Minutes of the Tenth Meeting of the

Industry Steering Committee on
Wellbore Survey Accuracy

British Geological Survey, Edinburgh
17 Sep 1998

Present:

Hugh Williamson (Chairman and Minutes)	BP Exploration
David Kerridge	BGS
Toby Clark	BGS
Susan Macmillan	BGS
Graham McElhinney	Halliburton
Ken Hamlin	Halliburton
Jerry Codling	Halliburton Landmark
Jim Towle	Scientific Drilling / ATA
Tim Dallas	Gyrodata
Roger Ekseth	Gyrodata
Torgeir Torkildsen	Statoil
Anne Holmes	Sperry-Sun Drilling Services
Dave McRobbie	Sperry-Sun Drilling Services
Patrick Knight	Sperry-Sun Drilling Services
Alewijn van Asperen	Shell International
Wayne Phillips	Anadrill
Chris Chia	Anadrill
Harry Wilson	Baker Hughes INTEQ
Steve Grindrod	Copsegrove Developments
Maurice Cotterill	Elf Exploration (UK)
David Roper	Sysdrill
Michel Le Bars	Total
Alistair Davidson	Enterprise Oil
Hans Dreisig	Maersk Oil & Gas
Angus Jamieson	Tech 21

1 Introduction

Hugh Williamson welcomed those present and thanked Dr. David Kerridge for hosting the meeting. He then gave a brief review of the reasons behind the formation of the ISCWSA, and outlined its work to date.

2 A New Error Propagation Document

Hugh Williamson confirmed that the error propagation document co-written by BP, Statoil, INTEQ and Sysdrill had been completed, and that some members had already received copies. More copies were distributed at the meeting.

Completion of the document had been delayed largely due to a lengthy debate on the proper interpretation of along-hole depth errors. This had been satisfactorily resolved by presenting alternative treatments, and by briefly describing the applicability of each. A software implementation of both methods had since suggested that they give identical results except for the along-hole component of position uncertainty.

The document is intended to contain sufficient detail to implement the method in software and to calculate the uncertainty implied by the Committee's Basic MWD error model. Nevertheless, some of the finer points of implementation will need to be agreed by interested parties if different implementations are to give identical results.

Note: Hard copies of the document are available from Hugh Williamson on request.

3 Basic MWD Errors Model

3.1 Sensor Errors

At the previous meeting, the four major directional / MWD companies had committed to preparing some results from their investigations for this meeting.

Wayne Philips reviewed the preliminary results he had presented in Denver. These related to calibrations at room temperature and had been made deliberately conservative.

He then presented some recently acquired data which compared the calibrations of sensors just received from the manufacturers with their re-calibrations after their first return from the field. The data presented were for calibrations at 125° C.

The accelerometers showed a systematic shift in scale factor of about 500 ppm, with a standard deviation around this value of less than 200 ppm. This was almost certainly the result of some difference in the calibration environment. Patrick Knight suggested a gravity anomaly at one of the calibration sites might be the cause.

The magnetometer data were consistent with the preliminary estimates. Typical shifts in scale factor and bias were 1400 ppm and 50nT respectively. An exception was the "z-axis" magnetometer (y-axis in more usual convention), which exhibited a typical scale factor shift of 2000 ppm. Patrick Knight noted that in his experience the same sensor was the one most likely to fail.

Anne Holmes presented the results of analysing 163 pairs of consecutive calibrations of 125 sensor packages. The data were a combination of calibration shifts at several temperatures. Shifts in the calibration constants at the test temperatures had been separated from shifts in the thermal model values at the same temperatures. The shifts in the thermal models were generally 3 to 5 times smaller and would have little effect on the overall estimates of performance.

Typical values for accelerometer scale factors and biases were 1000 ppm and 0.0003 g respectively and for magnetometer scale factors and biases 1000 ppm and 35 nT respectively.

One surprising result was the large and highly correlated values of the misalignment of the x-axis and y-axis accelerometers and magnetometers in the plane perpendicular to the tool axis. It was suggested this was likely to be an artefact of the toolface referencing system used in calibration, and as such could be eliminated by a change of method.

Responding to a question from Hugh Williamson, Patrick Knight confirmed that the data included tools which had both passed and failed the re-calibration check, but not tools in which a “hard failure” had occurred.

Harry Wilson presented the recent calibration histories of five tools. The drift specifications on scale factor and bias which triggered a recalibration were approximately 2000 ppm and 0.0011 g for accelerometers and 3000 ppm and 150 nT for magnetometers. Most of the re-calibration checks fell well within these bounds, but a number did not.

Actions:

- INTEQ and Halliburton to collect similar data to that presented by Sperry-Sun and Anadrill and to forward the results to Hugh Williamson in a similar format.
- Hugh Williamson to compile the results into a common format from which typical current industry values can be abstracted.

3.2 Rotation Shot Data and BHA Misalignment

Hugh Williamson summarised the researches presented by John Turvill in Houston. These indicated that based on current specifications, radial tool misalignments between the sensor package and the MWD collar OD of the order of 0.1° were to be expected. He reminded the Group of the commitment made in Houston to gather rotation shot data which could be used to support this estimate.

Hugh then presented the results of a simple analysis of 46 4-station rotation shots taken from the Wytch Farm field. This analysis indicated a root-mean-square value of 0.095° for the misalignment. The associated BHAs were typically steerable assemblies, but the magnetic spacing was such that the MWD sensors were typically about 90 feet behind the bit and the MWD collar could be expected to be lying flat against the borehole. Wayne Phillips pointed out that the results would also include a contribution from sensor errors, and that the true physical misalignment would be somewhat less than the figure presented.

Alewijn van Asperen presented the results of an analysis of 50 rotation shots. He had recorded the reduction in the overall inclination spread before and after SUCOP correction. The reduction was typically about 0.2° for vertical hole, falling (as expected from the properties of the correction) to near-zero at above 60° inclination. Patrick Knight thought that a more illuminating result would be the size of the residual inclination spread after correction. Again, the analysis did not properly differentiate between physical misalignment and apparent misalignment caused by sensor errors. Hugh Williamson suggested that the contribution of sensor errors to apparent misalignment could be estimated by simulation, and that the effect could then be subtracted from the field results.

Anne Holmes had gathered data from six rotation shots and estimated the associated misalignment using a sine-curve fit. The apparent misalignments obtained varied from 0.025° to 0.16°. The data represented a mix of hole sizes and BHAs.

Harry Wilson had gathered some raw sensor data from rotation shots taken with electronic multishot tools, but had not yet processed them.

Action: Hugh Williamson to use simulation to estimate the apparent misalignment caused by typical sensor errors.

3.3 Measured Depth Errors

Hugh Williamson reminded the Group of some of the physical parameters that had been used by Roger Ekseth in his estimate of depth errors, and presented "back of the envelope" estimates of the stretch (2.87m) and thermal expansion (1.84m) of a drillstring suspended in a 3500m vertical well. Of the total stretch, 1.11m was attributable to the weight of the collars, and 1.76m to the weight of the drillstring.

Patrick Knight was doubtful that the results could be applied to long horizontal sections, where buckling of the drillstring would tend to counteract the other stretch-type errors.

In response to a question on the relative importance of other sources of depth error, Roger Ekseth confirmed that his studies had concluded that at measured depths of greater than 2000m, stretch-type errors tended to dominate. The exception was offshore wells, where reference errors due to rig heave, ballasting etc, could account for a significant proportion of the total.

A brief discussion of the nature of the systematic and theoretically correctable stretch-type errors ensued, without firm conclusion.

3.4 Axial Drillstring Interference

Hugh Williamson summarised a problem in the estimate of these errors. Modern BHA design methods take account of a well's orientation and typically attempt to reduce predicted azimuth errors below a pre-set threshold. However, the well-known "sin(Inc)sin(Azi)" dependency of the error predicts zero error in north, south and vertical wells.

Hugh had attempted to predict the maximum errors to be expected from following standard monel charts, in the light of the typical magnetic pole strength previously established by the Group. Depending on precise geographical location, the error to be expected at the least favourable. "90/90" hole direction, could vary between 0.5° and 0.8°.

The joint conclusions were that

- In order to optimise survey programs and well placement in the future, some BHA details would need to be incorporated in the analysis. Any "one-number-fits-all"

compromise would be so crude as to lessen the value of the overall uncertainty prediction.
- The Group still needed one or more numbers which it could include in its basic MWD error model and use to advertise the capabilities and limitations of these tools.

Hugh suggested that a combination of a constant error and a directionally-dependent sin(Inc)sin(Azi) error would come closest to providing the necessary compromise. He suggested that the terms

$$0.25^\circ$$
$$0.6^\circ \sin(\mathrm{Inc})\sin(\mathrm{Azi})$$

if treated independently, would provide as close a fit as possible to typical BHA design practice.

Angus Jamieson suggested that a much closer fit could be obtained by using a more complex weighting function. Hugh responded that although that might give a better numerical result, there would be a loss of credibility if the Group moved away from weighting functions grounded in physical reality.

4 Standardising on Minimum Curvature

Harry Wilson distributed a document which he and Hugh Williamson had prepared. It contained recommendations to the Industry concerned with standardising on minimum curvature as a means of survey calculation.

Alistair Davidson acknowledged the problem, but thought that oil companies which continued to use alternative survey calculation methods were well aware of it also and were unlikely to be influenced by the Group. Others too failed to see the value of the proposed recommendations. Harry responded that the document, if endorsed by most of the companies present, would at least demonstrate that a reluctance to support alternatives to minimum curvature was shared across the Industry.

There was some comment that the definition of the minimum curvature method appended to the document might not cover all current implementations. Hugh Williamson responded that the definition was intended to be inclusive, and that there had been no intention to prescribe a preferred version. Angus Jamieson mentioned that he had developed a version of the method which avoided the use of cut-off values in the calculation of the radius factor.

Actions:
- All members to review the document in its entirety and come to the next meeting prepared to comment on it.
- Angus Jamieson to provide Hugh Williamson with details of his calculation method for incorporation in the document.

5 Software Demonstration

Hugh Williamson gave a brief demonstration of a Visual Basic application he had written to implement the error propagation mechanism and the Group's basic MWD error model.

The graphical results grouped the various error sources into four classes and distinguished their separate contributions. The classes chosen were:

- Sensors (biases, scale factors and, although absent from the current model, misalignments)
- BHA (radial misalignment, sag, axial and cross-axial magnetic interference)
- Magnetic Field (declination, and in the case of z-axis corrected data, dip and total field errors)
- Depth (all measured depth errors)

The example shown was for the "out-and-back" profile ISCWSA #2 described at the previous meeting. The results showed that the contribution of the declination uncertainty to the lateral component of position uncertainty twice returned to zero. This occurs at the depths where the well is perpendicular to the line joining it to the origin.

Harry Wilson thought that the contribution of the sensor errors should exhibit the same behaviour, and show a decrease as the well returned back under itself. Wayne Phillips disagreed, because of the effects of cross-axial errors. He thought that if these were eliminated, the contribution of the z-axis sensor errors alone should decrease as the well returns below the wellhead.

6 Link between QA parameters and Error Models

Alewijn van Asperen showed a table of the various QA parameters used by MWD companies for B-total, G-total and Dip. As an example, tolerances on B-total varied from 175 nT to 1000 nT. Alewijn felt this variation could not be justified and called for standardisation. He added that any such standardisation must include a proper allowance for geographical location.

As an exception to the general picture, Alewijn noted that Sperry-Sun's Helmholtz coil calibration practices agreed well with the QA parameters applied in the field.

Action: Standardisation of QA parameters will be discussed in detail at the next meeting.

7 Drilling Capabilities of the BGS

Alastair Skinner of the BGS described some of the recent work of the BGS concerned with shallow drilling investigations in deep water.

He described how geophysical data could be used to produce high resolution images of horizontal planes at various depths, and illustrated this with an image of boulders across part of the Clair field.

The BGS has various coring tools appropriate for different depths of water and depths of sea bed penetration. Recent coring work had involved sampling drilling cuttings from the sea bed around a platform. An electrically powered rotary core, capable of working in depths of up to 4000m, had recently been used in paleomagnetic studies near to an ocean spreading ridge. The in-built compasses provide information on the in situ orientation of the core.

Another type of corer suitable for deep water is the “hammer corer”. It can penetrate up to 30 metres, and has in-built heave compensation. The BGS are currently looking for a deep-water location in which to trial it.

An oil-field supply vessel had been equipped with a drilling capability. Cores can be wireline retrieved through drillpipe. The use of aluminium drillpipe allows depths of up to 2000m to be achieved. The drill string is turned using a top drive. No BOPs are used. Apart from the divertors, the main defence against blow-outs is not drilling in hydrocarbon provinces and screening for shallow gas using HR seismic data. The daily cost of the vessel is about $50,000.

Alastair described the BGS involvement in the Deep Ocean Drilling Project, where 1500m penetrations had been achieved in 6500m of water. Several wireline logging tools had been tested in this low-cost-per-day environment, and it was suggested that innovative MWD technologies could also be included in the drillstring for trial purposes. The Project had recently been experimenting with riser-less drilling.

Finally, Alastair mentioned a drilling project which the BGS had proposed to UKOOA. The work would involve developing water-based drilling fluids capable of controlling a variety of difficult formations. Hugh Williamson suggested that the Drilling Engineering Association might be a useful forum for presenting such proposals to the Industry.

8 Magnetic Disturbance Prediction

Alan Thomson of the BGS described the causes, manifestations and prediction of magnetic disturbances.

1998 marked the beginning of an upturn in the 11-year cycle of solar activity, characterised by various phenomena such as coronal mass ejections. These events triggered changes in the interplanetary magnetic field, which in turn interacted with the magnetosphere, producing disturbances on the Earth. Alan showed some results of recent work which demonstrated the correlation between the solar wind speed, the z-component of the interplanetary magnetic field (measured by the ACE satellite), and magnetic field disturbances on Earth.

Moving onto data more pertinent to in-field referencing, Alan showed how, on a magnetically quiet day, the variation in the magnetic field at Eskdalemuir could be predicted almost exactly from the variations at Hartland and Lerwick, between which it lies. On a disturbed day however, the quality of the prediction is not so good. During one of the most violent disturbances of recent years, the interpolated and observed values still exhibited strong correlation, but the threshold value of 0.1° difference was regularly exceeded for short periods. The greatest disagreement observed during this disturbance (27-28 August 1998) was 0.7°.

A map of the British Isles showed that by using data from the Lerwick observatory alone, it was possible to predict time variations in the magnetic field over a large part of the North Sea with a high degree of confidence. Alan stressed that there was now no technical obstacle to the provision of observatory data for use in this context in real-time or near-real-time.

Turning to disturbance prediction, Alan likened the current state-of-the-art in prediction to weather forecasting 100 years ago. This was due in large part to the paucity of data available - one or two satellites compared with thousands of weather stations. The result was that large magnetic storms could still not be predicted routinely.

Recent work using neural network techniques had shown that these could improve the performance of forecasts slightly over linear predictions, but that performance for large amplitude events was still poor. One of the difficulties in disturbance prediction was that global and local disturbances do not always coincide. A global activity index could indicate a highly disturbed day, without significant disturbances being seen at some sites.

9 Advantages and Limitations of In-Field Referencing

Torgeir Torkildsen started by reminding the Group that the most important correction made was for main field declination, and that this dominated all others.

He showed some data for crustal anomalies in Northern Norway. Declination anomalies reached 1.5°, with changes of up to 2° over only 30km. This gradient was typical of areas to the east and west of large amplitude total field anomalies.

Torgeir pointed out that magnetic field modelling was done on the Earth's surface, or just above, whereas for wellbore surveying the field was required deep in the ground, closer to the sources of anomalies. This raised the question of the likely declination residuals at survey depths. Torgeir estimated that they might be 60-75% greater than predicted at surface.

Turning to variations in time, Torgeir reviewed data for Trömso for the quiet year 1996. Standard deviations in declination, dip and total field for this year were approximately 0.2°, 0.095° and 47 nT respectively. With secular variation removed, the figures for declination and dip reduced to 0.18°, 0.085° respectively.

A Fourier transformation of the field with time showed a peak at 24 hours corresponding to diurnal variation. David Kerridge confirmed that another peak was also detectable at 27 days, corresponding to the solar rotation period. The typical period over which the field varies resulted in a distinction between the errors induced in MWD and electronic multishot surveys. Errors were likely to be randomised over the acquisition period of an MWD survey, but not for an electronic multishot survey.

A probability density distribution of field variations showed that they diverged significantly from the normal distribution, particularly at the tails. Significant errors would be incurred if the normal distribution was assumed for high amplitude anomalies.

Torgeir concluded that due to randomisation effects, crustal anomalies were far more important in practice that time variations. It was therefore vital to obtain good local field models. These models could also improve the performance of magnetic interference correction algorithms. He estimated that use of IIFR could halve the errors otherwise inherent in MWD.

10 The Nautronix External Magnetic Observatory

Angus Jamieson described the NEMO system and experience with it to date. He introduced Nautronix as a company with wide marine acoustic experience.

The seabed observatory itself communicates with the rig via an acoustic transponder. Data is sent on request by interrogating the observatory. The data could be used simply to apply variations to a baseline azimuth previously established by a gyro multishot in the well. Alternatively, it could be effectively calibrated using surface observations.

In addition to a seabed observatory, Nautronix had developed a buoy for offshore geomagnetic mapping. Shell had used this to acquire a survey of the entire Brent field. The buoy consists of a GPS gyro mounted on a superstructure which also contains motion sensors. Beneath the surface of the sea, a tri-axial magnetometer package records the instantaneous magnetic field. Power supply and data transmittal is via an umbilical attached to the tow line.

The GPS antenna had proved capable of a determining the buoy orientation to an accuracy of 0.025° at 50Hz. The 3D motion sensor records pitch and roll also at 50Hz. Using a knowledge of the various delays in the electronics, it is possible to determine the exact orientation of the buoy when each of the magnetometers measures the magnetic field. An instantaneous earth-referenced field vector can then be calculated.

Some interference between the magnetometers had been noted during the first trial, which had caused some degradation of the accuracy of the calculated vertical field component. Contour maps for declination, field strength and dip had been produced for the area of the Brent field (18km x 6km). These exhibited larger anomalies than those predicted from aeromagnetic data. The strongest magnetic feature was a flotel, whose anchor chains, 150m below the sea surface, could be clearly seen on the maps.

A study of the entire system had been used to compile an error budget:

- GPS gyro 0.05°
- Magnetometers 0.1°
- Baseline alignment 0.02°
- Buoy alignment 0.05°
- Software / processing 0.05°
- **Total 0.13°**

Angus estimates that a declination accuracy closer to 0.1° might have been achieved in practice. The dip accuracy was probably in the range 0.2°-0.25°, but could be improved by applying the lessons learned during the trial. For observing the total field, a proton magnetometer had been deployed on the end of a boom. This had achieved an accuracy of better than 20 nT.

It was likely that a subsea observatory would be difficult to justify in terms of cost except in far northern fields, where magnetic disturbances are larger and far more common. A mapping exercise using the buoy would be advisable in any area where the aeromagnetic survey data indicated high amplitude anomalies.

11 General In-Field Referencing Discussion

Torgeir Torkildsen asked whether it was possible to get information on the sub-surface magnetic field from vector data observed at surface. David Kerridge responded that techniques for downward continuation of the magnetic field using potential theory were possible, but that there was a non-uniqueness problem which didn't apply to deriving the field on a surface.

Hugh Williamson showed a comparison between IIFR-corrected MWD data and gyro multishots for 6 wells in the North Sea. For each well, the average difference in well azimuth was less than 0.25°.

12 Any Other Business

Angus Jamieson felt that the error model which had been developed by the Group might require the user of any software which incorporated it to make several technical selections and define a number of complex parameters. David Roper felt this was a human-computer interface problem, and was not inherent in the model itself.

13 Next Meeting

Hugh Williamson felt that given the welcome influx of first-time attendees at this meeting, it would be wise to hold the next meeting in Europe also. Amsterdam, to co-incide with the SPE/IADC drilling conference (9-11 March) was suggested.

Action: Hugh Williamson, and Alewijn van Asperen to confirm date and venue to participants.