: (Master Orientation Line) - A straight reference line marked down each continuous interval of core.

PALEOMAGNETIC M.O.L.: Compass orientation of the M.O.L. in core coordinates, based on paleomagnetics. Since the M.O.L. is straight, one measurement applies to an entire interval.

E.S.I. SURVEY M.O.L.: Compass orientation of the M.O.L. based on the final version of the Electronic Survey Instrument (E.S.I.) reports.

A95: Semi-angle of the cone of 95% confidence for the distribution of paleomagnetic measurements from each continuous interval.

PB: Magnitude of the "Plugging Bias" correction applied to correct measured magnetization directions for a biasing magnetic overprint imparted during core plugging.

TABLE #5
Core # 21

SFBU 4-62 WELL

E.S.I. Core Orientation Final Report
(Company B)

Measured Depth	Shot	Reference Groove (E.S.I.)	Observed on Core*
8370	472	135.8	
8371	477	142.9	143
8372	N.A.	130.2	146
8373	N.A.	145.8	149
8374	N.A.	150.9	152
8375	N.A.	148.1	

* Orientation of the reference groove as measured directly on the core relative to the compass bearing of the first electronic survey instrument orientation measurement at the top of a continuous interval of core.

TABLE #6

SFBU 4-62 WELL
Core #21

E.S.I. Core Orientation Initial Data
(Company B)

Shot	Reference Groove	GTotal[1]	HTotal[2]	Dip[3]
472	126.8	1004	54210	61.4
473	131.5	1002	54310	63.3
474	130.4	1003	54450	64.5
475	127.2	1018	54530	54.3
476	134.8	1005	54240	62.4
477	133.9	1006	54330	60.6
478	133.0	1029	54540	51.8
479	135.8	1007	54370	72.6
480	139.0	1004	54350	72.9

[1]GTotal is the measured acceleration of gravity at each shot point.

[2]HTotal is the measured geomagnetic field intensity at each shot point.

[3]Dip is the measured inclination of the geomagnetic field at each shot point.

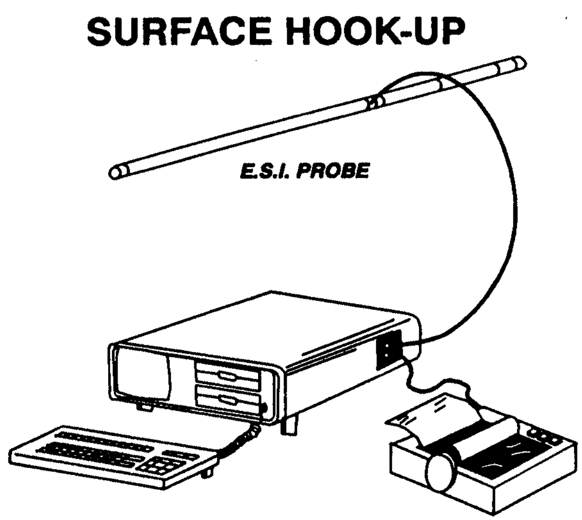

Figure 1 - Surface hook-up for arming a typical E.S.I. tool prior to a survey and for reading and storing data using a portable computer at the well site when the survey is complete (from Brindley, 1988).

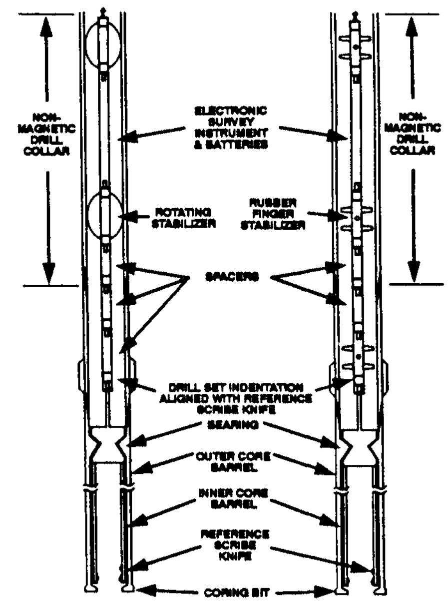

Figure 2 - Schematic diagram showing an E.S.I. tool and orienting core barrel assembly with rotating stabilizers and a similar assembly with rubber finger stabilizers.

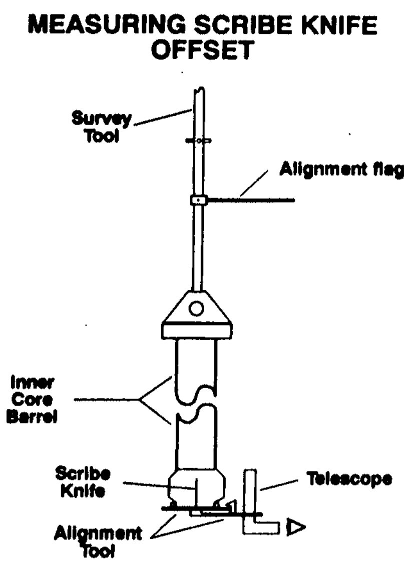

Figure 3 - Schematic diagram of setup for measuring the angle between the E.S.I. toolface and the reference scribe knife at the well site. The orienting tool and core barrel assembly hang vertically in the derrick during this procedure.

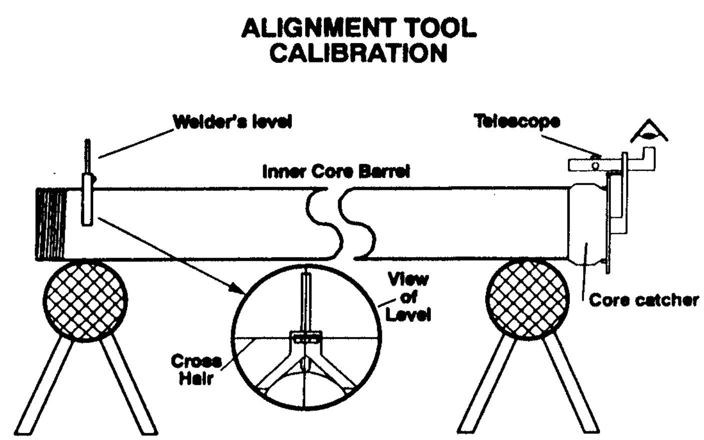

Figure 4 - Schematic diagram of the well site procedure for calibrating the E.S.I. telescopic protractor alignment instrument.

"FLAG" ALIGNMENT

(View Through Alignment Tool Telescope)

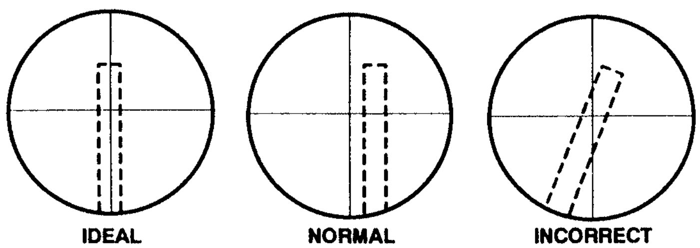

Figure 5 - Alignment flag viewed through the E.S.I. protractor alignment instrument telescope. A) Protractor properly aligned on flag under ideal conditions with straight inner core barrel. B) Protractor properly aligned on flag with bent inner core barrel. C) Protractor improperly aligned on flag.

VIBRATION EFFECT ON E.S.I.

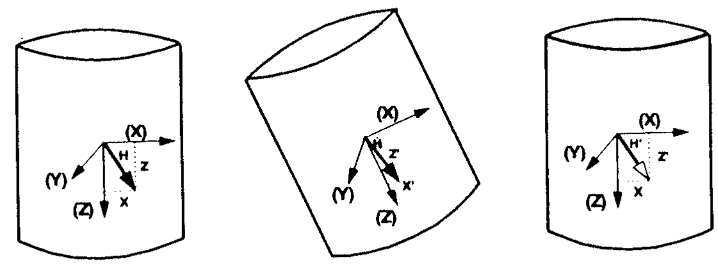

Figure 7 - Affect of vibration on magnetometer readings from a down-hole, electronic core orienting survey instrument. Diagram A shows the three, orthogonal magnetometer sensors, (X), (Y), and (Z) in their normal position, accurately recording the direction and intensity of the earth's magnetic field H by measuring the vector components x and z (y is assumed to be zero). Diagram B shows the orientation of the instrument after tool vibration has caused it to momentarily rotate about the (Y) axis of the magnetometer. Since the orientation of magnetometer axes (X) and (Z) has changed relative to H, the measured vector components of H now have new values, x' and z'. Diagram C shows the erroneous value, H', recorded by the magnetometer if vibration occurs during a scan of the three magnetometer sensors such that x is measured correctly but z' is measured instead of z due to instrument vibration.

SCRIBE KNIFE PLACEMENT

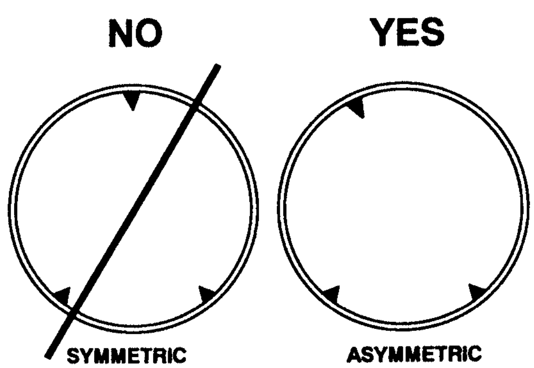

Figure 6 - Schematic diagram showing the proper, asymmetric set-up of the primary, reference scribe knife and the two support knives in an orienting core barrel scribe knife shoe.

CORE LAYOUT AND MARKING

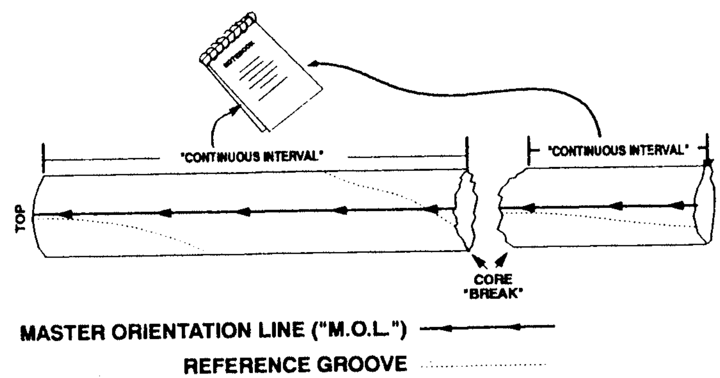

Figure 8 - Correct core layout and marking for a core orientation study.

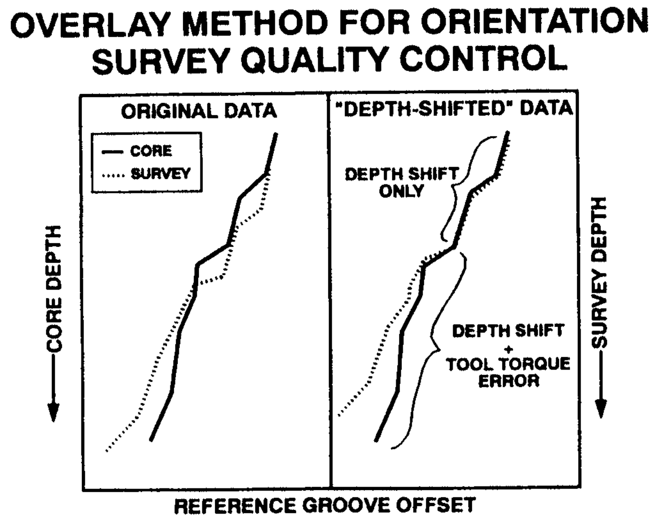

Figure 9 - Overlay method for quality control of down-hole electronic core orientation surveys (Bleakly, et al., 1985b).

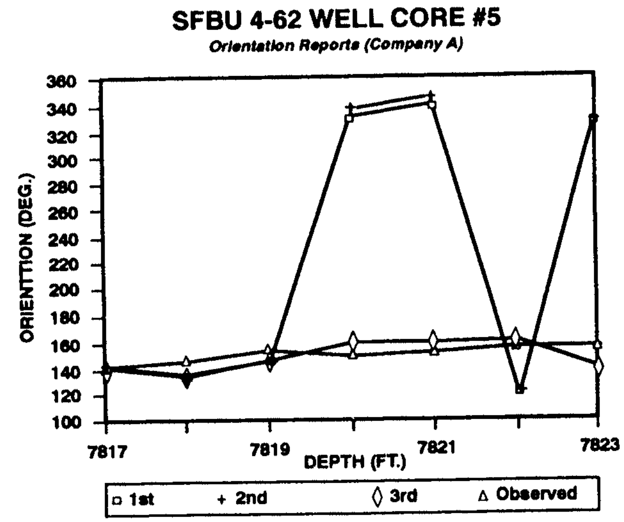

Figure 11 - E.S.I. reference groove compass orientation reported by company A for the second oriented core taken from the SFBU No. 4-62 well. The 1st and 2nd reports are as in figure 10. The 3rd report is similar to the 2nd report but with a different selection of shot points from 7820 to 7823 feet.

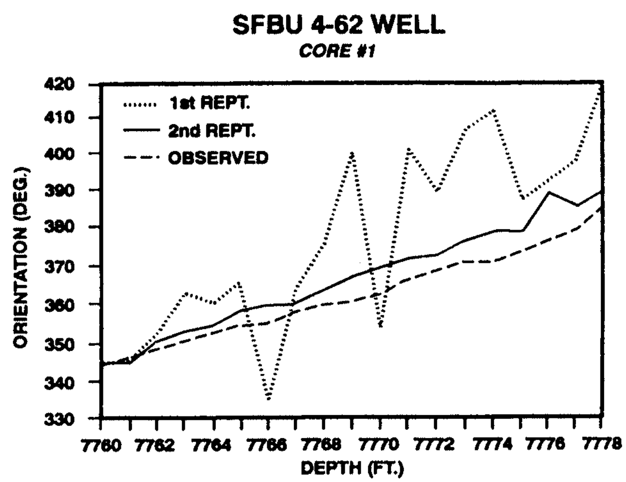

Figure 10 - E.S.I. reference groove compass orientation reported by company A for the first oriented core taken from the SFBU No. 4-62 well. In the 1st report accelerometer data obtained during coring was used to determine the vertical reference for each shot point. The 2nd report used data recorded while the tool was stationary in the hole prior to the start of coring.

Note the pronounced discrepancy between the 1st report and the observed orientation of the reference groove relative to a straight line drawn on the core. The 2nd report is in much better agreement with the direct observations, but note the tendency for the survey to deviate with depth toward increasingly higher orientation values indicating a systematic, clockwise bias looking down the core. This is common for down-hole surveys and may result from the survey tool assembly torquing or twisting during coring.

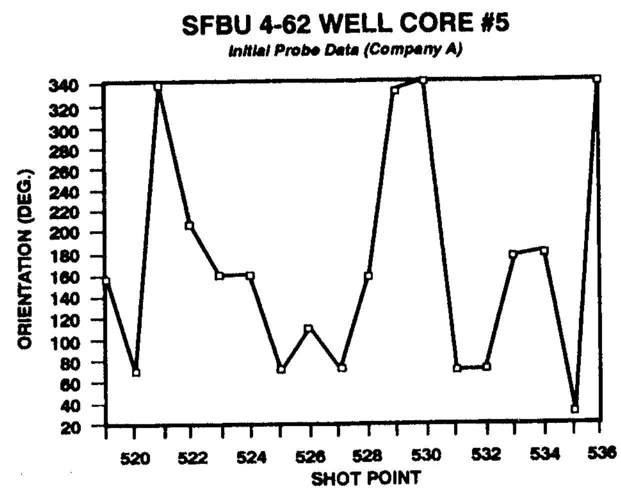

Figure 12 - Initial E.S.I. shot point data used to generated the core orientation data shown in Figure 11. Note the erratic variation in orientation values even though the orientation should be constant because the reference groove is straight over this continuous interval of core.

REPORT A

[redacted]
TOOLFACE REVIEW REPORT
version 1.27 Page 1/1

Company: [redacted] Probe #: 2014
Location: ECTOR COUNTY, TEXAS
Field: Well no: SFBU 4-62
Declination -> 9.14 Time Interval : 60 Seconds
Operator: [redacted] Holdoff Time : 300 Minutes
Time: Wed Nov 5 13:15:46 1986
Filename: ORIENT3 Depth Units -> FEET
Azimuth values below are corrected for declination.
Toolface type - Magnetic Only Toolface. (corrected for declination)
Comments:

Shot	Measured Depth	Inc	True Azimuth	Toolface	Additional Offset	Final Toolface
587	7850.0	6.7	164.63	87.2	-95.5	351.7
600	7851.0			34.4	-95.5	298.9
613	7852.0			82.7	-95.5	347.2
636	7854.0			95.6	-95.5	360.1
678	7858.0			78.6	-95.5	343.1

REPORT B

[redacted]
TOOLFACE REVIEW REPORT
version 1.27 Page 1/1

Company: [redacted] Probe #: 2014
Location: ECTOR COUNTY, TEXAS
Field: Well no: SFBU 4-62
Declination -> 9.14 Time Interval : 60 Seconds
Operator: [redacted] Holdoff Time : 300 Minutes
Time: Wed Nov 09 10:54:30 1988
Filename: ORIENTIO Depth Units -> FEET
Azimuth values below are corrected for declination.
Toolface type - Magnetic Only Toolface. (corrected for declination)
Comments: THIS IS ORIENT 3

Shot	Measured Depth	Inc	True Azimuth	Toolface	Additional Offset	Final Toolface
166	7849.0	1.7	318.29			
170	7850.0			193.2	-95.5	97.7
184	7851.0			196.1	-95.5	100.6
196	7852.0			223.1	-95.5	127.6
204	7853.0			223.7	-95.5	128.2
224	7854.0			234.8	-95.5	139.3
236	7855.0			233.7	-95.5	138.2
248	7856.0			234.1	-95.5	138.6
262	7857.0			234.1	-95.5	138.6
270	7858.0			234.3	-95.5	138.8
286	7859.0			236.1	-95.5	140.6
319	7860.0			237.5	-95.5	142.0

Figure 13 - Two E.S.I. final orientation reports by company A for the third oriented core taken from the SFBU No. 4-62 well. Reference groove compass orientations are listed under the "Final Toolface" heading. Note the major discrepancy between report A, for which the time-depth correlation was incorrect and report B, which was generated using the correct correlation of time with depth.

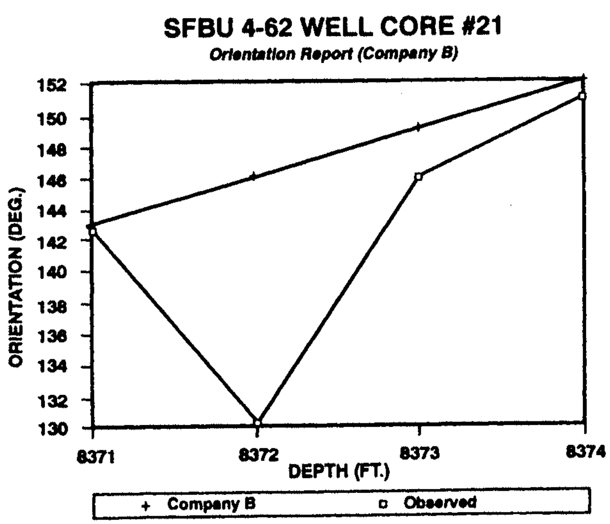

Figure 14 - E.S.I. reference groove compass orientation report by company B for one continuous core interval from the SFBU No. 4-62 well. Note that the reported orientation values vary up to 15° even though the reference groove is nearly straight.

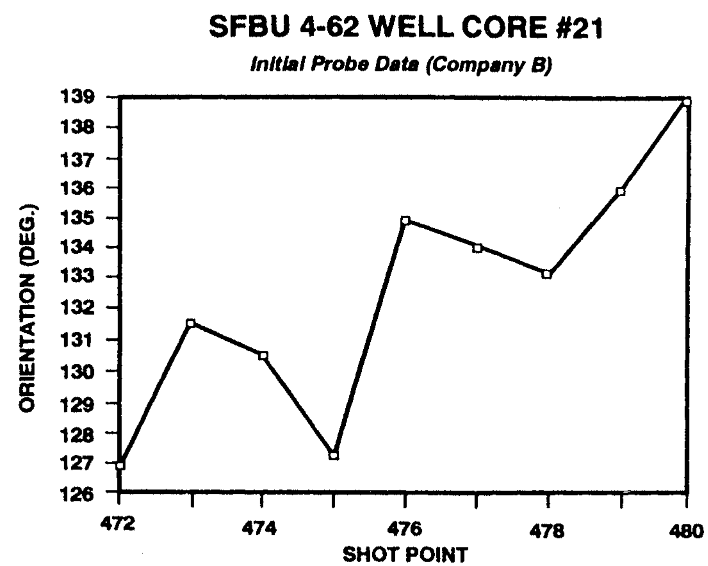

Figure 15 - Initial E.S.I. shot point data used by company B to generate the core orientation data shown in Figure 14. Note that the orientation values are variable but considerably less erratic than the data shown in Figure 12, which were used by company A to orient the third oriented core.