Minutes of the Eleventh Meeting of the

Industry Steering Committee on Wellbore Survey Accuracy

British Geological Survey, Edinburgh
23/24 May 2000

Present:

Hugh Williamson (Chairman and Minutes)	BP Amoco
David Kerridge	BGS
Toby Clark	BGS
Susan Macmillan	BGS
Alan Thomson	BGS
Graham McElhinney	Pathfinder
Tony Swarbrick	Pathfinder
Jerry Codling	Landmark
Brett Van Steenwyk	Scientific Drilling
Allan Clark	Scientific Drilling
Steve Mullin	Gyrodata
Roger Ekseth	Gyrodata
Torgeir Torkildsen	Statoil
Oddvar Lotsberg	Statoil
Anne Holmes	Sperry-Sun Drilling Services
Dave McRobbie	Sperry-Sun Drilling Services
Patrick Knight	Sperry-Sun Drilling Services
John Weston	Sperry-Sun Drilling Services
Koen Noy	Shell E&P
Wayne Phillips	Schlumberger
Chris Chia	Schlumberger
Alastair Oag	Schlumberger
Harry Wilson	Baker Hughes INTEQ
Andy Brooks	Baker Hughes INTEQ
Odd Helge Boe	Baker Hughes INTEQ
Simon McCulloch	Baker Hughes INTEQ
Robert Estes	Baker Hughes INTEQ
Phil Gurden	Baker Hughes INTEQ
Steve Grindrod	Copsegrove Developments
Maurice Cotterill	Elf Exploration (UK)
David Roper	Sysdrill
Olli Coker	Conoco
Alistair Davidson	Enterprise Oil
Barry Foreman	DSV
Hans Dreisig	Maersk Oil & Gas
Angus Jamieson	Tech 21

The first part of the two day agenda was devoted to an open User Group meeting of the BGS Global Geomagnetic Model (BGGM), chaired by Dr. David Kerridge. Only the follow-up discussions, of more general interest to the ISCWSA, are recorded here.

1 A Nomenclature for Geomagnetic Referencing

David Kerridge suggested a standard terminology for geomagnetic referencing (GR) techniques and services. The dual motivations were:
- the need to precisely define which services were being requested or offered
- to enable appropriate tool error models to be defined and selected.

He then showed two simple flow diagrams which would help vendors and clients agree the appropriate means of correcting for crustal and disturbance effects respectively.

The classification scheme for GR services should answer three questions:
- which magnetic field sources had been accounted for ?
- what type of data was used for the correction ?
- how had the data been applied ?

The crustal field data could be applied as a single value (0D ?), as values interpolated along a straight, horizontal line (1D), as values along the plan view of the wellpath (1.5D), as values interpolated along a sloping line (2D), or as values along the true wellpath trajectory (2.5D).

Many felt that a "3D" (crustal) correction should mean the application of a 2D map, plus a correction for "downward continuation" of the field. Some felt that "4D" could then be used to indicate the additional correction for field disturbances, by whatever method, but Patrick Knight objected that disturbance corrections may on occasion be applied in the absence of crustal corrections.

Chris Chia didn't see the need for using different language between specialists and drilling engineers.

Unanimous consensus was not reached, but the subject remains open for individuals to contribute their own ideas or lead by example.

2 Marine Magnetic Surveying

Angus Jamieson described his past and present work investigating the feasibility of making magnetic field maps from a small vessel.

Initial efforts used an instrumented buoy towed behind a large vessel, such as a supply boat. The buoy housed magnetometers and GPS antennae in a configuration which allowed the instantaneous attitude of the sensors to be measured. Contour maps of the magnetic field in the vicinity of the Brent field were generated using this technology. These trials revealed several drawbacks to this approach:
- a large, expensive towing vessel was needed
- the quality of the results was very sensitive to the sea state
- an expensive umbilical between the buoy and the boat was required to achieve the necessary data rates.
- calibration of the instrumentation required man-handling of the whole buoy, and was therefore very awkward.

More recently, Angus's company, Tech 21, had joined forces with the BGS to investigate an alternative approach - the use of a small, dedicated vessel, with all the sensors mounted on a rigid, removable frame on board. This would address all the problems associated with the towed buoy.

The 21 ft boat has twin non-magnetic outboard engines. The sensor frame houses a caesium vapour magnetometer, Bartington triaxial magnetometers and a GPS position and orientation system.

Sea trials, being sponsored by BP Amoco, will be conducted later in the Summer, over an area of the Moray Firth with good quality existing magnetic data which includes a significant crustal field.

The program of work to be carried out this year includes: establishing procedures for calibration, marine operations and data processing, and publishing the results of the feasibility study.

Chris Chia asked if the acquired data on field direction could be validated by comparing it with the direction calculated from the total field measurements. Toby Clark replied that unfortunately, the total field data would not be sufficiently dense to be used for generating field direction.

Toby Clark summarised the calibration work that had already been done. Each of the three magnetometers had four unknowns (2 rotation, scale factor and zero field offset). These were determined by a least squares adjustment of observations made with the frame in different attitudes at a site of known magnetic field.

The boat itself has been surveyed and been found to be magnetically "clean" to 10-20nT. It may be possible to remove or correct for this residual field.

Robert Wylie asked what accuracy was anticipated for crustal field maps generated in this way. Toby expected the results to be better than 0.1° in direction and 20nT in intensity.

3 Recap of ISCWSA Work to Date

Hugh Williamson gave a brief review of the work undertaken by the ISCWSA since its formation in 1995. It was summarised in the paper "Accuracy Prediction for Directional MWD" (SPE 56702) presented at the SPE ATCE in Houston in October 1999.

There was plenty still to be done. Hugh mentioned standardisation of MWD quality control measures, linking them more closely to error models, and the achieving for gyroscopic and inertial tools what had been achieved for magnetic tools.

This meeting was to focus on discussion of a broad range of topics, without the need to further any specific work program.

4 Shell and the Standard Survey Platform

Koen Noy summarised Shell's historical interest is survey accuracy, starting with the development, by Wolff and de Wardt, of a systematic error model. In 1995, Shell completed, but did not publish, an error modelling system called Sestem, which models tool errors, environmental errors, and the effects of different running procedures.

Shortly afterwards, following the formation of the ISCWSA, Shell asked for the commitment from the service companies represented to deliver the quality of data in the field which they claimed on paper. The response, in Shell's view, was disappointing. Since then, Shell has taken an interest in the progress of the ISCWSA, without always taking an active part. This was partly because the Company's interest lay more in the assurance of execution in the field, rather than in error prediction itself.

Shell's model of survey management is a three phase loop, consisting of:
- Well Design and Planning (using Sestem)
- Wellsite Execution (using the Standard Survey Platform - SSP)
- Completion (using database management tools).

Shell expect their wellsite survey data manipulation platform, SSP, to contribute to reducing development costs, increasing ultimate hydrocarbon recovery and reducing the response time of emergency technical services, such as would be required in the event of a blow-out. The Platform is designed to facilitate the checking of major survey quality control parameters in the field.

Applications already built into the SSP include Sucop, Sucop+ and a sag correction algorithm. An IFR correction module is currently being worked on. Further development of the SSP has been out-sourced to Logica, a specialist software house.

Shell have requested that Logica a cost indication for coding the ISCWSA error model in a self-contained module. The module will be available to the industry at large, with costs to be shared amongst the buyers. The aim is to avoid proliferation of subtly different implementations, as well as realising the financial benefit of shared development.

The SSP is available to all companies for a one-time license fee of about $20k. Dave McRobbie asked if Shell Expro were likely to start using SSP. Koen was not sure, but confirmed that they were not one of the operating units currently pushing for implementation of the software.

Shell had also developed an MWD data exchange format and agreed it with the major service companies. It was a public domain format and Koen took an action to distribute details to individuals who expressed an interest. This format was not the same as the DTI/CDA deviation data exchange format in which Shell Expro had participated (see 9 below).

5 Acceptance Values for MWD Magnetic Surveying

Oddvar Lotsberg presented a proposal, jointly developed by Statoil and Baker Hughes INTEQ, for rationalising the quality control of single MWD surveys. Current procedures have the drawback of being overly sensitive to tool orientation, hole direction, and the local magnetic field strength and dip. There is also little consistency in values used by different operators and service companies.

The new criteria were developed by modelling MWD tool performance using the ISCWSA error model and Statoil's work on geomagnetic referencing. The threshold for all acceptance/rejection decisions was set at 3 standard deviations.

A single quality parameter ("B-vector difference" was suggested as a name at the meeting) is derived from the two conventional quality parameters for B-total and dip:

$$\Delta(B\Theta) = \sqrt{(\Delta B)^2 + (B\Delta\Theta)^2}$$

where	$\Delta(B\Theta) =$	B-vector difference (nT)
	$B =$	Theoretical field strength (nT)
	$\Delta B =$	Difference between measured and theoretical field strength (nT)
	$\Delta\Theta =$	Difference between measured and theoretical dip angle (radians)

For a single survey station, the acceptance threshold for B-vector difference depends on whether or not axial interference and geomagnetic reference corrections have been applied:

Acceptance Threshold	Standard Referencing	Enhanced Referencing
No Axial Mag Correction	650 nT	500 nT
With Axial Mag Correction	425 nT	300 nT

The equivalent acceptance threshold for G-total is 0.023 m/s² for all cases.

The same link between error model and acceptance criteria can also be applied to comparing computed inclination and azimuth results from two single MWD surveys. Acceptance limits have been derived as follows:

Inclination Limit = $k.1$ Azimuth Limit = $k.\left(1 + \frac{1}{\cos\Theta}\right)$

where the k-value depends on the type of surveys being compared:

***k*-value**	
Rotation shot: Single vs. Single	0.45°
Check shot, same run: Single vs. Rotation	0.25°
Check shot, same run: Single vs. Single	0.35°
Check shot, different runs: Single vs. Rotation	0.35°
Check shot, different runs: Single vs. Single	0.45°

Graham McElhinney and Brett Van Steenwyk thought that the correlation between the corrected values for dip and field strength might invalidate the criteria for axially corrected surveys. Andy Brooks explained that the method was valid for all commonly applied corrections, which share much the same theoretical basis.

Harry Wilson confirmed that Baker Hughes INTEQ would rather use these criteria in the field than the ones they currently use.

Koen Noy suggested that the proposals needed to be trialled in the field, and the number of rejections noted. Fine tuning of the thresholds might be necessary before formal adoption.

Chris Chia pointed out that there were other solutions to this problem which had much the same properties. Schlumberger had developed some similar criteria but presented them slightly differently.

6 ISCWSA Error Model Implementation

Steve Grindrod described his experiences in implementing the ISCWSA error model within his software. He used various source information as it became available, changes in which resembled trying to hit a moving target.

Most of the effort had gone into I/O formatting, units clarification and definition, and resolving the distinction between error sources and weighting functions.

Steve had learned valuable lessons, particularly in the area of programming standards. In particular, the issues of variable names, units, special diagnostic results files and error trapping code had to be solved.

It had eventually proved possible to closely duplicate all the results in the SPE paper, but sometimes more information than was presented in the paper had been required. The results for ISCWSA profile 1 had been easy to duplicate. Profile 2 presented a much stiffer challenge. Profile 3 largely tested the logic for tie-ins between surveys. Steve felt that good agreement with all the SPE paper examples was a pre-requisite for validation of any implementation.

Steve showed a comparison between the ISCWSA model for MWD, and that presented by Wolff and de Wardt in their paper. The agreement was generally good, although there was a suggestion that the new model may be overly optimistic for north-south wells.

A comparison plot between results for MWD with and without axial interference correction showed a larger-than-expected subset of hole directions where application of an axial interference correction is likely to degrade rather than enhance accuracy.

David Roper described how the model had been implemented in Director. The aim was to match the results in the SPE paper as closely as possible, although implementation was started long before the paper was available. Experience had shown it was difficult to reproduce the results using just the information in the paper. In particular, the examples section could have been expanded to include earth-referenced axes and results at tie-points. David also felt that more description on how tie-points are incorporated into the calculations would have been useful. For the purposes of introducing the model to clients, a better physical justification of the depth errors in the MWD error model would be useful.

David saw no reason why, with sufficiently precise definitions and instructions, independent implementations of the ISCWSA error model shouldn't agree to five decimal places.

Anne Holmes had implemented the ISCWSA model using the published SPE paper as a sole reference. She had managed to duplicate the results of other implementations to a high degree of accuracy. Anne's software is called Odisseus.

Jerry Codling described how the model had been implemented in Compass. Error terms which included both inclination and azimuth components had been decoupled into separate terms, so that all weighting formulae could be interpreted at run-time. This gives the user interface a high degree of flexibility. The correct correlation effects between decoupled terms were maintained by using the name and order of the terms to signal which should be correlated.

Hugh Williamson accepted the various inadequacies of the paper which had been identified. He showed a plot of how well the various implementations for which he had received results agreed with the SPE paper and with each other. The SPE paper could not be regarded as the "truth", since the software used to generate it, *Sputnic*, had undergone some revisions since the paper was written. In general, all the implementations agreed with each other to about 0.2% per ellipsoid axis or better.

Eventual publication of the peer-reviewed paper would allow all the results, and other errors and inconsistencies in the paper, to be corrected. Space however, was limited, and it would be difficult to include more examples without exceeding the maximum allowed paper length.

7 Gyro Error Modelling

Torgeir Torkildsen introduced the subject of gyro tool error modelling. His experience was that it was generally tougher to generate realistic results for gyro tools than for magnetic tools.

The complexities of gyro error modelling were generally in estimating azimuth performance. For straight wellbores, gyro azimuth error sources broadly fell into three classes, depending on whether their propagation was random, linear or quadratic. Error sources could change class depending on whether to tool is rotating or sliding.

Torgeir divided the physical error sources affecting gyro azimuth measurements into three groups:
1. Initialisation Errors. These accounted for perhaps 80% of the total azimuth error budget in medium step-out wells (3-4km reach). A proper understanding of the alignment process was necessary to determine the amount of redundancy in the azimuth determination and the presence of any effects which may act as disturbances.
2. Azimuth Drift. Usually controlled by "zero-velocity updates". Not clear in all cases whether propagation should be treated as a systematic drift or a random walk.
3. Misalignments. These included internal and external misalignments, and could exhibit either random or systematic propagation, depending on tool rotation and running gear.

This grouping of error sources pointed the way to a common means of error modelling. Statoil had succeeded in reducing the number of distinct error models they used from about forty down to only five. There was a possibility this work could be used by the Group as a basis for further development.

There followed a wide-ranging discussion, some of which covered ground already well trodden in previous meetings of the Group. The following is just a selection of the points made.

Oddvar Lotsberg thought a far simpler suite of gyro models than the one currently incorporated in Director could be developed, without significantly affecting the results. He thought agreement to within 5-10% of the full model results was achievable.

There was consensus that the structure used for the MWD model would not need to be altered in order to incorporate gyros. Quadratic azimuth terms, resulting from gyro drift, could be modelling by including an along-hole depth factor in the weighting function, linked to time by an assumption about running speed.

The vexed issue of along-hole depth errors would arise when treating tie-ins between gyro and MWD. Andy Brooks was comfortable that this case was properly modelled by the "assigned depth" formulation described in the SPE paper, but there was consensus that the Industry needed a clearer, broader explanation of the issues involved.

Several of the Operators present stressed that azimuth accuracy was not necessarily the paramount discriminator in gyro system selection. Improved TVD accuracy was increasingly in demand, with commercial factors such as rig-time, survey cost and reliability also being involved in the decision. Steve Mullin pointed out that while this may be the case in North Sea, many operations around the world still relied on bottom-line accuracy figures when making tool selection decisions.

8 Standards for Anti-Collision

Harry Wilson gave an overview of current Industry practice in anti-collision, pointing out that it was one of the important end-uses of the Group's work on error modelling.

Minimum separation criteria had evolved through four stages:

1. Centre-to-centre calculations (C): No explicit account taken of position uncertainty.

2. Ellipse-to-ellipse calculations (E): Can be misleading depending on error ellipse size.

3. "Separation Factor" calculations: Combination of C and E - typically C/(C-E). Separation Factor (SF) is plausibly linked to risk of collision. Most operators and directional companies currently employ this method in some form.

4. Collision probability calculations: Seen as the "holy grail", to which the industry should aspire. Various formulations are circulating, but few are in use. BP Amoco and Statoil are exceptions.

Harry illustrated that the apparently simple concept of the separation factor could be defined in numerous ways. Some of the variables included:

- which error model ?
- what confidence limit ?
- which ellipsoid radius ?
- include casing / hole diameters ? how ?
- include additional per-depth term ?
- cap the per-depth term ? at what value ?
- include surface uncertainty ?
- SF acceptability limits: 1, 1.5, 2 ?
- other factors (eg. starting from last gyro survey)?

Harry saw the value of standardising the definition on Separation Factor, so that anti-collision criteria would be comparable between operations.

Angus Jamieson promoted the idea of evaluating collision "risk", defined as the probability of collision divided by the probability of detection prior to collision. This quantity, he felt, provided a physically meaningful and valuable measure of any close-drilling situation.

Hugh Williamson and David Roper explained their differing approaches to evaluating collision probability. Hugh stressed the need to evaluate the probability at the planning stage. David was more interested in updating the calculations while drilling proceeded.

9 Any Other Business

Angus Jamieson described a format for well deviation data which had been developed by a working group on behalf of CDA. CDA (Common Data Access) is a company with close links to the DTI, which defines and manages data exchange issues for the petroleum industry.

The format had been designed to include all the information which a recipient of a wellbore survey would need in order to identify the well and locate its trajectory in space. In addition, data on survey tool types would allow some recipients to make an estimate of the reliability and accuracy of the well trajectory.

Angus also described a field development software tool which his company has been helping to develop for ARCO. It consisted of an integrated well planning and cost model, housed in a "cave", inside which users could interact with the data and development design. Of particular interest to the Group was the anti-collision planning facility, which showed 3D "curtains" around nearby wells, colour-coded according to the severity of the collision risk.

Graham McElhinney described a series of experiments he had performed to investigate the magnetisation of BHA components. A number of components had been rotated lengthwise in a plane containing the earth's field vector and horizontal east-west, with a fluxgate magnetometer fixed on the tool axis and rotating with the tool. A variety of steel components were tested, including cross-overs and stabilisers. The purpose was to differentiate between the permanent and induced components of the magnetic field.

Graham thought that the prevalent view in the Industry was that the induced component of BHA magnetism was negligible, typically having perhaps 2% of the intensity of the permanent component. In contrast, the experiments revealed large induced fields, sometimes equal to the permanent fields. These findings may have implications for the ISCWSA error model, especially when drilling east or west.

Graham requested that other companies perform similar experiments, in order to validate the findings. He would send the procedures he had used to Patrick Knight and other interested individuals.

10 Next Meeting

The next meeting will be held in Houston on 5/6 October, to follow on from the SPE ATCE, taking place in Dallas earlier in the week. Andy Brooks offered Baker Hughes INTEQ's facilities to host the meeting.