PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, SOUTH BRUCE

WP05 Data Report: Geophysical Well Logging and Interpretation for SB_BH01

APM-REP-01332-0322 **January 2024**

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Phase 2 Initial Borehole Drilling and Testing, South Bruce

WP05: Data Report for Geophysical Well Logging and Interpretation for SB_BH01

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Revision Tracking Table

Revision	Revision Release Date	Description of Modifications/Edits
R0D	June 20, 2023	Initial Release to NWMO for Review (Drafts R0A through R0C were internal within Geofirma)
R0E	October 31, 2003	Revised draft addressing NWMO comments
R0F	December 21, 2003	Revised draft addressing NWMO comments
R0	January 12, 2024	Final Release

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1 INTRODUCTION

1.1 Background

Geofirma was retained by the Nuclear Waste Management Organization (NWMO) to complete a drilling and testing program for two deep bedrock boreholes (SB_BH01 and SB_BH02) as part of the NWMO's Phase 2 Geoscientific Preliminary Field Investigations.

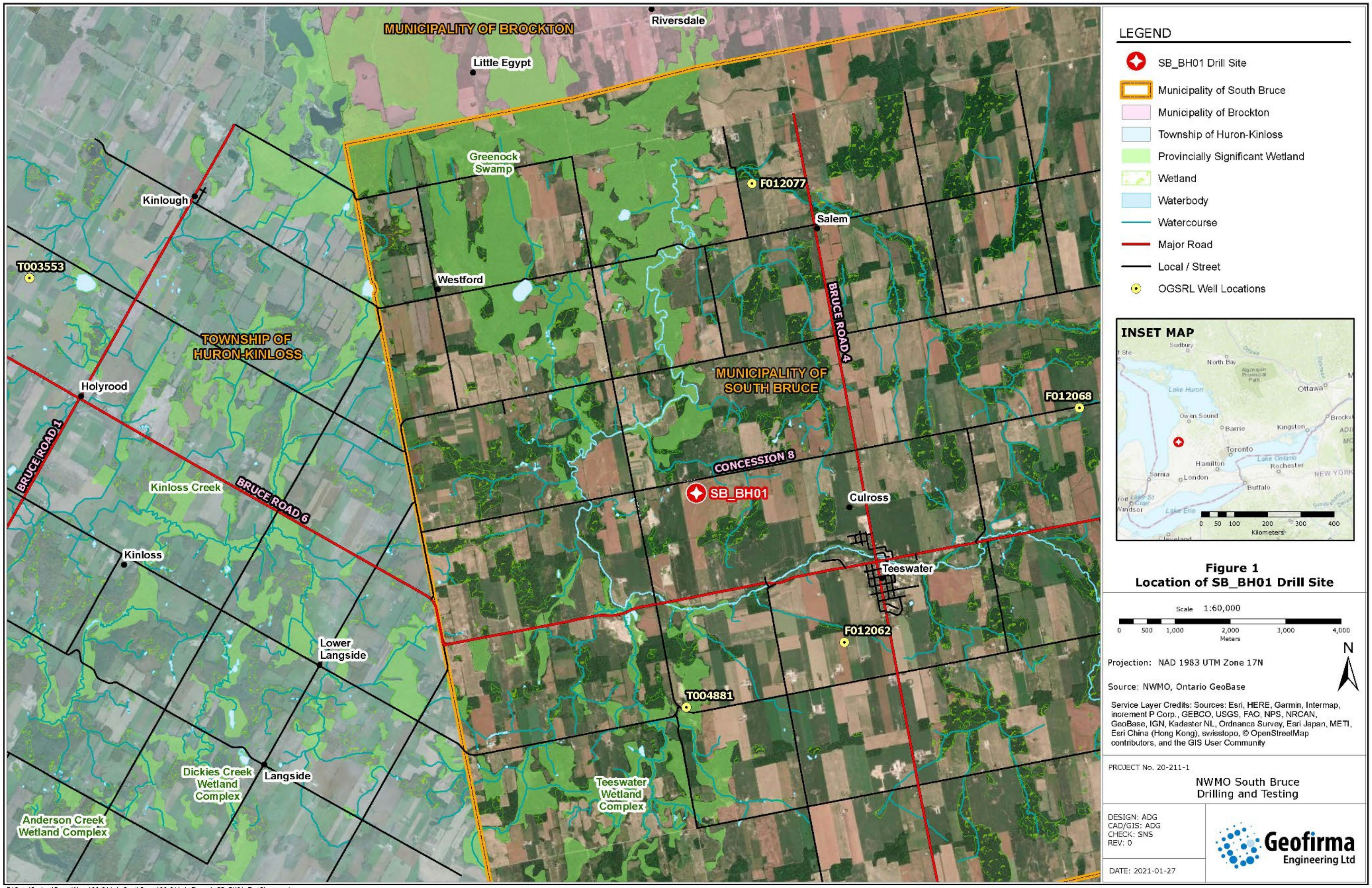
Phase 1 of NWMO's APM plan included preliminary desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the Preliminary Assessment. The Phase 1 Preliminary Assessment of the South Bruce area identified the Cobourg Formation as the preferred host formation for a deep geological repository for used nuclear fuel. The Initial Borehole Drilling and Testing study is a key component of the Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's APM plan.

Borehole SB_BH01 is located approximately 3.5 km northwest of the community of Teeswater, Ontario. SB_BH01 was drilled through the entire sedimentary bedrock sequence to approximately 20 m into the Precambrian basement, to a total depth of 880.84 meters below ground surface (mBGS). The borehole was drilled using PQ3 wireline coring equipment that produces a 123 mm nominal diameter borehole and 83 mm nominal diameter core.

The geophysical well logging program described in this report was completed to obtain high-quality geophysical logs and use those to interpret the following for each sedimentary formation logged at the SB_BH01 borehole:

- Lithology
- Stratigraphic boundaries
- Petrophysical rock properties, e.g., porosity
- Geomechanical characteristics, e.g., rock mass structure and borehole breakouts, compressional and shear-wave velocity, Poisson's ratio, Young's modulus, bulk modulus, and acoustic impedance
- Oriented structures (e.g., fractures, fracture zones, bedding, layering) from optical and acoustic televiewer logging
- Hydrogeological/hydrogeophysical characteristics of the formations, e.g., hydraulically transmissive fractures, water content, fluid mobility, salinity and relative hydraulic pressures based on electrical conductivity, temperature, flow meter, porosity from borehole nuclear magnetic resonance (NMR) and nuclear logging, as well as estimates of hydraulic conductivity and transmissivity
- Borehole geometry and orientation

Figure 1 SB_BH01 Drilling Location



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1.2 Geological Setting

The sequence of rocks encountered in the SB_BH01 borehole consist of Paleozoic-aged strata that were deposited within the Michigan Basin northwest of the Algonquin Arch in Southwestern Ontario. The Michigan Basin is a circular-shaped cratonic basin that is composed primarily of shallow marine carbonates, evaporites, and shales that were deposited while eastern North America was in tropical latitudes during the Paleozoic Era (Armstrong and Carter 2006). West of the Algonquin Arch, strata from the Michigan Basin tend to gradually dip westward into the Michigan Basin. Borehole SB_BH01 was drilled through the entire Paleozoic sequence to approximately 20 m into the Precambrian basement, which is composed of high-grade metamorphic rocks of the Grenville Province.

1.3 Technical Objectives

The primary objective of the borehole geophysical logging program was to obtain high quality geophysical data over the entire borehole length and further use these data to help with interpretation of the following properties for each sedimentary formation logged:

- Lithology
- Stratigraphic boundaries
- Petrophysical rock properties (e.g., porosity)
- Geomechanical characteristics (e.g., rock mass structure and borehole breakouts, compressional and shear-wave velocity, Poisson's Ratio, Young's Modulus, Bulk Modulus, Acoustic Impedance)
- Oriented structures (e.g., fractures, fracture zones, bedding, layering) from optical and acoustic televiewer logging
- Hydrogeological/hydrogeophysical characteristics of the formations (e.g., hydraulically transmissive fractures, water content, fluid mobility, salinity and relative hydraulic pressures based on electrical conductivity, temperature, flow meter, porosity from NMR and nuclear logging
- Borehole geometry and orientation

2 DESCRIPTION OF ACTIVITIES

Geofirma was the Lead Contractor for borehole geophysical logging and interpretation (WP05) at SB_BH01. Waterloo Geophysics Inc. (WGI) was hired by Geofirma to act as their Technical Lead and QA specialist. Geofirma contracted with Colog Inc (Colog), a specialized borehole geophysical logging subcontractor, to acquire the suite of geophysical logs as part of the WP05 program. The Geophysical logging was conducted in accordance with Colog's *Technical Procedure and Work Instruction for Geophysical Logging – General Procedure (Colog, 2015)*, and ASTM D5753-05 Standard Guide for Planning and Conducting Geophysical Logging (ASTM, 2010). All borehole geophysical logging was conducted in accordance with Geofirma's project specific Health, Safety, and Environmental Plan (HSEP).

2.1 Geophysical Logging Phases

The geophysical logging was conducted in two phases. Figure 2 shows the borehole and casing depths during each of the two phases.

Phase 1 (Shallow Geophysical Logging) included logging the upper portion of SB_BH01 during June and July 2021, after the borehole was drilled to a depth of 152.89 mBGS and before the production casing was installed. At this time of logging the borehole was lined with steel intermediate casing with an outside diameter of 265 mm and cemented in place to a depth of 66.38 mBGS. The remainder of the borehole was left open down to a total depth of 152.89 mBGS. Phase 1 logging included:

- optical televiewer (OTV)
- acoustic televiewer (ATV)
- natural gamma
- density and
- neutron

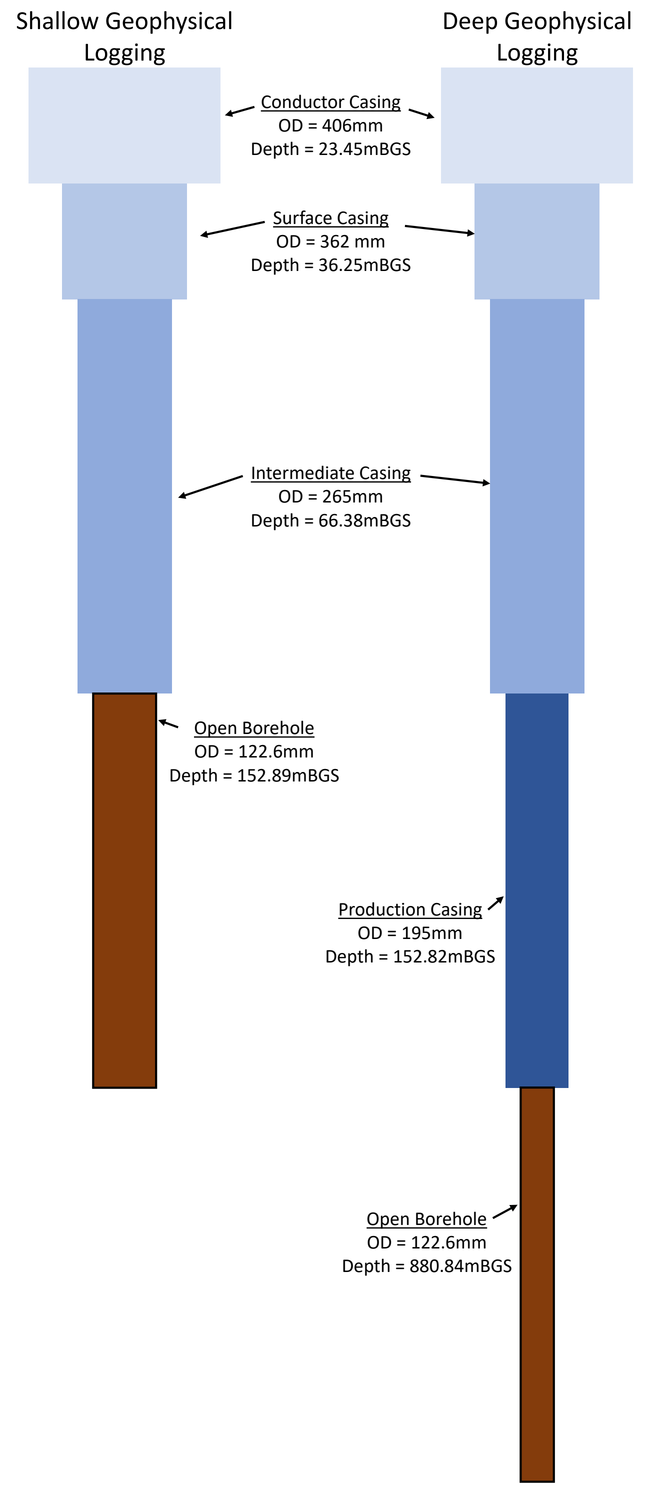


Figure 2 Borehole and Casing Depths During Geophysical Logging.

Phase 2 (Deep Geophysical Logging) included logging the main borehole at SB_BH01 during September 30 to June 3, 2022. At this time of logging the borehole was lined with a steel production casing with an outside diameter of 195 mm and cemented in place to a depth of 152.82 mBGS. The remainder of the borehole was left open down to a total depth of 880.84 mBGS. Phase 2 logging included:

- the same 5 logs used during Phase 1 (shallow logging)
- fluid electrical conductivity (FEC) / temperature
- spectral gamma
- resistivity (Elog) including single point resistance and spontaneous potential
- apparent conductivity (electromagnetic induction)
- caliper (3 arm)
- full waveform sonic
- magnetic susceptibility
- borehole magnetic resonance (NMR) (stationary)
- impeller flowmeter (continuous); and
- electromagnetic (EM) flow meter (stationary)

The bulk of the geophysical data collection in Phase 2 was completed prior to October 11, 2021 (details Table 3) at which time a portion of the borehole was blocked at a depth of approximately 623 mBGS before NMR and flowmeter testing was completed below this depth. The remaining borehole geophysical logging was completed on April 8, 2022 (static flow meter testing) and between June 2-4, 2022 (NMR) after the borehole was cleared and hydraulic testing was completed.

2.2 Site Logistics and Communication

During normal geophysical well logging operations, logging was conducted 24 hours per day. Staffing was organized into two 12-hour shifts, with day shift running from 7am to 7pm and night shift running from 7pm to 7am. Typically, 1-2 subcontractor staff were on site during logging, with Geofirma staff responsible for site supervision and the reviews of equipment calibration and log data quality was conducted by the WP05 Lead.

During shift changes (i.e., 7am and 7pm) Geofirma, Colog and WGI staff held meetings to report and discuss information about the previous shift activities. Data was shared over the internet on an ongoing basis for prompt review and parameter refinement.

Note that the geophysical logging was successfully completed during the initial stages of the Covid19 pandemic, therefore both government mandated and site specific mitigation policies were implemented as part of the comprehensive health and safety program.

2.3 Field Equipment and Software

Geofirma retained a specialized geophysical well logging subcontractor, Colog Inc (Colog), to acquire the suite of geophysical logs collected as part of the WP05 program. The geophysical equipment used for the logging program was owned or rented by Colog. Table 1 provides a summary of the equipment used for WP05 geophysical logging field activities.

Software used for WP05 activities are listed in Table 2. WellCAD (Versions 5.2 to 5.4) have been used for data analysis and interpretation as part of WP05 activities. These programs are classified as a Grade 3 software for the project. All other software was used for data acquisition only and are therefore exempt from NWMO software verification.

Table 1 Summary of Field Equipment for WP05 Geophysical Logging

Component	Component Description
1000 m Wireline Winch and Depth Decoder	Mount Sopris Instruments 4WNA-1000 or equivalent with a minimum of 1000 m of geophysical data line.
Logging Box/Data Acquisition System	Advanced Logic Technology (ALT) Matrix, Scout, or OPAL; Robertson MicroLogger II; Stockholm Precision Tools (SPT) Surface Unit: Century System VI
Laptop Computer with Logging Software	64-bit PC running Windows 10 Pro OS. Minimum 8 GB RAM and sufficient disk space to store all test data. All data backed up to an external drive following each test following the data management section of the test plan.
Tripod and wheel	Tripod: or rig mounted sheave wheel with sufficient height to lift probes completely out of the borehole. Depth measurement encoder wheel with a minimum of 600 pulses per meter.
Geophysical Probes	Probes used to acquire geophysical data. Detailed information about probe models and specifications are provided in Section 2.4 and Appendix A.
Geophysical Probe Calibration Equipment	Equipment used to calibrate logging probes: • On site: induction conductivity calibration disk, normal resistivity resistor array, caliper ring set, or multi-radial jig, OTV color strip, FTC meter, Corehole Dynamic Flowmeter (EM) static (zero flow) test cell, Brunton compass, Cesium check source (unregulated). • Off site: ATV tank with reflectors at 2 different radii, solid blocks of known density (e.g., 2.60 g/cm^3 aluminium and 1.74 g/cm^3 magnesium), sleeve of gamma-emitting unprocessed uranium ore, sonic velocity check water filled steel pipe, water tank
PQ Centralizers for Geophysical Probes	ALT non-magnetic CuBe springs for PQ boreholes
Silicon Grease	Dow DC-111 food grade dielectric silicone grease
Electronic Water Level Tape (100 m)	Solinst Model 101 water level meter. Used to measure water level within the borehole during the geophysical well logging. Metric tape with mm-scale graduations.
Tape Measure	Steel non-stretch metric measuring tape (with mm-scale graduations)
Cable Degreaser	Used to clean logging probes and equipment.
Climate controlled environment (Logging Truck)	Critical data acquisition equipment will be maintained in enclosed logging truck or trailer including an appropriate heat source to allow for changing temperatures.
Decontamination Equipment	Equipment used for decontamination and cleaning of logging equipment, including paper tower, Alconox soap, buckets/bins, fresh, and deionized water.
Generator and Accessories	On-board 60Hz AC generator with GFCI and overcurrent protection used for powering winch, data acquisition system and field laptop. Generator accessories such as a power bar, extra gasoline, and extension cord.
Toolbox/toolkit	Various hand tools used for troubleshooting, repair and maintenance of geophysical logging equipment.
Personal PPE	All field staff were provided onsite access to PPE. Minimum PPE for geophysical logging is steel toed boots. Additionally, eye protection, gloves, hard hats, hearing protection and masks were employed as dictated by specific work activities.

Table 2 Software List for WP05 Geophysical Logging and Interpretation Activities

Software	Version	Software Use	NWMO Software Verification/Grade
Microsoft Excel	365 (License)	Data collection (in DQC workbook), data visualization, and calculations	Exempt
Microsoft Word	365 (License)	Assemble memos and reports	Exempt
WellCAD (ALT)	5.2, 5.3	Data visualization, processing, and interpretation	Grade 3
Matrix Logger (ALT)	12.1.2388	Specialty data acquisition for ALT / Mount Sopris probes	Data acquisition only - Exempt
Winlogger (Robertson)	v.1.9.516	Tuns Micrologger II for specialty data acquisition using Robertson probes	Data acquisition only - Exempt
“GTD” (SPT)	v.1.491	Runs the SPT’s probe’s surface unit	Data acquisition only - Exempt
Javalin Pro Plus	V3.5	Specialty data acquisition for Vista Clara MNR probe	Data acquisition only - Exempt

2.4 Equipment Checks and Calibration

All geophysical logging equipment used as part of this work were inspected and calibrated prior to use. The calibration and verification were performed in accordance with the specific probe documentation. These methods are listed below in Table 3. The results of these calibrations and checks are recorded in the Data Quality Confirmation forms.

Additionally, tool response was continuously monitored in real time by an experienced operator and within a day after completion for quality control (QC) review by WGI. When probe damage or malfunction was identified in field checks, the equipment was repaired or replaced. During logging some typical data collection technical issues occurred such as changing collection parameters and communication loss that required logging interruptions to correct. Beyond the typical issues, the following technical issues were encountered:

- On Sept 30 and Oct 1, 2021, the site supplied power was interrupted. The power source was switched to an isolated dedicated circuit.
- The Fluid Temperature/Conductivity (FTC) probe initially mobilized was model QL40-FTC-I, a design intended to be “in-line” (i.e., set above other sensors) such that water enters the side of probe through ports. Geofirma recommended (NWMO confirmed) that the probe be replaced with the QL40-FTC, designed with the water intake directly at the bottom thereby minimizing mixing and disturbance prior to measurement. The order of logging was changed such that the ATV was collected prior to the FTC to maintain productivity. Given logging speeds and direction the water column would have “restabilized” more than approximately 36 hours before FTC logging, which is deemed adequate especially as the borehole was still likely in thermal dis-equilibrium from drilling and subject to vertical flow.

- The NMR probe had intermittent noise and communications interruptions. The probe was extracted from the borehole, cleaned of metal filings and logging continued with overlap.

- The borehole became blocked (October 10, 2021) at approximately 643 mBGS necessitating the collection of the stationary flowmeter data below in the April mobilization (details 2.1). The NMR probe produced unacceptably high noise in April 2022. The system was demobilized to proceed with hydraulic testing pending return in June 2022 during geophysical logging of SB_BH02. Once returned the same probe (Probe 009) was used in SB_BH02, but redeveloped noise and a spare system (Probe 003) was used to complete SB_BH01. Data collection in select sections (with contrasting characteristics) were repeated with both systems,

2.5 Equipment Setup

The geophysical logging workstation was organized adjacent to the borehole in the shelter of a customized truck or trailer. The drill rig structure was used to center the deployment wheel over the borehole and the wireline and winch were installed so the operator could visually monitor and control the equipment. The drill rig foot clamp was used as the depth reference for geophysical logging during Phase 1 and was measured to be approximately 2.59 m above ground surface (mAGS) at SB_BH01. For Phase 2 blow out protection and eventually the drill rig were removed and a plywood cover over the corrugated steel drill pit (0.47 mAGS) was used as the reference point. The elevation of the refence points relative to the site reference was surveyed by Geofirma staff. The elevation reference points allow the borehole data to be adjusted so the depth of each measurement is relative to the ground surface.

2.6 Data Quality Assurance and Quality Control

Several data quality assurance and quality control (QA/QC) measures were implemented by Geofirma staff during the logging program and subsequent analysis and reporting. Verification of results was completed following Geofirma's project-specific quality verification procedures and acceptance criteria which were reviewed during development of the test plan for this work package. All data acquisition and analysis were reviewed and verified, dated, and signed by a Geofirma technical staff member. The data was then uploaded for review by the NWMO work package lead.

The common QA/QC steps for all probes are as follows:

- Depth control is of critical importance and full details are provided below (Section 2.7).
- Probes were initially powered on surface and allowed to thermally stabilize for at least 15 minutes before data collection.
- Functionality / calibrations tests were conducted prior to logging. Files were recorded and details documented in data quality forms. The process was repeated after logging to ensure ongoing performance and assess stability.
- When data are collected moving upwards the probe output is monitored while the probe is lowered to the bottom to assess performance.
- A quality control check log of greater than 5% (~10-12 m for the upper portion and ~50 m for lower) was collected (typically near the bottom of the borehole) for comparison against the main full log to assess probe repeatability, stability, and depth control.

- At the bottom of the borehole any slack in the cable is eliminated and the bottom of the borehole depth (and time) noted.
- For all probes critical data are monitored on an ongoing basis in real time by experienced operators to:
  - ensure ongoing down hole communications
  - monitor probe speed, data gap frequencies, and adjust speed appropriately
  - confirm critical probe responses (data) are consistent and within the range of expected values
  - assess spurious variability (noise)
- Occasionally a primary data set was interrupted because:
  - collection parameters were no longer optimum (e.g., OTV light intensity)
  - a communication error occurred
  - data quality deteriorated due to electronic noise
  - sever weather protocols necessitated a stoppage
  - a power interruption occurred

  In these cases, the file was terminated, a corrective measure implemented (and noted), the probe moved back in the opposite direction past a distinct feature in the data (either primary or gamma), and a new file created collecting data with overlap from the previous file. The number of such occurrences for each log is noted in Table 3.
- As soon as possible after the data collection the raw data files were transferred to the WP05 Lead and imported into WellCAD for confirmation of quality. In the event of a deficiency (either in calibration, depth or quality) the cause was further investigated. If determined to be caused by a system or data collection issue the data set was recollected at the earliest (logistically practical) opportunity. When a borehole condition or environment was the cause options for mitigation or alternatives were discussed with NWMO to determine actions.
- Preliminary completed logs were digitally communicated to NWMO on an ongoing basis and the results discussed as needed.
- During data collection an ongoing raw data montage was maintained to compare depths of features and identify any inconsistencies between data sets.

2.7 Field Depth Control

At the start of each logging phase 100-150 m of wireline was measured, marked, and rewound to check for encoder accuracy. The encoder increment was adjusted, and the process repeated to ensure encoder increment accuracy. At the start of each log the probe was “zeroed” with the joint between the cable head and the probe aligned with the surface reference point while minimizing parallax (Figure 3). The control files (“tol” for ALT probes, “hed” for Robertson, etc.) allocates the various data sets to appropriate depth; at the sensor where the measurement is depth discrete (e.g., gamma, ATV, etc.) or halfway between the source and receiver for active probes (e.g., neutron, density, Elog, etc.). The only exception is the full waveform sonic where receiver data are aligned to the bottom of the probe (discussed further in Section 3.3.10). Note that the depths monitored on screen and reported in the quality control files all refer to the bottom of the probe and differ from the individual data sets in digital files according to the sensor offset.

Figure 3 Field Equipment Setup Phase 1: Winchline extended from field office trailer over pulley on drill floor to "zero" at surface reference. Phase 2: Winchline extended from Colog truck.

The preferred direction of the probe is upward from the bottom of the borehole towards the surface. However, for OBI and fluid temperature/resistivity measurements the probe records data while moving downwards from the surface to minimize the probe's disturbance of the water column. The details of tracking the reading depth varied slightly based on the direction of the probe while collecting data. Accordingly:

- Initially a deep reference point was established after lowering the first log to the bottom and marking the cable at the surface reference point. As each subsequent probe was used the offset of the mark was noted to provide an extra level of quality control as needed.
- For most probes (details in Table 3 and described below) the probe was lowered to the bottom of the borehole and the 5% QC log (described above) was collected. The probe was then returned to the bottom of the borehole and the primary data set was collected while moving upwards and thereby returning the probe to surface. The After Survey Depth Error (ASDE) is determined as the offset between the initial depth recorded when the probe is at the top of casing and that measured on return to the surface reference point. This is the preferred mode of data collection because the entire system is under tension and the likelihood of the probe remaining stationary as the cable moves past the depth encoder is minimized.
- For the fluid temperature/conductivity and optical televiewer probes, where the motion of the probe could compromise the reading by disturbing the water column, primary data are collected moving downwards. In these cases, the probe is lowered to the bottom first collecting the primary data set. After reaching close to the bottom (generally the operator avoids placing the sensor into any mud in the very base of the borehole), the final offset is noted. Approximately 5% repeat QC data is collected to confirm probe operation although because of water column disturbance

the detailed repeatability of that data with the primary data set is likely to be poor. Upon return to surface the ASDE is recorded although it has limited usefulness.

- Primary data is collected in both directions for some probes. This is done when it is either logistically optimal because of stationary readings (NMR) or where a comparison of data collected while moving downwards to that collected upwards improves interpretation such as impeller flowmeter measurements.
- All probes (except magnetic susceptibility, NMR and EM flowmeter) concurrently collect a complimentary passive gamma log with the primary data sets so as to allow for depth alignment between probes, details of the application in post processing are provided below (Section 3.1).
- For those probes which cannot collect useable data within casing (e.g., Elog, magnetic susceptibility, etc.) data collection was terminated once within casing or slightly below the bottom of the casing (for the NMR where collecting data within steel could damage the probe). Note the ASDE was still recorded on return to surface.
- When the main data set was divided (see above) the operator insured data overlap across distinctive features for reference in post processing.

3 BOREHOLE GEOPHYSICAL DATA ACQUISITION AND PROCESSING

After each data set was successfully collected, reviewed, confirmed to have met objectives of the work plan and deemed to be of adequate quality, the following processing was conducted:

1. Assembly into a single log as necessary
2. Depth adjustment correction to common alignment
3. Individual corrections for casing effects, drift, etc.
4. Preliminary processing for select parameters

The resulting data were assembled into groups (suites) pertaining to rock characteristics. The details of the geophysical data collection are provided in Table 3.

3.1 Geophysical Logging Depths

The geophysical data were recorded at regular measured intervals as appropriate for each data set and essentially continuous with depth. Each geophysical data set is collected independently, so minor offsets occur between logs due to varying logging directions, speeds, multiple data subsets, etc. It is critical for higher level interpretations that these offsets are corrected, and that the complete geophysical suite is depth aligned with other forms of data such as core, hydraulic testing, etc.

All data (geophysical and non-geophysical) are collected in depth relative to temporary reference points on surface (often a point on the drill rig or casing assembly) the elevation of which are surveyed relative to a site-specific benchmark. All the depth measurements have some inherent uncertainty. It was deemed that because the drill rods lengths are manufactured to the highest tolerances that as much as possible all data are to be aligned with the core. The steps and considerations to achieving that alignment are described below.

3.1.1 Merging of Data Subsets

As described in Section 2.6 circumstances necessitated that some logs were collected in segments (subsets) with overlap. These were consolidated into a single data set as follows:

1. Regardless of logging direction the data sets are assembled from top to bottom with the ASDE correction applied as appropriate.
2. The lower data set is depth adjusted to overlap with the data above based on either main data set or the complimentary gamma log.
3. If the reason for separating files was data deterioration the overlapping poorer quality data is trimmed to the start of the newer data set and files merged.
4. If data quality of the overlapping portions is similar the files are averaged for line data.
5. However, ATV and OTV image logs deteriorate on averaging, and these are trimmed prior to merging.
6. Steps 2-6 are repeated as needed until a complete data set along the entire length of the borehole.
7. Note that data collected under potentially distinctly different borehole conditions (Section 3.2), e.g., flowmeter data, are not merged and remain as distinct data sets.

3.1.2 After-Survey Depth Error

For probes where data are collected upward the offset between the initial depth recorded when the probe is at the top of casing and that measured on return to surface, the After Survey Depth Error (ASDE), is adjusted accordingly.

3.1.3 Wireline Cable Stretch Correction

The data were collected using a four conductor, 4.78 mm steel armoured (2 layers) wireline cable. The manufacturer (Rochester Corporation) specifies an elongation factor (EF) of approximately 1.15 m/km/KN [1.173×10^{-4} m/km/kg] for the cable. The cable stretch is influenced by the weight of the probe in water and weight of the wireline itself. According to the manufacturer, the wireline weight is 75 kg per 1000 m of cable in fresh water. The cable stretch correction factor (CF), expressed in units of m/km, would theoretically be applied to data for each individual probe based on the excess probe weight.

$$CF = EF\ [(W_p - \rho_w \times V_p) + W_c$$

where:

W_p Dry weight of probe (kg)
ρ_w Density of borehole fluid (kg/m^3)
V_p Volume of probe (m^3)
W_c Weight of cable (kg)

For example: the combined ATV and gamma probe (V_p=0.0032 m^3, W_p = 11 kg) at a borehole fluid density (ρ_w) of 1000 kg/m^3 would have a cable stretch correction factor (CF), or offset, of 0.0080 m at 900 m depth. This value is at best an estimate because:

- The entire cable weight experienced is allocated to all the cable from surface rather that incrementally along it's length due to progressively decreasing cable weight with depth.
- It assumes a free hanging probe and does not account for any additional stretch created by sleeve friction or centralization, or decreases due to increased in fluid density etc.
- The cable manufacturer (Rochester Corporation) does not provide specifications for the thermal effects on the stock (type 4-H-181A) wireline cable, however data available for similar cable from the same manufacturer indicates a change in stretch of no more than 0.005% for 20°C increase in fluid temperature.

Given these unknown offsetting factors and the final depth adjustment to core (as described in Section 3.1.4), the calculated depth error of 0.001% due to cable stretch is considered to be negligible and therefore was not applied.

3.1.4 Standardizing Alignment of Geophysical Data with Core

When data are collected upwards (under tension) the geophysical depth encoding is essentially continuous with a known ending point at the surface reference but a starting depth with an unknown error introduced during downward motion. The depth of the rock core is determined based on machined steel drilling rods with accurate lengths, however the exact depth of a logged feature in core may also have minor inherent depth errors due to a variety of factors, including:

- core loss due to mechanical deterioration during drilling,
- lost or extra core due to incomplete retrieval in core barrel in successive runs,
- changes in reference elevation over the long drilling period,
- potential human error during surface referencing and,
- measurement errors between core extraction and final alignment on the core tray.

However, due to the overall confidence in position of the core barrel during normal drilling conditions, features logged in rock core are considered to be the most accurate depth reference for which the geophysical data are aligned to.

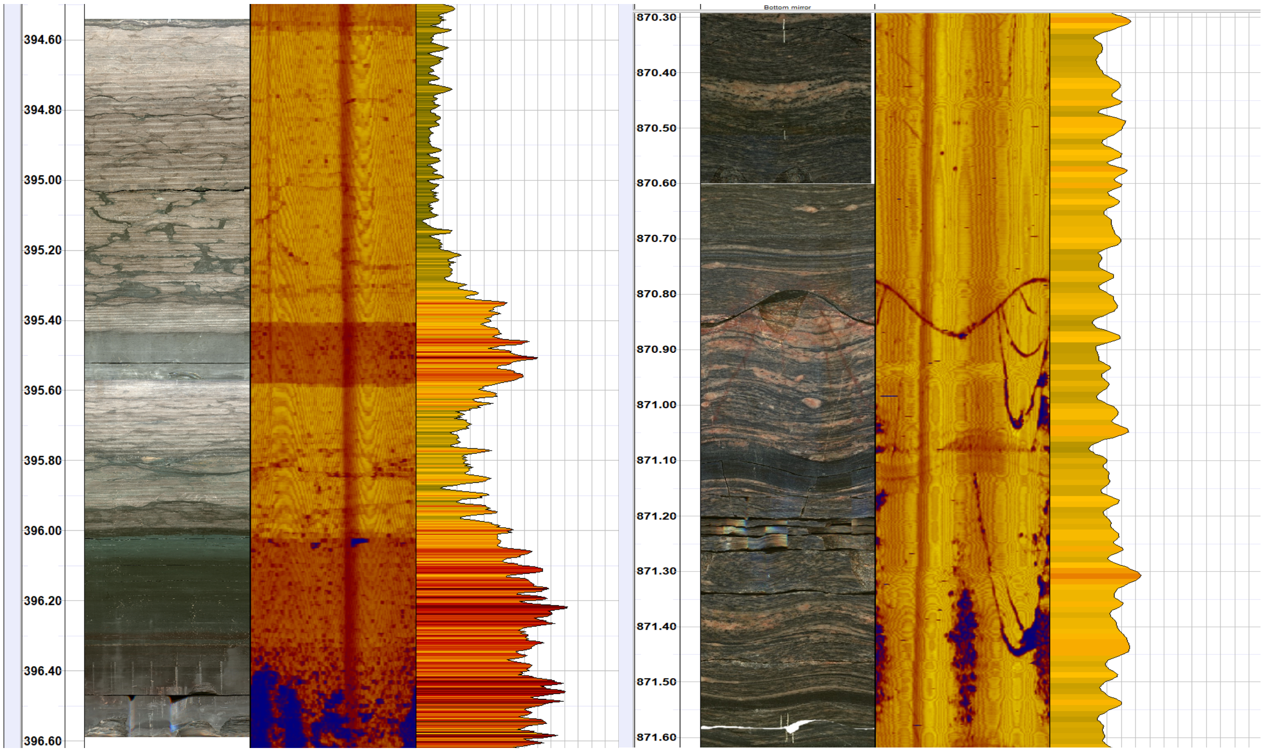
The steps taken to align the shallow borehole geophysical data with the core included:

1. The cable was marked at 50 m intervals to 150 m (total borehole depth during geophysical logging 152 mbref.
2. After ASDE correction the ATV and OTV data (with synchronous gamma logs) were stretched to account for the measured offset when at the bottom of the borehole.
3. The neutron and density data sets also each included a gamma log. These data sets were stretched to align with the gamma log collected with ATV (adjusted in step 2).

Aligning the deep borehole geophysical data was slightly more complicated because it was impractical to measure and mark the cable to the total length of the deep borehole (~900 m). In addition, the OTV image was of poor quality due to low fluid transparency and therefore only the ATV was available for alignment of geophysical data to core data (by comparing to core photos) over most of the length. As such, the steps taken to align the geophysical data with the core included:

1. The ATV data and coincident gamma log were aligned to surface reference by applying the ASDE correction.
2. The ATV and gamma data were stretched to match select unambiguous distinctive features in core photos where there was 100% core recovery and therefore high confidence in depth position. Two such features were selected in SB_BH01 and include (A) midway along the borehole near the Cabot Head boundary and (B) a fracture near the bottom of the borehole within the Precambrian (870.82 mBGS) (Figure 4).
3. After depth adjustments were completed based on these two features, the overall accuracy of alignment between stretched ATV and core photos was completed. In total, an additional thirty-eight other distinct, unambiguous bedding surfaces and fractures were identified along the entire borehole length in the both the core photos and the ATV image and were compared. Figure 5 shows the offsets observed between these features in core photos and the ATV images plotted against depth (mBGS) as well as the percent recovery for the specific core run in question. Overall, the offsets are shown to be within +/- 15 cm and were considered to be acceptable.
4. To assess whether the offset is related to core recovery the two parameters are cross plotted in Figure 6. The analysis confirms that there is no obvious systematic variation between the offset between core and the ATV image and the differences appear random. Since the ATV is

continuous and systematic the nominal offset of ±5 cm (with few exceptions; average absolute offset = 4.1cm) is likely related to drilling, core recovery and processing.



A: Cabot Head 395-396 mBGS **B: Fracture 870.82 mBGS**

Figure 4 ATV (Gamma) to Core Offset after Depth Adjustment

A: 0.24 m upward, B: 0.04 cm downward

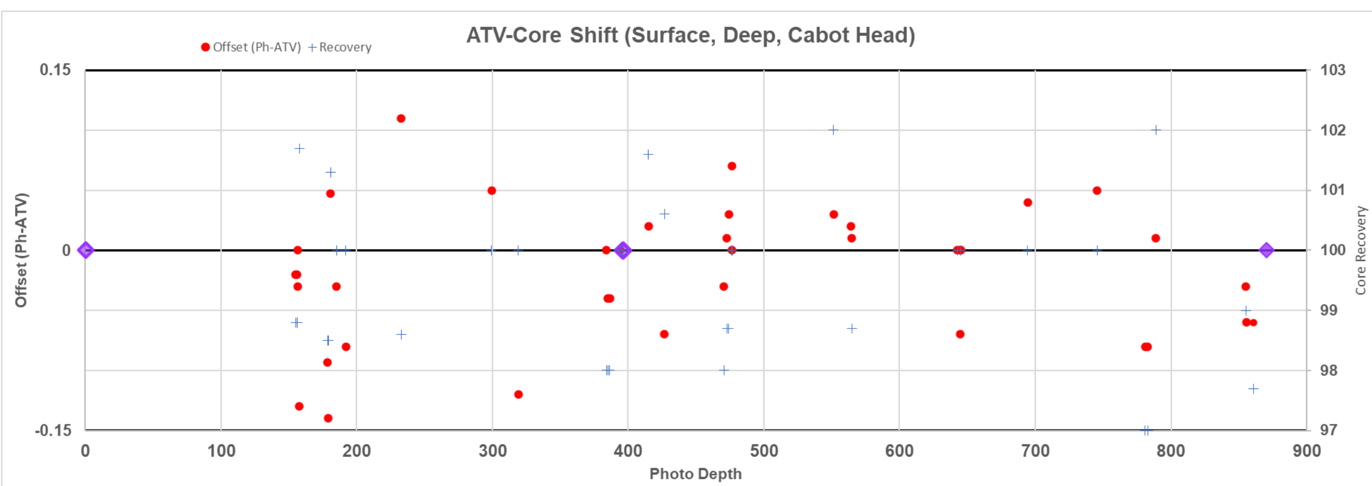


Figure 5 Core to ATV Offset after Depth Adjustment

Purple diamonds: Reference points. Red dots: Offset at intermediate features; Blue cross: % core recovery at intermediate features (right hand scale).

5. The results of Step 4 resulted in a "master gamma log" aligned with core. Most other data sets were collected with coincidental gamma data, and these were adjusted (stretched) to match the "master gamma log" rather than aligning presumed lithologic boundaries. The only data sets that did not include a coincidental gamma log during their collection, due to the primary data probe not being able to configure a gamma probe in series, were magnetic susceptibility, NMR, and EM flowmeter (discussed below).
6. As discussed in Step 5, due to the lack of coincidental gamma data during data collection of magnetic susceptibility, NMR and EM flowmeter data, the following depth adjustments after ASDE correction were made:
    a. Magnetic susceptibility data was stretched between the top of the Precambrian and the bottom of the casing.
    b. NMR data was adjusted to match distinct changes in the neutron data, the only other probe that directly measures hydrogen content.
    c. EM flowmeter individual data sets stretched according to ASDE.

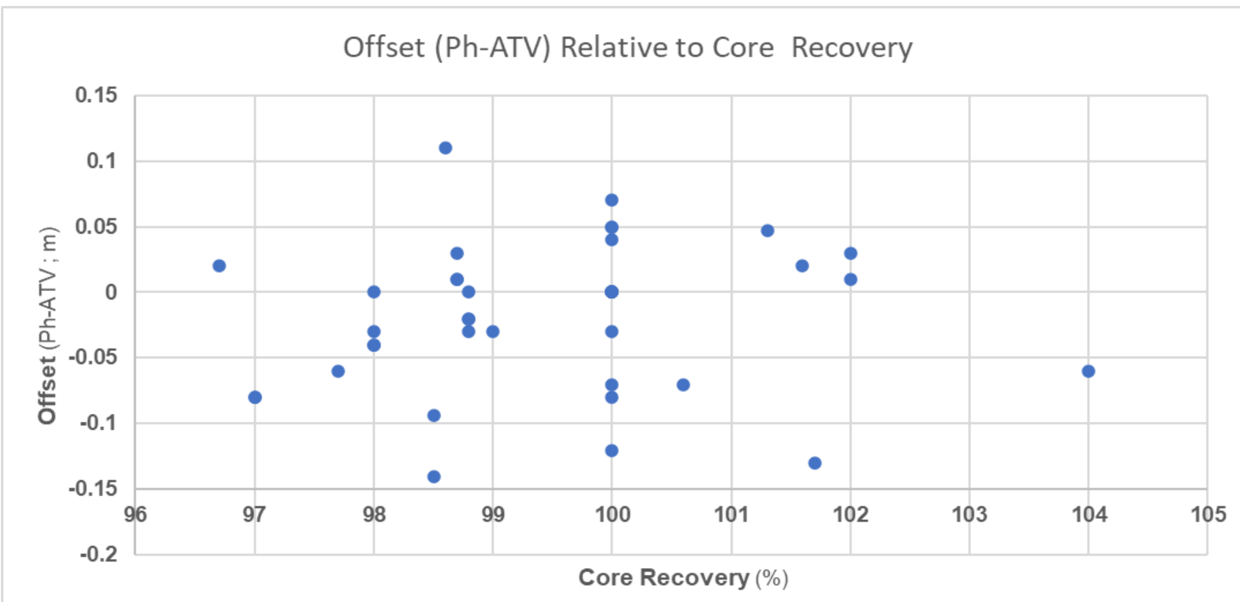


Figure 6 Core to ATV Offset Relative to Core Recovery

3.2 Variations in Borehole Condition and Hydraulics

Temporal variations of some borehole geophysical parameters is possible as the logging environment equilibrates after drilling, borehole flushing or as a result of normal hydrodynamic fluctuations. A summary of noteworthy changes associated with the SB_BH01 logging environment that could potentially influence borehole geophysical measurements include:

- SB_BH01 was drilled over a period of several months (June to September 2021) with various activities influencing the borehole environment, including:
    - flushing with water at thermal disequilibrium with the insitu groundwater,
    - friction generated heat,

    - although the drilling fluid was brine-based below the Salina Formation F-shale unit, its composition was likely not at equilibrium with the formation water throughout the borehole,
    - pumping as part of drilling fluid circulation may cause either a positive or negative hydraulic pressure in the borehole relative to various portions of the formation thereby causing formation water to mobilize into the borehole or drilling fluid to penetrate into the formation.
- The borehole was flushed (first with brine and then with fresh water) after drilling and before geophysical logging (September 25 to September 26, 2021) potentially increasing thermal and chemical disequilibrium between the borehole and the formation.
- Vertical hydrostratigraphic variations exist (as confirmed by flow along the open borehole) but could be temporally variable due to:
    - gradual re-equilibration of pressure and water density effects imposed during drilling,
    - temporary blockage of the borehole during hydraulic testing,
    - indications of daily variations in local pumping were noted during shallow testing and could impact flow along SB_BH01.
- The borehole experienced a localized blockage at a depth of approximately 643 mBGS (October 10, 2021) after the majority of geophysical data had been collected. As a result, localized changes in borehole diameter were measured and documented by ATV after clearing which can influence NMR readings in the larger void section. A reorganization of the work schedule was implemented to allow for hydraulic testing (WP06) before the completion of stationary EM flow meter and NMR data collection in the lower portion of the borehole. Although no influence is anticipated on NMR data, the hydrodynamics may have changed influencing flowmeter testing. Overlapping repeat data were collected to assess changes above the blockage.

3.3 Probe Specific Details and Data Collection

A summary of the full geophysical logging scope completed at SB_BH01 is provided in Table 3. Details of the individual primary datasets and the data collection follow. Appendix A provides technical information for each probe. Note that many probes also record secondary data sets (e.g., logging speed, temperature, raw counts per second (cps), etc.) as part of the acquisition; these data were provided as part of the raw data deliverable but are not included in main data montages included in this report. The order of data presentation is grouped by general type/purpose (e.g., image logs, lithology, hydrodynamic, etc.) and other particulars are included in the summary table. The response statistics for each data set are provided in Section 4 below.

Table 3 Geophysical Logging Probes and Acquisition Parameters

	Geophysical Test	Probe Model	Sample Interval (m)	Nominal Logging Speed (m/min)	Logging Direction	Order	Number of Segments in Final	Data Coverage (mBGS)	ASDE (-above/+below)	Calibration	Raw File (*.xxx)	Date (Started)	Comments
Upper 152.82 mBGS, cased to 66.38 mBGS	Natural Gamma Log (Master w ATV)	ALT QL40-GAM	0.0025	1.1	Up	2	1	-1.05-152.03	0.16	Puck, air	.TFD	27-Jun-2021	
	Optical Televiewer	ALT QL40-OBI-2G	0.0004	0.6	Down/Up	1	2	-1.05-152.03	0.16	Colour Card, Compass Level	.TFD	27-Jun-2021	Each data packet has 4 traces
	Acoustic Televiewer	ALT QL40-ABI-2G	0.002	1.1	Up	2	1	151.99-49.16	0.05	Ref bar, Compass, level	.TFD	28-Jun-2021	
	Gamma-Gamma (Focused Density) & Lithodensity	Century 9339, incl.1-arm Caliper	0.01	2	Up	3	1	151.40-0.38	0.28	AL & Mg blocks, Caliper jig	.TFD	28-Jun-2021	
	Neutron (upper 152.89m)	Robertson DNNS	0.05	2.3	Up	4	1	151.36-1.74	0.29	Water tank	.HED .LOG	09-Jul-2021	

Main Borehole (890 mBGS, cased to 152.82 mBGS)	Natural Gamma (Master w ATV)	ALT QL40-GAM	0.002	1.2	Up	3	2	873.36-217.29	0.91, 0.82, 0.48	Puck, air	.TFD	30-Sep-2021	
	Optical Televiewer	ALT QL40-OBI-2G	0.0015	1.2	Down	1	5	0.00-878.89	1.199	Colour Card, Compass Level	.TFD	30-Sep-2021	Each data packet has 4 traces
	Acoustic Televiewer (ATV)	ALT QL40-ABI-2G	0.002	1.2	Up	3,6	3	873.36-217.29	0.91, 0.82, 0.48	Ref bar, Compass, level	.TFD	01-Oct-2021	733-786 recollected to improve centralization
	Fluid Electrical Conductivity (FEC) /Temp,	ALT QL40-FTC	0.01	0.9	Down	2	2	0.00-872.92	0.91, 1.32	Solutions	.TFD	02-Oct-2021	
	Spectral Gamma	ALT QL40-SGR-BGO	0.01	0.9	Down	2	2	0.00-872.92	0.91, 1.32	Pucks	.TFD	02-Oct-2021	
	Resistivity (Elog), Single Point Resist., Spontaneous Potential	Robertson ELXG	0.05	2.5	Up	4	1	872.33-141.50	0.82	Resistor Array	.HED .LOG	03-Oct-2021	
	Apparent Conductivity (electromagnetic induction)	Robertson DUIN	0.02	2.5	Up	5	1	872.65-1.10	1.10	Coil	.HED .LOG	04-Oct-2021	
	Caliper (3 arm)	ALT QL40-CAL	0.005	2.5	Up	7	1	867.16-0.98	0.97	Caliper Jig	.TFD	04-Oct-2021	
	Full Waveform Sonic	ALT QL40-FWS	0.02	1.5	Up	8	1	869.59-0.12	-0.12	Pipe	.TFD	05-Oct-2021	
	Magnetic Susceptibility	Robertson BMSG	0.005	2.5	Up	9	1	870.9-149.14	0.61	Coil	.HED .LGX	06-Oct-2021	
	Gamma-Gamma (Focused Density) & Lithodensity	Century 9339	0.02	2.5	Up	10	3	867.18-1	0.97	AL & Mg blocks, Caliper jig	.TFD	06-Oct-2021	
	Neutron (Near and Far)	Robertson DNNS	0.02	2.5	Up	11	2	868.72-1.09	0.20	Water tank	.HED .LOG	07-Oct-2021	
	Nuclear Magnetic Resonance (NMR) – Continuous	Vista Clara Javelin 238	0.13	0.27	Both	14,17	8	156.36-610.56	0.6,.35,.63	Factory	.JRD	09-Oct-2021	Hole blocked @ ~642 mbref, repeats & lower portion 08-06-,2022.
	Nuclear Magnetic Resonance (NMR) – Stationary	Vista Clara Javelin 238	0.2,0.5	0	Both	15,16	19	248.36-506.36	0.35, 0.63	Factory	.JRD	13-Oct-2021	Hole blocked @ ~642 mbref, repeats & lower portion 08-06-,2022.
	Impeller Flowmeter (continuous)	ALT QL40-SMF	0.005	4,8	Both	12	4	0-868.01	0.60, 0.32	No-flow cell	.TFD	08-Oct-2021	4 data sets (down/up at 4&8m/min)
	EM Flow Meter (stationary)	Century 9722	varies	0	Both	13	26	118.78-877.82	0.60,0.82, 0.75, 0.47	No-flow cell	.TFD	07-Oct-2021	Hole blocked @ ~642 mbref, repeats & lower portion 18-04-2022.
	Borehole Deviation	From ATV and OTV											

3.3.1 Optical Televiewer

For this study, Colog used an OTV probe manufactured by Advanced Logic Technology (ALT) (model: QL40-OBI-2G) with a natural gamma probe attached above the Optical Borehole Imager (OBI) tool. Optical Televiewer (OTV) logs provide high resolution visual images (digital camera with LED lighting) of the borehole wall oriented using magnetometers and inclinometers. The primary purpose is the identification of bedding features and structures oriented in three dimensions. The probe is centralized and also measures the tilt and azimuth of the borehole. OTV data quality is highly dependent on borehole fluid clarity and varied dramatically along the length of the borehole. To minimize sediment disturbance the OTV was initially collected moving downwards. Each data packet contained 4 traces.

Data quality in the upper portion of the borehole was excellent producing a clear high-resolution image that required no subsequent manipulation. The image quality in the lower portion varied from moderate (~170-230 mBGS) to very poor (attributed to low transparency of the borehole fluid although it was flushed with brine and fresh water before logging). Logging parameters were varied to improve resolution to negligible benefit. The image was initially assembled (Section 2.8), subdivided into sections based on quality, then each section was contrast and brightness optimized, and re-merged for the final deliverable. The magnetometer orientated image of the rock is distorted by the steel within the casing to approximately 4 m below the bottom of the casing. The distortion was corrected by assuming the probe does not rotate immediately below the casing. An unoriented version of the image is trimmed to the lower limit of the magnetic affect, the result is rotated to align with the lower magnetometer orientated image and the images merged overwriting the distorted portion of the image.

The quality variations over the lower borehole occur at distinct intervals generally coincident with broad lithologic changes and variations in borehole water flow. Much of the image has a distinct greenish tinge as a result of the fluorescein used as a tracer of drilling fluid but appears brownish colour below approximately 619 mBGS. Note also that the quality improves slightly below 680 mBGS towards the lower portions of the borehole with banding consistent with lithologic layering.

3.3.2 Acoustic Televiewer

Acoustic televiewer (ATV) logs provide a detailed, oriented image of acoustic reflections from the borehole wall. The ATV probe used in this study, referred to by ALT as their acoustic borehole imager (ABI) tool (model: ALT ABI-40-2G) has a focusing system that can resolve bedding features as small as 2 mm and is capable of detecting fractures with apertures as small as 0.1 mm. Note however that the representation of thin features is limited to the beam width (approximately 1.5 mm width at the focal point but varies with borehole diameter). The acoustic image is oriented using a 3-axis magnetometer with dual accelerometers. A copy of the probe manual is provided in Appendix A for reference.

The ABI-40 transmits ultrasonic pulses from a rotating sensor and records the signals reflected from the interface between the borehole fluid and the borehole wall. The amplitude of these reflections is representative of the hardness of the formation surrounding the borehole as well as borehole wall rugosity. The travel time represents the borehole shape and diameter. Data were collected at a very high resolution of 2 mm intervals along the borehole at 1.25° and 2.5° increments for the upper and lower portion of borehole logs respectively. The probe was centralized and measured inclinometer and magnetometer data to determine the borehole azimuth and dip below the casing.

Because of the geometry of the reflections of the pulses, the ABI probe must be well centered in the borehole. Specialized centralizers are affixed to the ABI to improve centralization of the probe while logging. The gamma log collected with the ATV is considered to be the more accurate gamma log due to the slow speed in collection and ability to confidently depth correct with the ATV image compared to core logging. This gamma log is therefore considered to be the “master gamma log”.

Some noteworthy characteristics about ATV logging include:

- The probe only provides a usable amplitude and travel time data through water.
- Like the OTV, the magnetometer orientated image of the rock is distorted by the steel within the casing to approximately 4m below. The distortion was corrected by:
  - assuming the probe does not rotate immediately below the casing,
  - an unoriented version of the image is trimmed to the lower limit of the magnetic affect,
  - the result is rotated to align with the lower magnetometer orientated image and
  - the images merged overwriting the distorted portion of the image.
- The quality of the ATV image is generally uninfluenced by the clarity of the borehole fluid.
- The ATV image quality deteriorates when:
  - There is appreciable buildup of drilling mud or rock flour (fine cuttings) on the borehole wall.
  - The borehole wall is irregular (rough) due to drilling method or friable rock.
  - The probe becomes severely decentralized.
  - In highly irregular portions the system’s interpretation algorithm defaults the travel-time estimate to the probe’s outer surface, thereby resulting in misinterpretation of the minimum and average borehole diameter for that depth.

The data quality in both the upper and lower portions of the borehole are high. There are minor indications of de-centralization, coating on the borehole wall, and extensive borehole rugosity, however overall, the ATV data has excellent quality.

3.3.3 Natural Gamma

For this study, Colog used a natural gamma probe manufactured by ALT (model: QL40-GAM). The natural gamma log provides a measurement of natural radioactivity emitted by the formation, recorded in counts per second (cps). The primary purpose of natural gamma logging is for lithologic and stratigraphic identification/correlation. Gamma radiation is measured with a scintillation sodium iodide (NaI) detector. The usual interpretation of the gamma log, for sedimentology and hydrogeology applications, is that measured gamma counts are proportional to the quantity of clay minerals present. This interpretation assumes that the natural radioisotopes of potassium (primarily), and to a lessor degree uranium, and thorium occur in exchange ions, which are attached to the clay particles (further details and limitations in 3.3.4 below).

Some noteworthy characteristics about gamma logging include:

- Natural gamma emissions are random events with a Poisson distribution and therefore the longer the period of sampling the more representative the measurement is of the material being measured.
- Actual counts depend upon the detector size and efficiency.

- The probe is continuously moving while sampling and therefore the data quality depends on the sensor, data density and logging speed.
- The probe response (cps) is often normalized to standardized American Petroleum Institute (API) unit through a probe specific linear equation. 200 API units equal the detector response in a specially constructed physical model designed to simulate the typical shale. Cross correlation of a log completed with a probe that has been calibrated in API with a log from an uncalibrated probe in the same borehole allows the second probe to be converted to API.
- The assumption of a direct correlation between gamma levels and clay content in sedimentary rock is contradicted when:
  - a rock that has a significant clay sized component but does not have clay minerology such as micrite, or
  - the origin of a relatively coarse-grained matrix material has been derived from weathering of a high potassium rock, (e.g., potentially in the Cambrian sandstone weathered from Precambrian granites below).
- The gamma logs collected with the ATV (data at 2 mm with a nominal logging speed of 1.3 m/min moving upward with only 2 segments), averaged over 14 mm was used as the “master gamma log” for depth correction of all other data sets that were collected coincident with gamma logs (section 3.1.4.).
- Gamma logs can be measured through steel casing with 25% suppression for each layer of steel which can be mathematically corrected for.
- Compensating for casing by multiplying by a factor of 1.25 does not yield the correct formation levels if the casing has been sealed with either cement and/or bentonite which are both are strong gamma emitters.

The quality of the natural gamma logs collected are excellent, resolution is high and comparison for data alignment confirms repeatability. These data are a critical component in lithologic interpretation and establishing/confirming major stratigraphic boundaries as well as compensation for other data such as neutron porosity for shale content.

3.3.4 Spectral Gamma

For this study, Colog used a spectral gamma probe manufactured by ALT (model: QL40-SGR-BGO) equipped with a natural gamma probe. The Spectral Gamma is a temperature-compensated, fully digital probe which samples 256 channels of natural gamma radiation in the energy range of 100 keV to 3 MeV at a rate of one complete spectrum, per second. The standard detector used is a 38 mm by 150 mm thallium-activated sodium iodide (NaI(TI)) crystal. Operation software allows the complete spectrum, total gamma count rates as well as Ur, Th and K energy windows to be estimated.

The gamma-emitting radioisotopes that naturally occur in geologic materials are potassium-40 and nuclides in the uranium-238 and thorium-232 decay series. Potassium-40 occurs with all potassium minerals, notably potassium feldspars. Uranium-238 is typically associated with dark shales and uranium mineralization. Thorium-232 is typically associated with biotite, sphene, zircon and other heavy minerals.

Some noteworthy characteristics about spectral gamma logging include:

- Industry standards of reporting both uranium and thorium in ppm while potassium is a percent (%) are followed.
- Most of the principles regarding the nature and data collection provided above for natural gamma (3.3.3) also apply for spectral gamma but are accentuated by the high level of discretization needed to reliable measure components generally occur at low quantities.
- The multiplier of 1.25 for each layer of casing does not necessarily apply to individual isotope components.
- There is overlap in the energy spectrums of various isotopes. The manufacturer's recommended algorithm has been applied, but others exist and may warrant future consideration.

The data exhibits distinct differentiation between various lithologies and good correlation with the "master gamma log" collected with the ATV data. The potassium and thorium portions have the most differentiation between geologic layers and uranium more subtle variations. The relative levels, as well as the ratios between isotopes, (together with the lithology recorded from WP03 core logging) provide a suitable basis for stratigraphic correlation, refinement of transitions/contacts between units, as well as establishing rock matrix characteristics.

3.3.5 Neutron

For this study, Colog used a neutron probe manufactured by Robertson Geologging Inc. (model: DNNS) equipped with a natural gamma probe. The neutron probe has an americium-241/beryllium radioactive source that emits thermal neutrons and has two neutron detectors (near, far) as well as a gamma sensor. The high energy neutrons interact with the media that surrounds the probe including the borehole fluid and formation. The interaction with the formation is complex, but the critical factor is that there is a proportional loss of energy due to collisions with hydrogen atoms and the response is therefore assumed to be inversely proportional to total water content.

Some noteworthy characteristics about neutron logging include:

- The near and far sensors respectively have 25 cm and 40 cm offsets from the source.
- The ratio far/near and the borehole diameter are used to correct the output to "porosity units" based on a manufacturer provided calibration/relationship.
- Total water content in a saturated formation varies by the clay content because clay minerals contain a significant volume of bound water. In the presence of increased proportion of clay mineralogy, the interpretation of the neutron log results in an erroneously elevated estimate of porosity (referred to as the "shale effect"). Further details are provided in Section 4.3.
- Also, it is possible that hydrogen in pore spaces occurs in other forms besides water (e.g., oil, gas etc.) or mixtures of these. Given that continuous core will be collected and undergo detailed assessment, the geophysical data would not be the primary diagnostic tool for such occurrence.

The results of the neutron log exhibit distinct differentiation between lithologies to support lithologic interpretation, refinement of stratigraphic contacts, subdivide geologic units, correlate between wells, and establishing rock matrix characteristics.

3.3.6 Gamma-Gamma Density

For this study, Colog used a focussed density photoelectric logging tool (gamma-gamma density probe) manufactured by Century Geophysical LLC (model: 9339) equipped with natural gamma probe and a 1-arm caliper arm. Gamma-gamma density logging uses a columnated tool that subjects the formation to gamma radiation using a radioactive source (150 mCi {5.55 GBq} cesium-137) and measures the returned response at two columnated detectors 20 cm (near) and 35.8 cm (far) above. The probe measures electron density based on gamma energy loss from collisions with electrons in the surrounding geologic formation.

The near detector also measures photoelectric (PE) decay; the low-energy region of the scattered gamma ray spectrum separately in units of barns/electron. The primary function of PE logging is to differentiate between limestone, dolostone, and sandstone which can be poorly distinguishable on other geophysical logs (e.g., gamma).

Some noteworthy characteristics about density logging include:

- The response to the source is protected against direct radiation from the source by extensive shielding.
- Values are reported directly in g/cm^3.
- Photoelectric absorption, which is controlled by the atomic number, Z which strongly correlates with lithology: Calcite = 5.1 barns per electron (b/e), dolomite = 3.1 b/e, quartz = 1.8 b/e.
- PE does not obey a linear, volumetric mixing law while fresh water = 0.36 b/e and brine (120 kppm NaCl) = 0.81 b/e.
- The arm used to force the probe against the borehole wall also provides a single arm caliper measurement of diameter.

The density data quality is high with good repeatability, low noise and strong consistency with other data sets. The results provide support for lithologic and stratigraphic characterization/correlation, establishing geologic boundaries and a complimentary estimate of porosity. The density estimates are basic material property and a key component of the estimations of mechanical properties.

3.3.7 Normal Resistivity, Self-Potential and Single Point Resistance

For this study, Colog used a resistivity tool (normal resistivity, spontaneous potential, single point resistance) manufactured by Robertson Geologging Inc (model: ELXG) equipped with natural gamma probe. A geologic formation's resistance to the flow of electricity (resistivity) is dependent on the type of matrix material (minerology, clay content, etc.), formation fluid content (%), and fluid chemistry. The effects of these properties on the measured resistivity allow for interpretation of lithology, correlation of beds, estimation of fluid quality, and in some cases estimation of porosity as well as identification of possible fracture/flow features.

The resistivity probe (i.e., Elog) creates an alternating current flow between two electrodes (A, B [the cable above a nonconductive bridle is used to increase offset]), while the voltage drop is measured between a surface electrode (N) and downhole potential electrodes (M_1, M_2…). The potential electrodes are separated from the current electrode (A) at fixed distances which control the depth of investigation; for this probe 0.4 m and 1.6 m (16 and 64 inches). The resistivity of the surrounding media is calculated from Ohm's law and the geometry of the electrode arrangement. The probe also measures the single point resistance (SPR) between A-B and the spontaneous potential (SP) which is the ambient voltage difference between N-M_1.

Some noteworthy characteristics about resistivity logging include:

- Data can only be collected below the blended water level in the borehole.
- Steel casing short circuits the array, precluding measurement.
- The sampling volume is proportional to the A-M_x electrode spacing; the 0.6 m (64") array measures deeper into the formation, but at lower vertical resolution, than the 0.4 m (16").
- Resistivity measurement is extremely sensitive to the zone immediately around the electrodes and therefore highly influenced by both borehole diameter and fluid conductivity.
- Resistivity logs are typically presented at a log scale to enhance resolution in conductive (low resistivity) environments.
- Since the path of the current for SPR is not known, these results cannot be used for quantitative interpretation; however, the SPR response is a good boundary indicator.
- The SP is a measurement of the naturally occurring potential differences in the borehole, most often resulting from a concentration gradient between the borehole fluid and formation fluid (electro-chemical) at a clay rich/porous media interface. Reduction/oxidation (redox) interfaces and streaming potentials (electro-kinetic) caused by the flow of fluid in or out of the borehole are also causes for the occurrence of spontaneous potential.

The quality of the resistivity data is high, exhibiting good correlation of boundaries and consistency with other geophysical logs. The values measured are relatively low, ranging from 4 to 1000 ohm-m, with the 0.4 m (A-M_1) readings 3 to 10-fold higher than the 1.6 m (A-M_2) readings below approximately 250 mBGS implying the formation fluid is more conductive than that in the borehole.

3.3.8 Electromagnetic Induction (Apparent Conductivity)

For this study, Colog used an electromagnetic induction (apparent conductivity) tool manufactured by Robertson Geologging Inc (model: DUIN) equipped with natural gamma probe. The apparent conductivity probe measures the bulk apparent conductivity of the rock around the borehole using the principle of electromagnetic induction. As with resistivity, the major controlling factors of the bulk apparent conductivity/resistivity of the subsurface include lithology, porewater conductivity, porosity, as well as water and clay content. The instrument is designed with two receiver coils to differentiate the effects of varying borehole fluid conductivity from formation conductivity.

Some noteworthy characteristics about apparent conductivity logging include:

- The apparent conductivity readings are provided in units of millisiemens per metre (mS/m); $\{1\,^{mS}/_{m} = {}^{1000}/_{ohm\text{-}m}\}$.
- Interference from the steel casing causes an erratic uninterpretable conductivity response.
- Remanent metal from drilling and or metallic minerals created discrete irregularities in the log over short distances.
- Since the apparent conductivity varies with both clay content and porewater conductivity, the results are usually best interpreted in the context of a gamma log which can be used as a clay indicator but does not respond to variation in porewater conductivity.

- Resolution of apparent conductivity is best in electrically conductive layers where the Elog resolution is poorest. The apparent conductivity and Elog data sets are therefore complimentary and should be used in combination.
- Conductivity probes are extremely sensitive to temperature variations changing the distance between coils. The probe is allowed to thermally stabilize prior to logging, is “zeroed” in air as well as measured in a reference coil prior to logging and both again immediately after logging to quantify drift. Based on the calibrations a linear correction was applied to both the deep ($CndD_{corr}$= [Rdg+110]*1.009) and medium ($CndM_{corr}$= [Rdg+125]*1.018).

The overall quality of the conductivity logs is good. There are a few sporadic irregularities (e.g., 276 mBGS) indicative of discrete metal, most likely resulting from the drilling process. Below 860.80 mBGS the apparent conductivity values within the Precambrian are highly irregular, presumably due to minerology as well as possibly exacerbated by metal from drilling settling towards the bottom of the borehole.

3.3.9 Magnetic Susceptibility

For this study, Colog used a magnetic susceptibility tool manufactured by Robertson Geologging Inc (model: BMSG). The magnetic susceptibility tool did not allow for the addition of a natural gamma probe to be attached during data collection. Magnetic susceptibility (MS) is an atomic scale property that is controlled by variation within different molecules, minerology, and rock type. Magnetism is a vector property and therefore the observed values depend on both the minerology (how many magnetic poles are present and their magnitude), as well as the alignment of the magnetic poles. Although minerology is the dominant controlling factor, depositional history, pressure, and heat also influence alignment of the magnetic dipoles and magnetic susceptibility.

In its most simple conception, magnetic susceptibility is a dimensionless proportionality constant that indicates the degree of magnetization of a material in response to an applied magnetic field.

$$J = kH$$

Where: J = Intensity of magnetization (ampere / meter), H = Magnetizing Field Strength (ampere / meter), and k = Magnetic susceptibility (unitless).

Some noteworthy characteristics about magnetic susceptibility logging include:

- Magnetic susceptibility (k) is a unitless parameter, values are reported in either “rationalized system unit” [cgs] designated as electromagnetic units (emu) or in SI.
- Collecting magnetic susceptibility data is extremely sensitive to the presence of cultural interference (e.g., stray electromagnetic fields or metal from the drilling process such as spurious metal within a borehole from wear of the drill rods).
- The MS measured is commonly normalized by density.
- Although theoretically MS values can be negative, this is rarely the case in sedimentary rocks.
- The measurement is made with a multi-coil system, the physical state of the system, in particular temperature, is a critical factor (see discussion from Conductivity).

- considerable care must be taken during measurement and sensor calibration. The process is particularly challenging when surface temperatures vary for pre and post calibrations (10°C and 15°C respectively) while temperatures down hole ranged from 5°C to 16°C.
- The magnetic susceptibility data displayed good repeatability with the QC log, but both had clear correlation to downhole temperature. Within that correlation (R^2=0.969) each has inherent variability with MS varying because of:
    - geologic variability
    - metal in the borehole
    - inherent instrument noise
    - temperature which includes localized variability due to
        - groundwater flow (fracture and matrix) and
        - instrument variability
    - superimposed over broad changes due to
        - vertical water movement in the borehole,
        - geothermal gradient and broad scale changes with thermal recovery.
- to correct for temperature influence on the MS data (Figure 7):
    - the MS data between the bottom of the casing and the Precambrian (averaged over 1m to minimize small scale geologic and instrument variability) were cross-correlated to temperature (median filtered over 1 m) and a linear relationship established (Figure 7 red)
    - to establish a lower bound (minimize geologic influence) (Figure 7 purple),
        - MS data were screened to those values offset from the predicted value based on temperature by more than 1 standard dev (2.414),
        - 1 standard deviation was subtracted, and a regression established as the correction along the lower bound (normalization=-4.4082T+29.075) and subtracted from the original data.
    - The normalization was applied to the original data (1m average, red) to provide a MS log which honours the variability of the raw data and relative values while minimizing temperature influences with a nominal zero lower limit. (Figure 7 green).

As described above, the magnetic susceptibility data, although repeatable within measurement error, was impacted by temperature influences. The normalized MS data are elevated and highly variable within the Precambrian. Within the sedimentary rocks, the MS data have considerable variability with distinct changes and trends consistent with other data sets suggesting the results have potential to considerably enhance lithologic correlations.

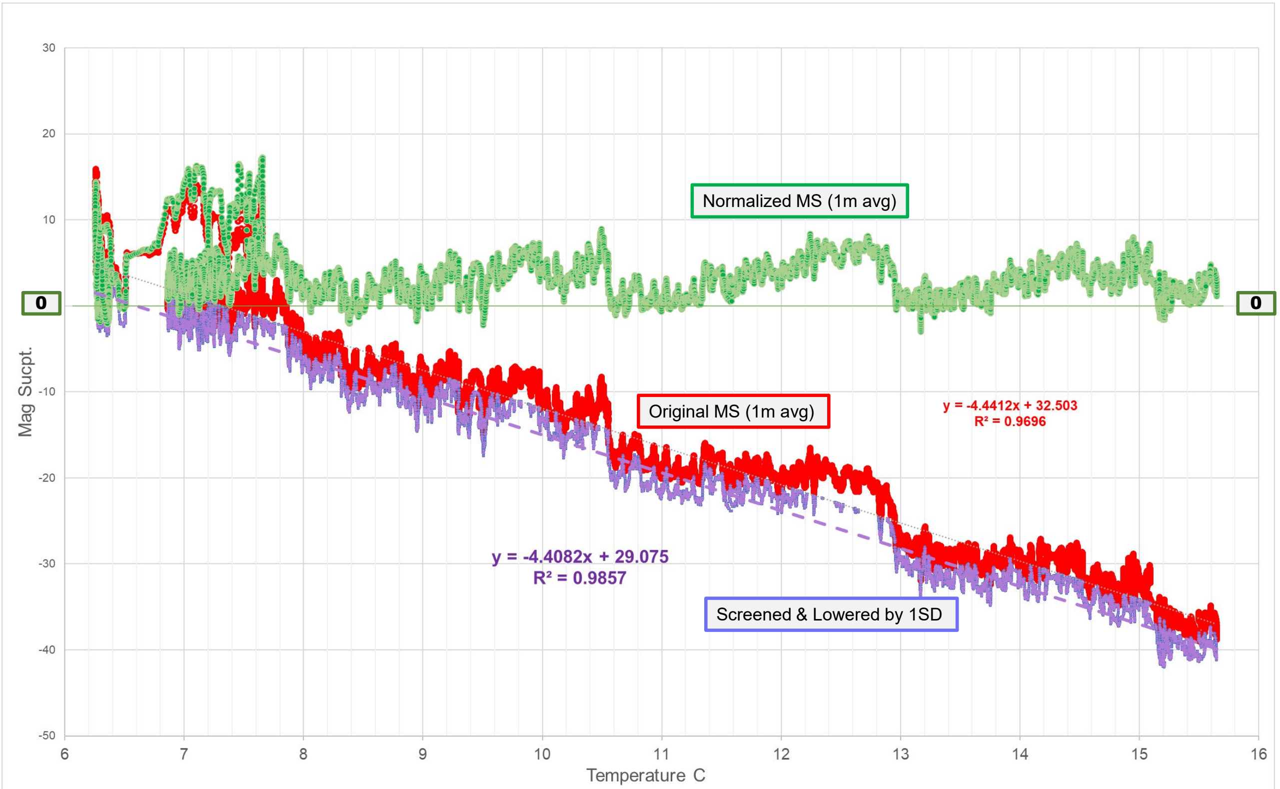


Figure 7 Magnetic Susceptibility Temperature Normalization Process

3.3.10 Full Waveform Sonic

For this study, Colog used a full waveform sonic (FWS) tool manufactured by ALT (model: QL40-FWS) equipped with a natural gamma probe. The FWS probe creates and monitors acoustic vibrations relative to time (µs) as the energy travels from a transmitter (TX) near the bottom of the probe along the borehole wall to three successive receivers ($RX_{1,2,3}$). The probe outputs a wide frequency primary signal that is sampled across the full frequency spectrum and low frequency subsets to enhance interpretation of tube waves and chevron waves.

Some noteworthy characteristics about FWS logging include:

- The probe must be within the borehole fluid for proper operation.
- All vibrations are detected:
  - the response includes superposition of energy:
    - compressional (P) waves are fastest and first energy to arrive,
    - shear (S) waves are relatively slower (typically ¼ to ½ the P wave velocity with lower frequency and typically of larger amplitude),
    - tube waves and other body waves are low frequency and high amplitude late arrivals and
    - noise from movement of the probe along the borehole wall and/or along the wireline (typically small amplitude, high frequency and incoherent).

   - S wave energy does not travel through water and the energy undergoes mode transformations (i.e., TX-borehole wall as P waves, along the borehole wall as S waves, and wall-RX as P waves).
- The energy from the TX travels in all directions around the circumference of the borehole and therefore the actual signal measured is a superposition of each wave form (e.g., the P wave along one side may arrive at a slightly different time than the other thereby distorting the arrival),
- The probe was centralized to enhance coherence of arrivals from either side of the borehole but at the expense of requiring additional mode transformations,
- Borehole irregularities and large fractures typically cause delayed arrivals and reduced amplitude.
- The three receivers measured over a time span of 2000 µs, in three modes, but the first 800 µs of wide band signal measured by RX_2 is presented on a colour scale to provide a visual qualitative indication of signal strength, changes in rock competence, and the locations of fractures and fracture zones.
- The FWS probe does not automatically align data to the measuring point (i.e., ½ between the TX and RXs), to allow for semblance processing (details in "Interpretation 4.4"). However, the offset of the attached gamma is honoured during data collection.

The quality of the FWS data is high with relatively low noise except where borehole enlargements occur at some fractures (e.g., 229.6 mBGS, 791.95 mBGS, etc.) and a few broader intervals (e.g., 396-410.6 mBGS, 770.5-775.3 mBGS, etc.). There is good correlation of changes at lithologic boundaries as inferred from other geophysical logs. The FWS data and the interpretation are used to characterize rock mass as well as lithology, consolidation, formation weathering, rock strength, and presence of discontinuities. Processing and interpretation of the FWS data are used to produce additional data sets described below (4.4).

3.3.11 Mechanical Caliper

For this study, Colog used a 3-arm mechanical caliper tool manufactured by ALT (model: QL40-CAL) equipped with natural gamma probe. The caliper log mechanically measures the average borehole diameter determined by the extension of three spring-loaded arms. The measurement of the borehole diameter is determined by the change in the variable pot resistors in the probe, which are internally connected to the caliper arms.

Some noteworthy characteristics about caliper logging include:

- The single measurement is the average extension of the three arms and may be distorted depending on the lateral size of an enlargement.
- Caliper logs may show diameter increases at large fractures, cavities and, depending on drilling techniques used, in weathered zones. Features identified in 3-arm caliper logs do not represent in-situ fracture size or geometry; rather they represent areas of borehole wall breakage associated with the mechanical weakening at the borehole-fracture intersection.
- The arms pivot from a fixed point above the end of the arms and therefore the shape of an enlargement can be distorted as the arm gradually contracts on the upper edge creating a saw-tooth pattern.

- An apparent decrease in borehole diameter may result from mud or drill-cutting accumulation along the sides of the borehole (mud cake), a swelled clay horizon, or a planned change in drill bit size. The very bottom of the borehole can also induce a small diameter reading from the caliper, due to the caliper leaning up against one side of the borehole.

The caliper log can be used to support the interpretation of fracture zones, for the interpreting flow rates (l/min) for water velocity measured by the impeller flowmeter and has been used to plan of other forms of testing including packer placement during hydraulic testing, borehole sealing and instrumentation placement.

3.3.12 Fluid Temperature and Conductivity (FTC)

For this study, Colog used a fluid temperature and electrical conductivity tool (FTC) manufactured by ALT (model: QL40-FTC) equipped with natural gamma probe. An open borehole creates a conduit facilitating water flow between layers that would normally be hydraulically isolated. The water in the formation and fractures is often in thermal and/or chemical disequilibrium with the borehole fluid creating measurable changes in both the temperature and fluid resistivity as water enters or leaves the borehole. Refer to 3.2 for a discussion of borehole stability and potential causes of temporal variability. The temperature is measured with a thermistor and the fluid resistivity is measured with a closely spaced Wenner electrical array concurrently on the same probe with gamma measurements.

Some noteworthy characteristics about FTC logging include:

- Thermal gradients in the near surface vary temporally, usually dominated by weather and seasonal influences. These variations occur over both short (weather events) and long term (seasonal changes).
- The changes in temperature are largely a result of the movement of water in thermal disequilibrium with the geologic formation and are moderated (diminish) with depth to the heterothermic-homothermic boundary. In rock, small scale temperature changes are indicative of flow through fractures.
- Below the heterothermic-homothermic boundary the water and rock are in thermal equilibrium formation and change gradually with depth according to the geothermal gradient,
- Similarly, the groundwater can have natural conductivity stratification within layers of varying chemical composition. Fluid flowing through fractures can be in disequilibrium with the rock matrix.
- Drilling a borehole, and having it open, transects the natural temperature and conductivity stratifications creating a column laterally in disequilibrium. The borehole and drilling process:
    - Can introduce different water into a formation
    - create heat from friction
    - drilling effects will dissipate over time as the local environment re-equilibrates
    - however, the open borehole provides a conduit for vertical cross-connected flow that can enhance disequilibrium and persist over time.
- Temperature and electrical conductivity (EC) responses are affected by the drilling method, duration of drill fluid circulation, as well as drill fluid temperature and salinity. The degree of drilling impacts on EC and temperature measurement depends considerably on the hydrogeological conditions and the amount of flow within the borehole. However, from the

perspective of identifying water movement, drilling induced chemical and/or thermal disequilibrium can enhance detection.

- Presentation of the data is a challenge because although the probe has temperature resolution (0.004°C) and electrical conductivity accuracy of 1% between 5 µS/cm and 2.5 x 10^5 µS/cm to measure the small local changes, the range of values in the deep borehole is comparatively large. In addition to standard logs of fluid conductivity and temperature, gradient logs are calculated by dividing the difference in readings over a short spacing (0.05 m). Gradient logs highlight small scale variations caused by water movement in/out of the borehole that are difficult to identify within the larger-scale changes that occur over the length of the entire borehole.
- The fluid conductivity data are presented at a log scale as the data ranges over three order of magnitude and the gradient over two ranges (-500 to 500 µS/cm and -10000 to 10000 µS/cm) to highlight variability at both extremes.

The primary purpose of these data is to identify flow in and out of fractures based on changes in the temperature and/or electrical conductivity of the water. Patterns are influenced by vertical water movement along the borehole annulus, both artificially enhancing some features and suppressing others. The broad scale data provide important support to the interpretation of the hydrostratigraphy from flowmeter results. The temperature data is also used for normalizing of other data sets (e.g., magnetic susceptibility). The data quality is high with variations that are consistent with interpretations of fractures, NMR porosity variations and flowmeter results.

3.3.13 Impeller and Electromagnetic (EM) Flowmeter

Flow meter logs measure the changes in vertical flow velocity within the borehole caused by pressure (head) gradients between different intervals of the open borehole. Flow into the borehole occurs at intervals at higher formation water pressure and flow out of the borehole occurs at intervals at lower pressure. The rate of inward and outward flow is a function of the head gradient and the permeability of the flowing intervals.

3.3.13.1 Impeller Flowmeter

For this study, Colog used an impeller flowmeter tool (normal resistivity, spontaneous potential, single point resistance) manufactured by ALT (model: QL40-SMF) equipped with natural gamma probe. The impeller flowmeter measures the velocity of water movement based on the spin rate of an impeller. The water velocity along the borehole is converted to flow by multiplying by the cross-sectional area of the borehole from the caliper log. The instrument is directional, differentiating between flow towards the impeller from below from that down past the impeller from above.

Some noteworthy characteristics about impeller flowmeter logging include:

- The cross-section of the impeller blades presented to the flowing water is different when the fluid moves into the full face of the impeller from below in comparison to that water moving down along and around the probe body onto the edges of the impeller from above. Consequently, the calibration of spin to velocity is different for each case.
- There is an inherent static friction that must be overcome before the impeller spins and therefore there is flow rate (in each direction) below which the instrument does not respond (dead zone).

- To minimize the "dead" zone the instrument uses low friction ceramic bearings which are manually tensioned by the operator. The degree of tension is one of the potential sources of error in the readings.
- To eliminate static friction and only deal with dynamic friction the instrument is typically used in continuous mode moving up and down the borehole at a constant logging speed.
- Using multiple logging speeds (in this case both down and up, at both 4 and 8 m/min) the relationship between rotations (cps) and relative velocity as well as the "dead zone" interval are estimated.
- The water velocity is measured relative to the moving probe rather than the fixed borehole. Therefore:
    - The measurement can enter the "dead zone", or reverse spin direction, when the probe is moving at a similar rate and direction to the water relative to the borehole.
    - The dynamic calibration must be completed in a portion of the borehole where the fluid is known (most typically stagnant, within the casing). A potential error is introduced if the blended water level is changing during logging such that the presumed stagnant zone has flow.
- Other fundamental assumptions to the interpretations are:
    - The logging speed of the probe is relatively uniform and accurate. This is likely the case with the probe moving upward when the system is under tension, but not as assured when moving downward especially where the borehole diameter is irregular.
    - That flow past the probe is laminar. This is not always the case, for example turbulent flow can occur where water enters the borehole from a fracture (and to a lessor degree at outflows). Such an occurrence can be identified by an irregular response over a short distance or a localized spin direction reversal in a more extreme case.
    - Non-laminar flow and/or velocity changes can also occur at localized borehole enlargements even if there is no exchange of water with the formation,
    - The spin-flow rate relationship assumes a constant water density throughout the borehole. This may not always be the case where saline water is used for drilling, cuttings (rock flour) settle out towards the bottom of the borehole, and/or there is a significant exchange of water with the formation. All of these are potential factors for these data.

The impeller flowmeter results are intended to inform changes of flow related to fracture flow in/out of the borehole and support the overall interpretation of the hydrostratigraphy along with other flow related logs. The four data sets exhibit changes in level at similar depths although the pattern of response differ depending on logging direction. All data sets exhibit localized variations at several borehole enlargements (e.g., 400 mBGS, 600-800 mBGS). The two logs collected with the probe moving upwards are relatively similar in pattern and have the same range of response above 780 mBGS; below the patterns differ. The patterns of the down logs exhibit similar trends but with poorer correlation above 600 mBGS. Below 600 mBGS both down logs exhibit irregular changes with numerous flow reversals.

3.3.13.2 EM Flowmeter

For this study, Colog used an electromagnetic (EM) flowmeter tool manufactured by Century Geophysical LLC (model: 9722). The EM flowmeter tool did not allow for the addition of a natural gamma probe to be attached during data collection equipped with natural gamma probe. The electromagnetic flowmeter measures the flow rate based on the movement of a conductor (water) through an EM field within the probe. The probe has conical rubber diverters to force water through the body of the probe. Since the cross-sectional area is controlled, the measurement is calibrated directly into flow (L/m). Measurements are taken relative to time with the probe stationary providing a trace of flow relative to time at each measurement point.

Some noteworthy characteristics about EM flowmeter logging include:

- At each measurement depth the probe was allowed to stabilize prior to estimating flow (average flow) over the interval.
- The stability of the measurement is assessed by determining the minimum, maximum and standard deviation of the flow over the interval.
- Multiple data sets were collected:
  - Data were collected in two phases: in October 2021 above a borehole blockage at approximately 643 mBGS and in April 2022 after the borehole was reopened.
  - Within each phase the probe was removed from the borehole to confirm performance producing multiple data sets.
  - Within each data set select readings were repeated at the same depths to:
    - confirm instrument response where readings were stable,
    - assess the variability of borehole hydrodynamics.
- The main sources of potential error and inconsistencies are:
  - As the probe is moved down the borehole the diverters can restrict probe movement and thereby errors depth. Additional weight was added above the probe when that was suspected.
  - At borehole enlargements the diverters may not completely seal the borehole and force all flow through the probe.
  - Turbulent flow can create a noisy response.
  - The probe also measures fluid resistivity and temperature. The manufacturer acknowledges that the conductivity of the fluid can influence the flow measured (Pers. Comm). The relationship is not well documented, preliminary testing indicated that over a flow range of 0 to 960 L/m and a water conductivity of 286-10^5 µS/cm there was no systematic error in the measurement, but the measured values differed from the actual flow between -2.8% and +1.9%.

The EM flowmeter results are intended to compliment the other hydrogeophysical measurements where flow is below the lower limit of impeller measurements (the dead zone) so as to provide additional insights into controls (fracture and matrix) on the hydrostratigraphy. The results are generally consistent with other data sets suggesting portions of the borehole are hydrostatically variable both in short and long term (e.g., 292-363 mBGS) and other intervals relatively stable (below 440 mBGS). The range of values is considerably lower than observed with the impeller although further analysis and complete integration will be conducted as part of the work package 10 (WP10) study.

3.3.14 Borehole Nuclear Magnetic Resonance (NMR)

For this study, Colog used a borehole nuclear magnetic resonance (NMR) tool manufactured by Vista Clara (model: Javelin 238). The NMR tool did not allow for the addition of a natural gamma probe to be attached during data collection. Borehole nuclear magnetic resonance (NMR) logging technology uses the quantum mechanical response of proton spin to a changing magnetic field to investigate hydrogen in pore fluids and characterize volumetric water content (porosity in fully saturated materials). The NMR tool contains strong magnets that polarize hydrogen (primarily in groundwater) and then apply a series of radio-frequency pulses to induce a spin-echo decay signal between each pulse. These repeated pulses create measurable signals with diminishing amplitudes which are “fit” with a multi-exponential curve representing the transverse T2 relaxation time. The initial signal amplitude of the T2 curve is directly proportional to the total volume of water excited by the tool. The shape (or decay) of the T2 curve is influenced by the pore sizes. An amplitude-weighted T2 distribution, obtained using an inversion of the decay curves, indicates how fluid is distributed within the material’s pore spaces. Signals at short T2 indicate clay bound water, at intermediate times capillary-bound water, while long T2 signals indicate more mobile water.

Some noteworthy characteristics about NMR flowmeter logging include:

- The system collects data at two frequencies 314 kHz and 429 kHz concurrently providing measurement shell diameters of 0.23 m, and 0.28 m respectively. The thickness of the shells is in the order of a few mm (Vista Clara, pers comm).
- The stationary vertical sample volume specified by the manufacturer is 0.25 m in length. Note that testing of Vista Clara probes (Pehme, et al., 2022) indicates that approximate 20% of the reading represents the rock at the measuring point, decreasing vertically such that approximately 80% of the volume measured is within plus/minus the specified resolution.
- For each frequency the reading includes a combination of short pulses to characterize the initial portion of the decay curve and an extended portion to characterize the slower decaying energy.
- NMR signals are inherently weak, and the reading is repeated (stacked) to improve signal to noise. Noise originates from:
    - ambient atmospheric noise
    - spurious magnetic influences, both related to drilling and magnetic minerals
    - electronic noise
    - changing lithologies if the probe is moving over the span of a reading
    - if the borehole diameter is larger than the measurement shell the results report erroneously elevated mobile water.
- Data were collected both in continuous mode along the length of the uncased portion of the borehole and in stationary mode at either 1.0, 0.5, or 0.2 m increments over select depth intervals. Continuous operation has the benefit of 100% sampling and time efficiency but at the expense of some degree of smoothing (varying with logging speed), shorter time intervals and lack of precision to obtain adequate sampling density. The stationary mode data with the parameters optimized for lithology is to provide data to assess the degree that the continuous data are compromised.
- Prior to logging a series of tests were conducted (within different lithologies) to optimize logging speed, sampling duration, and the number of stacks:
    - Continuous: Long = 6 avg, T_{rec} 1.5 s, Scan 120 ms; Short = 36 avg, T_{rec} = 0.1 s, Scan 20 ms
    - Stationary (porous): Long = 12 avg, T_{rec} = 4 s, Scan 250 ms; Short = 60 avg, T_{rec} = 0.15 s, Scan 25 ms

  - Stationary (clay): Long = 12 avg, T_{rec} = 1.5 s, Scan 120 ms; Short = 60 avg, T_{rec} = 0.1 s, Scan 20 ms.
- The logging speed is also controlled by the practical lower limit of the winch motor. Data were collected at a nominal 0.26 m/min, which combined with logging parameters yielded a nominal sampling density of 0.12 to 0.15 m.
- The signals at the two frequencies are combined on a noise weighted basis. The nominal residual noise for continuous logging was 6-7% and for the static logging 4-5%.
- The response is divided into clay bound, capillary and mobile water components based on subdivision of the T2 distribution at specific cut-off times which vary broadly with material types (e.g., unconsolidated, sandstones, limestone etc.) based on published calibrations values. For preliminary comparisons limestone parameters (bound <3 ms and mobile >90 ms) are presented.
- The probe lost communication several times and occasionally needed to be removed from the borehole to remove spurious drill cuttings. The final continuous data consist of 8 individual segments of data stitched together.
- The depth of the final data set is unified to other logs using marker intervals that were consistent with the neutron data (the only other data set directly measuring hydrogen).
- Data collection in select portions of the SB_BH01 (with contrasting sections characteristics) were repeated to confirm similar response between October (Probe 009) and June (Probe 003), Figure 8. Note that the portion of the borehole immediately above the blockage (approximately 600-620 mBGS) had undergone extensive drilling activity in the process of removing the blockage, potentially changing the borehole diameter and introducing spurious metal. The distribution of the water contents are similar before and after remobilization as are the noise levels (nominally 6-7%) in continuous mode. Note also that during both mobilizations the noise levels for data collected incrementally (stationary) mode were approximately 1-2% lower than data collected continuously through the same interval.
- The continuous measurement below the blockage (620 mBGS) indicates high variability and elevated (up to 20-30%) mobile and capillary bound water content. In contrast the stationary measurements collected over select intervals have water contents of 2-5% with little mobile water. Also, the noise levels of the stationary readings were lower and are relatively uniform.
- Notably the repeated continuous readings described above were collected prior to the variable data below 620 mBGS (moving downward) and the stationary readings after (upward as the probe was returned to surface), suggesting that cause of the variability is not a probe malfunction, or a result of motion.
- Analysis of the cause of the variability, whether related to: geology, the logging environment or the system continues and includes data and testing beyond the scope of this project. Causes under consideration include:
  - Metallic debris, however, there are no observations of spurious metal on the probe when retrieved within the notes although there is photographic evidence. However, if it were a cause, it would be expected to influence the stationary readings that were collected after the continuous log.
  - Intersection of the measurement shell with the borehole annulus. Recent (unpublished) testing at the MG360 test facility (Pehme, et al., 2022) suggests that when the measurement shell is partially within the borehole annulus the mobile water content but does not increase the noise levels. Comparisons of the statistics of the borehole diameter

with the NMR probe specifications indicate that at the median diameter (132.8 mm) the narrower shell is approximately 43 mm into the rock, but at the maximum (173 mm) diameter the inner shell could be sampling 4 mm of rock, potentially within the disturbed zone. However, the increase in the recent testing was uniform along the borehole rather than variable as observed here.

- Sub-optimal cut-off times, the water content distributions are currently presented using industry standard generic cutoff times for in limestone. The implications of using site local lithology specific cutoff times and varying borehole fluid from fresh water to brine and/or possible hydrocarbon or gas mixtures needs to be assessed.

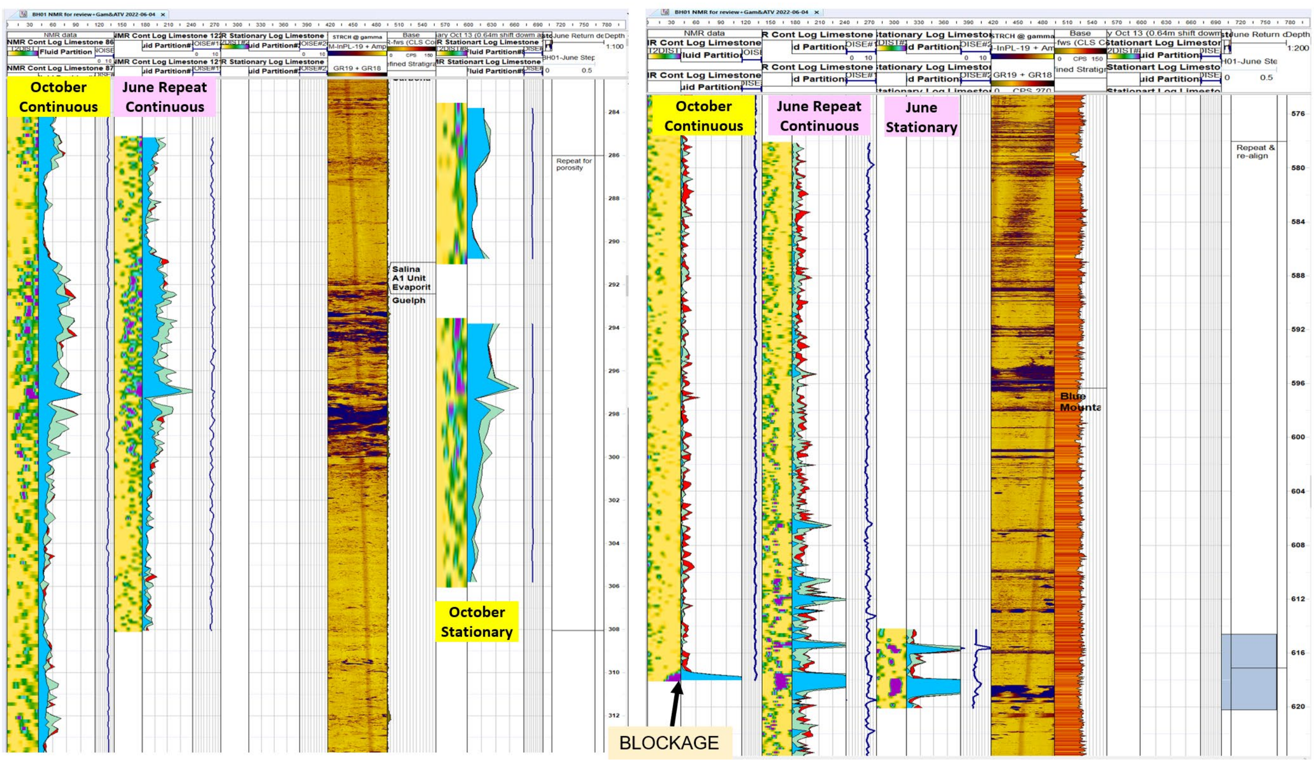


Figure 8 Example of Repeat NMR Data Before (October 2021) and After (June 2022) Localized Borehole Blockage. Left: 284 to 312 mBGS depth range; Right: 576 to 620 mBGS depth range.

The final data sets have good repeatability and changes generally correlate well with other lithologic variations indicated by other tools. Combined noise levels were consistently nominally between 6% and 10% (Vista Clara specifies 20% as "adequate"), Detailed statistics of porosity variations are provided in Table 4. Note that the industry standard T2 cutoffs applied provide a preliminary relative distribution and should be refined once laboratory results become available for specific lithologies. The NMR results provide strong evidence for further subdivision based on porosity and will provide support to the interpretation of hydrostratigraphy. Further analysis considering other forms of testing and data from SB_BH02 should be completed to fully assess and utilize the NMR data.

3.3.15 Borehole Deviation

For the overall purposes of the project the borehole orientation is determined using incremental gyroscope measurements collected during drilling operations and reported in the data report for Borehole Drilling and Coring at SB_BH01 (WP02). Both the ATV and OTV imaging sondes collect borehole tilt and azimuth (relative to magnetic north) at each reading. Cumulatively these are combined to produce deviation logs (below the steel casing and extrapolated to surface based on gyro data) and used to evaluate borehole inclination, declination, northing, easting and true vertical depth for interpretation of the geophysical measurements. The high-resolution deviation logs from ATV and OTV are used to correct interpreted structure and lithology orientations to true dip and true north orientations.

4 PRELIMINARY INTERPRETATIONS

The results of the geophysical logging and preliminary interpretations discussed in this report are presented as a series of figures, prepared using WellCAD software, grouped by targeted data interpretation focus. In total four groupings of data are presented, including:

- ***Lithology Suite:*** including natural gamma, spectral gamma, neutron, Elog (including single point resistance and spontaneous potential), formation conductivity, magnetic susceptibility, density, PE, OTV, full waveform sonic.
- ***Structure Suite:*** including OTV, ATV, caliper, interpreted lithology, interpreted structure, borehole orientation (tilt, azimuth, TVD).
- ***Hydrogeology Suite:*** including caliper (mechanical and ATV virtual), NMR, FEC – temperature, impeller flowmeter, EM flowmeter.
- ***Engineering Suite:*** including compensated density, caliper, full waveform sonic, calculated engineering properties (Poisson’s ratio, shear modulus, Young’s modulus, bulk modulus, bulk compressibility, acoustic impedance).

Figures B.1 through B.4 (Appendix B) are full borehole length WellCAD images for each geophysical data suite listed above. Tables B.1 through B.4 summarize each of the datasets, including name of log as listed in the header, the units, range of units presented, date of data collection, and tract number (e.g., position in the figure).

Where data are collected in both the upper and lower borehole, they are provided both individually and as merged data sets along the entire length of the borehole. Although the OTV has been merged post processing (and vertically subsampled to a common increment) further analysis is best undertaken on the upper and lower portions individually because of the different data quality discussed in Section 3.

A summary of statistics of each track (minimum, maximum, average, median and standard deviation) (excluding “images” e.g., amplitude, travel time, T2 distribution etc.) are provided in Appendix C (Table C.1). The log responses for the various individual lithologies intersected (e.g., limestone, shale, salt seams etc.) can vary considerably and therefore summarizing single values for the entire borehole of limited value. The data is therefore divided into four sequences relative to the repository (shale) sequence, grouping all the rock above (66.7 or 150 to 424.37 mBGS, varying in length whether collected in Phase 1), the shale (424.3 to 644.85 mBGS), the sedimentary rock below (644.85-860.33 mBGS) and the Precambrian (860.33 to the bottom of each data set nominally 875.8 mBGS). Note that:

- Although the lithologic boundaries in the rock are generally distinct (excluding gradual facies changes) and are defined within the accuracy of the core depth, geophysical measurements tend to vary gradually between lithologies, in particular when there is a transmitter/source to receiver offset (e.g. neutron, density, FWS, Elog….). Given the thickness of the subdivisions and the large number of readings this smearing of geophysical response at boundaries will have minimal implication on average and median values but could skew the maximum or minimum parameter. To minimize this impact, the statistics are calculated using a 1 m exclusion buffer (0.5 m above and below the specified sequence boundary.

- The minimum and maximum include the natural variability within the lithology as well as the noise inherent in the probe's measurement and the variability within the borehole (changes in diameter, spurious metal etc.)
- Depending on the nature of the measurement (e.g., gamma data is Poisson distributed) the average can also be skewed by the extremes of the measurement (noise, see above).
- The Median value provides the best representation of a characteristic value for the sequence as the value minimizes the influence of the outliers.
- The geologic variability is best assessed from the standard deviation and difference between the average and the median.
- Although provided a few parameters (e.g., PE, shale corrected neutron porosity etc.) have limited applicability in the Precambrian and are shaded in gray in Table C.1.

Note that although the data are grouped within specified suites for convenience and consistency with other work, final interpretation of site conditions should use all pertinent data (e.g., interpretation of flow will require appreciation of fracturing and all available porosity information etc.).

The following sections summarize some preliminary data interpretations that are largely completed based on the independent geophysical data sets collected during WP05 at SB_BH01. Further refinement and consolidation of these interpretations with additional data collected outside of WP05 and from other boreholes will be completed as part of WP10 Data Integration.

4.1 Stratigraphy

The geophysical data are a key tool for refining the interpretation of lithology, boundary depths and assigning stratigraphic units initially determined from the core and reported within WP03. As discussed above, the integration of core logging data (WP03) and borehole geophysical logging data (WP05) will be completed during data integration (WP10).

4.2 Structures and Lithologic Boundaries

The OTV and ATV (amplitude and travel time) images are oriented, unwrapped 2-D representations of the borehole wall (OTV and ATV amplitude) and distance (ATV travel time). Planar features (fractures or bedding planes) that intersect the borehole appear to be sinusoids on the unwrapped image. The amplitude of the sinusoid (h) and the borehole diameter (d) are required to calculate the dip angle of a fracture or bedding feature. The angle of dip is equal to the arc tangent of h/d, and the dip direction is picked at the trough of the sinusoid (Figure 9). Sinusoidal features are identified by visual inspection (manually rather than an automatic picking algorithm) and interpretation of the OTV and ATV (amplitude and travel time) images using the interpretive module within WellCAD, which assigns the depth, dip, and dip direction for each logged feature. Aperture is also estimated in WellCAD (ver5, build 214) for larger aperture fractures. Initially features are interpreted relative to the borehole (magnetic north) and subsequently converted to true north (declination 9.33°W, IGRF-12 (2015) model) and true dip based on the measured borehole inclination.

The time required for the acoustic signal to travel to the borehole wall and back to the probe is directly related to the distance travelled and the fluid properties. Travel time data acquired by the acoustic televiewer are used to produce a virtual caliper log using an estimated velocity (1490 m/s) for the wellbore fluid. The detailed borehole diameter information acquired can be used to develop cross-sections of the borehole for setting packers and are useful in the analysis of borehole breakouts due to stress.

Interpretations of fractures and lithologic boundaries are inherently subjective and depends highly on:

- The data quality (image clarity) for the OTV varies dramatically within SB_BH01 from excellent (e.g., 67-152 mBGS) to uninterpretable (e.g., approximately 279-330 mBGS and 521-690 mBGS) with the other portions showing varying shadows depending on rock type but no detailed resolution.
- The data quality of the ATV images over most of the open borehole are of high quality but there are sections where the borehole diameter is enlarged and irregular (e.g., 205-212 mBGS, 618-619 mBGS) or there the amplitude image is indistinct, possibly due to particulate on the borehole wall (e.g., 800-830 mBGS). Consequent to these data quality and resolution variations, the detail of the interpretation also varies along the length of the borehole.

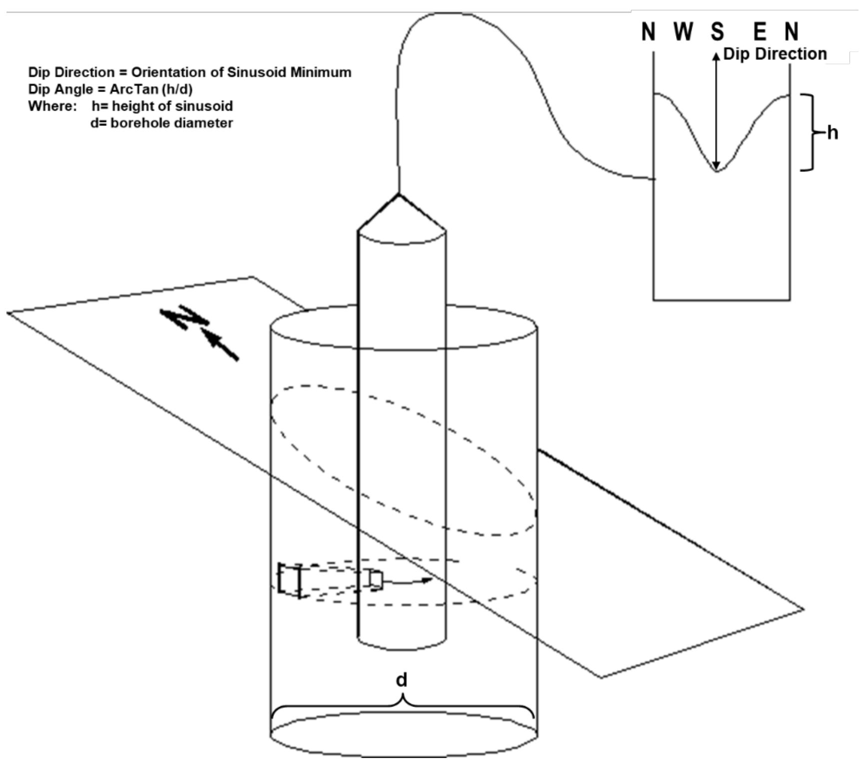


Figure 9 Geometric Representation of a Fracture Plane and Corresponding ATV Log

- While major fractures and distinct lithologic changes are generally consistently interpreted, small aperture and subtle features are particularly subjective, especially where data quality varies and deteriorates. If only clear and distinct features are identified some small aperture fractures will be missed. Conversely if every shadow in the image is identified as a feature the overall data set will inevitable be over picked and fracture frequency skewed.

The results are presented as tadpoles (Figure 10, Figure 11) with the dip (0-90°) represented by location across the track and the dip direction 0-360° clockwise relative to Magnetic North and True North upwards. For consistency, it is critical that limitations are recognized and that a consistent approach is adhered to.

4.2.1 Structural Interpretation

All features interpreted to represent discontinuities were identified (1097 in total) and presented in the WP05 Structural Suite as tadpoles (Appendix B, Figure B.2). The legend in Figure B.2 shows discontinuities were subdivided into 8 categories as tadpoles, which is reproduced in Figure 10 for reference in this discussion.

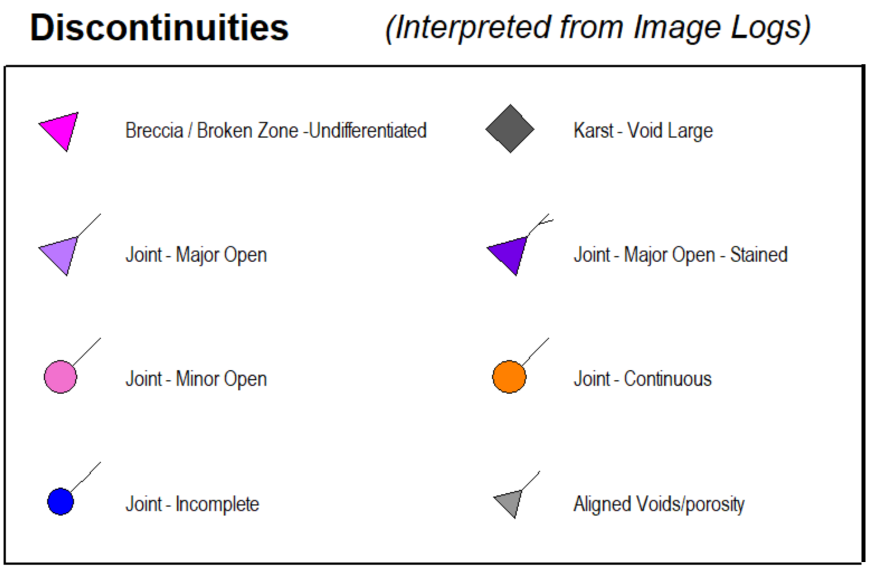


Figure 10 Structural Interpretation Classifications

Noteworthy characteristics about structural interpretation of ATV and OTV data include:

- Discontinuities were subdivided into 8 categories based on the following criteria:
  - Breccia: broad zones with numerous undifferentiated fractures and rock fragments with indistinct dip direction.
  - Karst: large open voids with no discernable dip direction.
  - Joint (Major Open): open discontinuities with measurable aperture around the circumference of the borehole and a distinct nominal dip direction.
  - Joint (Major Open Stained): open discontinuities with measurable aperture around the circumference of the borehole and a distinct nominal dip direction plus clear indications of discolouration due to chemical reactions (e.g., oxidation). Note these can only be identified in high quality OTV images.
  - Joint (Minor Open): partially open discontinuities with measurable aperture around the majority of the circumference of the borehole.
  - Joint (Continuous): discontinuities clearly identifiable around most of the circumference of the borehole. These features generally do not have measurable aperture.

- Joint (Incomplete): discontinuities only detectable around a limited portion of the circumference of the borehole.
- Aligned Voids/porosity: multiple elongated small openings that form along a distinct plane around the circumference of the borehole.

Although the discontinuities are subdivided the differentiation between groups is gradational. Every effort was made to maintain consistency.

- The consistency of the identification of features is subject to limitations described above.
- At a scale beyond the 5” borehole discontinuities are neither planar nor of uniform aperture (i.e., all fractures are closed at some location). The characteristic values interpreted are nominal estimates at the borehole wall.
- The interaction of the drill bit with the edges of the fracture can enlarge the apparent aperture.
- The ATV energy beam has a finite width that broadens with distance. Discontinuities of less than 3 mm in length will all appear to be of similar breadth.
- Misidentification of fractures can occur most commonly due to:
    - Salt seams and beds that are dissolved by drilling waters are prevalent within the interval from approximately 150-250 m. These occurrences are identified and eliminated based on confirmation with core photos that salt is generally occurring within the depth interval and individually by careful attention to travel time images (using refined expanded colour ranges) to confirm material within the feature.
    - Horizontal irregularities caused by the drilling process.
    - Thin, soft lamina can create a weak reflection.

4.2.2 Lithologic Boundaries

The abundance of layering (units, beds, lamina) in a complex sedimentary bedrock layer makes identification of all features impractical. The legend in Figure B.1 shows lithologic boundaries were subdivided into 3 categories as tadpoles, which is reproduced in Figure 11 for reference in this discussion.

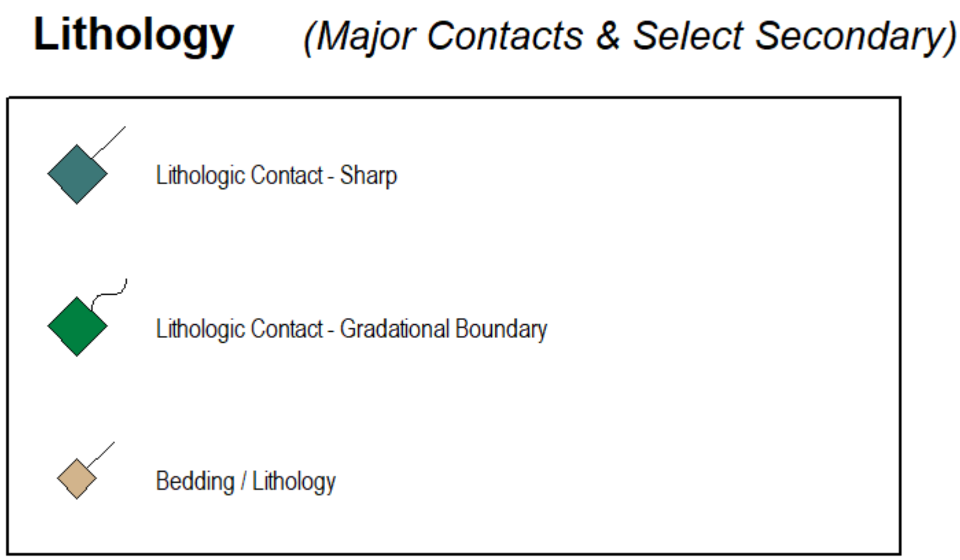


Figure 11 Lithologic Boundary Classifications

Some noteworthy characteristics about lithologic classification based on ATV and OTV data include:

- Three categories of lithologic boundaries are based on the following criteria:
  - Lithologic Contact-Sharp: The closest distinct sharp change in the reflectivity (and/or colour), typically with a coincident change in gamma levels, to a stratigraphic boundary identified in WP03.
  - Lithologic Contact-Gradational: The midway depth along a gradual change (~0.1 m) in the reflectivity (and/or colour), typically with a coincident change in gamma levels, to a stratigraphic boundary identified in WP03.
  - Bedding: Select (not all) distinct changes within stratigraphic units chosen to provide a representative indication of the complexity and distribution of geologic layering within each stratigraphic unit.
- The same limitations described above for structural interpretation also apply to the interpretation of lithology.

Summary stereonet plots (upper hemisphere, Schmidt {equal area}, without Terzaghi correction) of the lithologic boundaries are provided in Figure 12 (all features) and Figure 13 (major contacts). Most boundaries are of relatively low angle (less than 20°). The dip directions of the minor boundaries vary but are generally horizontal. Most of the major contacts dip towards the NW (less than 5°) but seven (at 143.00, 209.18, 230.74, 276.24, 291.06, 291.14, 652.62 mBGS) dip to the WSW (20-30°) skew averages.

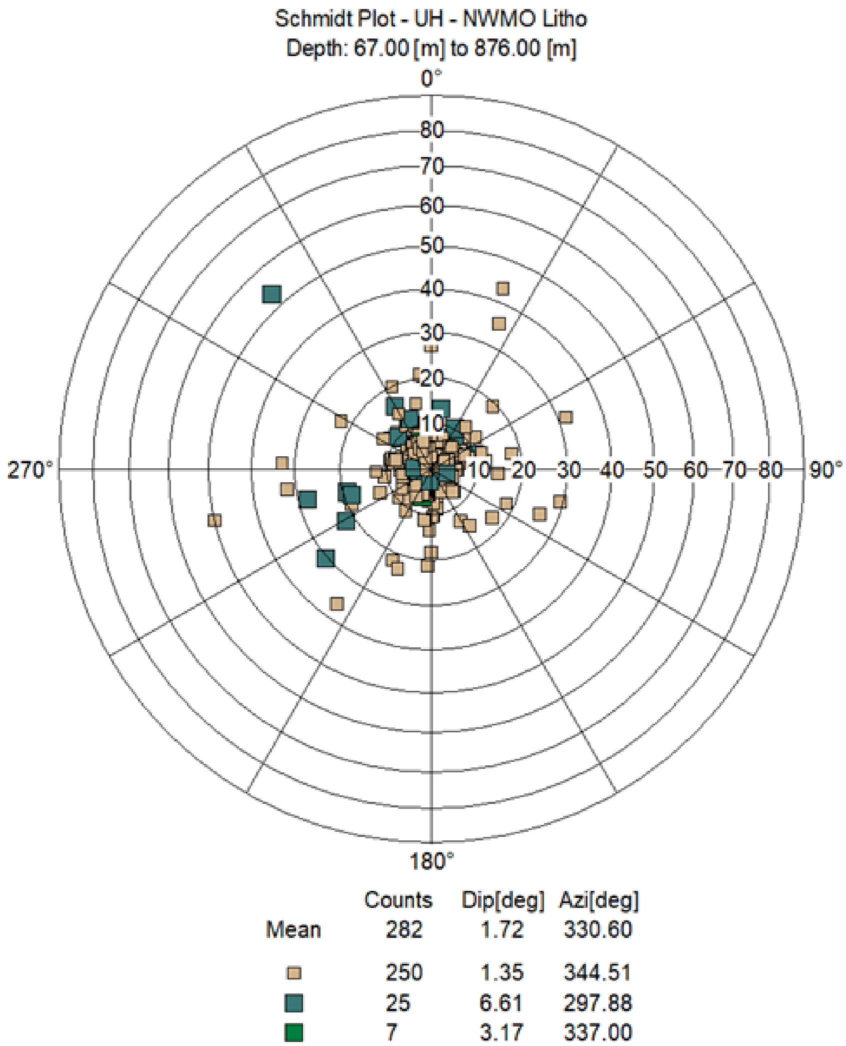
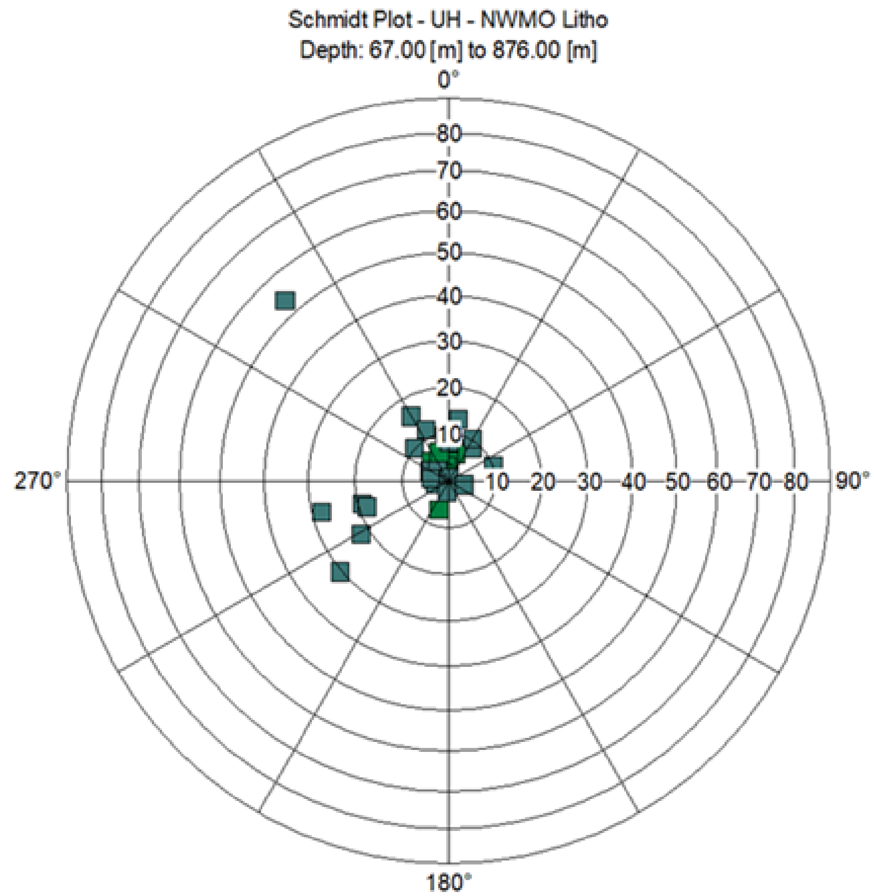


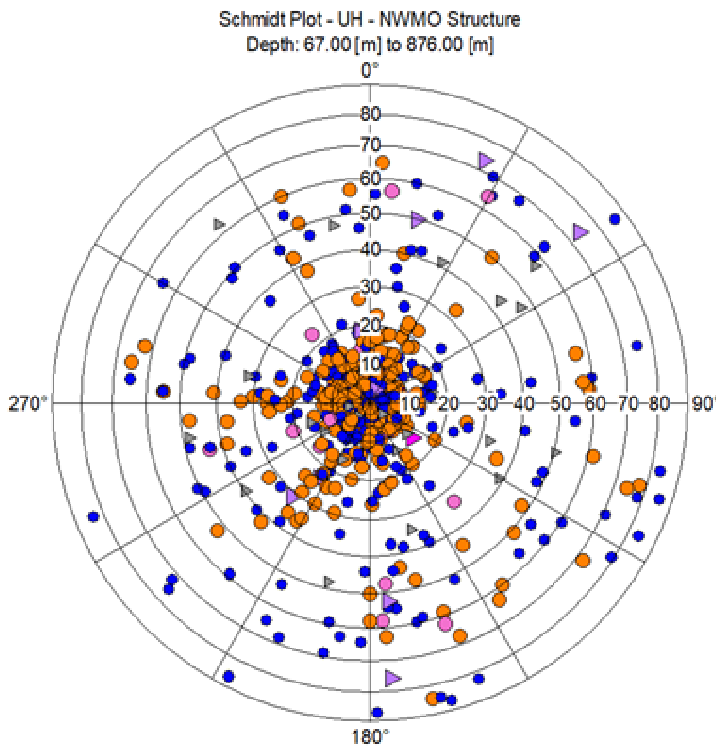
Figure 12 Stereonet plots of the Lithologic Boundaries: All Features - True North and Dip



	Counts	Dip[deg]	Azi[deg]
Mean	32	5.66	302.67
■ (dark teal)	25	6.61	297.88
■ (green)	7	3.17	337.00

Figure 13 Stereonet plots of the Lithologic Boundaries: Major Contacts - True North and Dip

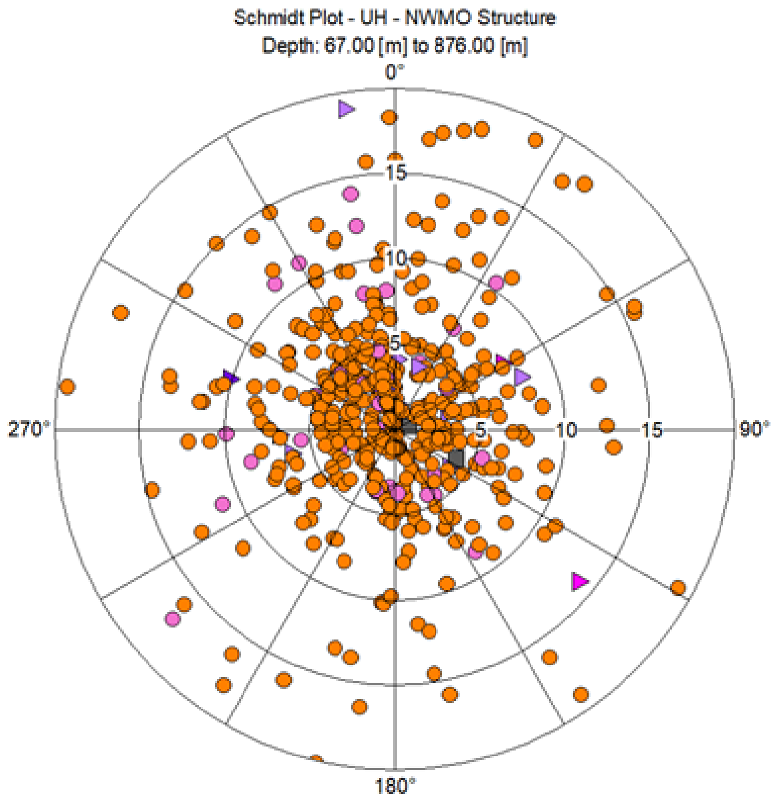
The results of the interpretation of discontinuities are shown as stereonet plots (upper hemisphere - Schmidt, equal area - without Terzaghi correction) in Figure 14 (all features) and Figure 15 (continuous and longer features). The majority of the discontinuities are near horizontal (less than 7°) with a slight dominance towards the NNW.



	Counts	Dip[deg]	Azi[deg]
Mean	1096	0.74	286.48
● (blue)	453	0.90	274.41
● (pink)	48	1.71	268.47
● (orange)	538	0.84	297.05
▷ (violet)	17	0.27	356.82
■ (grey)	2	2.33	109.12
▸ (grey)	33	4.11	98.47
▶ (purple)	1	10.20	287.13
▶ (magenta)	4	4.84	98.14

Figure 14 Stereonet plots of the Interpretated Discontinuities: All Features - True North and Dip

However, several (5) large aperture fractures steeper than 45° are present (122.94, 292.40, 296.75, 296.93, and 618.72 mBGS), dominantly dipping towards the NNE or S-SSE; note that steep fractures are underrepresented in a near vertical borehole relative to the surrounding rock mass. Also, the data represent over 800 m of rock and 33 stratigraphic units, further subdivision, and fracture analysis will be completed in WP10 after reconciliation of data with core.



	Counts	Dip[deg]	Azi[deg]
Mean	610	0.84	293.80
(pink circle)	48	1.71	268.47
(orange circle)	538	0.84	297.05
(light purple triangle)	17	0.27	356.82
(grey square)	2	2.33	109.12
(dark purple triangle)	1	10.20	287.13
(magenta triangle)	4	4.84	98.14

Figure 15 Stereonet plots of the Interpretated Discontinuities: Continuous and Larger: Zoomed 0-20°: True North and Dip

4.3 Porosity

Five of the geophysical data sets can be used to estimate formation porosity. Each have inherent limitations, require assumptions of parameter or empirical constants, and/or have applicability limited to specific lithologies. The five borehole geophysical methods that can be used to help interpret porosity include:

- NMR data are based on the decay of electromagnetic signals resulting from the spin of hydrogen.
- Neutron data are based on the interaction between neutron radiation and hydrogen, corrected for shale content.
- Density data are dependant on assumed matrix and fluid density.
- Resistivity data, based on Archie's Law, are most accurate for sandstones.
- Sonic data uses several models based on the assumed matrix and fluid slowness.

Of these methods, only NMR and Neutron directly estimate hydrogen (water) content. Initial (first order) estimates of porosity, based on best guess input parameters, are reported. These initial estimates should be reanalysed once laboratory testing is completed to refine the generic parameters currently applied. Details of estimating porosity values using NMR and neutron data, and some limitations of each approach, are presented below.

4.3.1 NMR Porosity

The processing of the NMR data was completed using Javelin ProPlus software (v3.5, Vista Clara Inc.) as described above. The processing stream adopted within the algorithm:

- Calculates a noise weighted average response of the two frequencies.
- Calculates a best fit T_2 distribution.
- Estimates the total porosity based on the area under the T_2 distribution.
- Default industry standard cut-offs were used to assess the energy in the T2 distribution and partition the water content into clay bound (<3 ms), capillary bound (3-90 ms) and mobile (>90 ms).

Although the total porosity is estimated from the full curve, the limestone cut-off times used are generic averages and not locally specific. Therefore, further analysis is warranted (see 3.3.15), particularly after site specific laboratory results are available and data from SB_BH02 are incorporated into broader context.

4.3.2 Neutron Porosity

Estimation of porosity from neutron data is a two-step process:

1. Robertson Geologging Inc provides the calibration relationship to estimate a neutron porosity based on the ratio of the Far/Near counts and the borehole diameter.
2. The neutron porosity calculated above does not account for the increased porosity resulting from the presence of hydrogen in clay minerals. To correct for the clay content influence on porosity interpretation, standard practice is to estimate the shale component based on the natural gamma response, extrapolating between the lowest levels (sandstone, G_{ss}) and the

highest (shale, G_{sh}) and followed by subtraction of a proportional percentage from the neutron porosity.

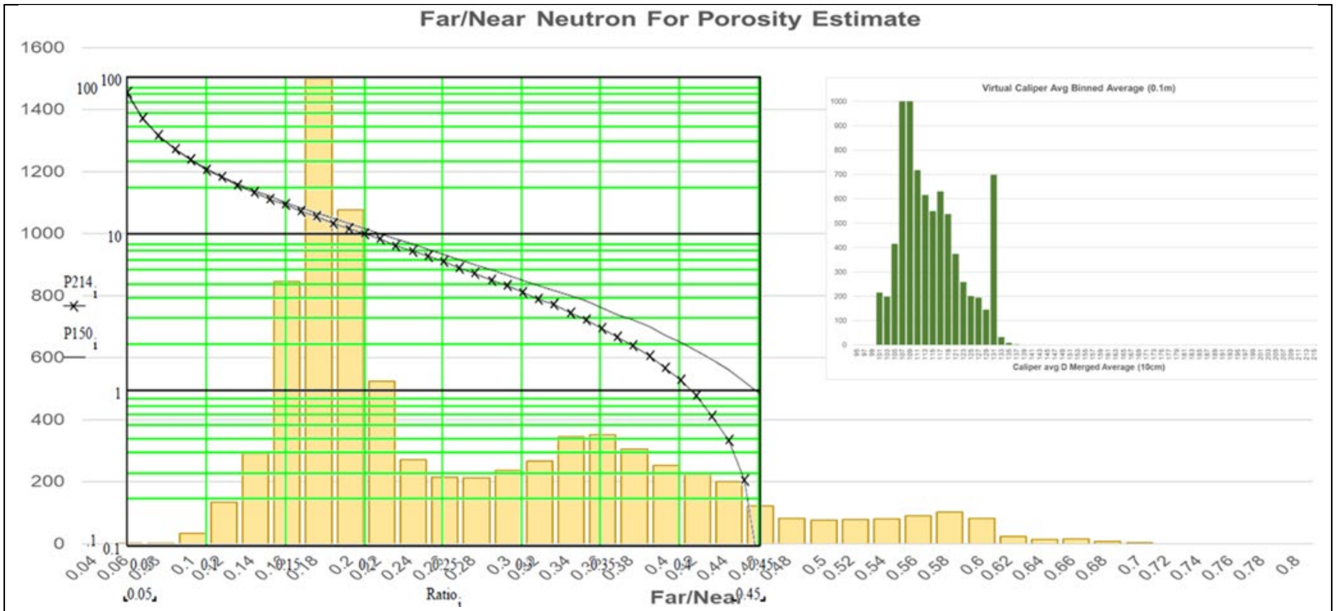
Some noteworthy characteristics about porosity estimation based on neutron data include:

- The initial step is the determination of an integrated “limestone neutron porosity” from the ratio of far/near counts and the borehole diameter as specified by the manufacturer (RG). That calibration is determined from a facility in Budapest Hungary. Note:
  - RG’s calibration (Appendix A) is superimposed on a distribution plot of far/near readings measured in SB_BH01 (averaged over successive 0.1m increments [bins]) in Figure 16a. The distribution plot is trimodal with:
    - the majority (5603 bins) having a far/near ratio less than 0.32 where there is minimal dependence on borehole diameter,
    - 1457 bins between the ratios of 0.32-0.45 where the curves progressively diverge signifying a progressively increased dependence of the neutron porosity estimate on borehole diameter
    - 971 bins with ratios greater than 0.45 (i.e. beyond the calibration curve) where the extrapolation of the calibration is likely unreliable.
  - Figure 16B displays the dependence of the neutron porosity estimate on the far/near ratio and indicates that neutron porosity estimates are less than approximately 1.5% (in many cases negative) and are beyond the calibration curve. Note that these values are almost exclusively below 780 mBGS. Since the borehole diameter below that depth (nominally 107 mm) is typical of much of the shallower portions of the hole that is not a controlling factor. Rather the cause of the high ratio is more likely related to minerology and/or porewater chemistry.
  - Pending laboratory results to create a site-specific calibration tuned to local conditions, it is reasonable to assume porosity values beyond the calibration curve are between 0 and 2% for the purposes of other work.
- Several models exist for the extrapolation of shale volume V_{sh}, the simplest is a linear extrapolation (also referred to as the shale index I_{sh}):

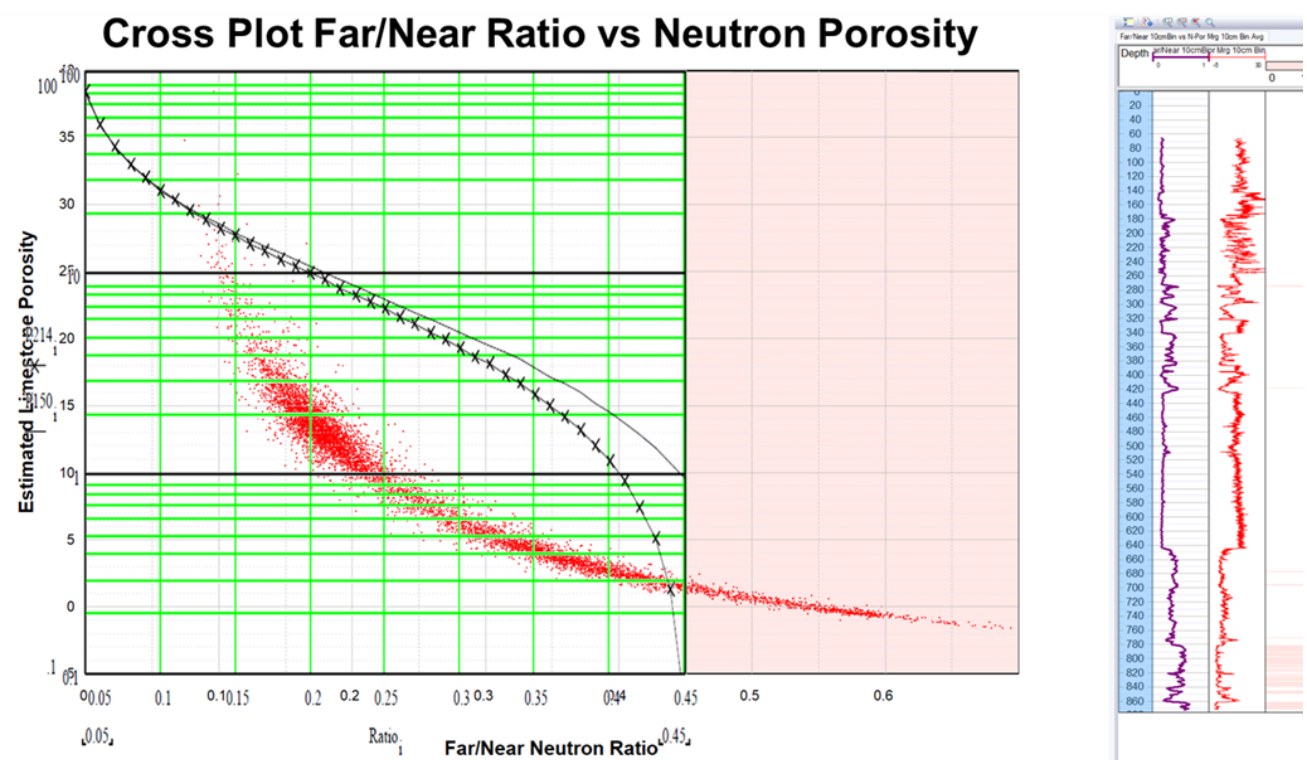
$$V_{sh} = I_{sh} = (G-G_{ss}) / (G_{sh} - G_{ss})$$

- Models available to refine the shale index further include: Clavier, Larionov (2 models based on age) and Steiber (provides the lowest V_{sh} estimate). To provide the upper and lower limit for the shale estimate the linear and Steiber are provided.
- The shale corrected porosity is determined by proportionally subtracting the neutron porosity values observed at 100% V_{sh}.
- The shale corrected porosity varies with the model chosen. Figure 16C compares the shale corrected porosity calculated using a Steiber V_{sh} estimate to those calculated using the linear model. The difference in porosity estimates towards the lower end of the range is 3.5 to 4% porosity.

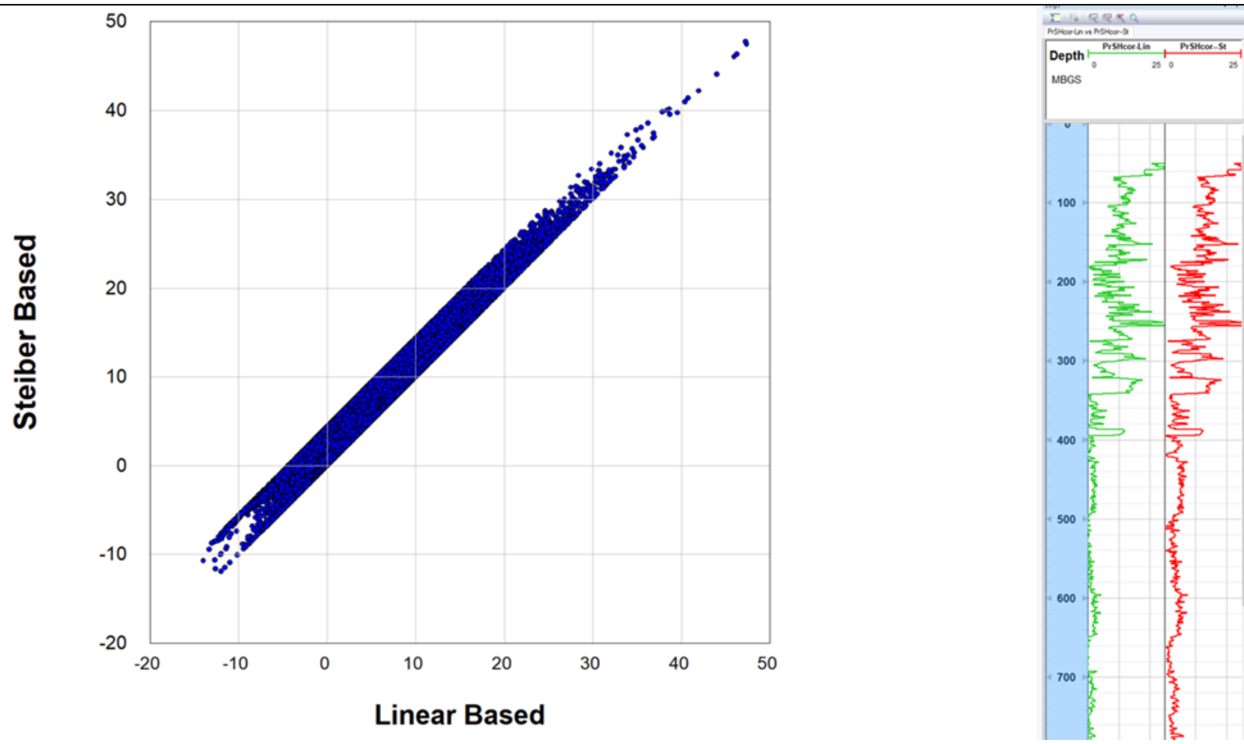
- Note also that a significant error is introduced into the V_{sh} estimate when gamma level increases are elevated due to increased proportions of radioactive minerals in forms other than clay. For example, the Precambrian granites can have elevated K, U or Th levels that produce elevated gamma readings not associated with increased porosity, as can also locally be the case for sandstone.
- The Steiber estimate of shale content appears to have provided a more robust first order estimate of porosity when assessing the entire borehole as one gamma-shale relationship.



A) Neutron Calibration Curve (Green, Appendix A) Superimposed of Distribution plot of Far/Near Neutron values (Orange) (see text for details)



B) Dependence of Neutron Porosity Estimate on Far/Near Ratio Relative to Calibration Curve (*Pink zone = data beyond calibration highlighted relative to data*)



C) Dependence of Porosity Estimate on Gamma Shale Estimate

Figure 16 Steps in Estimating Shale Corrected Neutron Porosity

4.4 Hydrogeophysical Characterization

The movement of fluids in, out and along an open borehole is complex. The fluid movement varies over time depending on both transient and permanent hydraulic pressures in both the fractures and matrix porosity. The process of drilling and circulating drilling fluid places the surrounding formations in hydraulic as well as both thermal and chemical disequilibrium that recover over time, each at different rates. The presence of the open borehole itself provides an open conduit cross-connecting hydraulic units that are naturally isolated that creates vertical flow along the borehole annulus herein assessed using impeller and electromagnetic flowmeters supplemented with temperature and fluid conductivity data. That vertical flow varies temporally as various fractures and layers with interconnected porosity hydraulically recover to drilling and/or respond to other influences e.g., regional pumping and weather events. Assessing fluid movement can also be further complicated by varying fluid characteristics such as density and temperature. Identifying hydraulically active zones (fractures and permeable lithologic layers) requires consideration of structural interpretations (from ATV and OTV), interconnected porosity (from NMR), lithology (primarily gamma) and borehole diameter (virtual and mechanical caliper) to assess when fundamental assumptions (e.g., laminar flow) may not apply.

A thorough interpretation of the hydraulic characteristics of SB_BH01 requires integration of other data such as hydraulic testing (WP06) and laboratory testing (WP04) along with shallow drilling results. However, based on the geophysical and hydrogeophysical data collected in the deeper (below approximately 166 mBGS) portion of SB_BH01, the major subdivision of hydraulic characteristics and inferences are described below. Please note, these depths are approximate, and observations of variability pertain to the time span between measurements and may not persist.

- 166.60 to 227.20 mBGS: Minor downward flow (0-3 l/min) that varied slightly over the logging period with numerous small in and out flows through fractures.
- 227.20 to 234.30 mBGS: Increased (3-5 l/min) downward flow into borehole from fractures near the top and out of the borehole at the bottom fractures, potentially indicative of a minor aquitard.
- 234.30 to 267.20 mBGS: Minor downward flow with perturbations at fractures. A gradual increase in mobile porosity and decrease in fluid conductivity with depth were measured.
- 267.30 to 275.90 mBGS: A zone of flow reversal from irregular but nominally downward flow from above to uniform and upward below (i.e., outflow) in the impeller. Few fractures but increased mobile porosity to 15-20%. Fluid conductivity was stable.
- 275.60 to 291.70 mBGS: Flow direction was measured as upward flow by the impeller and downward by the EM flowmeter, but both relatively uniform.
- 291.60 to 299.20 mBGS: A transitional zone with turbulent flow at large aperture fractures. Distinct temperature and fluid conductivity irregularities in this zone indicate fluid outflow from the borehole.
- 299.20 to 322.40 mBGS: Turbulent irregular dominantly upward flow, with few fractures but several steeply dipping layered of aligned porosity. A distinct change in the temperature profile and several sharp changes in fluid conductivity were measured.
- 322.40 to 340.70 mBGS: A zone of high porosity (17-20% mobile porosity) with few fractures but some aligned voids with relatively uniform downward flow.
- 340.30 to 379.10 mBGS: A zone of gradually transition from downward flow above 354 mBGS to upward flow below 354 mBGS. The interval has gradually increased temperature and declining fluid conductivity with depth. The zone has low flow and stabilized over time based on the EM flowmeter. Few fractures and low porosity were measured. These layers are likely an aquitard.
- 379.30 to 387.30 mBGS: A sharp increase in fluid conductivity and localized upward flow was measured with the impeller. The flow is presumed to originate from the 2 fractures near the base and/or the zone below.
- 387.40 to 395.00 mBGS: An interval with high (10-15%) mobile porosity and a peak in the fluid conductivity. The interval has transitional flow between upward flow above and downward flow below this zone.
- 395.40 to 407.90 mBGS: A distinct downward flow was measured by both EM and impeller flowmeters. The layer has high clay content, low porosity but several fractures (3 with large apertures).
- 408.40 to 420.40 mBGS: A zone of low vertical flow, few fractures, low porosity. The lithology transitions from moderately high clay content near the top to moderately low at the base.
- 420.30 to 468.00 mBGS: This interval has high (5-10 l/m) downward flow measured by the impeller and minor downward flow measured by the EM flowmeter. Fluid temperature increases and conductivity gradually decreases with depth.
- 468.20 to 499.90 mBGS: The impeller flowmeter measures a relatively uniform minor (2-4 l/min) downward flow. There is no fracture observed at the sharp transition with the interval above, however a low clay content seam coincides with the change.
- 499.70 to 589.50 mBGS: A gradually increasing upward flow as measured by the impeller flow meter. There are numerous incomplete fractures identified and small thermal variations observed in the temperature measurements which indicate minor flow conduits.

- 589.10 to 619.00 mBGS: An increase in fracturing coincides with irregular (2-10 l/min) flow as measured by the impeller. The EM flowmeter indicates little flow. A large aperture steep fracture presumably accepts the flow at the base of this zone.
- 618.70 to 643.10 mBGS: At the base of the thick shale zone, this interval has relatively uniform low downward flow and few fractures.
- 643.50 to 666.10 mBGS: A transitional zone in the impeller data from low upward flow (2-3 l/min) in the upper half (to 653.5 mBGS) to low downward flow (3 l/min) below. The EM flowmeter data shows the same trends but measures lower flow rates. There are few fractures and minor temperature and conductivity variability.
- 666.10 to 694.90 mBGS: Characterized by distinct downward flow in the impeller (3-7 l/min), and slight variability in the EM flowmeter measurements, this interval shows increased variability in the temperature gradient although no fractures were identified in the geophysical data.
- 684.60 to 770.50 mBGS: A relatively low but irregular vertical flow in both the impeller and EM flowmeter results. The temperature data exhibits numerous irregularities in the gradient log and the fluid conductivity a minor peak at 711.3 mBGS. Coincident with the irregularity in the hydrogeophysical data sets is abundant fracturing throughout the interval.
- 770.50 to 787.90 mBGS: This is a short irregular zone with data irregularity suggesting turbulent flow and abundant flow near the base of a distinct lithologic layer of moderately elevated gamma levels.
- 787.90 to 806.70 mBGS: A relatively uniform low (0-2 l/min) downward flow was measured in this interval.
- 806.40 to 855.60 mBGS: A 4-5 l/min flow in one upwards impeller log and minor (approximately 1 l/min) downward flow was measured in the other impeller and EM flowmeter data. The fluid conductivity gradually increases, and the fluid temperature exhibits moderate variability with depth. The lower limit of the zone coincides with the base of a thick layer of low gamma levels and minor incomplete fracturing.
- 854.50 mBGS to the bottom of data (nominally 870 mBGS, varying slightly with the data sets): Abundant steep angled fracturing and high gamma levels representative of Precambrian rock was measured. All the flowmeters indicate downward flow with moderate variability. The temperature gradient is highly variable and may be a result of particulate settling to the bottom of the borehole.

Please note the depths of fractures are approximate and may be refined as geophysical data is further reconciled with core results. Additional refinement to the inferences from these observations is expected based on the integration of data from other facets of the South Bruce study.

4.5 Seismic Velocities

Processing and interpretation of the FWS data is used to interpret characteristic compressional (P) and shear (S) wave velocities using the velocity analysis workspace in WellCAD. Specifically:

- The full wide frequency band data is used to produce a semblance plot; incrementally increasing delay times (µs/m) of the three RX in time at each depth and calculating coherence. The process quantifies the degree of resemblance between the three receivers incrementally for each receiver.

- The data is filtered in the frequency domain if needed to reduce spurious noise. However, filtering inherently distorts the true signal and the most accurate result occurs with minimal filtering.
- Theoretically, the delay time of the first peak semblance varies with the P-wave velocity. A processing algorithm supplemented by manual quality control and adjustments is used to identify the peak.
- The second peak in the semblance plot theoretically results from the shear wave (S-wave). Due to factors such as multiple mode conversions and borehole irregularities, the S-wave peak can be difficult to isolate. Manual intervention on the auto picking routine is usually required.
- Inevitably there are gaps (e.g., at breakout zones) though which semblance cannot be traced. These can be important to subsequent analysis and are not eliminated by extrapolation.
- The P and S wave travel times are converted to velocity and the P/S ratio calculated.
- After semblance analysis the individual RX responses are depth aligned to midway between TX-RX#. The semblance and interpretations are depth shifted to midway between TX-RX2.
- Details of the broad differentiation of seismic velocities into the four sequences (see above) is provided in Table 4. Notably although other related parameters (e.g. density) exhibit minor difference in the shale versus sequences above and below, both the compressional wave velocity (Vp) and shear wave velocity (Vs) are distinctly lower in the shale (median Vp=3742 m/s, and Vs=1866 m/s) than in the sequence above and below (Vp=5130, 5319m/s; Vs=2809, 2874m/s respectively). These contrasts in velocity follow through to the depended mechanical properties.

4.6 Rock Mechanical Properties

Based on the ratio (R_s=S_s/P_s) of the shear (S_s) and compressional (P_s) wave slowness (μs/m) interpreted above and the compensated density several standard mechanical properties of the rock were calculated. Specifically:

- Compensated density (D_c) was calculated from the near (D_n) and Far (D_f) measurements to account for the near borehole affects on the density measurement:

$$D_c = \frac{D_f + \left(D_f - D_n\right)}{3}$$

- Poisson's Ratio:

$$\left(\frac{0.5\left({R_s}^2 - 1\right)}{R_s\left({R_s}^2 - 1\right)}\right)$$

- Shear Modulus (MPa):

$$\frac{10^9\, D_c}{{S_s}^2}$$

- Young's Modulus (MPa):

$$2 \times Shear\ Modulus \times (1 + Poisson'sRatio)$$

- Bulk Modulus (MPa):

$$10^9\, D_c \times \left(\frac{1}{{P_s}^2} - \frac{4}{3{S_s}^2}\right)$$

- Bulk Compressibility (1/MPa):

$$\frac{1}{Bulk\ Modulus}$$

5 SUMMARY

Measurement and preliminary interpretation of geophysical data within borehole SB_BH01 was successfully completed as part of Work Package 5 (WP05) of the Phase 2 Initial Drilling and Testing activities at the South Bruce site. Geofirma completed the geophysical logging activities in two separate stages, namely the upper portion of the borehole (shallow logging) and the deeper portion of the borehole (deep logging).

The shallow logging scope was completed after drilling to a depth of 152.9 mBGS and before installation of steel production casing. The open borehole interval spanned from the bottom of this borehole (152.9 mBGS) up to the bottom of the steel intermediate casing cemented in place from ground surface to a depth of 66.4 mBGS. During the shallow logging phase, completed during June 2021, a subset of data was collected using optical televiewer (OTV), acoustic televiewer (ATV), natural gamma, density, and neutron probes.

The deep logging scope was completed after drilling the main borehole to a total depth of 880.8 mBGS within the Precambrian. The open interval spanned from the bottom of this borehole up to the bottom of the steel production casing cemented in place from ground surface to a depth of 152.8 mBGS. The majority of the data in the lower portion of the borehole were collected during October 2021 prior to a temporary borehole blockage at 623 mBGS, using the same 5 probes used during shallow logging, fluid electrical conductivity (FEC) / temperature, spectral gamma, resistivity (Elog) including single point resistance and spontaneous potential, apparent conductivity (electromagnetic induction), caliper (3 arm), full waveform sonic, magnetic susceptibility, electromagnetic (EM) flow meter (continuous), and impeller flowmeter (continuous). In addition, borehole nuclear magnetic resonance (NMR) and stationary EM flow meter logs were completed during June 2022 after the blockage was removed and straddle packer testing (WP06) activities were completed.

Overall, the borehole geophysical data quality in SB_BH01 is generally high with the exception of the OTV image in the lower portion of the borehole due to low borehole fluid clarity. The raw geophysical data were processed, and depth aligned using core logging descriptions and core photos. Preliminary interpretations of orientation of lithologic boundaries and discontinuities (dip, dip direction), porosity, seismic velocities (P and S wave) and mechanical properties were completed. Raw, processed, and interpretations are summarized in a series of figures (Appendix B) grouped by suites of data focusing on specified aspects of study (e.g., lithology, structure, hydrogeology, engineering properties). The estimates of shale corrected neutron porosity below 780 mBGS are beyond the manufacture’s calibration and although the specific value calculated is unreliable, it is likely within the 0 to 2% range. Similarly, in the NMR results there is unanticipated variability and mobile water content below approximately 645 mBGS that warrants additional analysis and confirmation with laboratory data. Note that in a sedimentary rock environment there are considerable interrelationships between the data suites and additional insights for each are available in others (e.g., interpretation of groundwater flow from flowmeters will largely be through fractures).

This report summarizes the geophysical data collection in SB_BH01, specifically: quality control processes, the operation and limitations of the probes, events that influence data quality as well as data processing and preliminary interpretation. Further analysis and interpretation, incorporating data from other work packages is beyond the scope for this report and will be completed separately.

6 REFERENCES

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Appendix A

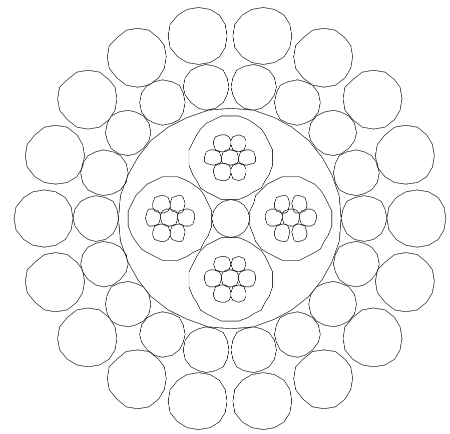
Borehole Geophysical Logging Probe Reference Information

751 Old Brandy Road
Culpeper, Virginia 22701

Tele: 540 825-2111
Fax: 540 825-2238

DATALINE®

Description	mm	Inch
CONDUCTORS (4) #24 AWG, 7/0.008" (0.20mm) BC	0.61	0.024
INSULATION 0.008" (0.20mm) Wall EPC	1.02	0.040
CORE 4 insulated cdrs twisted with fillers as necessary. Protective bedding over core.	2.54	0.100
ARMOR: Special GIPS Wire		
Inner: 18/0.0185" (0.47mm)	3.48	0.137
Outer: 18/0.0255" (0.65mm)	4.78	0.188



CABLE CHARACTERISTICS
(Nominal Values @ 20°C)

	Metric	English
PHYSICAL		
Overall Dimensions	4.78 mm	0.188"
Wt. in Air	90 kg/km	61 lb/kft
Wt. in Fresh Water	75 kg/km	51 lb/kft
Temperature Rating, normal	135 °C	275 °F
intermittent	149 °C	300 °F
MECHANICAL		
Breaking Strength (Minimum)	14.7 kN	3,300 lbf
Bend Diameter	25 cm	10 in
Elongation (approx)	1.15 m/km/kN	5.1 ft/kft/klbf
ELECTRICAL		
Voltage Rating	400 Vdc	400 Vdc
Insulation Resistance	15,000 MΩ•km	50,000 MΩ•kft
dc Resistance		
cdr	85.3 Ω/km	26.0 Ω/kft
armor	23.0 Ω/km	7.0 Ω/kft
Capacitance (cdr-armor)	171 pF/m	52 pF/ft
Velocity of Propagation @ 1 MHZ	67%	67%

Tyco Electronics **The Rochester Corporation**

Rochester Stock Type 4-H-181A

Date	Page	Revision	Part No.
01/22/2009	1	W	A240185

QL40

Stackable Logging Tools

MOUNT SOPRIS
INSTRUMENTS

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QL Stackable Logging Tools

The Quick Link (QL) series of slim-hole logging tools can be combined in custom configurations to acquire more data in a single logging pass.

Each QL tool can be used as a stand-alone probe or combined into a "string" or "stack" to yield multiple measurement parameters simultaneously.

This innovative flexibility saves time in field acquisition and allows for purchases to suit budgets and projects, as needed.

Examples of QL Logging Tool Applications in Mining, Water, Engineering and Energy

Lithology identification ▸ QL40 GR | QL40 OBI | QL40 DEN | QL40 NEU | QL40 FWS | QL40 ELOG | QL40 DLL3 | QL40 IND

Mineral detection and indication of mineralization ▸ QL40 GR | QL40 SGR | QL40 IP | QL40 MGS | QL40 IND | QL40 DEN

Stratigraphy and bed thickness ▸ QL40 GR | QL40 OBI | QL40 DEN | QL40 NEU | QL40 FWS | QL40 ELOG

Permeable zones and Porosity ▸ QL40 DEN | QL40 FWS | QL40 ELOG | QL40 DLL3 | QL40 NEU

Location of aquifers / aquitards ▸ QL40 DEN | QL40 FTC | QL40 OCEAN | QL40 SFM | QL40 IND

Density ▸ QL40 DEN

Water quality and contamination ▸ QL40 FTC | QL40 OCEAN

Fluid flow measurements ▸ QL40 SFM

Detection of weathered, fractured and permeable zones ▸ QL40 DEN | QL40 IND | QL40 FWS | QL40 ABI | QL40 OBI

Fracture identification and orientation ▸ QL40 ABI | QL40 OBI

Core orientation ▸ QL40 ABI | QL40 OBI

Local Stress (borehole breakout orientation) ▸ QL40 ABI | QL40 OBI | QL40 CAL

Rock Strength and elastic parameters ▸ QL40 DEN | QL40 FWS | QL40 ABI

Coal quality ▸ QL40 DEN | QL40 DLL3 | QL40 GR | QL40 ELOG

Cased hole integrity / cementation ▸ QL40 GR-CCL | QL40 ABI | QL40 FWS

Borehole shape, volume, integrity and orientation ▸ QL40 ABI | QL40 OBI | QL40 CAL | QL40 DEV

IMAGING TOOLS

QL40ABI

Acoustic Televiewer

Sensor
Ultrasonic Transducer

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Borehole diameter
0.05 – 0.50 m (2”– 20”) depending on borehole conditions

Diameter - Length
40 mm (1.6”) - 1.6 m (63”)

Weight
6.7 kg (14 lbs)

Measurements/Features
- 360° orientated acoustic image (amplitude & travel time)
- Borehole azimuth and tilt
- Tool internal temperature
- Relative bearing
- Magnetic field
- Gravity

QL40OBI

Optical Televiewer

Sensor
1/3” high sensitivity CMOS digital image sensor

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Borehole diameter
0.05-0.53 m (2”-21”) depending on borehole conditions

Diameter - Length
40 mm (1.6”) - 1.47 m (57,9”)

Weight
5,3 kg (11,7 lbs)

Measurements/Features
- 360° RGB true color oriented image
- Borehole azimuth and tilt
- Relative bearing
- 3 accelerometer calibrated components
- 3 magnetometer calibrated components
- Temperature of CMOS image sensor

Bottom In line

SONIC TOOL

QL40FWS

Full Waveform Sonic

Sensor
Ceramic piezoelectric

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
50 mm (2”)
2.27m (89.4’’)
1Tx-4Rx configuration

Weight
18 kg (39.7 lbs)

Measurements/Features
- Full waveform per receiver
- Real time p-wave velocity or slowness
- Real time CBL processing
- Additional post processing module available in WellCAD

MECHANICAL TOOL

QL40CAL

3 Arm Caliper

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 1.87 m (73”)

Weight
8.7 kg

Measurements/Features
- Calibrated measurement of borehole diameter in inches, centimeters or millimeters
- Easy exchangeable short and long caliper arms and wear tips

MAGNETIC TOOL

QL40MGS

Magnetic Susceptibility

Sensor
Bartington : 1.36 kHz Focused Dual Coil system

W-R : Two coil system with inter coil spacing of 25 cm operating at ~ 2Khz

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
Bartington : 43 mm (1.7”) - 1.4 m (56”)
W-R 45mm (1.6’’) - 1.1m (43’’)

Weight
Bartington :6.1 kg (13 lbs)

W-R : 7 kg (15,4 lbs)

Measurements/Features
- Magnetic susceptibility in CGS unit

DEVIATION TOOL

QL40DEV

Borehole Deviation

Sensor
APS544-3 axis magnetometer and accelerometer

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 0.7 m (28”)

Weight
5.3 kg (12 lbs)

Measurements/Features
- Angular values of azimuth, tilt and relative bearing
- Calibrated values of each accelerometer and magnetometer components

FLUID PROPERTIES TOOLS

QL40 SFM

Bi-directional spinner Flowmeter

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) excluding cage
0,9 m (35,4”)

Weight
3.2 kg (7 lbs)

Measurements/Features
- 60mm diameter pitch impeller/75 mm diameter cage
- 75mm diameter pitch impeller/100mm diameter cage
- Spinner speed in cps up and down

QL40 FTC & FTC-b

Fluid Temperature and Conductivity

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40mm (1.6’’) – 0.8m (31.5’’)
bottom sub
50mm (2’’) – 1.01m (39.8’’)
in line sub

Weight
3.3kg (14lbs) – 6.6kg (28lbs)

Measurements/Features
- Fluid temperature in °C
- Fluid conductivity in µS/cm or mS/cm
- Compensated conductivity at 25°C in µS/cm or mS/cm

QL40 OCEAN 303

Water Quality Probe

Sensor
Idronaut ocean seven 303,
Pressure, Temp, Fluid Conductivity,
Oxygen, PH, Redox

Temperature - Pressure
0-70°C (32-158°F)
150 bar (2175 psi)

Diameter - Length
44 mm (1.7”) - 1.4 m (55”)

Weight
4.9 kg (10.8 lbs)

Measurements/Features
- Pressure : in dbar
- Temperature : in °C
- Conductivity
  - Salt water : in mS/cm
  - Fresh water : in µS/cm
- Oxygen : in ppm.
- pH
- Redox : in mV

Bottom In line

ELECTRICAL TOOLS

QL40 ELOG

Normal Resistivity
(8”, 16”,32”, 64”, SP & SPR)

Temperature - Pressure
0 -70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
43 mm (1.7”)
1.9 m (75”)

Weight
9 kg (19.8 lbs)

Measurements/Features
- 8”, 16”, 32” and 64” Normal Resistivity in [Ohm-m]
- SP in [mV]
- SPR in [Ohm]
- Current (mA)

Bridles
QL40 IS 1
QL40 IS 2
QL40 IS 4

QL40 IP

Induced Polarization and Normal Resistivity
(8”, 16”,32”, 64”, SP & SPR)

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
43 mm (1.7”)
1.9 m (35”)

Weight
9 kg (19.8 lbs)

Measurements/Features
- Chargeability Ma in [ms] on 16” and 64” electrodes
- 2 spacing full wave data
- 8”, 16”, 32” and 64” Normal Resistivity in [Ohm-m]
- SP in [mV]
- SPR in [Ohm]

Bridles
QL40 IS 1
QL40 IS 2
QL40 IS 4

QL40 DLL3

Dual Laterolog

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
43 mm (1.7”)
2.83 m (111.4”)

Weight
15 kg (33 lbs)

Measurements/Features
- Time Multiplex dual spacing focused resistivity LL3-S & LL3-D in [Ohm.m]
- Potential value on measuring and guard electrodes in [V]
- Current value on measuring and guard electrodes in [mA]

Bridles
QL40 IS 1
QL40 IS 2
QL40 IS 4

NUCLEAR TOOLS

QL40GR

Total Count Natural Gamma

Sensor
NaI (Tl) crystal (1 x 3”)

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 0.9 m (35”)

Weight
4.3 kg (9.5 lbs)

Measurements/Features
- Total gamma counts in CPS and/or API unit

QL40GR-CCL

Natural Gamma & Casing Collar Locator

Sensor
GR: NaI (Tl) crystal (1 x 3”)
CCL: 32 x 280 mm coils & magnets assembly

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 1.16 m (46”)

Weight
5.9 kg (13 lbs)

Measurements/Features
- Total gamma counts in CPS and/or API unit
- CCL in mV

QL40SGR

Natural Spectral Gamma

Sensor
NaI (Tl) crystal (1 x 4”)
BGO crystal (1 x 4”)

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 0.93 m (36”)

Weight
4.4 kg (9.6 lbs)

Measurements/Features
- 256 channels spectrum
- spectrum stabilized (software)
- Nuclides concentrations
- Window gamma counts
- Total gamma counts in CPS and/or API unit

Bottom In line

ELECTRICAL TOOL

QL40IND

Dual Induction Probe

Sensor
Dual coil system with intercoil spacing : 50 & 80 cm
Operating Frequency : 100 kHz

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
45 mm (1.77”)
1.925 m (75.78”)

Weight
7 kg (15.4 lbs)

Measurements/Features
- Medium Induction : mS/m
- Deep Induction : mS/m

NUCLEAR TOOLS

QL40DEN

Formation Density Sonde

Sensor
CSI (Tl) crystals
SSD (20cm) and
LSD (35cm)

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
50 mm (2”) - 1.9 m (75”)

Weight
20 kg (44 lbs)

Measurements/Features
- SSD : in CPS
- LSD : in CPS
- SSD density : in g/cc
- LSD density : in g/cc
- Compensated density : in g/cc
- Caliper : in mm or inch
- PE option

QL40NEU

Neutron - Thermal Neutron

Sensor
Single He-3 thermal neutron detector

Temperature - Pressure
0-70°C (32-158°F)
200 bar (2900 psi)

Diameter - Length
40 mm (1.6”) - 1,34 m (46”)

Weight
5.5 kg (12 lbs)

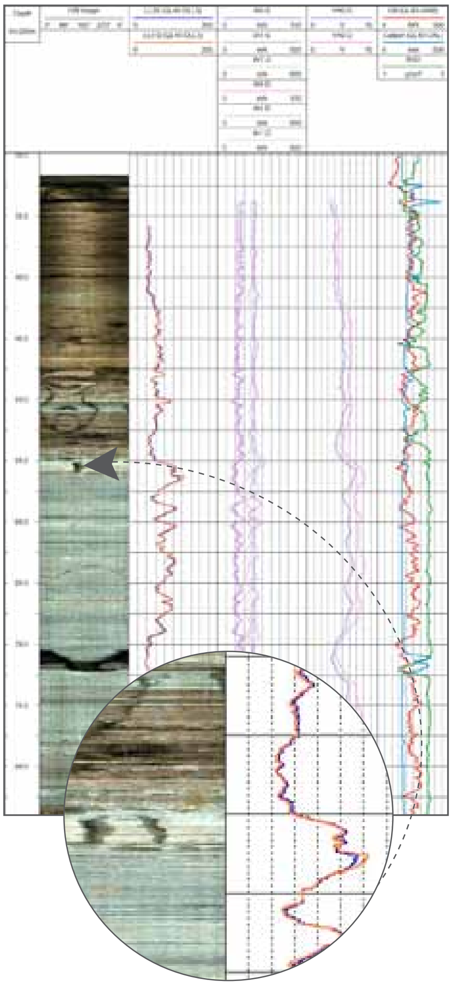
Range
0 - 100.000 CPS

Measurements/Features
- Qualitative measurement of formation porosity in open and cased holes.
  Measures hydrogen content of formation.

QL40GAM natural gamma probe

The natural gamma measure the naturally occurring gamma radiation. Gamma probes are versatile, ubiquitous probe functions with a wide range of applications. Natural gamma logs can be run in any borehole environment, cased, uncased, fluid or air.

The **QL40GAM is an in line sub. It can be combined with other logging tools of the QL (Quick link) product**



line or operated as a standalone tool Other QL probes commonly stacked with the QL40GAM include the QL40Elog, QL40FTC-B (temperature/ fluid resistivity), and the QL40CAL (3-arm caliper), but many possibilities exist owning to the flexibility of the QL (Quick Link) family of geophysical logging probe functions.

Application

- Depth correlation
- Lithology identification
- Evaluation of shale content of formations
- Locating radioactive sand or markers

Advanced Logic Technology

MOUNT SOPRIS INSTRUMENTS

QL40 GAM natural gamma probe

Principle of measurement

The probe contains a high sensitivity gamma sensor which measures the natural gamma radiation released from potassium
sub files can be modified to output gamma in API units and / or %wt. U3O8. Typical k-factor for QLGR probes is 1-3 x 10-6 in 4.5” water-filled open borehole

The tool is equipped with a Thallium doped Sodium Iodide (NaI(Tl)) crystal, which, when struck by a gamma ray, emits a pulse of light. This pulse of light is then amplified by a photo multiplier tube, which outputs a current pulse (see Figure 2-1). These pulses are then detected, digitized and combined with data from other subs (if present in the stack). The data is then transmitted up the wireline using a pulse coded digital data protocol.

Measurements / Features

· Sampling time in seconds
· Temperature at CPU board in °
· High tension at phot-multiplier in Vold
· Raw gamma ray counts
· Gamma ray in counts per seconds (cps) or calibrated units
· Measurement point : 0.18 m (0.71” from bottom connector

Operating Conditions

· Open and cased borehole
· Air/fluid filled
· Centralisation not necessary

Technical Specifications

· Diameter: 40 mm (1.6”) w/o insulating sleeve
· Length: 1.27 m (40.5”)
· Weight: 5 kg (11 lbs)
· Max. temp: 70°C (158°F)
· Max. pressure: 200 Bar (2900 PSI)
· Sensor(s): 2.22 cm x 7.62 cm (0.875”x3.00”) Na(Th)I Scintillation Crystal & PMT
· Measurement Range: 0-100,000 CPS (doc MSI)
· Accuracy: 1% full scale
· Resolution: 0.1 CPS

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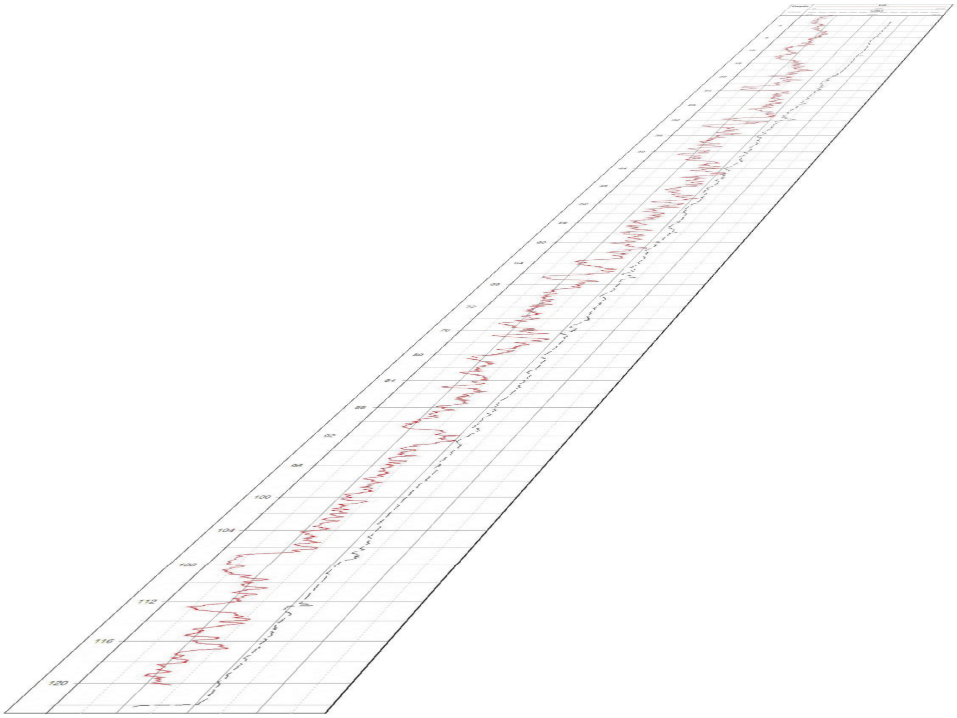

User Guide

QL40 GAM - Natural Gamma Ray Probe

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Table of Contents

1 General Information

The QL40 GAM is a stackable gamma ray (GR) sonde counting the natural occurring radioactivity emitted by the investigated formation.
The tool is supplied as an inline sub of the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a stand alone tool.
The QL40 GAM operates with the ALTLogger and Matrix logging systems and can be run on any standard wireline (mono, 4 or 7 conductor, coax).

1.1 Dimensions

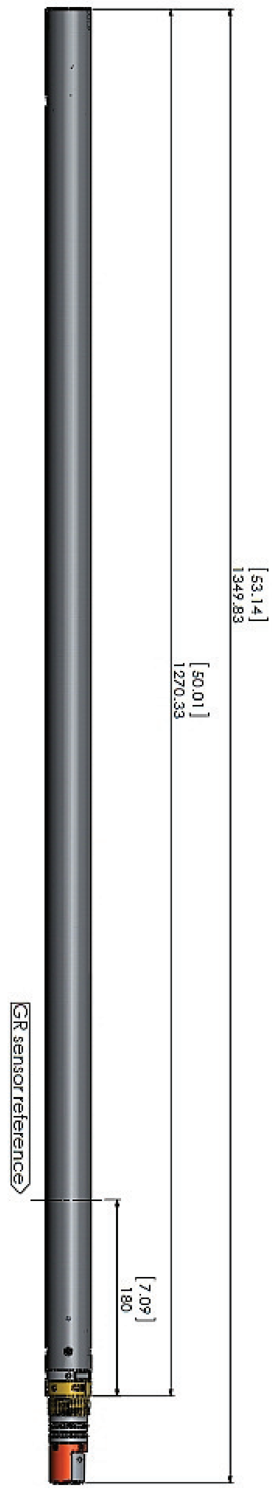

Figure 1-1 QL40 GAM Dimensions

1.2 Technical Specification

Tool	
Diameter:	42.3 mm (1.66”)
Length:	1.27 m (50.01”)
Measurement point:	0.18 m (7.1”) from bottom connector
Weight:	4.67 kg (10.3 lbs)
Min. Temp.:	0 °C (32 °F)
Max. Temp.:	70 °C (158 °F)
Max.Pressure:	200 bar (2900 psi)
Cable:	
Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – ABOX – Matrix
Sensors:	
NaI(Tl) crystal	2.22 cm x 7.62 cm (0.875” x 3.00”)
Power:	
DC voltage at probe top:	Min 80 VDC Max 160 VDC Nominal 120 VDC
Current:	Nominal 25 mA

2 Measurement Principle

The QL40 GAM tool is equipped with a Thallium doped Sodium Iodide (NaI(Tl)) crystal, which, when struck by a gamma ray, emits a pulse of light. This pulse of light is then amplified by a photo multiplier tube, which outputs a current pulse (see Figure 2-1). These pulses are then detected, digitized and combined with data from other subs (if present in the stack). The data is then transmitted up the wireline using a pulse coded digital data protocol.

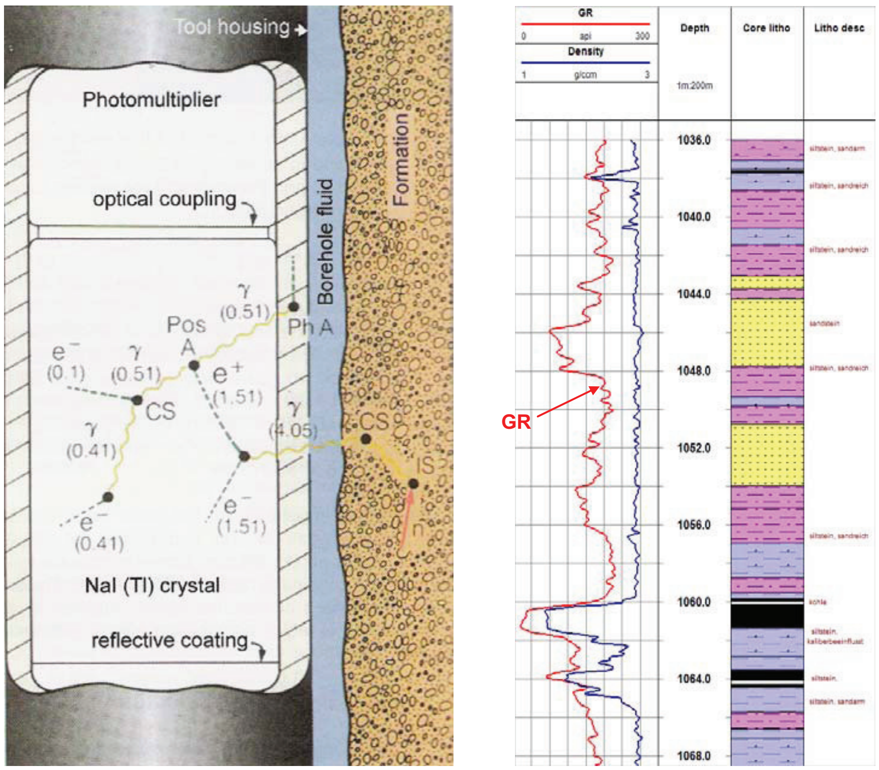

Figure 2-1 *Measurement principle (left, O.&L. Serra, 2004)and typical GR responses and data display (right)*

3 Notes on QL tool assembly

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

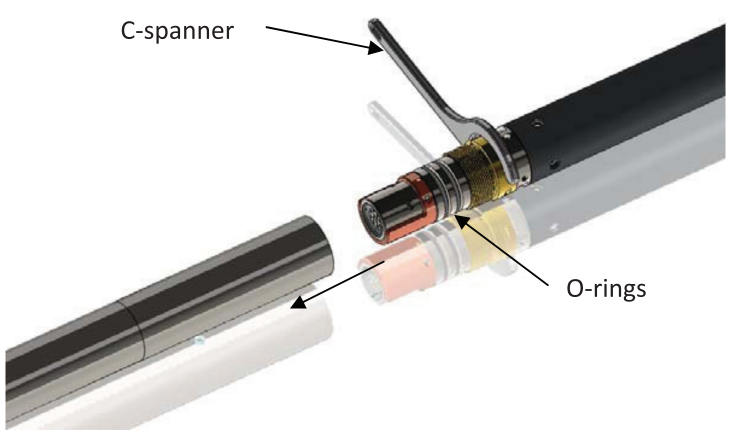

Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GAM and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GR sub stand-alone.

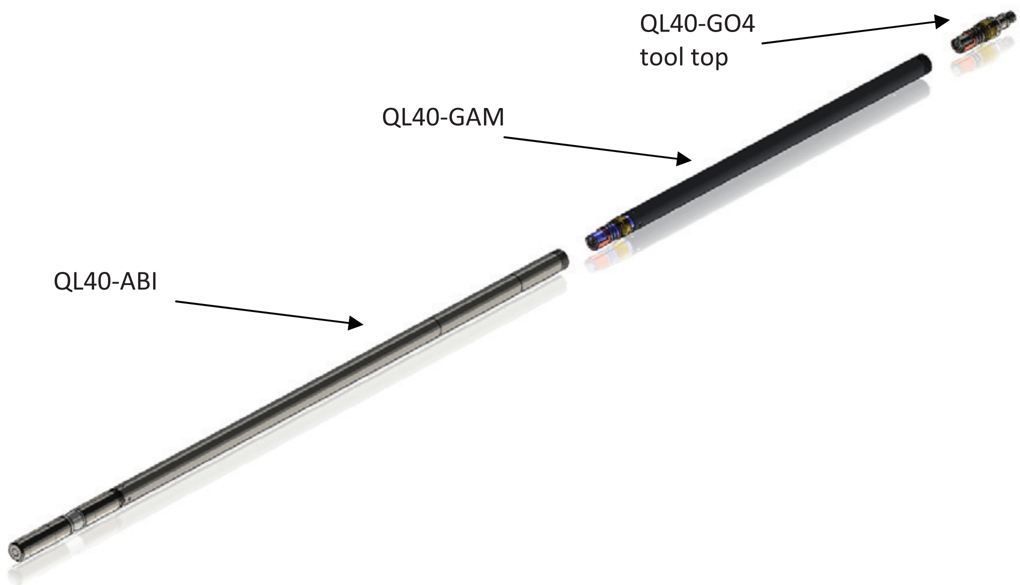

Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

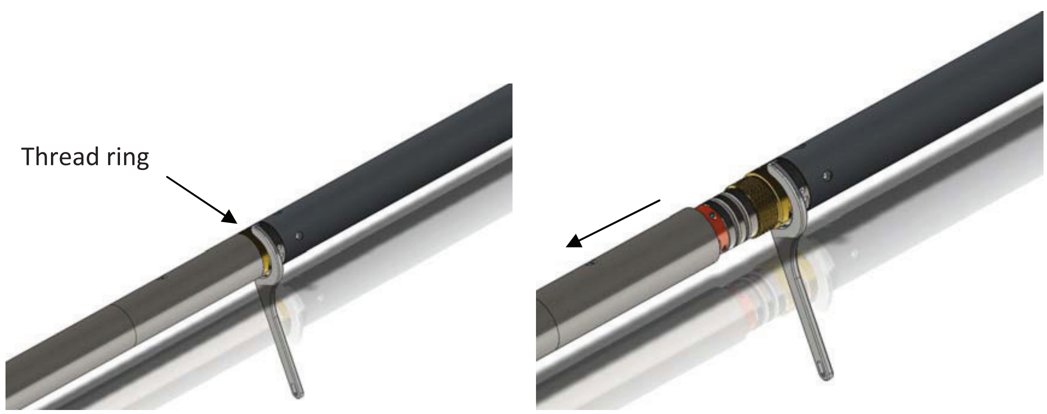

Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

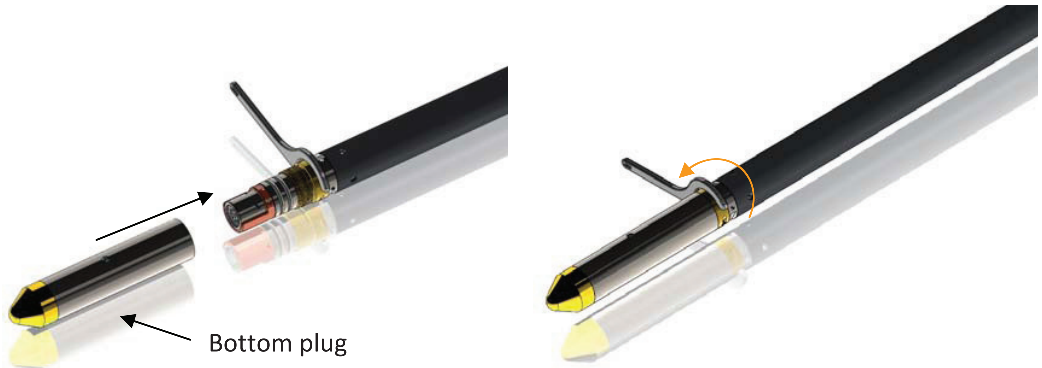

Figure 3-4 *Attaching the QL40-Plug*

The QL40-GAM can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-GAM mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in the sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant QL40 GAM tool from the drop down list (Figure 4-1) in the software's **Tool** panel (if your tool is not listed check that your tool configurations file is stored in the designated folder on your computer).

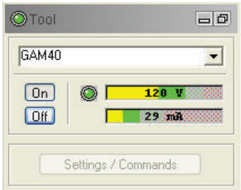

Figure 4-1 *Tool panel*

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in chapter **4.2** if error message is displayed.)

4. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button to configure your tool (see chapter **4.5** for details).

5. In the **Acquisition** panel (Figure 4-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

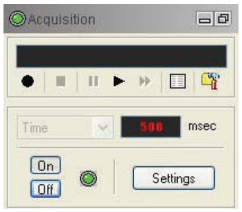

Figure 4-2 *Acquisition panel*

6. Press the **Record** button in the **Acquisition** panel (Figure 4-2), specify a file name and start the logging.

7. During logging observe the controls in the **Telemetry** panel (Figure 4-3):
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

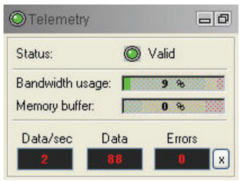

Figure 4-3 *Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

4.2 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

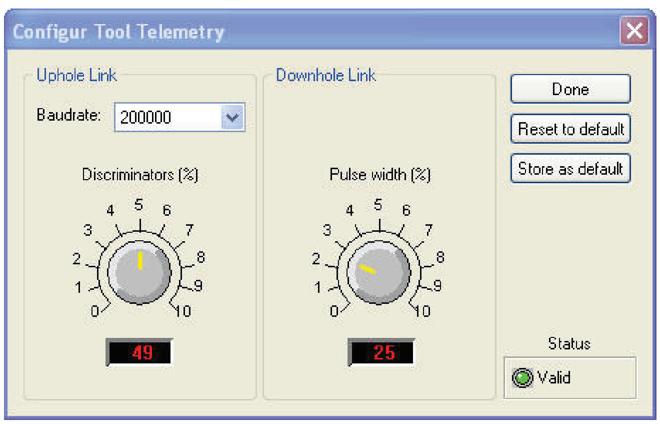

Figure 4-4 *Tool communication settings*

4.3 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-5) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.

The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

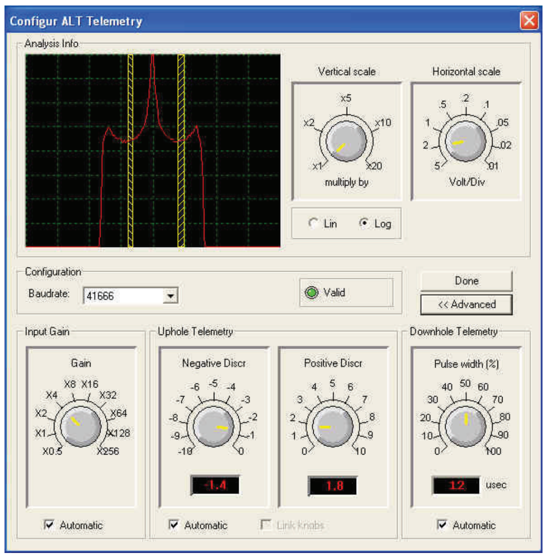

Figure 4-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in “Valid” status the next time the power is turned on.

4.4 Configuring Tool Parameters

The QL40 GAM does not have any configuration options.

4.5 Recorded Parameters, Processors and Browsers

4.5.1 Recorded parameters

The following data channels are recorded by the QL40 GAM tool.

Time	Sampling time in seconds
TCPU	Temperature at CPU board in °C
EHT	High tension at photo multiplier in V
COUNT	Raw gamma ray counts
GR	Gamma ray in counts per second [cps] or calibrated unit

4.5.2 MChNum Browser

Figure 4-6 shows a typical example of the numerical values displayed in the MChNum browser window during operation.

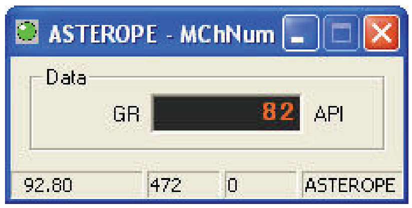

Figure 4-6 *MChNum Browser during operation*

4.5.3 MChCurve Browser Window

The MChCurve browser displays the recorded parameters by means of curves in real time (Figure 4-7).

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, gridding,….)

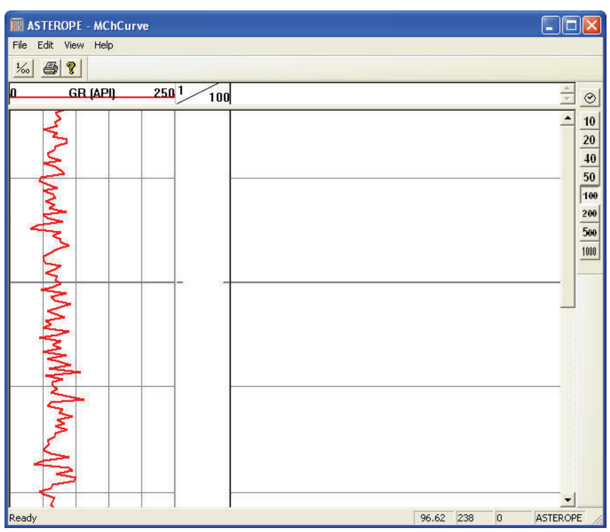

Figure 4-7 *QL40 GAM MCHCurve Browser Window*

5 Performance Check & Calibration

Calibrations are performed at the factory and require a basic knowledge and understanding of the tool. Performance checks for the gamma measurement can be made on the surface before logging. With the tool powered on and viewing data on the computer screen a small source of natural gamma radiation can be placed in close proximity to the detector area about 16.5 cm above the bottom of the probe. An increase in gamma counts will then be observed in the MChNum and MChCurve window if the tool is working properly.
The only sensible calibration can be carried out for the GR sensor.

Prepare to Calibrate:

1. Assemble the tool sub(s) and connect to the wireline.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
   Click Tool Panel **Settings / Commands** button.
   In the **Acquisition Panel** select **Time** and turn it **On**.
3. Click the Green LED at the top left corner of the MChNum Browser window or right click the top pane to display the MChNum context menu (Figure 5-1).
4. Select **Calibration Settings**.

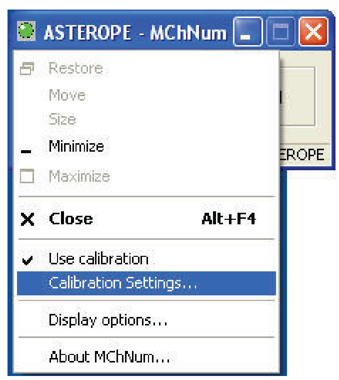

Figure 5-1 *MChNum context menu*

Calibration Settings

1. In order to measure the background radiation, place the tool away from any radioactive material at least 1.5m above the ground or, if available, place the tool in a water tank.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
3. In the **Calibration Settings** dialog box (Figure 5-2) click on **Sample** in the **Background Only** section and wait until an average value has been determined. The corresponding **Value** will be updated automatically. (The number of samples taken can be changed under **Options**.)

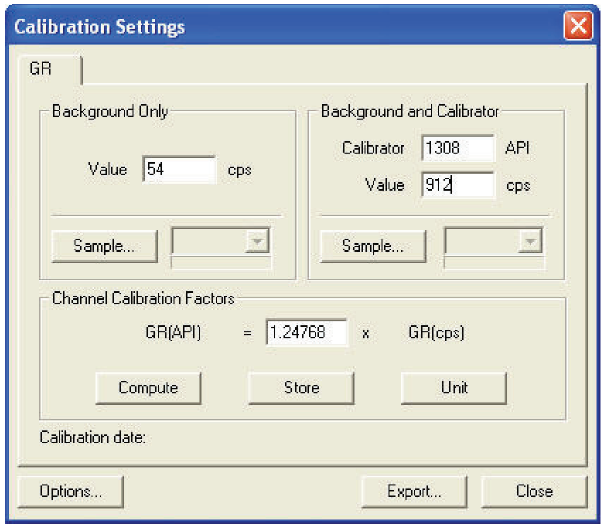

Figure 5-2 *Calibration Settings dialog box*

4. Place the calibrator on top of the sensor or lower the tool into the test pit.
5. Enter the known source strength into the **Calibrator** edit box. If necessary change the units by clicking on the **Unit** button.
6. Click on **Sample** in the **Background and** Calibrator section to determine an average value. The corresponding **Value** will be updated automatically. Click on **Compute** in order to compute the calibration factor.
7. **Store** the new calibration settings in the sub file by clicking on the corresponding button.

On the **Browsers & processors** panel click **Close All** then **Start All** to refresh the other Browsers and Processors. This must be done as they only read the calibration constants from the sub file once when they start.

6 Maintenance

6.1 Upgrading firmware

In accordance with the ALT policy of continuous development the tool has been designed to allow firmware upgrades.

Firmware upgrade procedure is as follows:

1. Checking the communication is valid.
2. Upgrading firmware

6.1.1 Checking the communication

- Connect the tool to your acquisition system.
- Start the data acquisition software.
- In the **Tool** panel select the appropriate tool and turn the power on.
- In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-1 or Figure 6-2).

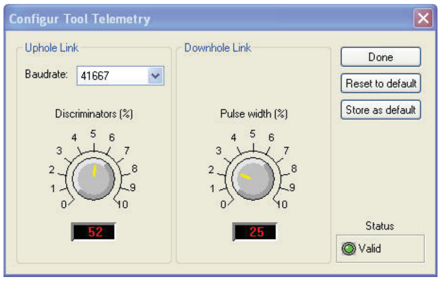

Figure 6-1 *Tool communication settings - ALTLog*

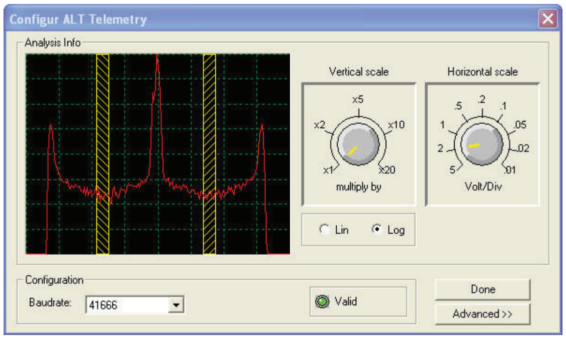

Figure 6-2 *Tool communication settings - Matrix*

Warning: The telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.1.2 Upgrading the firmware

Check that the communication status is valid. **Right Click** on the tool preview in the **ToolStack Manager** view and select **Upgrade Firmware** from the context menu (Figure 6-3).

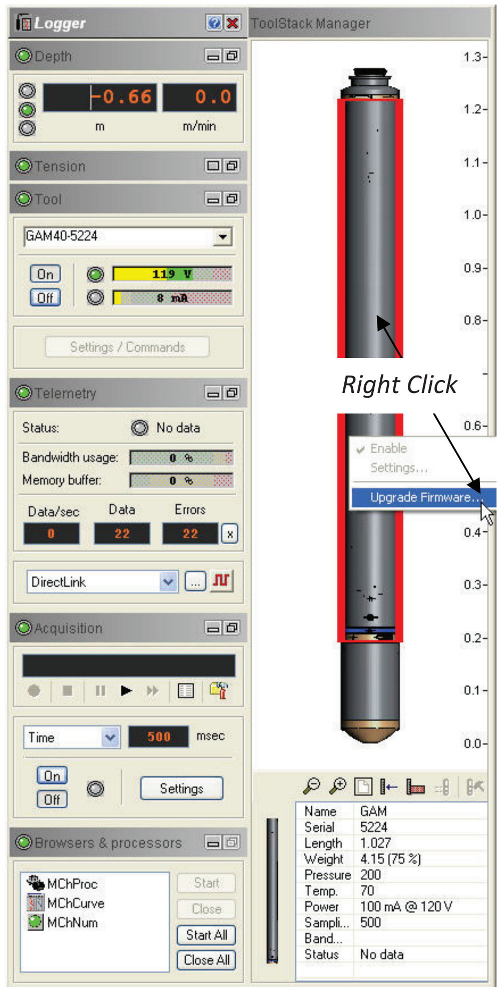

Figure 6-3 *Right Click into ToolStack manager view*

- The following message will appear (Figure 6-4). Click **Yes** to validate your selection.

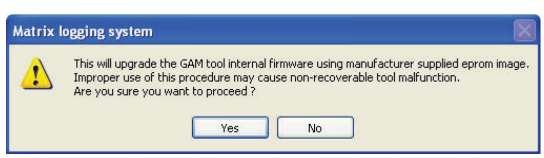

Figure 6-4 *Warning Message during firmware upload*

- Select and open the appropriate **.hex** file provided. The upgrade will start.
- During the upgrade procedure, the following message is displayed:

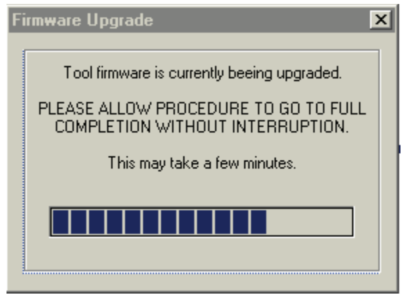

Figure 6-5 *Firmware upgrade progress window*

- Once the upgrade has been successfully completed (Figure 6-6), click on **OK** to turn the tool off.

Figure 6-6 *Successful upgrade*

- Power the tool on to start the upgraded firmware.

Note that the following error message (Figure 6-7) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

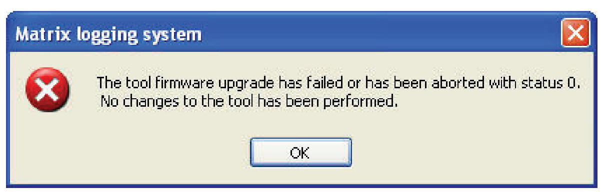

Figure 6-7 *Error message*

6.2 General Tool Maintenance

The QL40 GAM tool should require no maintenance other than a few salient points.

- Keep the probe and the tool top/bottom connectors clean.
- When the probe is transported, it needs to be contained in a vibration damped container to minimize stress on the sensors.
- The probe top/bottom connector should be periodically cleaned with oil free contact cleaning solvent.

7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been imported using the Logger Settings application (refer to the corresponding manual)? - Did you configure a stack for your tool (at least top, tool body and bottom plug)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use test cable provided by ALT to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu .
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Parts list

Please contact ALT or Mount Sopris for a list of spare parts and items included in the delivery kit.

8.2 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- QL40 GAM Wiring Diagram.

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Advanced Logic Technology

QL40-OBI-2G
OBI40-GR-2G
Optical borehole imager
30.06.2023

The QL40-OBI-2G and the OBI40-GR-2G are the new generation of slim hole Optical Borehole Imagers. The new system comprises a completely redesigned optical assembly with new electronics. It implements a high resolution CMOS digital image sensor combined with a fisheye lens. The tool produces an extraordinarily clear, sharp, 360° continuous - unwrapped digital picture of the borehole wall, either in air or clear water. Resolutions up to 1800 pixels over the borehole circumference can be achieved which makes it ideal for lithological, mineralogical and structural analyses.
A built in high precision orientation package incorporating a 3-axis fluxgate magnetometer and 3 accelerometers allows orientation of the images to a global reference and determination of the borehole's azimuth[1] and inclination.

The new QL40-OBI-2G is fully digital and can operate on standard wirelines. It is a bottom sub and can be either combined with other logging tools of the QL (Quick Link) product line to build tool strings or operated as a standalone tool.

The OBI40-GR-2G is a standalone tool version integrating a natural gamma sensor thereby enabling the measurement of gamma radiation emitted naturally from within the formations crossed by a borehole.

Also available with UV measurement see QL40-OBI-UV brochure.

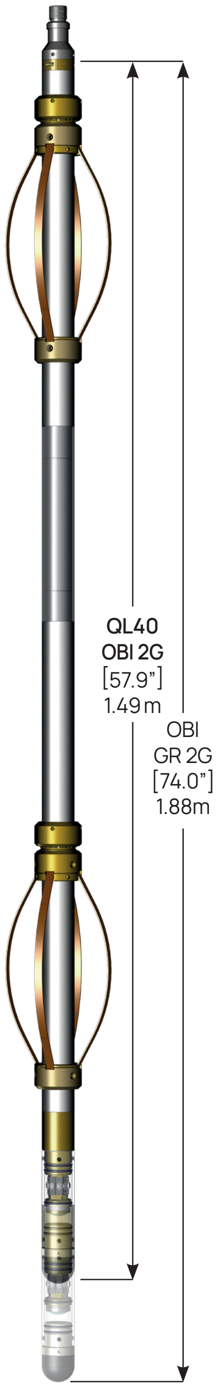
Application

OPEN HOLE

- Detailed and oriented structural information
- Reference for core orientation
- Fracture detection and evaluation
- Breakout analysis
- Lithology characterizations : Detection of thin beds, foliation, grain size, mineralogy, luminance, determination of bedding dip

CASED HOLE

- Casing inspection



Tool

Diameter : 40mm (1.6")
Length (min/max) : 1.49m (58.7") / 1.88m (74.0")
Weight (min/max) : 5.3kg (11.7 lbs) / 6.5kg (14.3 lbs)
Temp : 0 - 70°C (32 - 158°F)
Max. Pressure : 200bar (2900psi)

Optical system

Sensor : 1/3" high sensitivity CMOS digital image sensor
Color resolution : 24 bits RGB true colors
Azimuthal resolutions : 120, 180, 360, 600, 900, 1800 points
Vertical resolution : User defined. Function of depth encoder vertical resolution
Light source : High efficiency white LEDs

Natural gamma sensor

- 0.875" (22.2mm) x 3" (75.6mm) NaI (Ti) scintillation crystal
- Integrated (OBI40 GR) or in line sub (QL40 GR)

Orientation sensor

3 axis fluxgate magnetometer – 3 accelerometers
- Inclination accuracy : +/- 0.5 degree
- Azimuth accuracy : +/- 1.2 degree

Operating conditions

Cable type : Mono, multi-conductor, coax
Compatibility : ScoutPro / Opal (Scout / Bbox / Matrix)
Digital data transmission Telemetry : Variable baudrate telemetry according to cable length/type & surface system
Logging speed : Variable - function of image resolution, borehole diameter, wireline and surface system model.
Centralisation : Required
Borehole fluid : Dry or clear water
Measurement range : In air and in water : 2.3" to 21" (58 to 530mm)

[1] Only applicable in non magnetic environment

Principle of measurement

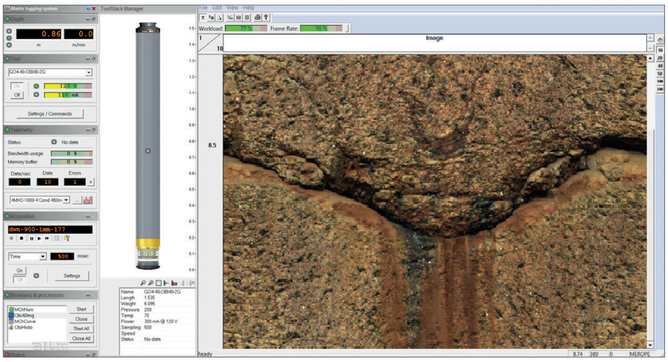
The tool incorporates a 1/3-inch CMOS digital image sensor and matching fisheye optics. The digital image sensor captures the light reflection of the borehole wall through the fisheye lens. The light source is provided by 10 high efficiency LEDs.

The displayed log image is derived from a single annulus extracted from the active pixel array. Azimuthal resolutions available are 120, 180, 360, 600, 900 and 1800 points per recorded circle. By using processed digital images in combination with deviation sensor data, the tool can generate an unwrapped 360° oriented image.

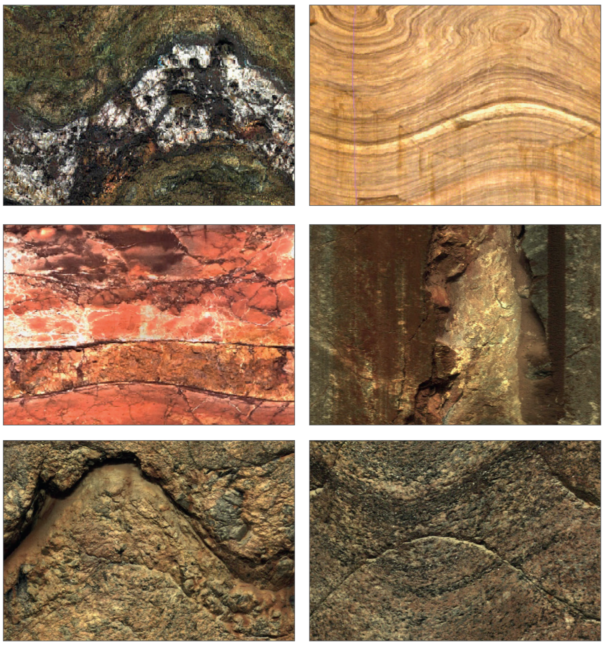
Measurement features

- 360° RGB true color oriented image
- 360° real time image filtering to enhance image contrast in dark environment (NEW)
- Deviation parameters: azimuth, tilt, tool relative bearing, magnetic field, gravity
- 3 accelerometer calibrated components, 3 magnetometer calibrated components
- Temperature of CMOS image sensor
- Natural gamma in cps or API units (optional – OBI40-GR-2G)
- Adustable exposure level while logging (NEW)

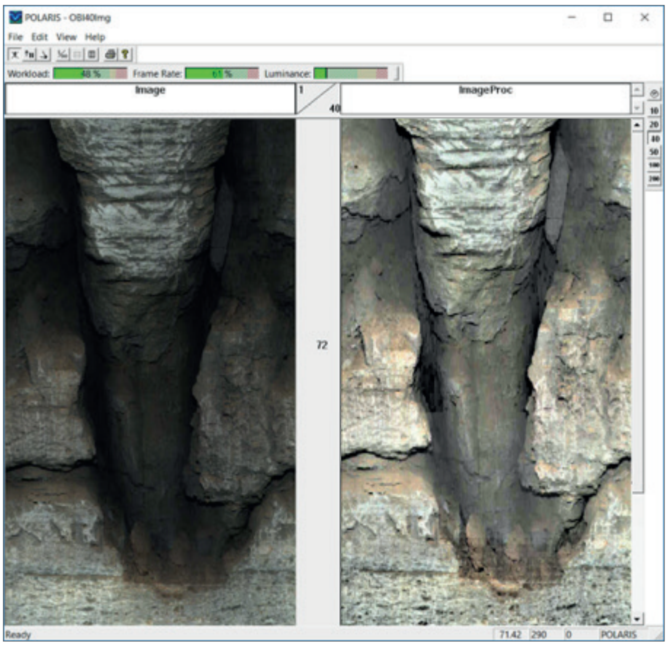
Optical assembly



LoggerSuite application and OBI real time display



OBI images in different geological environments



OBI image browser : cavity - broken zone in dolomitic sandstone
(left, real time OBI image - right, real time filtered OBI image)

User Guide

QL40 OBI-2G Optical Borehole Imager

MOUNT SOPRIS INSTRUMENTS

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v19.05.13

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Table of Contents

1 General Information

The QL40 OBI-2G is the new generation of slimhole Optical Borehole Imager. The new system consists of a completely redesigned optical assembly and electronics. It implements a high resolution CMOS digital image sensor combined with a fisheye lens. The tool produces an extraordinarily clear, sharp, 360° continuous - unwrapped digital picture of the borehole wall, either in air or clear water. Resolutions up to 1800 pixels over the borehole circumference can be achieved making it ideal for lithological, mineralogical and structural analyses.

A built in high precision orientation sensor incorporating a 3-axis fluxgate magnetometer and 3 accelerometers allows orientation of the images to a global reference and determination of the borehole's azimuth and inclination.

The QL40 OBI-2G is supplied as a bottom sub of the Quick Link (QL) product line and it can either be combined with other QL40 tools to form a tool string or be run as a standalone tool.

Applications:

- *Detailed and oriented structural information*
- *Reference for core orientation*
- *Fracture detection and evaluation*
- *Breakout analysis*
- *Detection of thin beds*
- *Determination of bedding dip*
- *Lithology and mineralogical characterization*
- *Casing inspection*

Measurement features:

- *360° RGB true colors oriented image*
- *Borehole azimuth and tilt*
- *Relative bearing*
- *3 accelerometer calibrated components*
- *3 magnetometer calibrated components*
- *Temperature of CMOS image sensor*

Operating conditions:

- *Dry or clear water filled borehole*
- *Centralizers required*
- *Borehole diameter range: 2 ½" to 21"*
- *Logging speed:* function of image resolution and wireline electrical properties
  i.e: 6 m/min with 900 pixels azimuthal resolution, 2 mm vertical sampling rate @ 100 Kbps

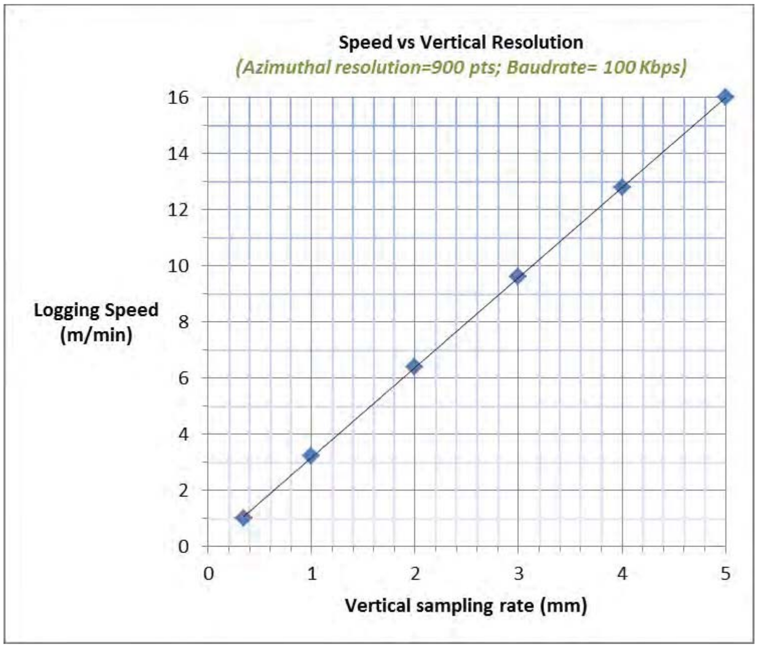


Figure 1-1-1 *Logging Speed vs Vertical Sampling Rate (900 pxls-100 Kbps)*

1.1 Dimensions

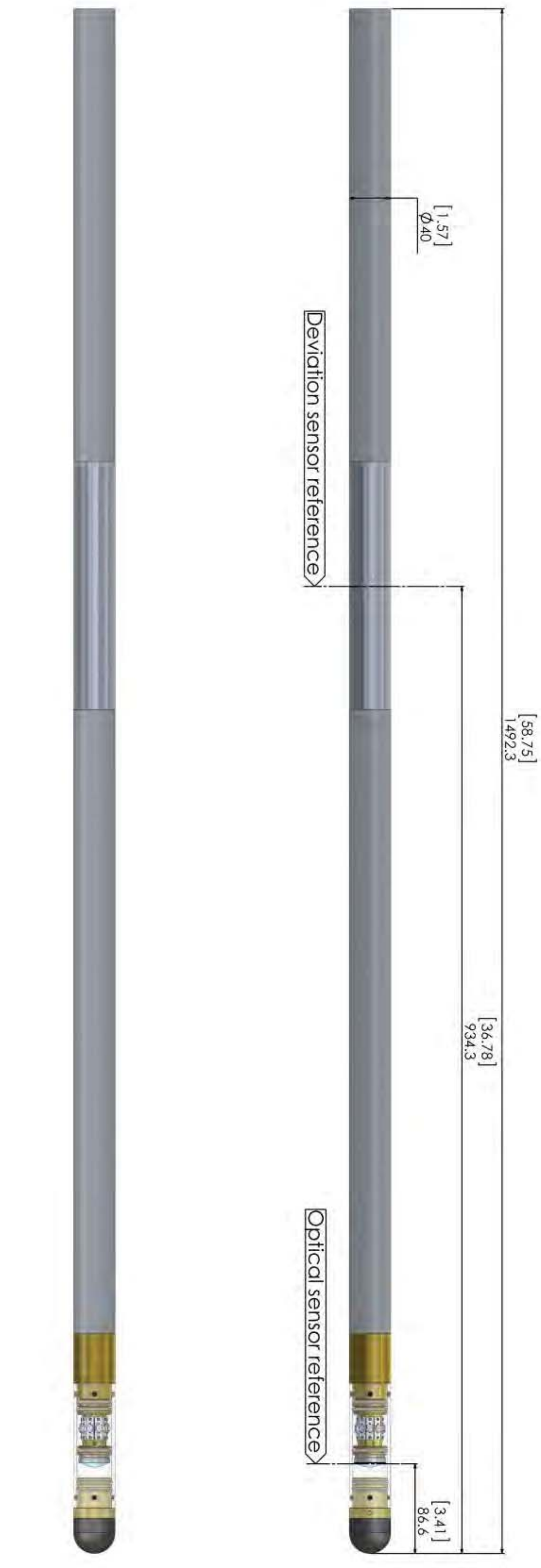


Figure 1-1 *QL40 OBI-2G overview*

1.2 Technical Specifications

Diameter:	40 mm (1.6”)
Length:	1.49 m (58.7”)
Weight:	5.3 kg (11.7 lbs)
Max. Temperature:	70°C (158°F)
Max. pressure:	200 bar (2900 PSI)

Optical system

Sensor:	1/3” high sensitivity CMOS digital image sensor
Color resolution :	24 bits RGB true colors
Responsivity :	5.48v/lux-sec
Azimuthal resolutions :	120, 180, 360, 600,900, 1800 points
Vertical resolution :	User defined. Function of depth encoder resolution

Light source

Light source:	High efficiency LEDs
Color temperature:	5600 K
Light intensity:	750 lm
Color rendering index:	80 %
Power max.:	5.60 W

Compatibility

Wirelines:	Multi conductor, mono or coaxial
Acquisition systems:	ALTLogger, BBOX and Matrix
Min. software configuration:	LoggerSuite 11.2 – WellCad 5.0 build 1103

Orientation sensor

Sensor:	APS544 – 3 axis magnetometer and 3 accelerometers
Azimuth accuracy:	+/- 1.2 deg
Tilt accuracy:	+/- 0.5 deg

2 Measurement Principle

The tool incorporates a 1/3-inch CMOS digital image sensor with an active pixel array of 1.2 Mp and fisheye matching optics. The digital image sensor captures the reflection of the borehole wall through the fisheye lens. The light source is provided by 10 high efficiency LEDs.
The displayed log image is derived from a single annulus extracted from the active pixel array. Azimuthal resolutions available are 120, 180, 360, 600, 900 and 1800 pixels per recorded circle. By using processed digital images in combination with deviation sensor data, the tool can generate an unwrapped 360° oriented image.

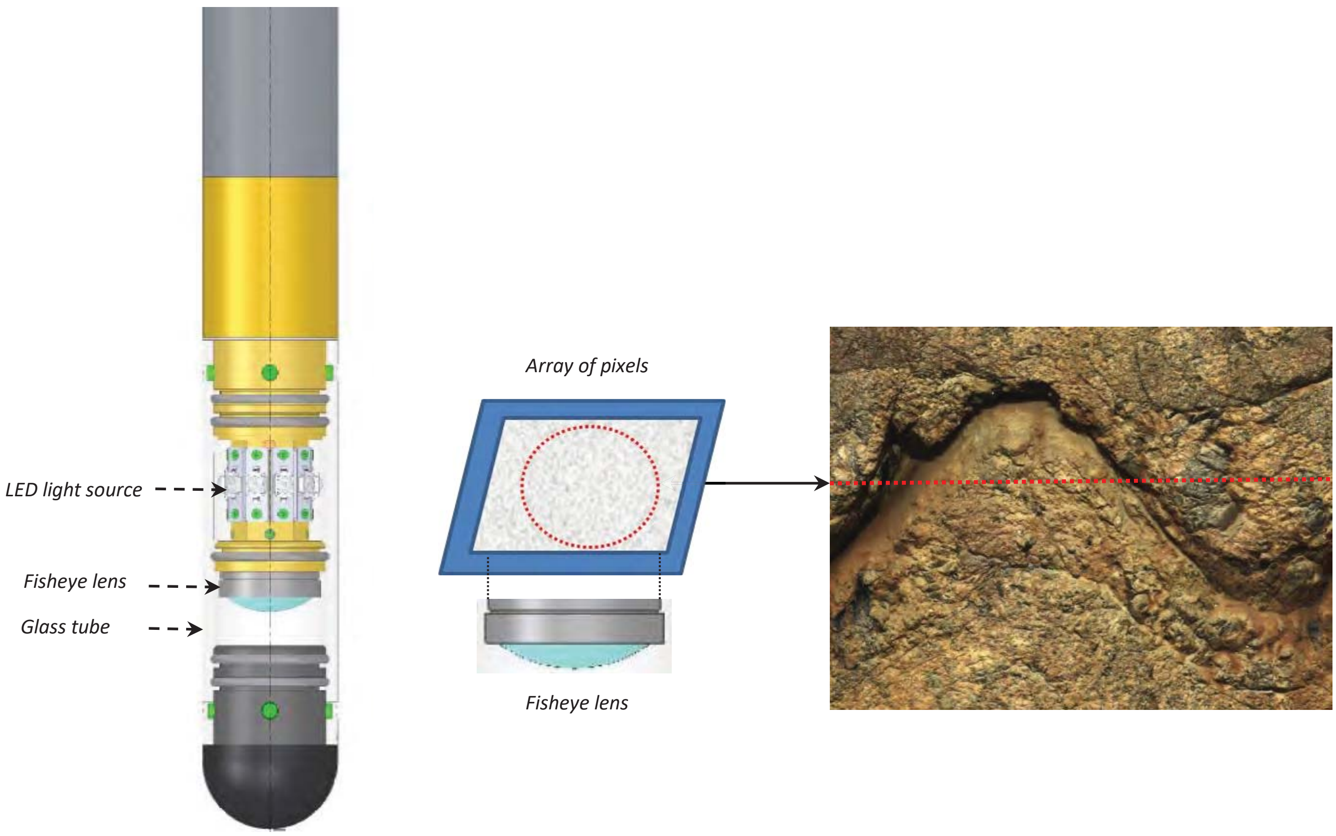


Figure 2-1 *Optical assembly and principle of measurement*

3 Notes on QL tool assembly

The following explanations are only valid for the QL40 OBI tool. OBI40 users can skip this chapter.

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

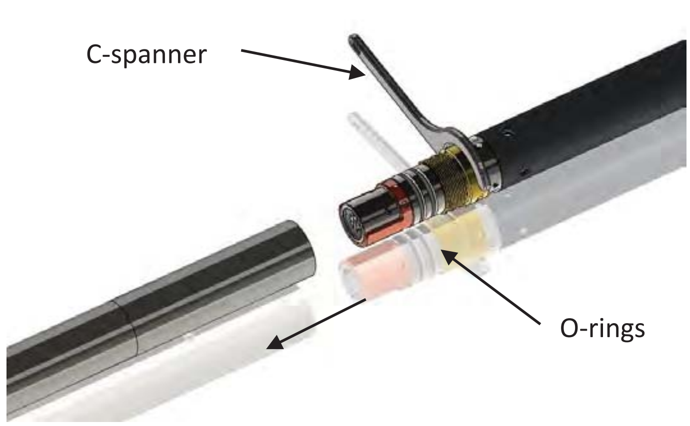


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GR and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GR sub stand-alone.

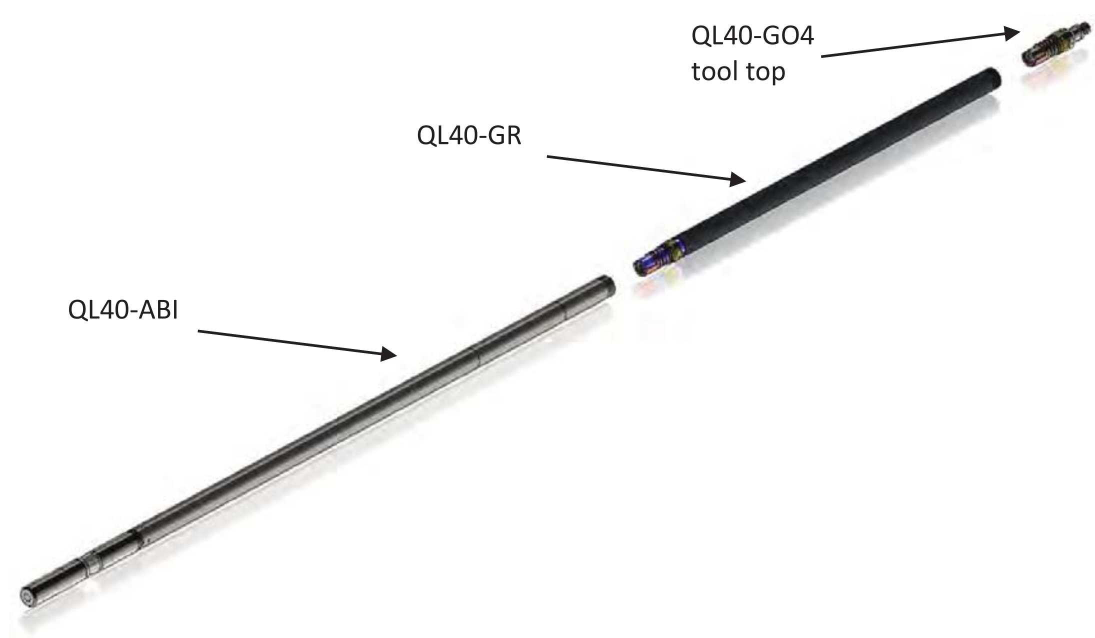


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

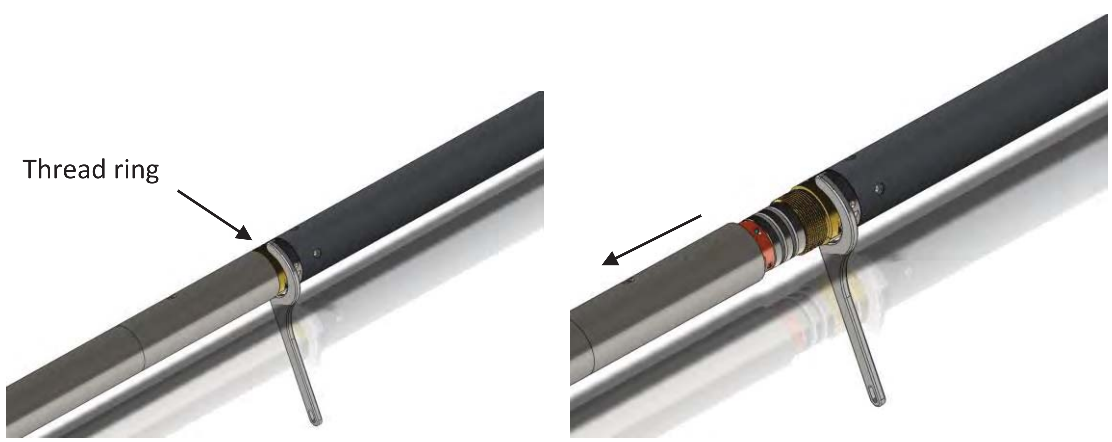


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

Figure 3-4 *Attaching the QL40-Plug*

The QL40-GR can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-GR mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in these sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant OBI tool from the drop down list (Figure 4-1) in the software's **Tool** panel (if your tool is not listed check that your tool configurations file is stored in the designated folder on your computer).

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup the tool communication as explained in section **4.2** if an error message is displayed.)

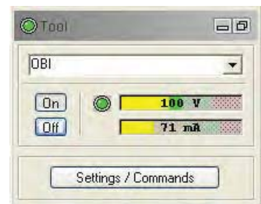


Figure 4-1 *Tool panel*

4. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button to configure your tool (see chapter **4.5** for details).

5. In the **Acquisition** panel (Figure 4-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

6. Press the **Record** button in the **Acquisition** panel (Figure 4-2), specify a file name and start the logging.

Figure 4-2 *Acquisition panel*

7. <u>During logging</u> observe the controls in the **Telemetry** panel (Figure 4-3):
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

   <u>In the OBI40Img browser the processor "workload" and camera "frame rate" must stay below 100%</u>

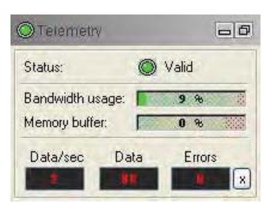


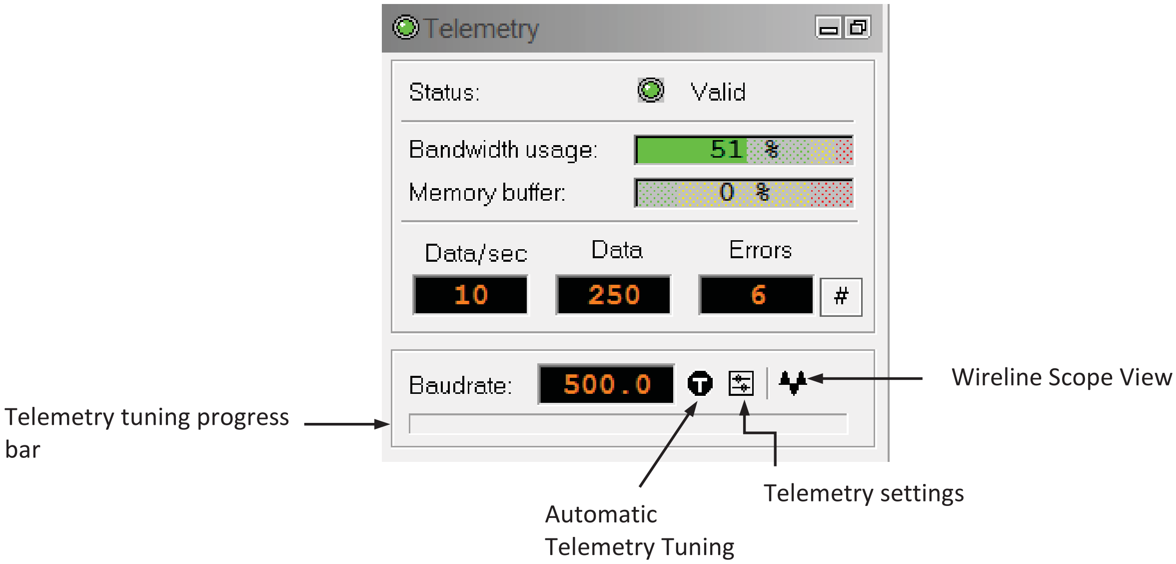
Figure 4-3 *Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

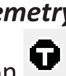
4.2 Tool Communication with OPAL/SCOUT (ALT MODEM)

The telemetry provided through the **OPAL-SCOUT** systems implementing the **ALT MODEM** controls and configures **AUTOMATICALLY** the telemetry settings for any wireline. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

The Tune button  resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.

A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

Refer to **Appendix** at the end of this manual for more information on the **advanced telemetry settings**.

4.3 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.

- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

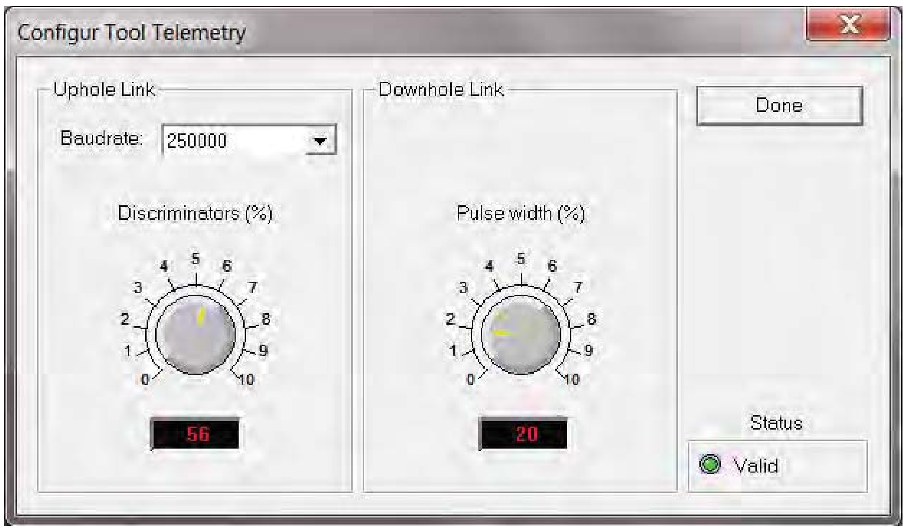


Figure 4-4 *Tool communication settings*

4.4 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-5) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5) for an example of a suitable discriminator position). There is also the option to

alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

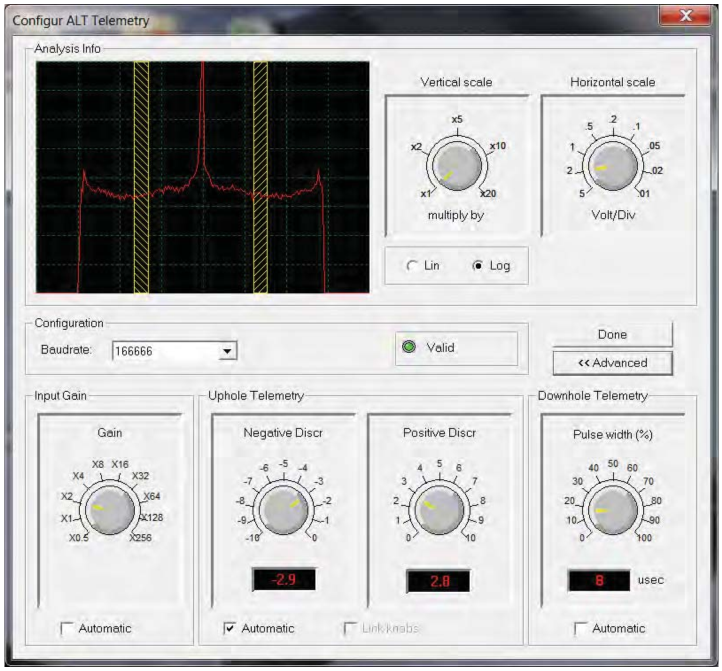


Figure 4-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in "Valid" status the next time the power is turned on.

4.5 Use of centralizers

Optical televiewer image quality is highly dependent upon tool centralization.
One set of centralizers is supplied with the OBI that is suitable for all tools with an external diameter of 40mm. The standard assembly comprises upper and lower mounting rings with sets of bow springs. Two C spanners are provided for tightening the locking ring. Bowsprings for other borehole diameters are available on request.
The following points relating to the use of centralizers should be considered:
The centralizers should be fitted before mating the tool with the wireline cable head and should always be fitted from the cable head end to avoid damaging the optical window. In case magnetic centralizers are used (the ALT centralizers are non magnetic) avoid mounting a centralizer over the deviation sensing point which is located in the middle of the roughened area on the pressure housing.
The "compression" ring of the centralizer, i.e. the one that is screwed tight, should always be fixed toward the **top** end of the probe. This is to avoid catching on a downhole obstruction when winching up.
Use the C spanner to fasten the fixing rings but take care not to cross thread or over tighten them as this could damage the pressure housing
(The weak point of the bowsprings is the welded bearing pin. Take care during assembly as the weld can be broken by reverse bending.)

4.6 Configuring Tool Parameters

The **Tool Parameters** dialog box for the QL40 OBI-2G is shown below (Figure 4-6). It can be accessed by clicking the **Settings / Commands** button from the **Tool Panel**. Changes and the effect of new settings on the image are displayed in real time in the **OBI image** browser.

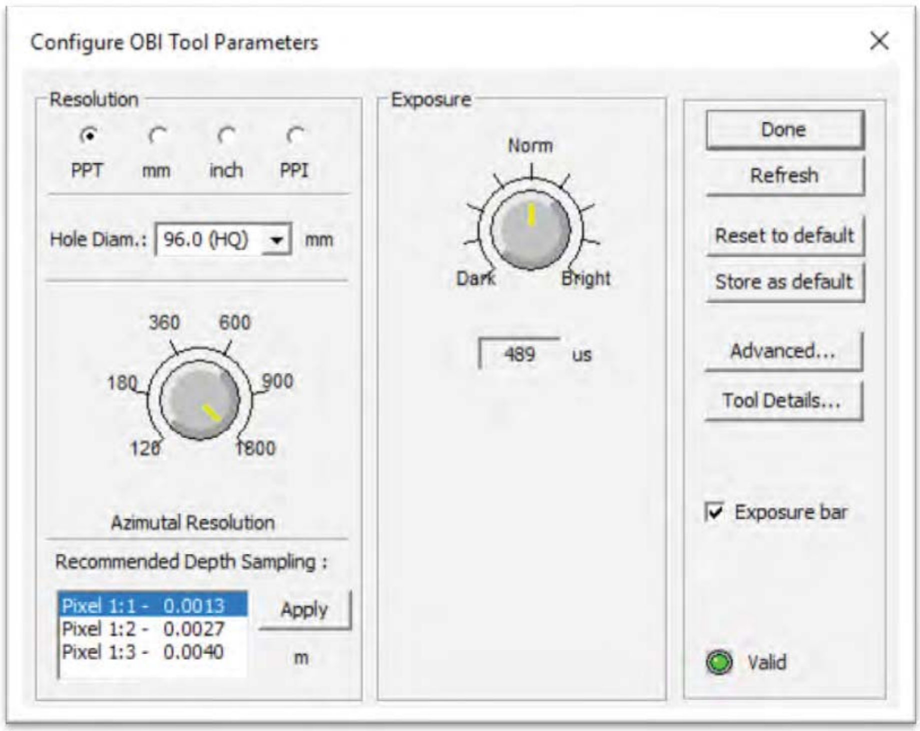


Figure 4-6 *Tool parameters dialog box*

4.6.1 Image resolution

The azimuthal resolution of the image can be defined by the operator. The choice of azimuthal resolutions is now extended to 1800 pixels over the borehole circumference.

Multiple options are possible for displaying the azimuthal resolution: points per turn (PPT), millimetres (mm), inches (inch) or points per inch (PPI).
By editing or selecting a nominal borehole diameter in the *caliper window*, the system computes automatically the azimuthal resolution values for each display options.

The system suggests in addition a *recommended vertical depth sampling rate for the selected azimuthal resolution* and offers a choice of different image ratios (ratio between horizontal and vertical resolutions). A link can be activated to apply automatically the recommended vertical sampling rate in the “*acquisition*” panel of the dashboard. Note that User is always free to edit manually the vertical depth sampling rate from the “settings” option in the “acquisition” panel of the dashboard.

Important remark:

The digital images recorded by the QL40 OBI-2G are compressed in real time to increase the transfer rate of the images to the surface acquisition system. To optimize the compression process, the tool records eight optical data frames per vertical sample. ***For***

this reason, the vertical sampling value to edit must be multiplied by a factor of eight. I.e. in practice, if the User wants to record an image with an effective 1mm vertical depth sampling rate, a value of 8mm (8x1mm) must be manually entered in the "acquisition" window of the dashboard.

4.6.2 Exposure

The "Exposure" control knob allows optimization of the exposure time set for the image sensor when capturing an image of the borehole wall under a given light level. (By default the lighting intensity is set at 100%, see Section 4.5.4). The exposure value is displayed below the knob in µsec.
Practically speaking, the exposure must be adjusted adequately for the borehole conditions: diameter, dry or water filled, rock colors.
By experience a lower exposure value is required in small diameter borehole, whitish formations and dry conditions. The reverse is applicable.

A good way to set the exposure time is to check the luminance distribution in the histogram view available with the "ObiHisto" browser (refer to chapter 4.6.3). The spectrum of the luminance should normally be centered on the luminance scale axis (Figure 4-7). A situation where the luminance spectrum is too far to the right on the luminance scale corresponds to an image saturated with light.

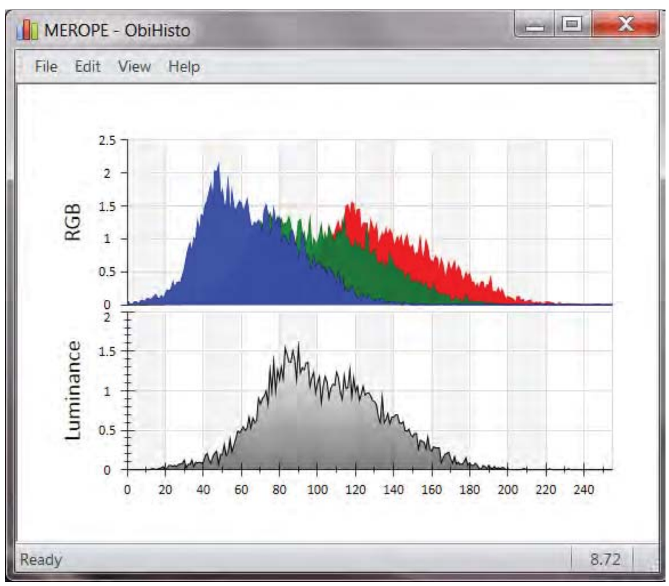


Figure 4-7 *Example of a correct luminance distribution and exposure level*

In borehole environment in which black formations are interbedded with white veins or layers it is recommended to under expose the image to avoid luminance saturation in front of the white features. The new image browser described in section 4.7.2 offers the option to re-process the image by applying a real time filtering on the raw data to enhance luminance contrast in the under exposed intervals.

By checking the "**Exposure bar**" option the "**OBI-Exposure**" box will be displayed in Logger application:

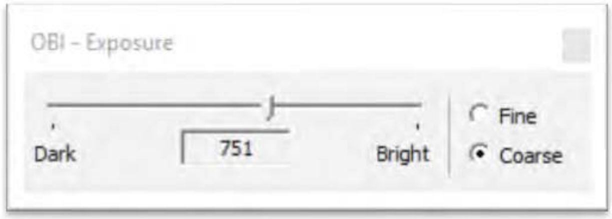


Figure 4-8 *OBI – Exposure bar*

The “OBI-Exposure” bar allows the user to adjust the camera exposure interactively while logging by the mean of a dedicated cursor. The cursor sensitivity can be switched from coarse to fine if required.

Note that the exposure value is recorded in the data acquisition file (tfd file) together with the image logs. At file import in WellCAD the “Exposure” log illustrates the exposure changes performed by the operator while logging.

Remark:
The Exposure bar option requires LoggerSuite 12.1.2356 or higher
The tool sub file must include the following key in the [Default] section :

```
…..
[Default]
…
EnableExposureBar = yes
…
```

4.6.3 Tool parameters buttons

- **Refresh**: Click to refresh the settings of the dialog box.
- **Store as default**: Selected settings can be saved as defaults in the tool’s default settings memory. The default settings are the tool settings loaded during the tool initialization sequence after the tool has been powered on.
- **Restore to default**: Load the default values from the tool’s default settings memory.

4.6.4 Advanced settings

By default the light level is always set to 100%. It is the recommended light level for most borehole conditions.
In a situation where the image is overexposed to light, first, the exposure control knob must be adjusted. If, when the lower exposure value is used the image is still too bright, the light level can be decreased.

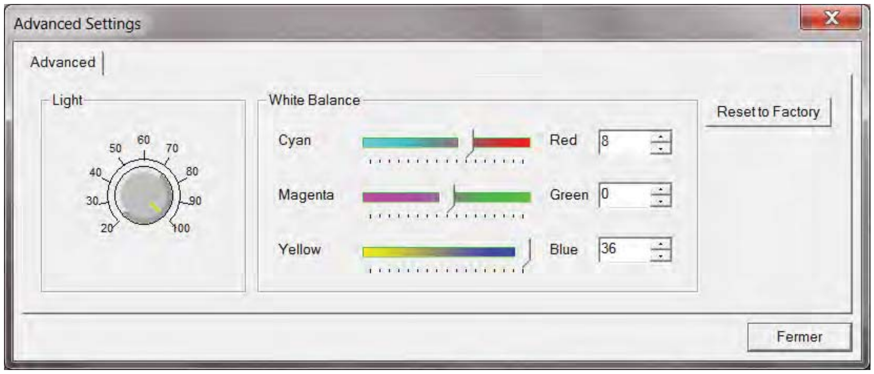


Figure 4-9 *Advanced settings dialog box*

The white balance controls the ratio between the three main colors (red, green, blue). In other words, the white balance calibrates the white color of an object or image.

The calibration of the white balance requires specific equipment and is performed at manufacturing time. No change should be applied to the white balance settings when the tool is operated under normal conditions.

- **Reset to factory:** Load the original image sensor settings stored in the tool's memory during factory calibration.

4.6.5 Tool details

The **Tool Details** window lists the tool parts serial number, firmware and hardware versions.

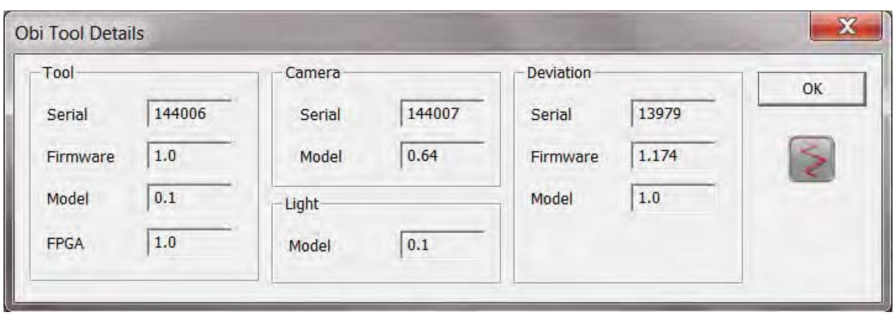


Figure 4-10 *Advanced settings*

4.7 Recorded Parameters, Processors and Browsers

4.7.1 Recorded parameters

Besides the image, the following data channels are recorded by the tool.

TCam[1]	Temperature of the image sensor - °C
FRate	Image sensor frame rate per second - fps
Workload	Percentage of the processor workload used for the image compression – %
Azimuth	Azimuth from Magnetic North – deg
Tilt	Inclination from verticality – deg
Roll	Tool relative bearing calculated from accelerometers - deg
MRoll	Tool relative bearing calculated from magnetometers - deg
MagnField	Magnetic field surrounding the borehole - µT
Gravity	Absolute value of the Earth gravity – g
TAPS	Temperature inside the deviation sensor - °C

4.7.2 "Obi40Img" Browser

Real-time 360° unwrapped images are displayed in the OBI40 image browser window (Figure 4-11). This browser has control buttons for choosing the system of orientation, time or depth mode, depth scale, grids and printing.

By clicking on "View" in the browser tool bar user has the option to display in addition to the standard OBI image a new "Processed Image". It is a real time processed image implementing some filtering algorithm to enhance the luminance distribution. The process is very powerful when the borehole wall is under exposed to light such as for instance in cavities or dark formations. It helps to emphasize the image contrast in unfavorable light conditions.

[1] *The light source of the QL40 OBI-2G is switched off automatically when TCam reaches 105°C which is the maximum operation temperature of the image sensor.*

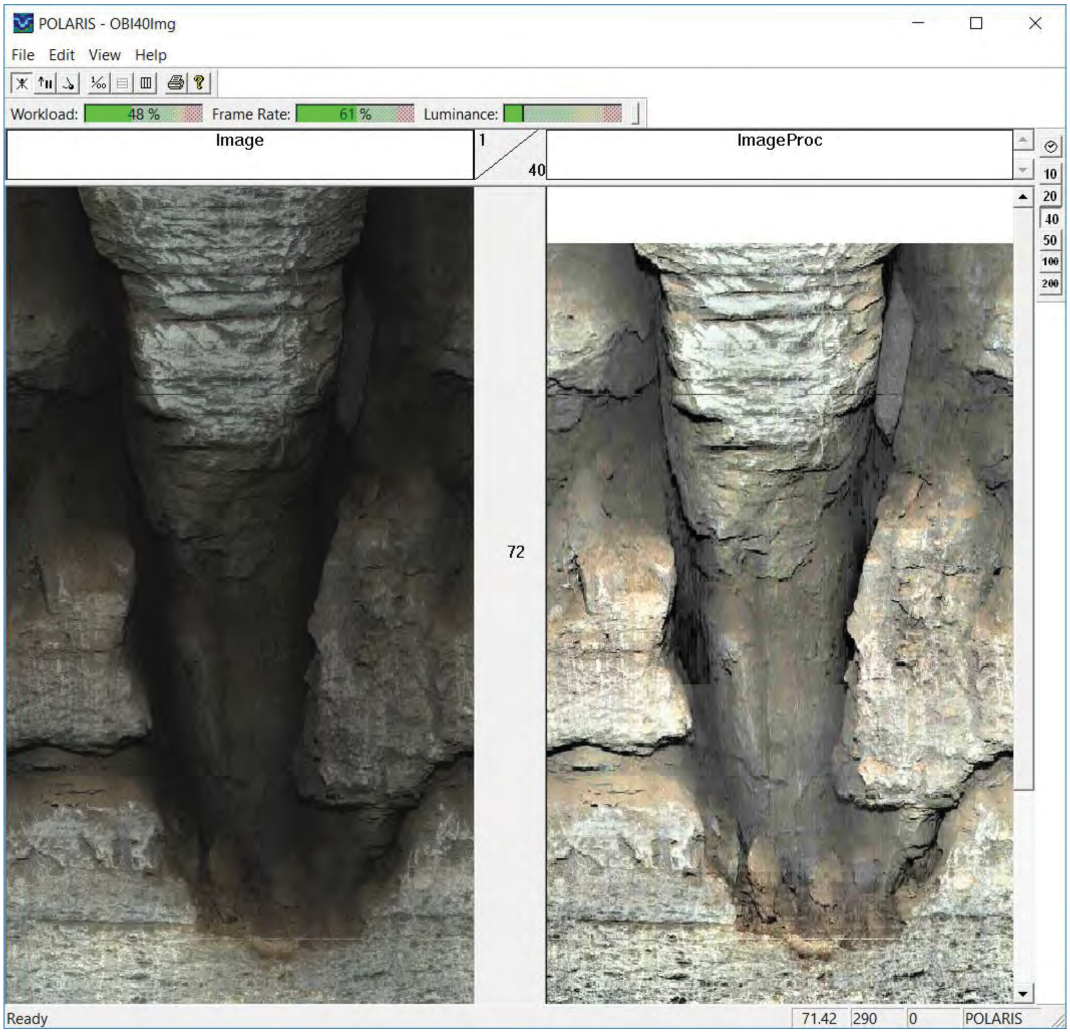


Figure 4-11 *OBI40 image browser*

At the top of the browser, two bar meters monitor in real time the camera processor workload and frame rate in percent.

The bar meters must be used to control the logging speed during a record. To avoid bad records it is recommended to keep the percentage values in the green range.

Image orientation:

 Image is non-oriented

 Orient image to magnetic North

 Orient image to High Side of the tool

There are two modes of tool data orientation: Orientation to High Side and orientation to North (Figure 4-12). Orientation to High Side is used in inclined boreholes when magnetic data is unavailable (for example in a cased hole).

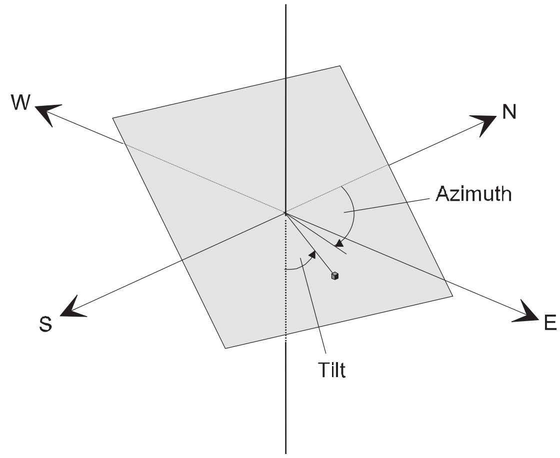
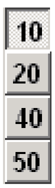


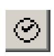
***Figure 4-12** Orientation to Magnetic North*

Vertical scales and grids:



Depth mode display and pre-defined depth scales

 Operator defined depth scales, interval spacing and settings

 Time mode display

4.7.3 “MChNum” Browser

Figure 4-13 shows a typical example of the numerical values displayed in the MChNum browser.

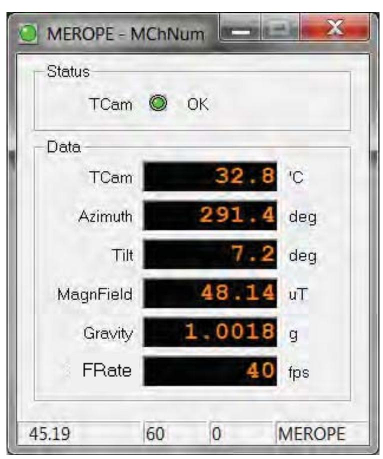


***Figure 4-13** MChNum browser*

TCam:	Temperature of image sensor - °C
Azimuth:	Azimuth from Magnetic North - deg
Tilt:	Inclination from verticality - deg
Magn.Field:	Magnetic field surrounding the borehole - µT

Gravity: Absolute value of the earth gravity - G
FRate Image sensor frame rate per second - fps

Right click on the MChNum browser title and select **Display Options to** add / remove channels.

4.7.4 "ObiHisto" browser

An histogram view is available to visualize the luminance and RGB colors distribution during the acquisition. The histogram view helps the user to set the adequate exposure level for the borehole conditions. Refer to chapter 4.5.2 to set adequately the exposure and luminance parameters.

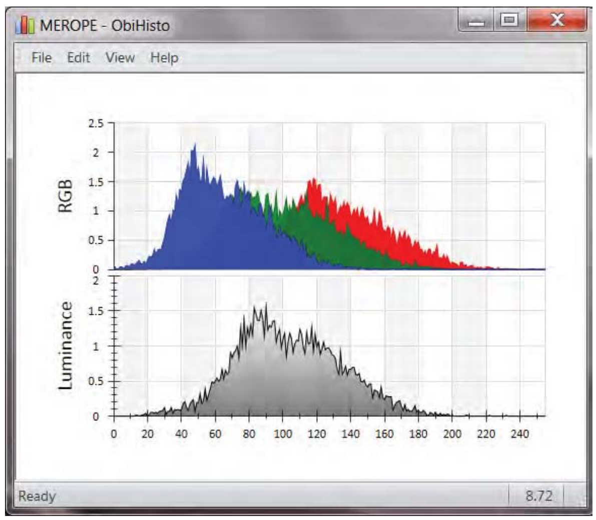


Figure 4-14 *Histogram view of the luminance and RGB colors*

The ObiHisto browser offers the option to zoom a defined area on the histogram view. To proceed left click on the histogram view and drag the mouse to highlight the area to zoom (Figure 4-15).

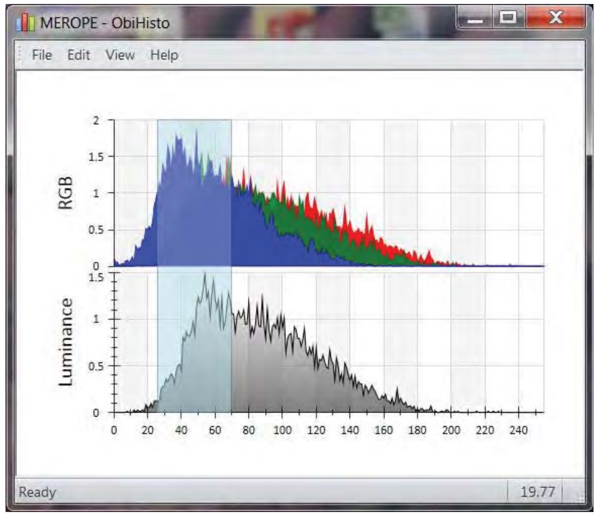


Figure 4-15 *Left click and drag the mouse to select a zoom window*

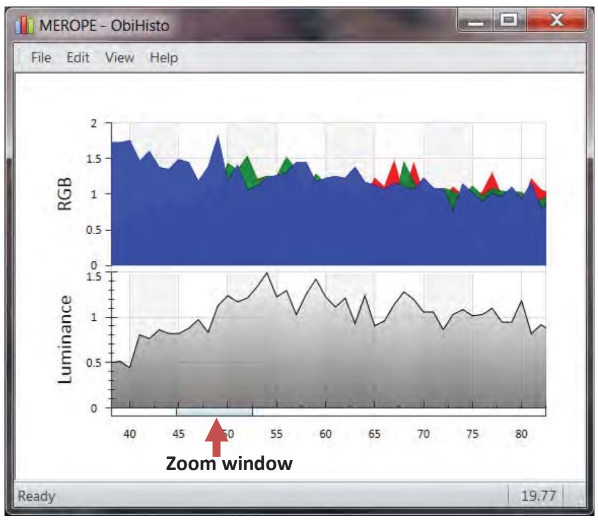


Figure 4-16 *Zoomed area in the histogram view*

The “zoom window” visible as a light blue rectangle (Figures 4-15 & 4-16) can be dragged on the horizontal axis to display the luminance and RGB colors distribution at the zoom scale.

To come back to the original histogram view right click on the ObiHisto browser.

Some additional options are available in the “File” and “Edit” menu to export (.bmp format) or copy the histogram view in a separate document.

5 Performance Check & Calibration

5.1 Testing the Deviation System

The QL40 OBI-2G deviation system is factory calibrated and does not require further calibration.

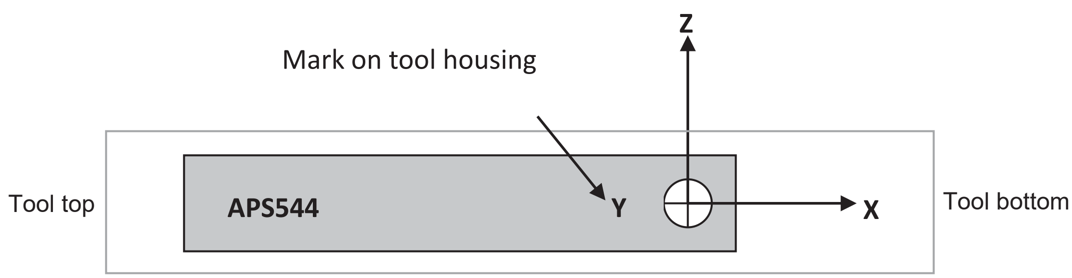


Figure 5-1 *Deviation sensor reference axis system*

The functionality test described hereafter should be executed to check that the tool is giving the correct deviation outputs:
To check Roll and Tilt outputs, place the probe on a flat surface with the Y mark engraved on the tool housing pointing up (Y axis of the coordinate system is pointing down, Figure 5-1).
Verify that the Roll and Tilt outputs are as follows:
Roll = 90° ± 0.5°
Tilt = 90° ± 0.5°
Next, roll the probe counterclockwise (looking towards the tool bottom) about its X axis in increments of 90° and verify that for each position the roll angle increments in succession to 0°, 270° and 180° while the tilt remains 90° ± 0.5°.
To verify inclination at 0° and 90°, position the probe so that the X axis is pointed down (0° inclination) and then horizontal (90°).
To verify azimuth accuracy, a good compass and an area free from magnetic materials should be used. Use a compass to orient the probe horizontal and North and verify that the azimuth reading is 0° ± 1°. Repeat the procedure for East, South and West directions.

5.2 Rolling Test – Azimuth And Tilt Check

Azimuth and tilt can be tested by rotating the tool about its long axis while maintaining both a constant inclination to the vertical, say 15°, and a fixed azimuth. The data imported into WellCAD should show a deviation of the azimuth less than the limit of ±2.5° and a deviation of the tilt less than the limit ±0.5°.

6 Maintenance

The QL40 OBI-2G optical televiewer is a delicate instrument and should be treated with care at all times. Excessive shock or temperatures should be avoided and the tool should always be carried in its transport case or a similarly cushioned enclosure. Never support the tool on its optical head that is the weakest part of the tool, and be particularly careful to avoid scratching the optical window.

6.1 Tool Top Adapter

The tool top adapter provides the connection between wireline cable head and chassis electronics and can be provided to suit 7 conductors, 4 conductors, mono or special wireline configurations. The adapter is fixed by the means of a threaded ring screwed in the pressure housing. To remove the tool top adapter, use the correct C spanners provided with the tool - see picture below (Figure 6-2).

Figure 6-1 *Removing the tool top*

The wireline cable head socket and tool top adapter connector pins should be checked for cleanliness before each use of the tool. The pin inserts, whether 4 or 7 pin, have a locating mark indicating WL1 or A that should line up with the slot mating with the cable head.

Check O-Ring seals and apply silicon grease before re-assembly. Silicon grease of a similar type to RS Components Ref 494-124 is suitable for this and other O-Ring seals.
(Rem: O-Ring reference for tool top and for the quick link 40 is AS215 26,57 x 3,53 Viton Shore 75)

6.1.1 Locking Ring assembly Maintenance

Tools required:

1.5mm Allen wrench
2 ea 40-42mm spanner wrench
Clean rags

Replacement Parts:

ALT26005, Large Threaded Ring, Qty 2
28-174-995 M2x8 SHCS, Qty 2

Disassembly:

Unscrew and remove the two M2x8 socket head cap screws and separate the two halves.
Four guide pins align the two ring halves and tend to hold them together after the screws are removed. To pry the halves apart you can use a pair of spanner wrenches inserted into the wrench holes on opposite sides of the ring mating surfaces to pull them apart slightly.
Do this carefully to prevent bending the guide pins.

Figure 6-2 *Disassembly of the locking ring –step 1*

Place something small in the opening and move the spanners to the other side and pry it open slightly. This should be enough to release the two rings as below.

Figure 6-3 *Disassembly of the locking ring –step 2*

Clean inside surfaces thoroughly and reassemble, coating the inside with a very light film of anti-seize compound. Nickel based compounds are best, to prevent any sticking between the brass and steel surfaces

6.2 Pressure housing

<u>Warning:</u> Removing the electronic chassis from pressure housing without prior consultation with ALT will void the tool warranty.
Disassembly of the electronic chassis from the pressure housing should never be attempted in the field.

Should it become necessary to open the tool, the tool parts must be separated in the following sequence:

1. Remove the tool top adapter
2. Unscrew the pressure housing from the optical system brass interface

Before screwing back the pressure housing make sure that the threads on the brass interface are clean and properly greased with anti-seized compound. Once fully screwed on verify the correct alignment between the pressure housing and orientation key of the multi-pin Lemo connector as shown on Figure 6-4.

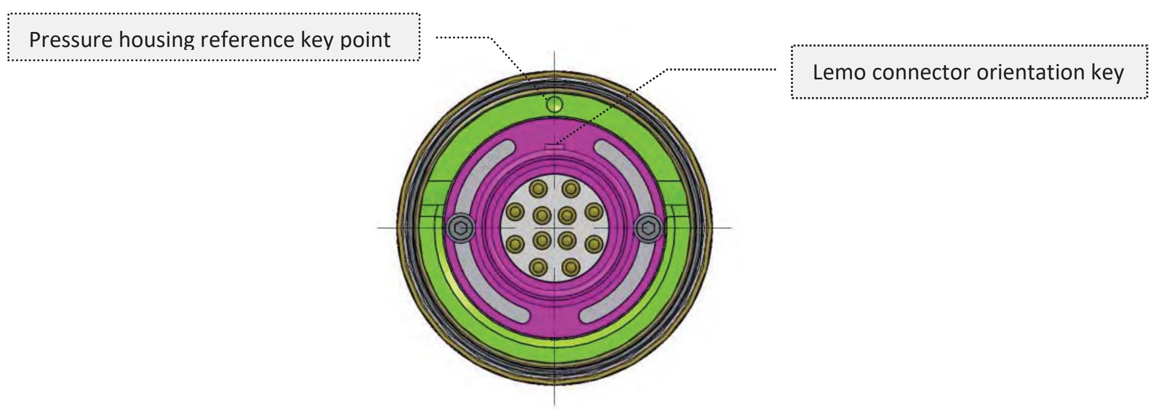


Figure 6-4 *Pressure housing top view - Correct orientation of the pressure housing and Lemo connector*

6.3 Optical system

<u>It is strongly recommended to inspect the integrity of the glass sleeve before each run</u>. **<u>Never immerse the tool in a borehole if any defect or crack is visible in order to avoid irreversible damage to the tool.</u>** Replace the sleeve with a spare one if necessary.

<u>Always use the ALT standard screws DIN912-M2.5x3 to fix the glass sleeve on the tool</u>. The size and shape of the screws are specifically designed for this purpose. Spare screws are usually provided with the tool spare kit.
<u>Note that the use of a different screw model may damage the glass sleeve when exposed to pressure and will void the tool warranty.</u>

7 Troubleshooting

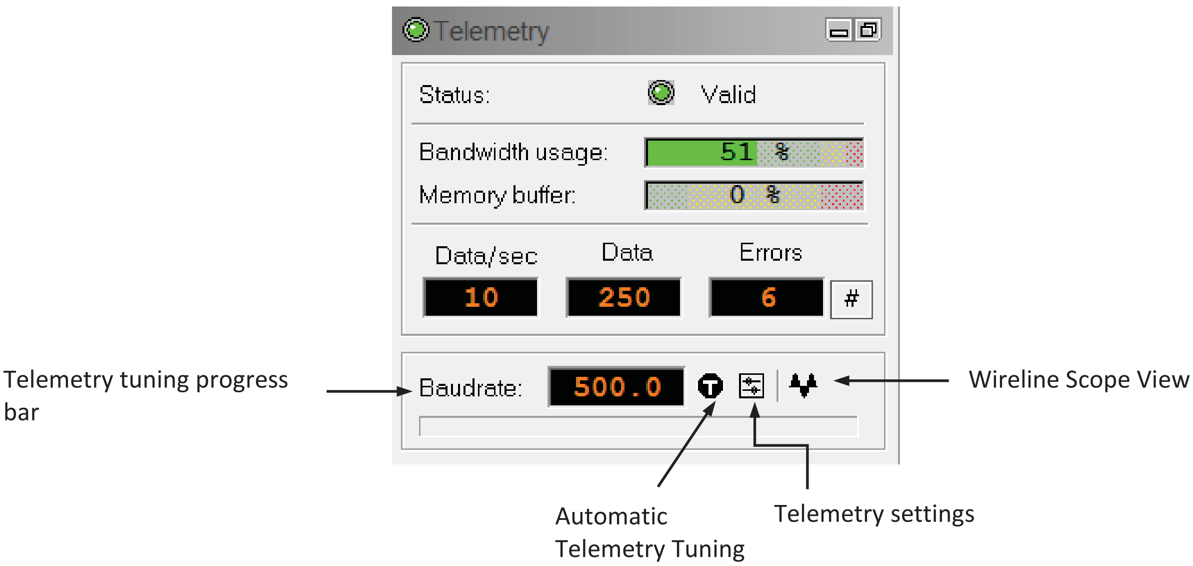
Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been copied into the …/Tools folder (refer to logger manual about details of the directory structure)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible short circuit (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use test cable (provided by ALT/MSI as an option) to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu or tech.support@mountsopris.com
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

Black image – the light source stopped working.	Verify the temperature of the image sensor in the MCHNUM browser. The light source is automatically switched off when the temperature of the image sensor reaches 105°C. Cool down the tool.

8 Appendix

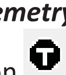
8.1 Tool Communication with OPAL/SCOUT

The telemetry provided through the OPAL-SCOUT systems implementing the ALT MODEM adapter is self-tuning. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

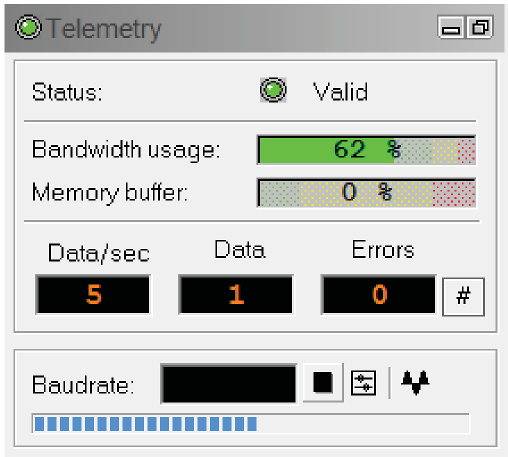
The Tune button  resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.[2] Refer to the **Equalizer** paragraph for more details.

The Automatic Tuning is very useful on wireline over 1000m length to optimize the telemetry performance and logging speed.

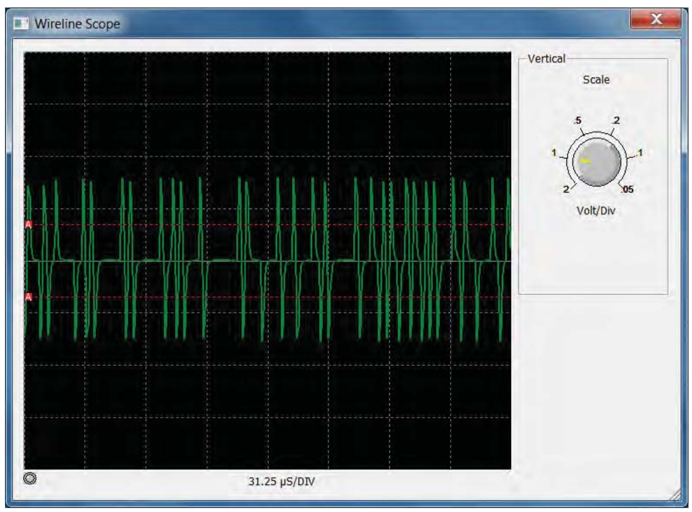
A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

[2] The transfer function and filter concept are only valid for tools implementing the latest generation of ALT MODEM telemetry board (i.e. QL40-ABI2G, ABI-GR-2G, QL40-OBI2G, OBI-GR-2G, QL43-ABI2G,…)



Scope:

Pressing the scope button  on the **Telemetry Panel** brings up a **Wireline Scope** view (Figure x), which displays the pulse strings transmitted through the wireline and received by the system at the surface.



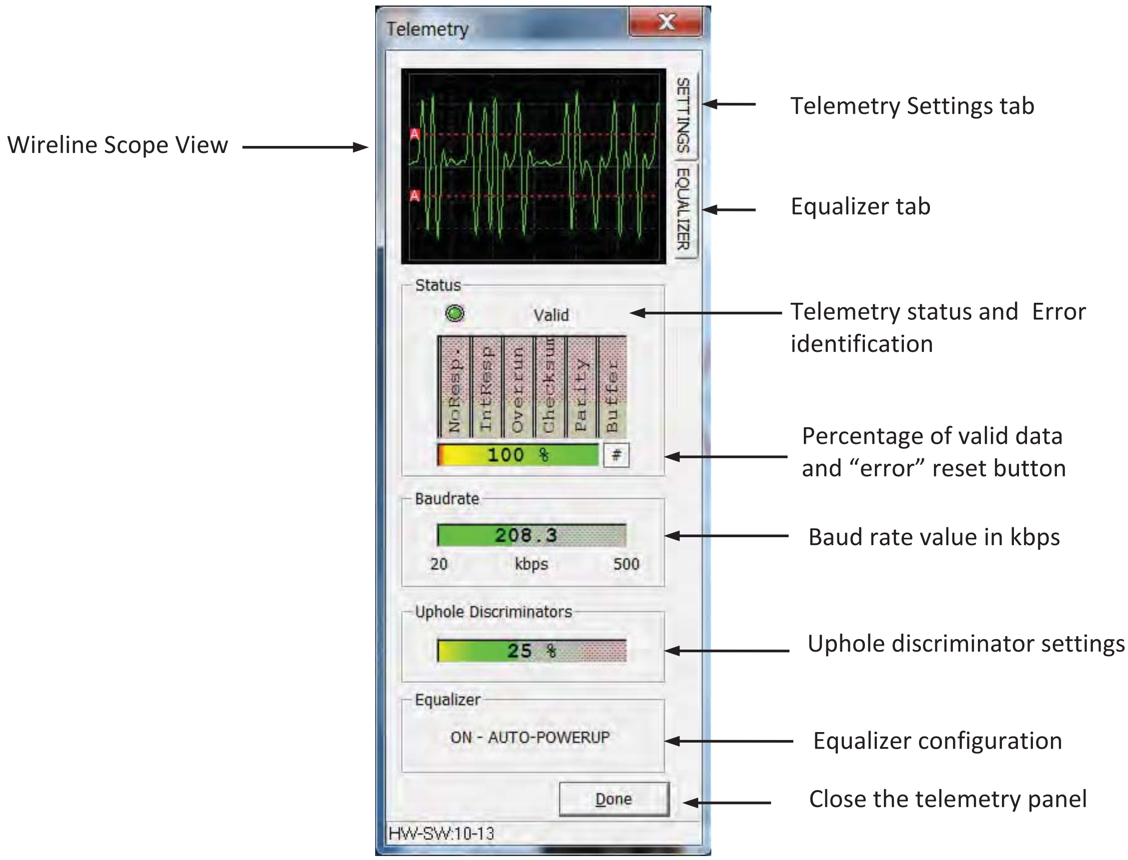
The two red-dashed horizontal lines help to visualize the position of the discriminator levels set for detecting the pulses at the surface. Discriminator levels can be tuned in the **Telemetry Settings** dialog – refer to section 3.6.1 for more information.

The Scale knob can be adjusted to show more or less vertical details. This view has no effect on the communications and is a visual aid only.

Telemetry Settings:

The Telemetry Settings button  opens a **Telemetry** control panel summarizing the telemetry status and configuration.

If the system cannot establish a stable communication with the tool, the **Settings and Equalizer tabs** allow the user to modify the telemetry settings and to apply a telemetry filter (Equalizer option)



Adjusting the Telemetry Settings:

By default the telemetry settings are set to Automatic mode and should stay in this configuration. When more advanced tuning is required (i.e. long wirelines having a limited bandwidth) the manual mode can be activated.

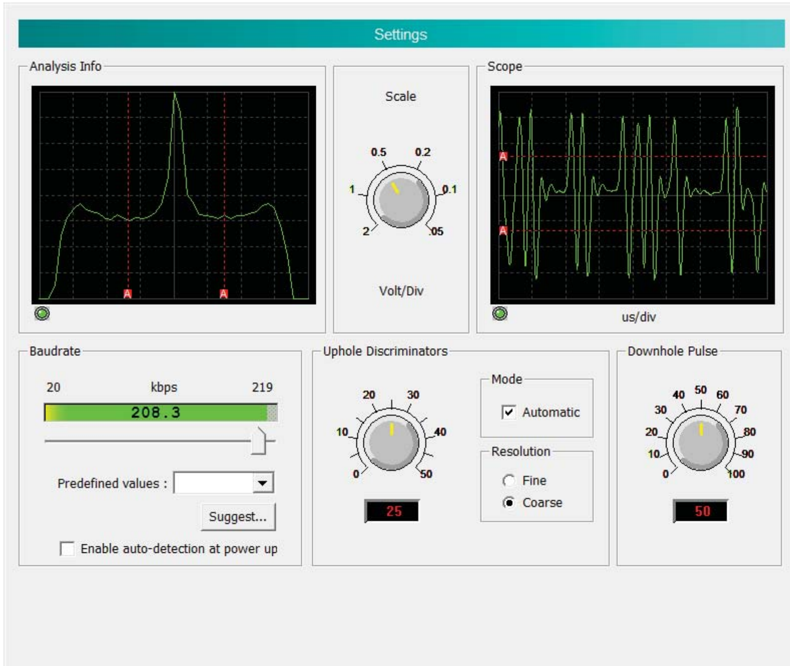
In Automatic mode the uphole discriminators are set automatically to detect the pulse strings.

The position of the discriminator levels are visible on the Scope and Analysis views and are represented by two red dashed lines – one for the positive pulses and the other for the negative pulses.

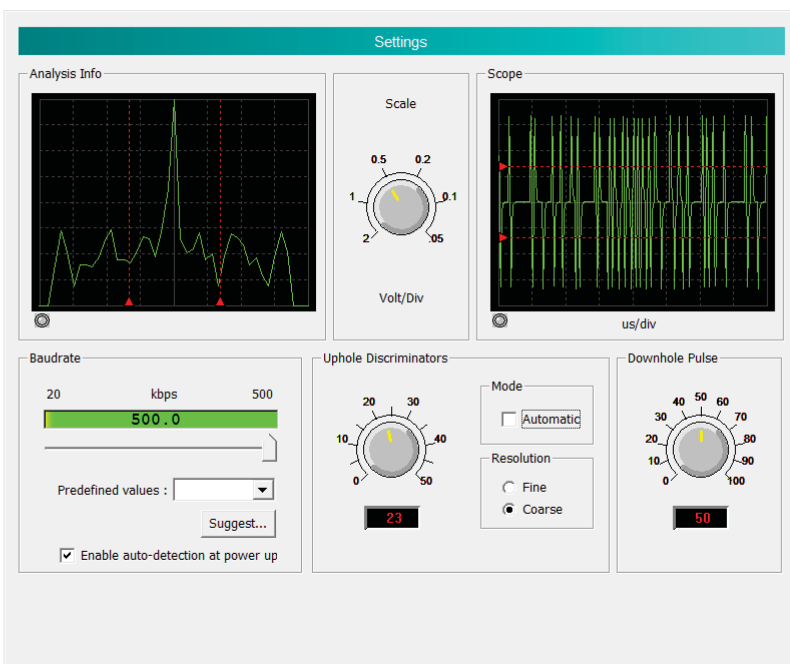
The “A” letter on the red square means that the discriminators are set in automatic mode.

The **Scale knob** controls the scale for the Analysis and Scope displays.

<u>Position of the discriminator lines should be set as illustrated below.</u>



When the automatic mode is unchecked user has the option to adjust manually the uphole discriminators using either the discriminator knob or by moving interactively the red dashed lines in the Analysis and Scope displays. The red triangles located at the extremities of the red dashed lines refer to manual mode. For fine tuning of the discriminators the **Fine resolution** can be chosen.



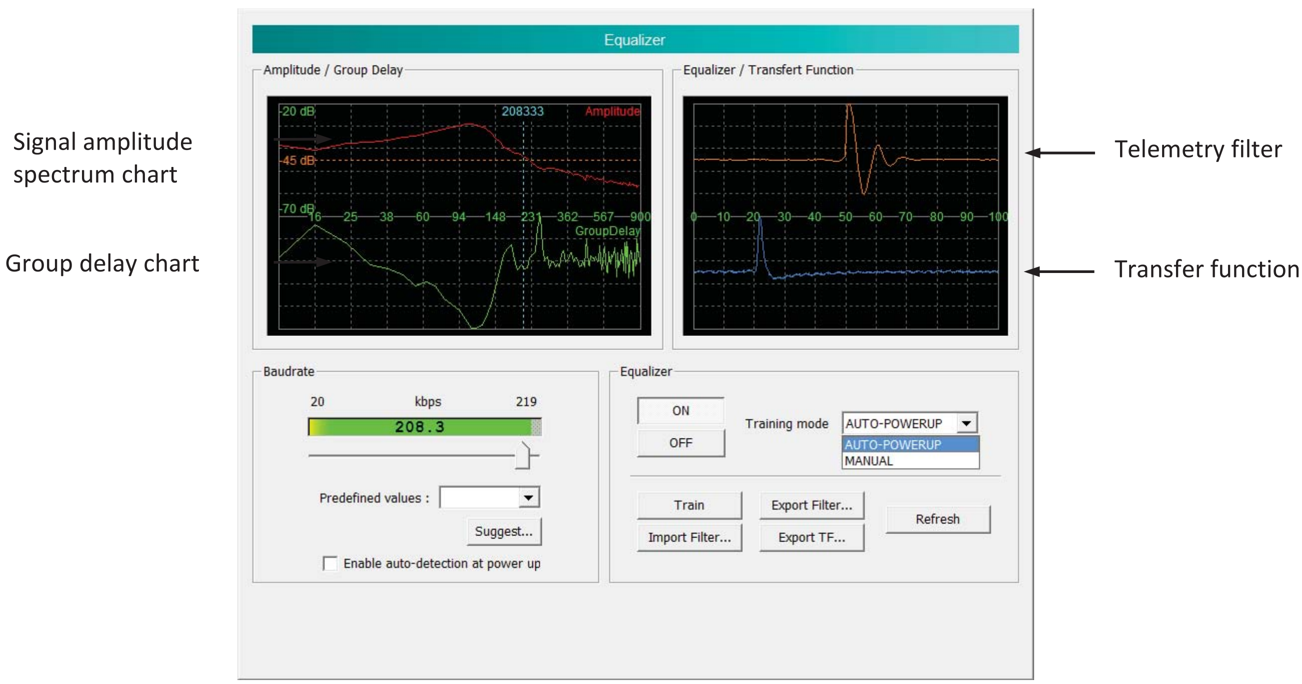
The **Downhole Pulse knob** controls the width of the pulse commands sent to the tool. It is set on 50 as a default value. This value is the preferred one and is suitable for a wide range of wirelines. For long wireline increasing the pulse width could help to stabilize the communication. The reverse for short wireline.

The **Baudrate** is generally set to the maximum value for which the communication status stays valid in order to optimize the logging speed for the wireline configuration.
The baudrate can be adjusted by moving the cursor below the baudrate bar meter or by selecting a predefined baudrate value from the select box.

When clicking the **Suggest** button the system is searching for the optimum baudrate value and keeps this value for the data transmission.

The **Enable auto-detection at power-up** configures the system such a way that the baudrate is reset to its optimum value each time a tool is powered up.

Applying the Equalizer



The **Equalizer** dialog provides some advanced telemetry settings described hereafter.

- The **Train** button computes the transfer function of a wireline - refer to the blue signal.
  When clicking on Train the tool sends a pilot pulse frame to the surface. The received signal at the surface is compared with the original pilot pulse frame to measure the distortion of the signal through the wireline. The result of this process is the definition of a transfer function specific to the wireline used.

  A filter is then derived from the transfer function - refer to the orange signal. The filter will be applied on the telemetry signal to counteract the distortion of the pulse strings through the wireline.
  Applying the filter will thus improve the telemetry performance of the system and logging speed on wirelines with unfavorable band width.

- The **Equalizer ON/OFF** buttons enables or disables the filter. The activation of the equalizer can be configured to **MANUAL** mode or to **AUTO-POWERUP**.
  The AUTO-POWERUP feature applies the telemetry filter upon tool power-up.

- The **Export TF** option exports the **Transfer Function** defined by the wireline training process in a ASCII file format

- The **Export Filter** option exports the **Filter** derived from the transfer function in a ASCII format

- The **Import Filter** option loads a saved filter configuration

- The **refresh** button is refreshing the Equalizer/transfer function display

The **Amplitude/Group Delay** charts are mostly used by ALT developers for telemetry signal and performance analysis.

The Equalizer dialog repeats the **Baudrate** settings already discussed in the previous paragraph “Adjusting telemetry settings”.

8.2 Parts list

Detailed part numbers and descriptions are available for tool delivery and spare part kits. Please contact support@alt.lu or tec.support@mountsopris.com for further details.

8.3 Technical drawings

The following technical drawings are available on request:

- Wiring Diagram.

Index

Advanced Logic Technology

QL40-ABI-2G
ABI40-GR-2G

Acoustic borehole imager

30.06.2023

The QL40-ABI-2G and ABI40-GR-2G are the latest generation of acoustic televiewers based on over 20 years of experience and market leadership. The tool benefits from new 2G telemetry protocol optimizing logging speed on long single or multi-conductor wirelines.

The acoustic borehole imager records a 360° unwrapped and 3D images of the borehole wall. The tool emits an ultrasonic beam towards the formation and records amplitude and travel time of the reflected signal. Amplitude records are representative of the impedance contrast between rock and fluid. Travel time is used to determine accurate borehole diameter data, which makes the tool ideal for borehole deformation description - stress field analysis and casing inspection.
A built in high precision orientation package incorporating a 3 axis fluxgate magnetometer and 3 accelerometers allows orientation of images to a global reference and determination of borehole azimuth[1] and inclination. Sophisticated algorithms and real time processes are also implemented to extend tool applications for casing thickness measurement, corrosion evaluation and measurement behind a PVC casing.

QL40-ABI-2G tool is a bottom sub in the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a standalone tool.
The ABI40-GR-2G is a standalone tool integrating a built in natural gamma sensor.

Application

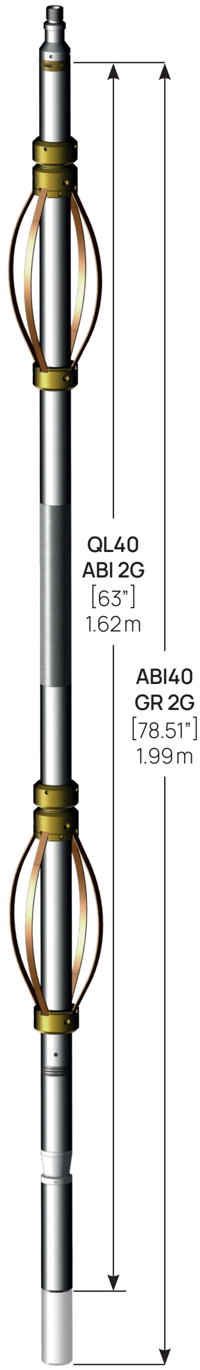
OPEN HOLE

- Detailed and oriented caliper and structural information
- Borehole deformation (stress field analysis)
- Fracture detection and characterization
- Breakout analysis
- Lithology characterization (Detection of thin beds, determination of bedding dip)
- Rock strength and fabric

CASED HOLE

- Casing inspection and corrosion evaluation
- Steel casing thickness

[1]Only applicable in non magnetic environment



Tool

Diameter : 40mm (1.6")
Length (min/max) : 1.62m (63") / 1.99m (78.51")
Weight (min/max) : 6.7kg (14.7 lbs) / 8.0Kg (17.6lb)
Temp : 0 - 70°C (32 - 158°F)
Max. Pressure : 200bar (2900psi)

Acoustic sensor

Acoustic sensor : Fixed transducer and rotating focusing mirror
Focusing : Collimated acoustic beam
Frequency : 1.2 MHz
Rotation speed : Up to 35 revolutions per second - automatic
Caliper resolution : 0.08mm (0.003")
Samples per revolution : 72, 144, 216, 288 and 360

Orientation sensor

3 axis fluxgate magnetometer – 3 accelerometers

- Inclination accuracy : +/- 0.5 degree
- Azimuth accuracy : +/- 1.2 degree

Natural gamma sensor

- 0.875" (22.2mm) x 3" (75.6mm) NaI (Ti) scintillation crystal
- Integrated (ABI40-GR) or in line sub (QL40-GR)

Operating conditions

Cable type : Mono, multi-conductor, coax
Compatibility : Scout Pro / Opal (Scout / Bbox / Matrix)
Digitaldata transmission Telemetry : Variable baudrate telemetry according to cable length/type & surface system
Logging speed : Variable - function of image resolution, borehole diameter, wireline and surface system model.
Centralisation : Required
Borehole fluid : Water, water based mud, brine, oil (oil based mud not applicable)
Measurement range :
Open hole : 2.5" to 20"
(64 to 500mm) depending on mud conditions
Cased hole[2] : 5" to 20" (127 to 500mm)
minimum thickness 5 mm

[2] Scrap casing before operation

Principle of measurement

The ABI produces images of the borehole wall which are based on the amplitude and travel time of an ultrasonic beam reflected from the formation wall. The ultrasonic energy wave is generated by a specially designed piezoelectric ceramic crystal and has a frequency of around 1.2MHz. On triggering, an acoustic energy wave is emitted by the transducer and travels through the acoustic head and borehole fluid until it reaches the interface between the borehole fluid and the borehole wall. By careful time sequencing, the piezoelectric transducer acts as both transmitter of the ultrasonic pulse and receiver of the reflected wave. Travel time for the energy wave is the period between transmission of the source energy pulse and the return of the reflected wave measured at the point of maximum wave amplitude. Magnitude of the wave energy is measured in dB, a unitless ratio of the detected echo wave amplitude divided by the amplitude of the transmitted wave.

Measurement features

Open hole mode

- 360° Unwrapped and oriented image of the borehole wall based on travel time and amplitude records : caliper and amplitude image logs
- Deviation parameters : azimuth, tilt, tool relative bearing, magnetic field, gravity
- 3 Accelerometer calibrated components, 3 Magnetometer calibrated components

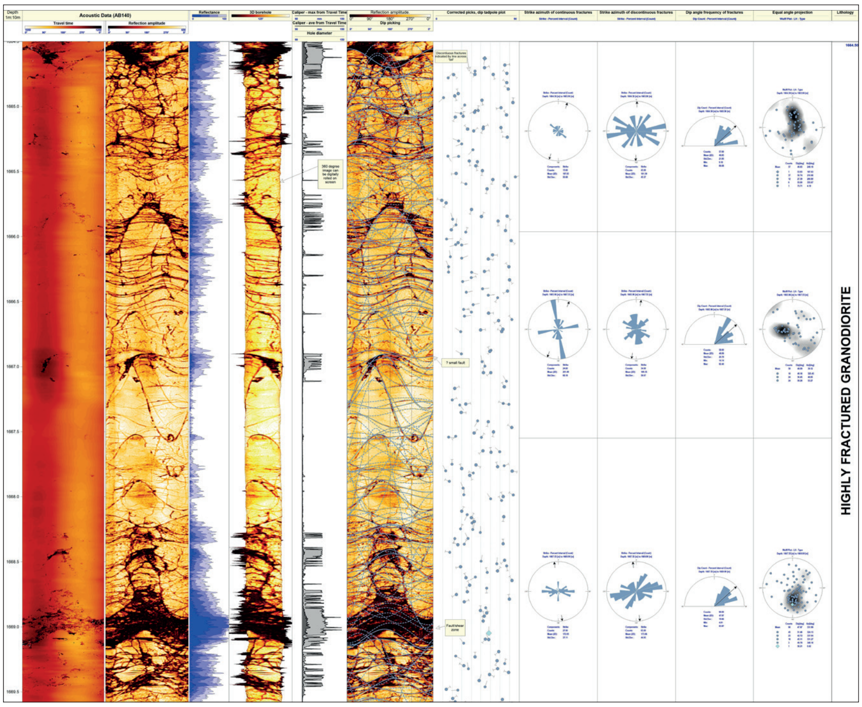
Behind PVC mode*

- 360° Unwrapped and oriented image of the PVC casing and borehole wall based on travel time and amplitude records : caliper and amplitude image logs
- Deviation parameters: azimuth, tilt, tool relative bearing, magnetic field, gravity
- 3 Accelerometer calibrated components, 3 Magnetometer calibrated components

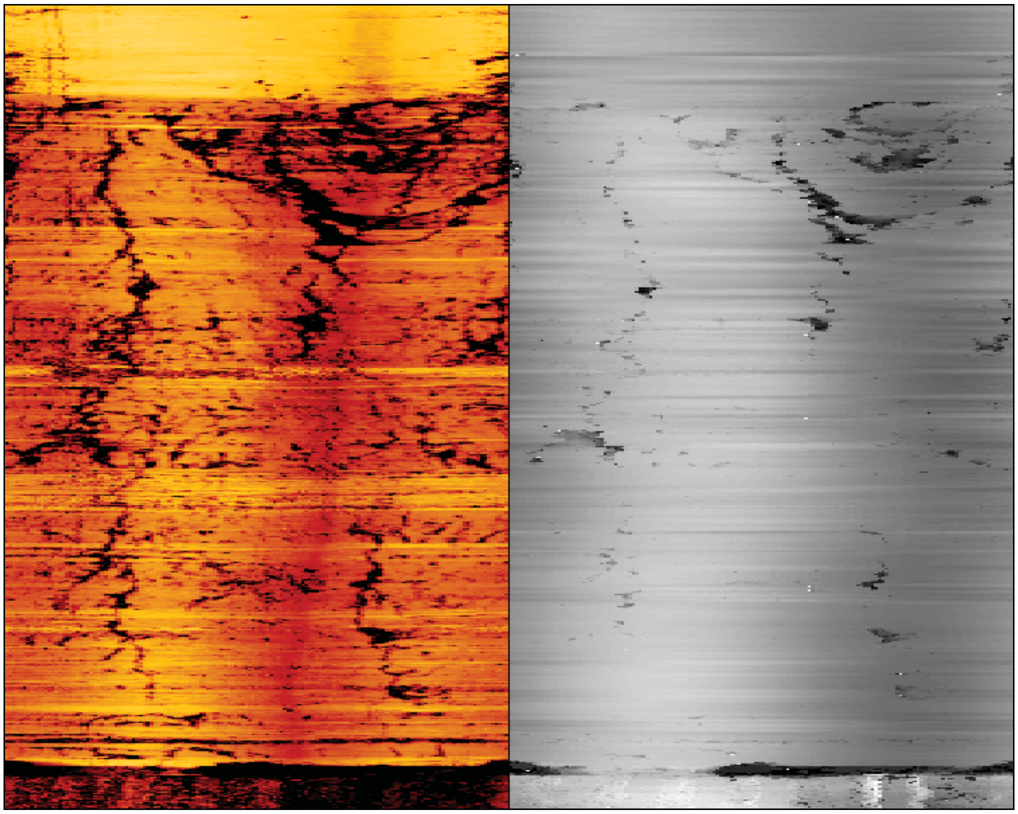
* PVC must be centered in borehole

Cased hole mode

- 360° Unwrapped image of the steel casing based on travel time and amplitude records : caliper, amplitude, thickness and score image logs
- Deviation parameters : tilt, tool relative bearing, gravity
- 3 Accelerometer calibrated components, 3 Magnetometer calibrated components



Processing with WellCAD image and structure interpretation module



User Guide

QL40 ABI (2G) Acoustical Borehole Imager

MOUNT SOPRIS INSTRUMENTS

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v13.09.02

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Table of Contents

1 General Information

The QL40 ABI is the latest generation of acoustic televiewer. Based on 20 years of experience and market leadership with BHTV technology, the new system consists of a completely redesigned acoustic sensor and new electronics. The electronic architecture uses a 96 dB-10Msps A/D converter directly coupled to a 150 Mflops DSP digital signal processor. The DSP is performing complex data processing operations in real time on each individual ultrasonic wave train and that allows a wider dynamic range of signal detection and easy field operation in a wide variety of logging applications.
The QL40 ABI tool is supplied as a bottom sub of the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a stand alone tool. The ABI40 is the standalone - non stackable - version.

1.1 Overview

Acoustic borehole scanner tools generate an image of the borehole wall by transmitting ultrasound pulses from a fixed transducer with rotating mirror and recording the amplitude - travel time of the signals reflected at the interface between borehole fluid and the formation (borehole wall). The QL40 ABI has multi-echo capability. This is achieved by digitally recording the reflected acoustic wave train. On line analysis of the acoustic data is made by the DSP. Sophisticated algorithms allow the system to detect the reflection from the acoustic window and to separate and classify all subsequent echoes. Minimum input from the operator is needed to enable:

- Automatic or manual adaptation to variable borehole conditions.
- Improved dynamic range of signal detection.
- Very high travel time resolution.
- The implementation of different operating modes. For example, when run inside PVC casing, the tool can record both the echo of the PVC casing and that of the borehole wall. With multi-echoes processing, application of the tool may be extended to steel casing thickness and corrosion evaluation.
  Tool upgrades can be done by simply downloading new firmware to the tool from the surface computer.

1.2 Dimensions

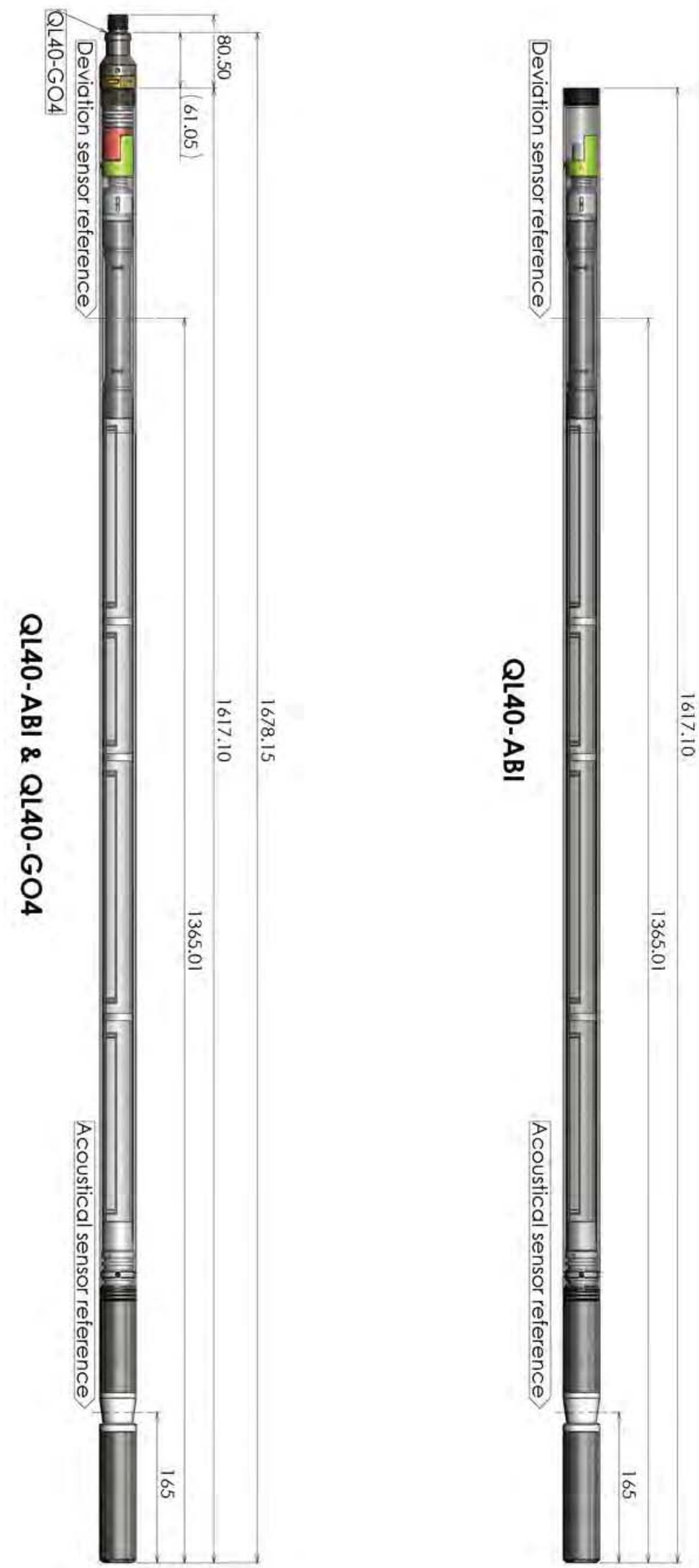


Figure 1-1 *QL40-ABI-2G dimensions*

1.3 Technical Specification

Tool

Diameter:	40mm
Length:	1.61m (63”)
Measurement point:	0.165m (from probe bottom)
Weight:	6.7 kg (14 .7 lbs)
Max. Temp:	70°C
Max.Pressure:	200bar

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – BBOX – Matrix

Acoustic sensor:

Figure 1-2 *Acoustic head*

Acoustic sensor:	Fixed transducer and rotating focusing mirror
Measurement range[1]:	2.5” – 20” (64mm-500mm)
Focusing diameter[2]:	6” (152mm)
Frequency:	1.2 Mhz
Acoustic beam width:	1.5 mm (at focal point)
Rotation speed:	Up to 35 revolutions per second - automatic
Azimuthal resolution:	72, 144, 216, 288, 360 operator defined
Caliper resolution:	0.08mm

Orientation sensor:

Sensor:	APS544
Location:	Middle point of sensor located at 1.365 m from tool bottom
Orientation:	3 axis fluxgate magnetometer, 3 accelerometers
Inclination accuracy:	0.5 degree
Azimuth accuracy:	1.2 degree

[1] Diameter range of the hole in which the measurement is possible (depends on borehole conditions).
[2] Diameter of the hole where the focusing of the acoustical beam is optimum.

Software requirements:

LoggerSuite:	11.1.1224 or higher
WellCAD	4.4.3303/13303 or higher

Logger Firmware requirements:

Matrix:	113 – 117 - 100
Jazz - BBOX	108

2 Measurement Principle

An understanding of the basic principles of operation of the televiewer is essential for successful use of the tool. The ABI produces images of the borehole wall which are based on the amplitude and time of travel of an ultrasonic beam reflected from the formation wall. The ultrasonic energy wave is generated by a specially designed piezoelectric ceramic crystal and has a frequency of around 1.2MHz. On triggering, an acoustic energy wave is emitted by the transducer and travels through the acoustic head and borehole fluid until it reaches the interface between the borehole fluid and the borehole wall. Here a part of the beam energy is reflected back to the sensor, the remainder continuing on into the formation medium at a changed velocity (Figure 2-1). By careful time sequencing the piezoelectric transducer acts as both transmitter of the ultrasonic pulse and receiver of the reflected wave. The travel time for the energy wave is the period between transmission of the source energy pulse and the return of the reflected wave measured at the point of maximum wave amplitude. The magnitude of the wave energy is measured in dB, a unit less ratio of the detected echo wave amplitude divided by the amplitude of the transmitted wave.

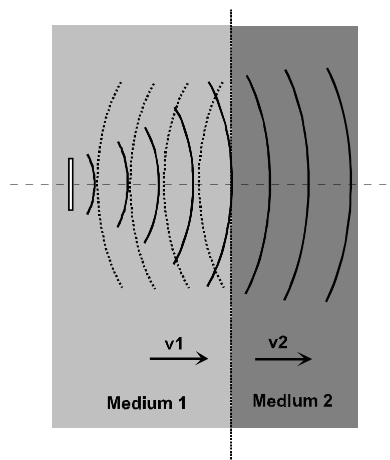


Figure 2-1 *Wave propagation*

2.1 Reflection coefficient

The strength of the reflected signal depends principally on the impedance contrast between the borehole fluid and the formation (Figure 2-1).
The reflection coefficient *r* is given by the following equation:
$r = (\rho_b v_b - \rho_m v_m) / (\rho_b v_b + \rho_m v_m)$

where ρ_b = density of formation
ρ_m = density of borehole fluid
v_b = velocity of sound of formation
v_m = velocity of sound of borehole fluid

The larger the reflection coefficient is the greater is the signal reflection and thus the ability to detect the signal. From the equation above it may be seen that when the properties of the borehole fluid and borehole wall are similar, i.e. $\rho_b v_b \approx \rho_m v_m$, the reflection coefficient *r* approaches zero and there is negligible reflection. In this situation determination of the true reflected wave is made more difficult.

2.2 Acoustic head operation

The acoustic wave is generated by applying a high voltage pulse across the two faces of a piezo ceramic disc. The applied voltage causes deformation within the crystal structure, either an expansion or contraction depending on the polarity of the applied voltage, with a resultant energy wave emitted normal to the free surface. It has been shown that the beam generated by this process has a maximum energy at a distance of twice the diameter of the disc and that after this point the beam tends to diverge. In order to optimize the beam energy at the point of investigation the ALT televiewer head has been designed as illustrated below (Figure 2-2).

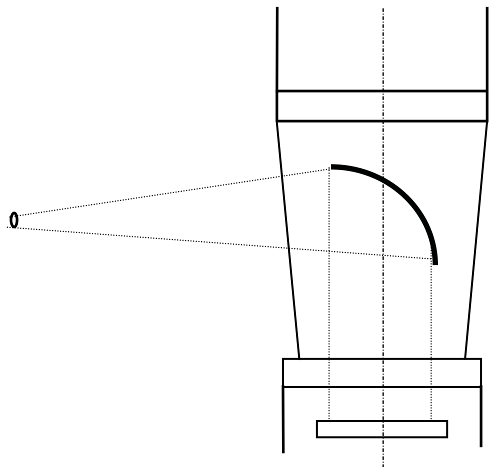


Figure 2-2 *Focussing arrangement*

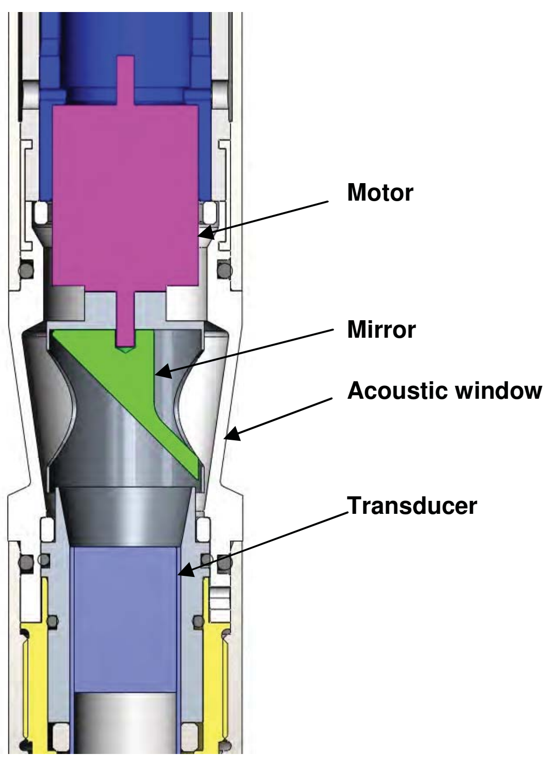


Figure 2-3 *QL40 ABI acoustic head architecture*

The acoustic wave propagates along the axis of the tool body and is then reflected perpendicular to this axis by a special reflector that focuses the beam to a high-energy point of +/- 1.5 mm diameter. The radial distance of the focal point from the axis of the tool is determined by the focal length of the mirror, +/- 75mm (for an acoustic head with a 6” focusing mirror).
The frequency of the transmitted wave is determined amongst other factors such as ceramic composition by the diameter of the piezo transducer, a smaller diameter giving a higher frequency. The ALT televiewer operates around 1.2MHz.

The reflector is mounted on the drive shaft of a stepper motor. This enables the position of measurement to be rotated through 360°. Sampling rates of 72, 144, 216, 288 and 360 measured points per revolution are available, thus at maximum resolution a near continuous image of the borehole wall is made. The higher sampling rate can be used for better resolution in larger diameter boreholes but is less useful in small diameters due to overlap of the sampling points.

3 Notes on QL tool assembly

The following explanations are only valid for the QL40 ABI tool versions. ABI40 “standalone” users can skip this chapter.

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

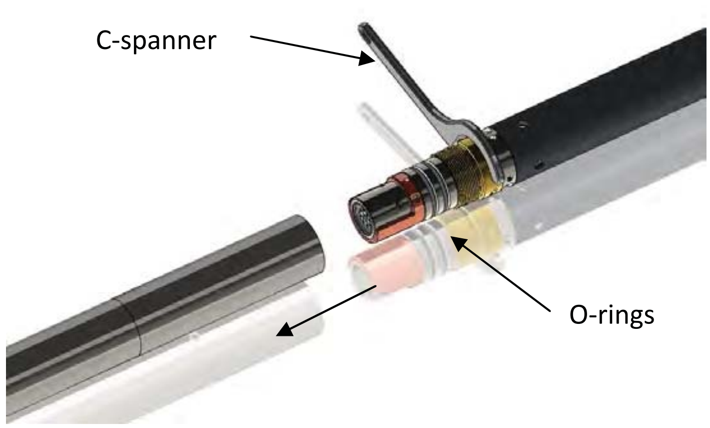


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GAM and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GAM sub stand-alone.

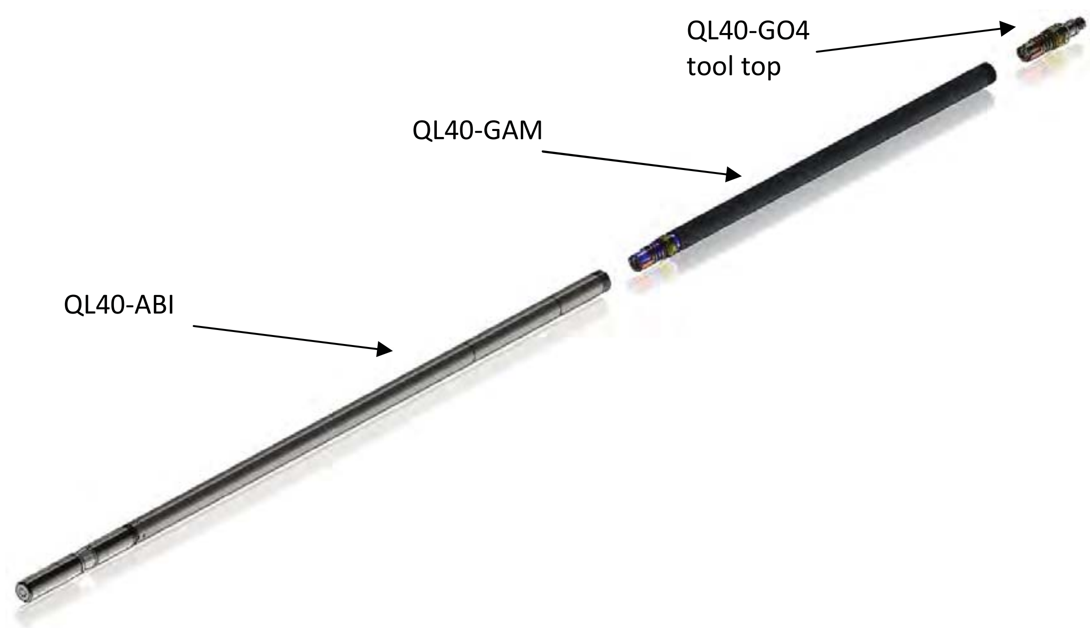


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

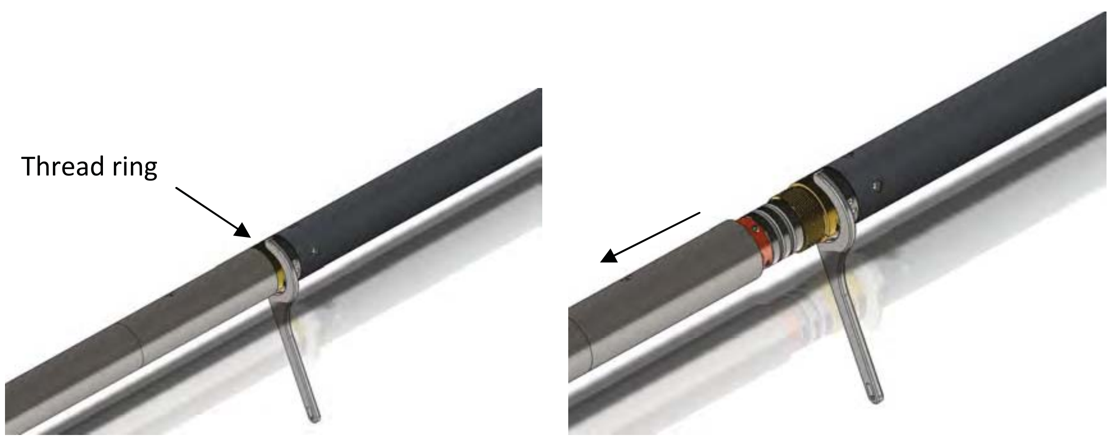


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

***Figure 3-4** Attaching the QL40-Plug*

The QL40-GAM can now be run stand-alone (Figure 3-5).

***Figure 3-5** QL40-GAM mid sub with tool top and bottom plug*

4 Operating Procedure

4.1 Preliminary note

Acoustic televiewer image quality is highly dependent upon tool centralisation.

One set of centralisers is supplied with the QL40 ABI and is suitable for all tools with an external diameter of 40mm. The standard assembly comprises upper and lower mounting rings with sets of 3”, 5” and 6” bowsprings. Two C spanners are provided for tightening the locking ring. Bowsprings for other borehole diameters are available on request.

The following points relating to the use of centralisers should be considered:

The centralisers should be fitted before mating the tool with the wireline cable head and should always be fitted from the cable head end to avoid damaging the acoustic window.

The compression ring of the centraliser, i.e. the one that is screwed tight, should always be fixed toward the **top** end of the sonde. This is to avoid catching on a downhole obstruction when winching up.

Use the C spanner to fasten the fixing rings but take care not to cross thread or over tighten them as this could damage the pressure housing

(The weak point of the bowsprings is the welded bearing pin. Take care during assembly as the weld can be broken by reverse bending.)

The QL40 ABI enables inspection behind PVC casing. In this situation, the PVC casing must be properly centred in the borehole and the tool correctly centralised in the casing to obtain satisfactory results.

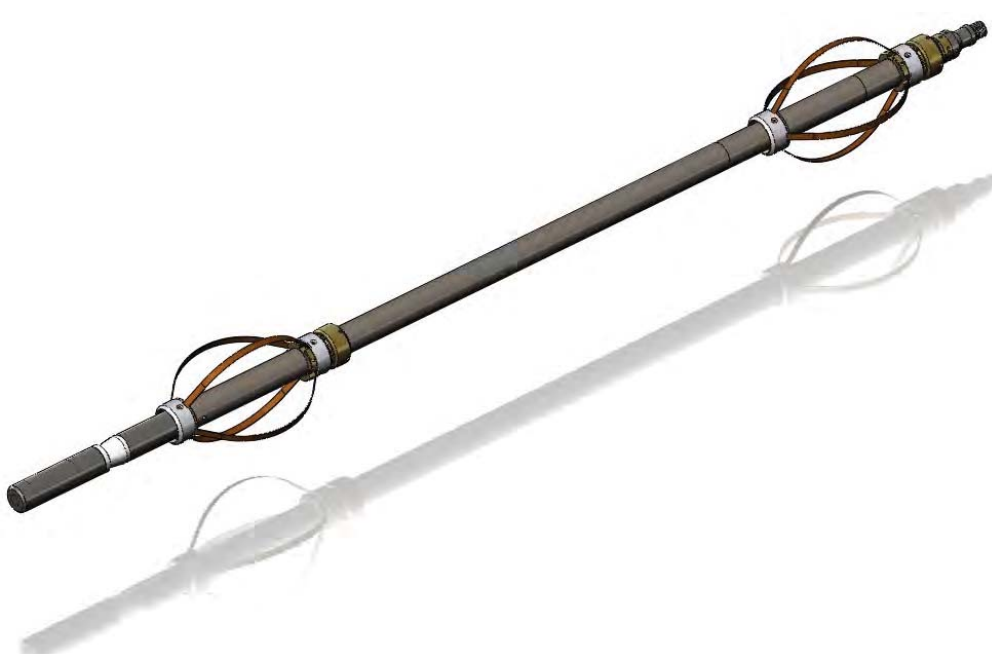


Figure 4-1 *QL40 ABI with mounted centralizers.*

4.2 Quick Start

Note: Parts of the topics discussed in these sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant QL40 ABI tool from the drop down list (Figure 4-2) in the software's **Tool** panel (if your tool is not listed check that your tool configurations file is stored in the designated folder on your computer).

Figure 4-2 *Tool panel*

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in chapter **4.5** if error message is displayed.)

4. On the **Tool** panel (Figure 4-2) click the **Settings / Commands** button to configure your tool for open hole/cased hole logging (see chapter **4.3** and **4.4** for details).

5. In the **Acquisition** panel (Figure 4-3) select the sampling mode ("depth" recommended). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

6. Press the **Record** button in the **Acquisition** panel (Figure 4-3), specify a file name and start the logging.

Figure 4-3 *Acquisition panel*

7. During logging observe the controls in the **Telemetry** panel:
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.
   - Verify motor status (synchronization) in MChNum browser is valid.
   - Do not log too fast! The **Data/sec** parameter must not exceed the speed of the motor rotating the mirror. Check against the **MotSpeed** displayed in the MChNum window.

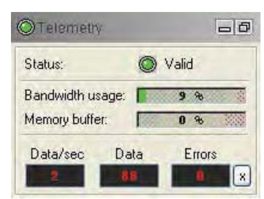


Figure 4-4 *Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

4.3 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-5). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

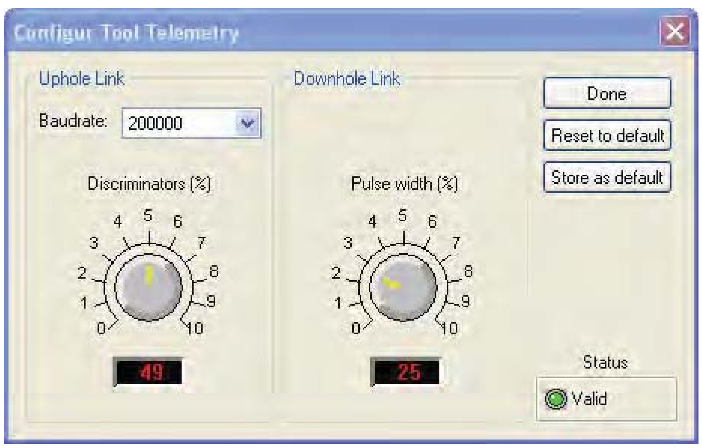


Figure 4-5 *Tool communication settings*

4.4 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-6) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.

The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-6) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

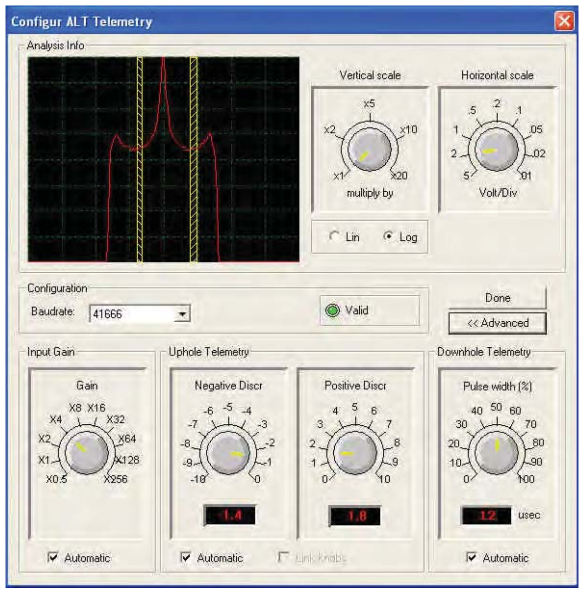


Figure 4-6 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in “Valid” status the next time the power is turned on.

4.5 Configuring Tool Parameters

The **Configure ABI Tool Parameters** dialog box (Figure 4-7) can be accessed by clicking on the **Settings / Command** button on the dashboard's **Tool** panel or by clicking on the tool's bitmap located in the **Tool Stack Manager** window.

4.5.1 Operating Modes

Three operating modes are possible for recording acoustic images with the QL40 ABI:

- Open hole mode
- Behind PVC mode
- Cased hole mode

4.5.1.1.1 Open hole mode

This record mode is used in open-hole conditions or to record the inner face of a casing.

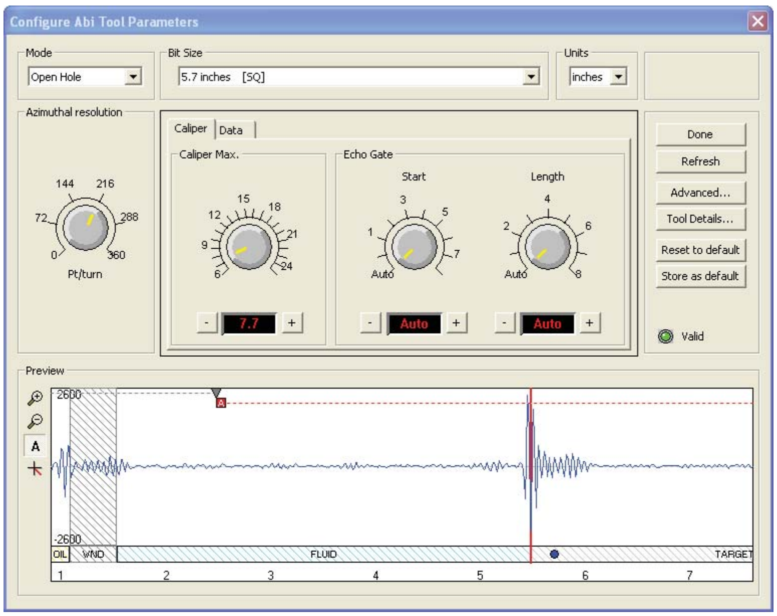


Figure 4-7 *Example of tool settings – Open hole mode*

When selecting a predefined bit size from the **"Bit Size"** dropdown list, the system configures in an automatic way the most adequate tool settings – *azimuthal resolution, caliper max, echo gates* - for the selected bit size or borehole nominal diameter. Note that User has always the choice to modify the tool settings as per his own requirements.

Imperial or **metric units** can be used for displaying the wave form preview and for configuring the caliper/echo gate settings.

The **“Open Hole”** mode gives access to two main tabs – **Caliper** and **Data** - for configuring the record:

Caliper tab:

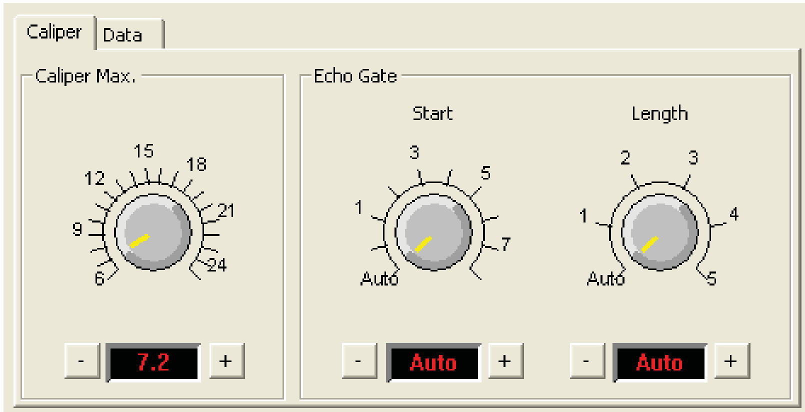


Figure 4-8 *Caliper and Echo Gate settings*

In the **Caliper** page, the **Caliper Max.** knob (Figure 4-8) controls the extension of the real time preview of the ultrasonic waveform. It must be adjusted for the borehole diameter to investigate to allow detection and recording of the main echo.

Echo Gate settings are set in the “Auto” mode by default. If required, User can define a **“Start”** gate and specify the **“Length”** interval for recording the reflected echo. The tool firmware will pick up the strongest amplitude in the signal train within the Echo Gate and records amplitude and tavel time of the borehole echo.

<u>Note that the **Echo Gate** settings can also be adjusted interactively in the waveform preview.</u>

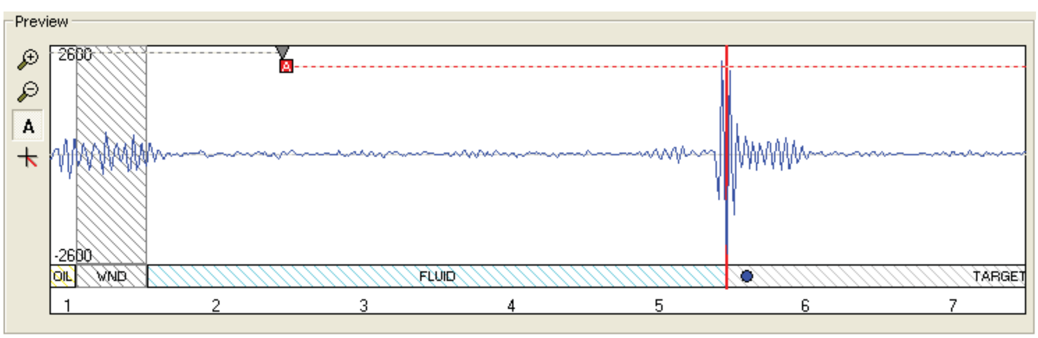


Figure 4-9 *Waveform preview - Echo gate Automatic setting*

For the open hole mode, the waveform preview allows the user to adjust the limits of two gates – the **Acoustic Window gate** and the **Echo Gate**. <u>The Acoustic Window is represented by a grey dashed line while the Echo Gate is shown as red dashed line.</u>

The Acoustic Gate allows determination of the tool’s acoustic window reflection time.

The **Echo Gate “Start”** limit can be determined automatically or adjusted interactively in the preview. Square and triangle symbols indicate whether the limit of the **“Start”** gate is automatically set (square symbol -) or if the user can adjust the limit with the mouse cursor (triangle -).

Three modes are supported to set the **Start** time of the Echo Gate - To toggle from one mode to another **right click** on the square or triangle symbol.

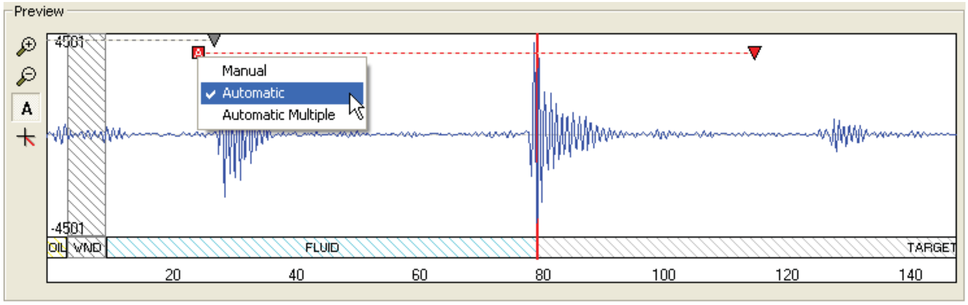


Figure 4-10 *Toggling between Echo Gate detection modes*

- *Automatic*: the system will automatically detect and record the highest amplitude occurring after the Acoustic Window Gate and the upper limit of the Echo Gate (Figure 4-11). Automatic is the recommended setting.

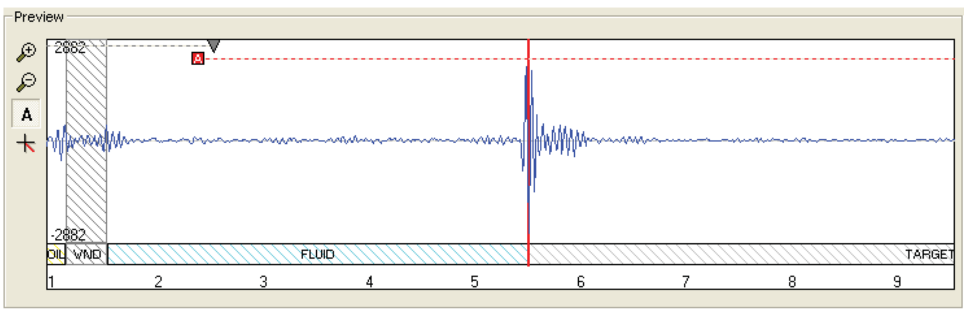


Figure 4-11 *Start gate set in automatic mode*

- *Automatic Multiple*: the system will automatically adjust the start time of the Echo Gate so that the first multiple of the Acoustic Window reflection is skipped. This setting is useful for large diameter boreholes when the amplitude of the first multiple of the Acoustic Window reflection is higher and arrives earlier than the echo from the borehole wall (Figure 4-12).

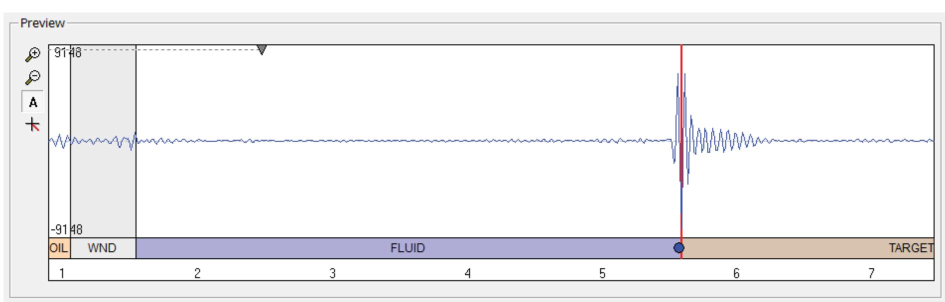


Figure 4-12 *Start gate set in automatic multiple mode*

- *Manual*: Manual adjustment of the Echo Gate start time is useful to exclude noise with amplitudes higher than the formation signal (e.g. exclude the reflection from the inside of a PVC casing) – (Figure 4-13).

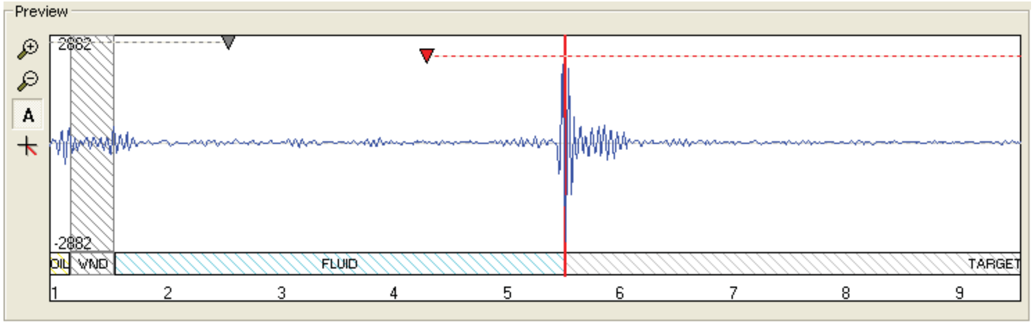


Figure 4-13 *Start gate set in manual mode*

Interactive adjustment in the waveform preview of the Echo Gate **Length** is also possible. It could be useful when multiple reflections with large amplitudes arrives towards the end of the gate period (e.g. exclude Acoustic Window reflection multiples when logging in soft formations).

<u>To toggle the Echo Gate **Length** from the automatic to the manual mode</u>, place your cursor at the right end of the red dashed line to display the double arrows symbol. Drag then the length limit to the desired position on the wave form preview.

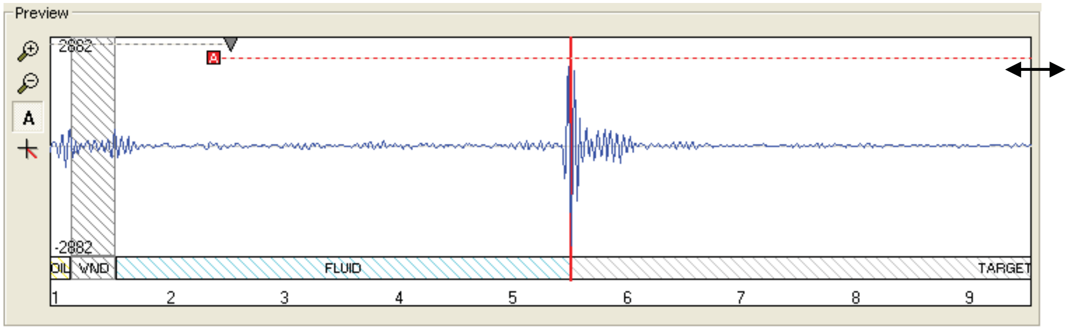


Figure 4-14 *Toggling the Echo Gate Length between automatic and manual mode*

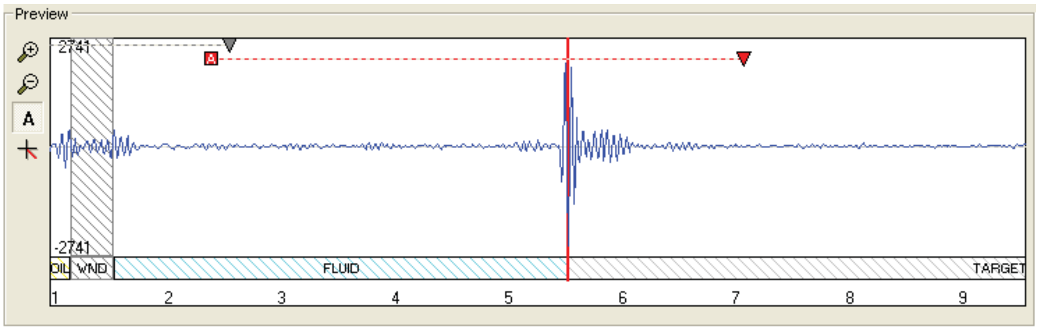


Figure 4-15 *Echo Gate Length set in manual mode*

<u>To toggle the Echo Gate **Length** from manual to automatic mode</u>, right click on the corresponding triangle symbol.

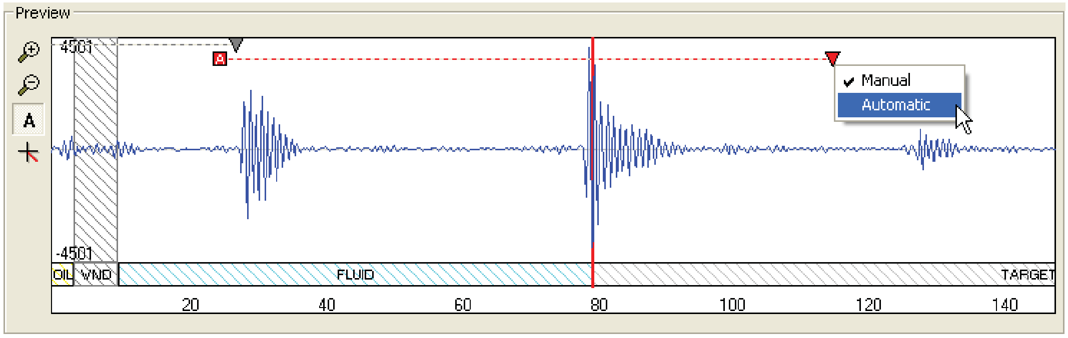


Figure 4-16 *Toggling the Echo Length setting from manual to automatic*

Data tab:

Figure 4-17 *Data record options for the Open hole mode*

The **"Target/Formation"** record option must always be checked. If unchecked, no acoustic image will be recorded and the warning message below will be displayed.

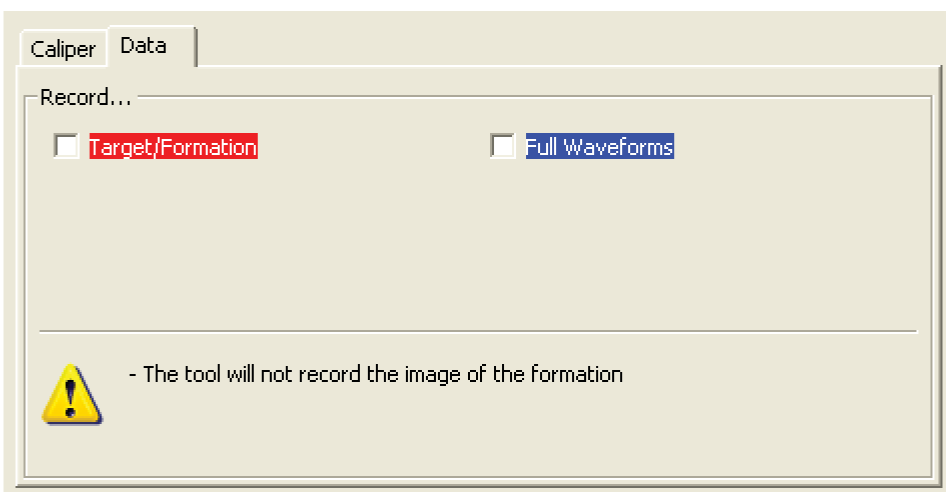


Figure 4-18 *Warning message when Target/Formation record is not checked*

For diagnostic purposes or advanced processing, the **“Full Waveforms”** record option can be activated. The system will record the complete ultrasonic waveform shown in the preview window.
Note that recording the ultrasonic waveform will affect the telemetry performance and will slow down the logging speed.

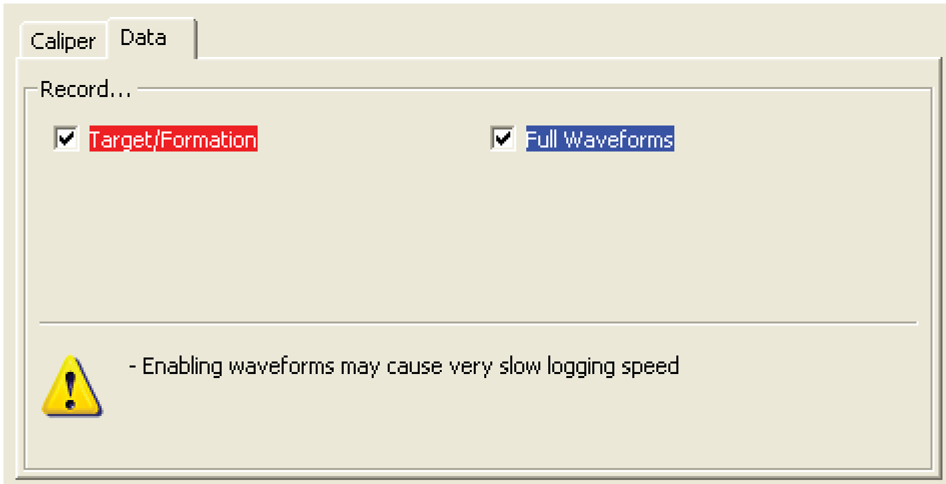


Figure 4-19 *Full Waveforms record option selected*

4.5.1.1.2 Behind PVC Mode

The **“Behind PVC”** mode is used in PVC cased boreholes. The main purpose is to log the borehole wall image located behind a PVC casing.
The algorithms implemented in the tool firmware detect and record all existing echoes on the ultrasonic waveforms. The detected echoes are then sorted and interpreted as a reflection from the casing or from the borehole wall (Figure 4-20).

Remind that for such application, the PVC casing must be properly centred in the borehole and the tool correctly centralised in the casing to obtain satisfactory results.

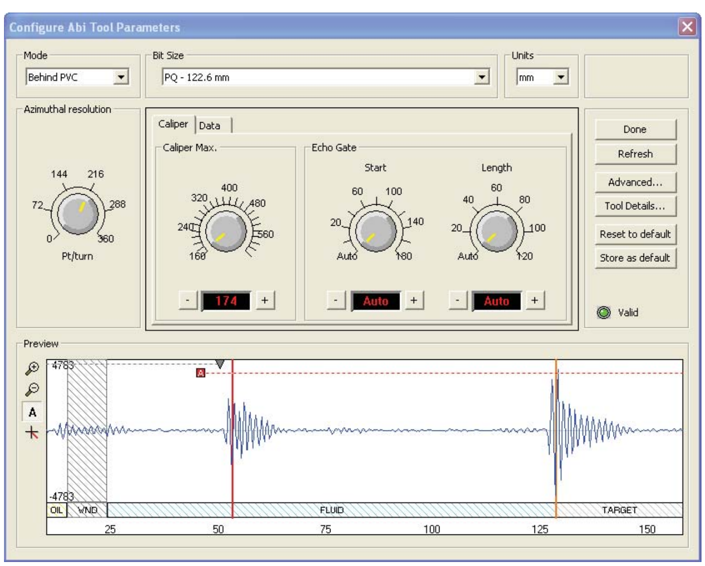


Figure 4-20 *Behind PVC settings – automatic settings*

The **"Behind PVC"** mode gives access to two main tabs – **Caliper** and **Data** - for configuring the record:

Caliper tab:

The caliper settings described in section 4.5.1.1 are applicable for the "Behind PVC" mode.

Mainly two major echoes are detected on the waveform preview. The first one is the reflected echo from the inner side of the casing. It is highlighted by the red vertical line. The second reflected echo, corresponding to the borehole wall, is highlighted by the orange vertical line.

Data tab:

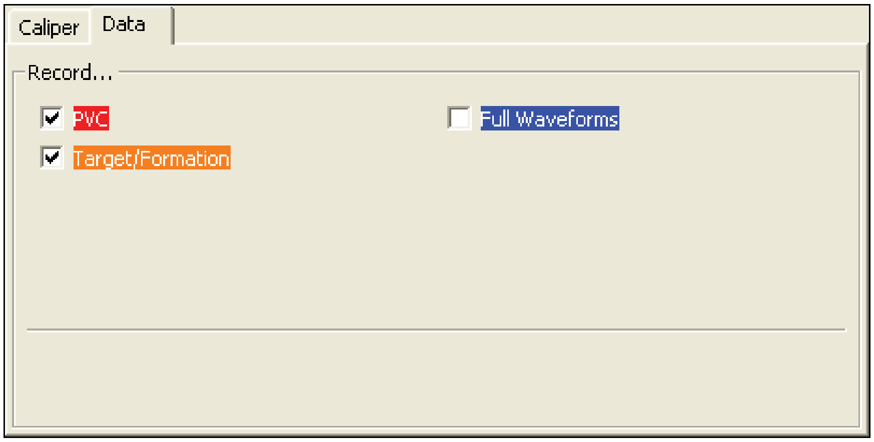


Figure 4-21 *Data record options for the Behind PVC mode*

By default, the system records both the PVC and the Target/Formation images.

The **"Target/Formation"** record option must always be checked. If unchecked, no acoustic image from the borehole wall will be recorded.

Option is given to the user to record or not the image of the inner face of the PVC casing. Recording the PVC image might be interesting to check the casing integrity or for looking at eventual encrustations.

For diagnostic purposes or advanced processing, the **"Full Waveforms"** record option can be activated. The system will record the complete ultrasonic waveform shown in the preview window.
Note that recording the ultrasonic waveform will affect the telemetry performance and will slow down the logging speed.

4.5.1.1.3 Cased hole mode

This acquisition mode is used to perform casing thickness measurements and corrosion evaluation in steel casings.

The operator will need to select from the dropdown casing list the nominal specifications of the casing under investigation (Figure 4-22).
When selecting a predefined **“Casing size”**, the system configures in an automatic way the most adequate tool settings – *azimuthal resolution, caliper max, echo gate, thickness, echo gate length* - for the casing external diameter and weight chosen.

User has also the choice to customize its own settings manually by adjusting the different knobs or interactively in the waveform preview window as described in a previous chapter.

Imperial or **metric units** can be used for displaying the wave form preview and for configuring the caliper - thickness settings.

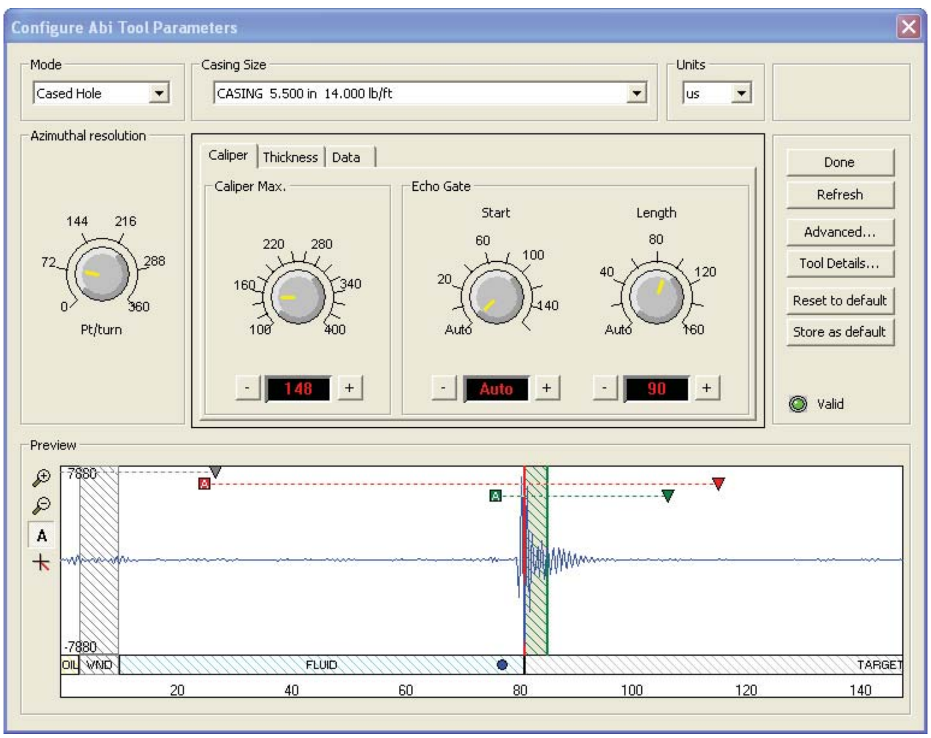


Figure 4-22 *Example of Cased hole settings*

Caliper tab:

The caliper settings described in section 4.5.1.1 are applicable for the “Cased hole” mode. Caliper settings must be adjusted for recording the echo reflected on the inner face of the steel casing.

Thickness tab:

From the thickness tab, the operator has the option to edit the internal (Low) and external (High) casing thickness dimensions manually for the record.
The Echo gate Length can be adjusted from this window or interactively from the wave form preview.

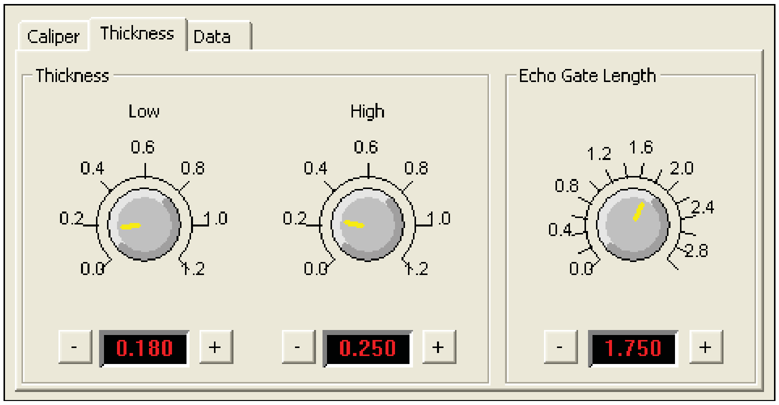


Figure 4-23 *Thickness and Echo Gate Length settings*

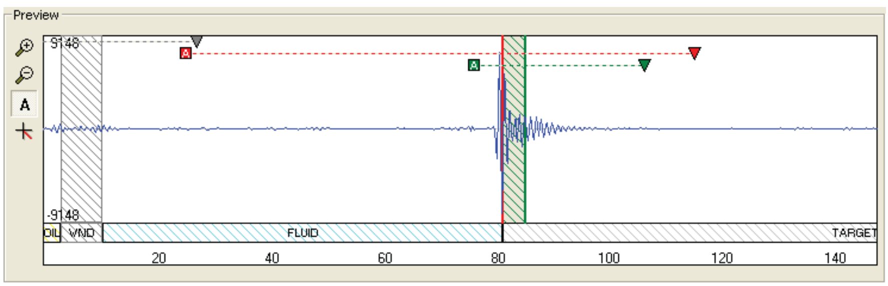


Figure 4-24 *Waveform preview – Thickness Echo Gate*

For cased hole application, in addition to the Acoustic Window and Echo Gates, a third gate - the **Thickness Echo Gate** (green dashed line – Figure 4-24) - is available for which only the end limit is user adjustable. Reduction of the gate length may be necessary if the ringing signal from the casing is superimposed by noise (e.g. multiples of the inner reflection) towards the end of the gate period.

The greyed - green hatched interval overlapping the recorded echo on the wave form preview is representing the casing thickness measured by the system for this specific ultrasonic trace and orientation.

Data tab:

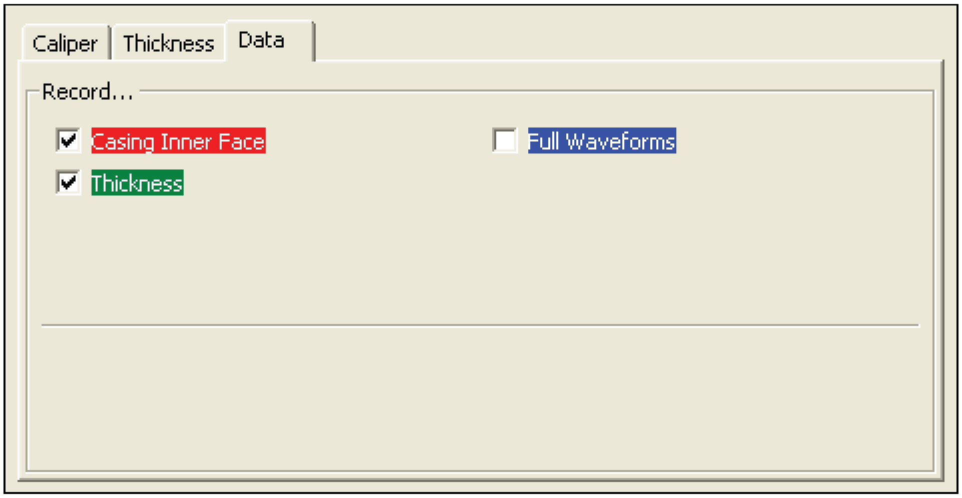


Figure 4-25 *Data record options for the Cased hole mode*

Option is given to the user to record or not the image of the inner face of the steel casing. Recording the casing inner face image is required for further internal caliper processing and for casing thickness/corrosion evaluation.

For diagnostic purposes or advanced processing, the **"Full Waveforms"** record option can be activated. The system will record the complete ultrasonic waveform shown in the preview window.
Note that recording the ultrasonic waveform will affect the telemetry performance and will slow down the logging speed.

4.5.2 Azimuthal resolution

The azimuthal resolution allows the operator to choose the number of points sampled per revolution of the focusing mirror. Sampling rates of 72, 144, 216, 288 and 360 measured points per revolution are available.

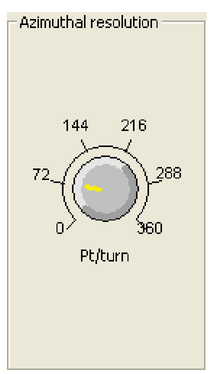


Figure 4-26 *choice of azimuthal resolutions*

The higher sampling rate can be used for better resolution in larger diameter boreholes but it might be less useful in small diameter hole as it would cause an overlap of sample points. The speed of rotation of the focusing mirror is directly linked to the azimuthal resolution and echo mode chosen.

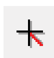
4.5.3 Additional notes on the waveform preview

Beside the interactive settings of the echo gates, the waveform preview is offering other tools to enhance the display of the ultrasonic trace:

 Zoom in the vertical scale of the echo amplitude

 Zoom out the vertical scale of the echo amplitude

 Set the vertical scale automatically with the best fit for the echo display

 Display the wave azimuth control knob and scan option

 Theoretical position of the main reflector for the corresponding bit or casing size selected

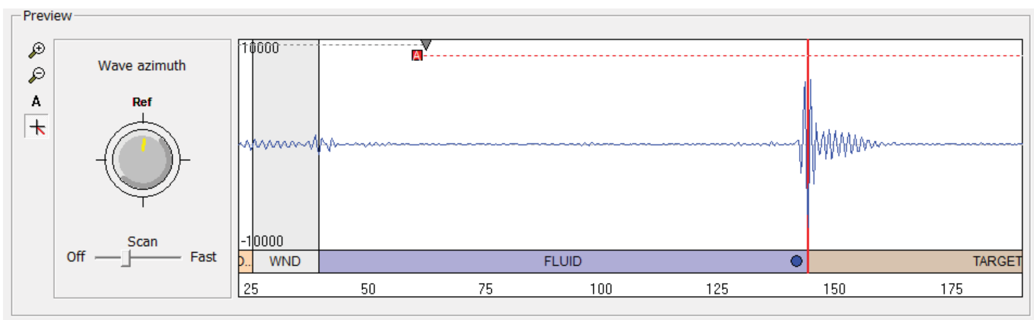


Figure 4-27 *Display of the wave azimuth control knob and scan option*

The **Wave Azimuth** knob in the full waveform preview box (Figure 4-27) gives the possibility to display the ultrasonic wave train in a preferential direction other than the reference position of the mirror.
The preview of the full waveform of the received signal is generated at the position indicated by the **Wave Azimuth** control knob. By turning the control knob, a different position relative to the tool internal reference side can be chosen.

To turn on an **automatic scan** move the slider bar handle from the **Off** position towards **Fast**. In that case the azimuthal scan position will continuously change with the azimuthal step increasing if the slider position is set towards **Fast.**

4.5.4 Advanced Settings

By clicking on **Advanced** in the "Tool Parameters" dialog box (Figure 4-28) the operator can edit the "Fluid and Casing velocity" constants to convert the acoustic travel time from µsec to metric or imperial units. The default values are 1480 m/s for the fluid velocity and 5850 m/s for the steel velocity.

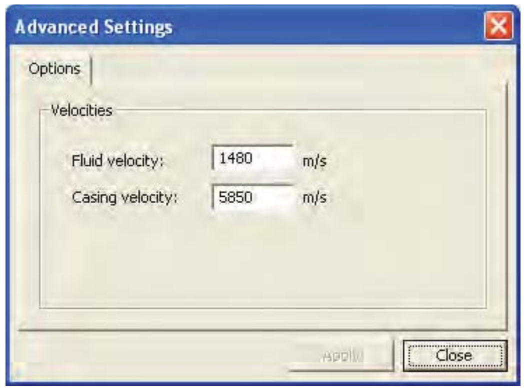


Figure 4-28 *Advanced settings*

4.5.5 Tool details

By clicking on the **Tool Details** button in the **Configure ABI Tool Parameters** dialog box four tabs (Figures 4-29 to 4-32) become available summarizing tool serial number, acoustic head details, deviation sensor model and analog front end. If necessary, newer tool firmware versions can be uploaded. The upgrade procedure will be explained in a later chapter.

Note: All the information displayed in the following dialog boxes can't be edited

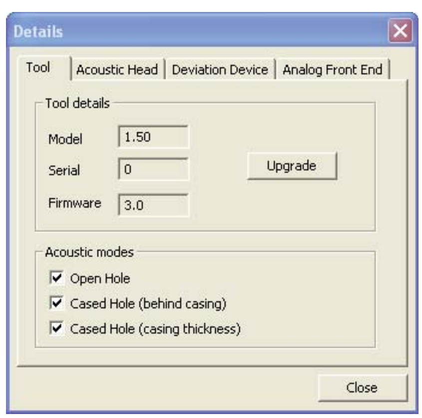


Figure 4-29 *Tool details*

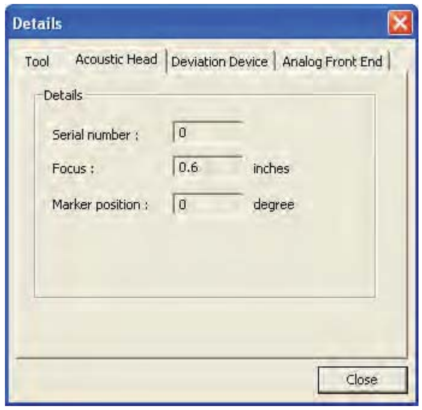


Figure 4-30 *Acoustic head details*

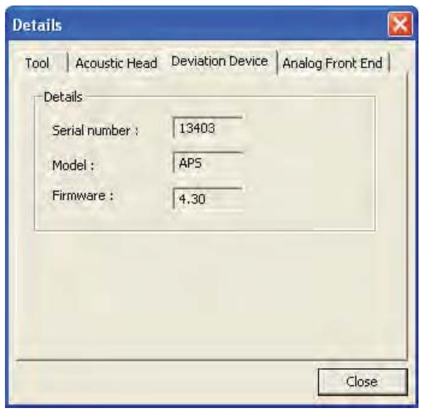


Figure 4-31 *Deviation sensor details*

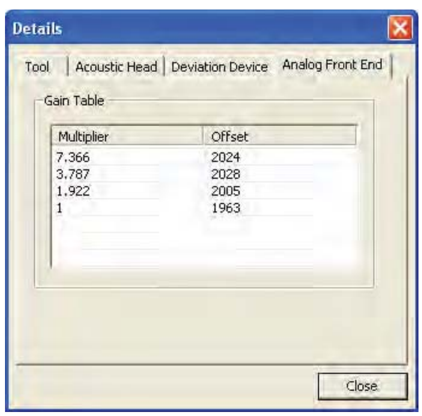


Figure 4-32 *Analog Front End*

4.6 Recorded Parameters and Browsers

4.6.1 Recorded parameters

The following data channels are recorded by the tool:

TravelTime (1^{st} echo):	Two Way Traveltime 1^{st} echo - µsec
Amplitude (1^{st} echo):	Amplitude 1^{st} echo (NM = North Magnetic, HS = High Side)
TravelTime2 (2^{nd} echo):	Two Way Traveltime 2^{nd} echo - µsec
Amplitude2 (2^{nd} echo):	Amplitude 2^{nd} echo (NM = North Magnetic, HS = High Side)
ThicknessTTime:	Two Way Traveltime within casing - µsec
Score:	Quality Index for thickness signal detection
Azimuth:	Azimuth from Magnetic North – deg
Tilt:	Inclination from verticality – deg
Roll:	Tool relative bearing calculated from accelerometers - deg
Mroll:	Tool relative bearing calculated from magnetometers – deg
Magn.Field:	Magnetic field surrounding the borehole - µT
Gravity:	Absolute value of the Earth gravity – g
Orientation:	Orientation diagnostic code
WndTime:	Two way traveltime of acoustic window reflection – µsec
WndAmpl:	Amplitude of acoustic window reflection
System Status	General system diagnostic code
VTool:	Tool head voltage - V
V12:	Internal tool voltage - V
RTHead :	Temperature sensor resistance - ohms
TCPU :	CPU temperature - °C
T APS:	Temperature inside the deviation sensor - °C
T Head :	Acoustic head internal temperature - °C
MotSpeed:	Motor - Speed of rotation – rps
Motor:	Diagnostic code
Motor Period:	Time for a single revolution – sec

4.6.2 MChNum Browser Window

Figure 4-33 and 4-34 show typical examples of the numerical values displayed in the MChNum browser window during logging.

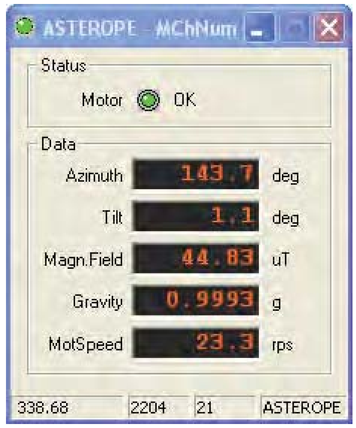


Figure 4-33 *MChNum browser display – example 1*

Motor:	Motor synchronisation status
Azimuth:	Azimuth from Magnetic North - deg
Tilt:	Inclination from verticality - deg
Magn.Field:	Magnetic field surrounding the borehole - µT
Gravity:	Absolute value of the earth gravity - G
MotSpeed:	Motor - Speed of rotation – rps

To display additional parameters in the MChNum browser right click on the MChNum browser title and select **Display Options** to add/remove channels and Led status.

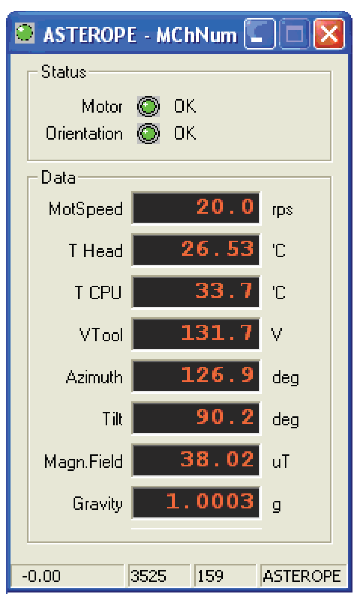


Figure 4-34 *Multi Channel Browser for Numerical Data (MChNum) displaying additional channels*

4.6.3 Surface Image Browser Window (AbiSurfaceImg)

The system returns an unwrapped image of the borehole wall based on the caliper and amplitude values of the recorded acoustic signal (Figure 4-35). The left column shows the caliper image and the right column the amplitude image.
These images consist of a succession of variable density colors. By double clicking on the log titles Minimum and Maximum scale values may be adjusted to enhance the log appearance.

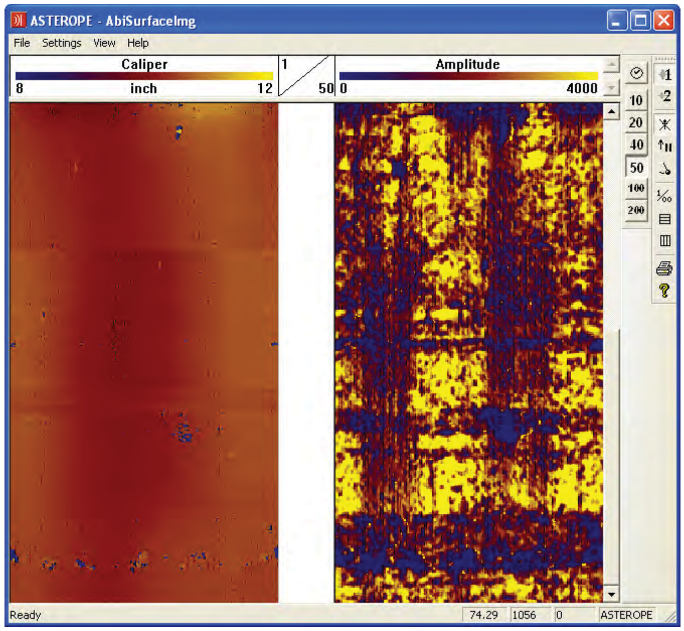
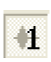


Figure 4-35 *ABI Surface Image browser window*

Note that the displayed units for the caliper log can be converted to either metric or imperial units via the menu bar's **Settings** option or by double clicking on the log title.

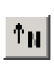
Echo selection :

 Echo1 is displayed (borehole wall or inner side of the casing)

 Display Echo2 (borehole wall behind a PVC casing)

Image orientation:

 Image is non-oriented

 Orient image to magnetic North

 Orient image to High Side of the tool

There are two modes of tool data orientation: orientation to High Side and orientation to North. Orientation to High Side is used in inclined boreholes when magnetometers data are unavailable (for example in a cased hole).

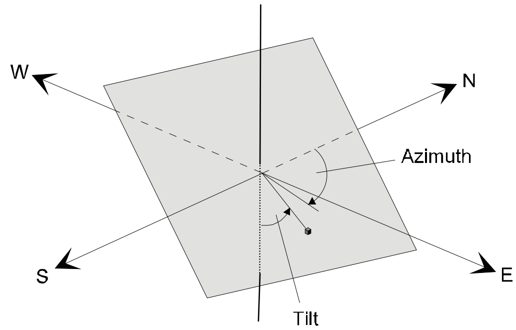
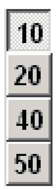


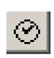
Figure 4-36 *Orientation to Magnetic North*

Vertical scales and grids:



Depth mode display and pre-defined depth scales

Operator defined depth scales, interval spacings and settings


Time mode display

4.6.4 Thickness Image Browser Window (AbiThicknessImg)

In Cased Hole Mode, the ABI Thickness browser displays on the left column an unwrapped color coded image of the **casing *thickness*** processed by the system (Figure 4-37). The right column is a color-coded image of the ***score****.* The ***score*** is a ***quality index*** on the thickness measurement. In a general way, high score values mean high reliability of the thickness measurement and the reverse.

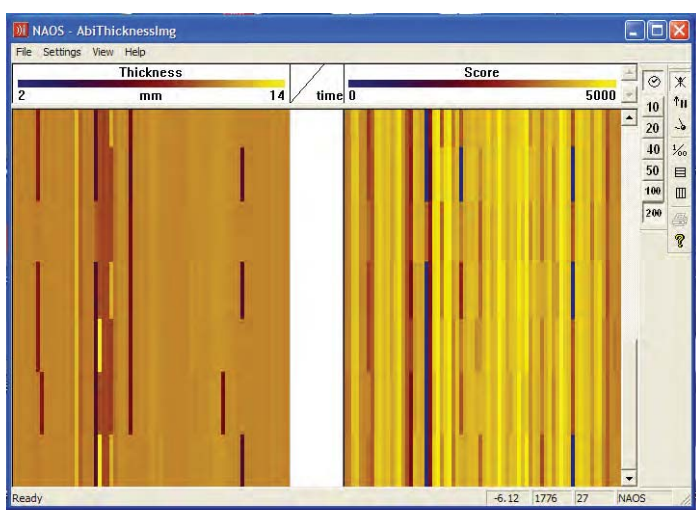


Figure 4-37 *ABI Thickness Image*

As for the Surface image browser, scales and units of the displayed parameters can be adjusted by double clicking on the log title or from the **Settings** option of the menu bar.

4.6.5 Caliper Browser Window (AbiCaliper)

Caliper browser - Open Hole Mode

The open hole caliper view (Figure 4-38) shows in real-time a cross-section of the acoustic caliper. Scaling, concentric gridding and displayed units are adjustable from the tool bar **“Settings”** option.

The black circle shows the external limit of the acoustic window.
The red circle is the cross section of the acoustic caliper corresponding to the main reflector detected by the system (borehole wall or inner surface of a casing).

As for the image browsers, the caliper view can be oriented to Magnetic North, High side or displayed without orientation.

During the acquisition, it is possible to centralize the caliper cross section to remove the effect of decentralization of the tool in the borehole.
Clicking the symbol  can do this.

Statistical caliper figures (Min, Max, Average) are displayed on the left side of the dialog box.

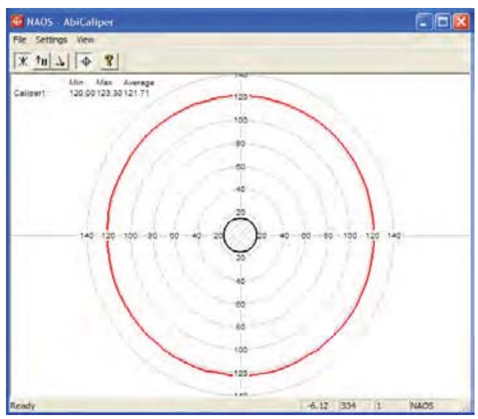


Figure 4-38 *ABI Caliper – Open Hole Mode*

Caliper browser – Behind PVC mode

The “Behind PVC” caliper view (Figure 4-39) shows in real-time a cross-section of the acoustic caliper of the PVC casing and borehole wall. Scaling, concentric gridding and displayed units are adjustable from the tool bar **“Settings”** option.

The red circle is the cross section of the acoustic caliper corresponding to the inner side of the PVC casing.
The orange circle is the cross section of the acoustic caliper corresponding to the borehole wall reflection.

As for the image browsers, the caliper view can be oriented to Magnetic North, High side or displayed without orientation.

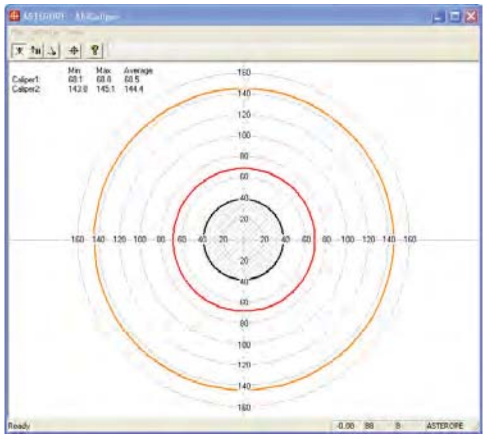


Figure 4-39 *ABI Caliper – Behind PVC Mode*

Caliper browser - Cased Hole Mode

Cross sections of both of the inner (red circle) and outer (orange circle) surface of the casing are shown in this browser (Figure 4-40), giving a good visualization of the casing thickness in real-time. The space between the 2 circles is filled with the corresponding color coded score values.
Orientation, scaling, concentric gridding and displayed units are adjustable from the menu bar's **Settings** option.

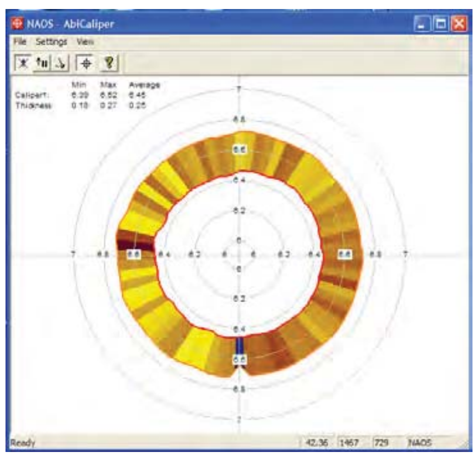


Figure 4-40 *ABI Caliper – Cased Hole Mode*

5 Performance Check & Calibration

5.1 Mirror rotation

Direction of motor rotation is **clockwise viewed from top of tool** (Figure 5-1):
Placing 2 fingers[3] on the acoustic window may check mirror rotation. In time mode, record the 2 finger traces shown[4] on the Abi surface browser. Remove your right finger from the acoustic window; the corresponding right finger trace on the Abi surface image should disappear.

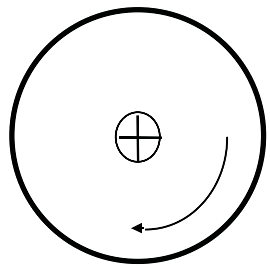


Figure 5-1 *Direction of mirror rotation*

5.2 Functionality test of the deviation system

5.2.1 Functionality test

The ABI's deviation system is factory calibrated and does not require further calibration. The functionality tests subsequently described have to be done to check that the tool is giving the correct deviation outputs:

To verify inclination at 0° and 90°, position the probe vertical (acoustic head pointing down) for 0° inclination and horizontal for 90° inclination. Note that uphole measurement is possible with the APS544 deviation system as it includes 3 accelerometers. In uphole, the inclination will be between 90° and 180° (probe vertical, acoustic head pointing up).

To verify azimuth accuracy, a good compass and an area free of magnetic materials must be used. Use a compass to orient North with the probe horizontal and verify that the azimuth reading is 0° ± 1°. Repeat the procedure for East, South and West directions.

5.2.2 Rolling test – azimuth and tilt check

Azimuth and tilt could be tested by rotating the tool about its long axis while maintaining both a constant inclination to the vertical, say 15°, and a fixed azimuth. The data imported into WellCAD should show a deviation of the azimuth less than the limit of ±1.5° and a deviation of the tilt less than the limit ±0.5°.

[3] Wet your fingers first for a better coupling
[4] Adjust the amplitude scale to enhance the finger traces

6 Maintenance

Warning: Removing the electronic chassis from pressure housing without prior consultation with ALT will void the tool warranty.

The ABI televiewer is a delicate instrument and should be treated with care at all times. Excessive shock or extreme temperatures should be avoided and the tool should always be transported in its transport case or a similarly cushioned enclosure. Never support the tool on the acoustic head. Experience shows that with attention to these points the QL40 ABI will give several years fault free operation.

The ABI televiewer separates into four basic parts

- The tool top adaptor
- The pressure housing
- The electronic chassis
- The acoustic head.

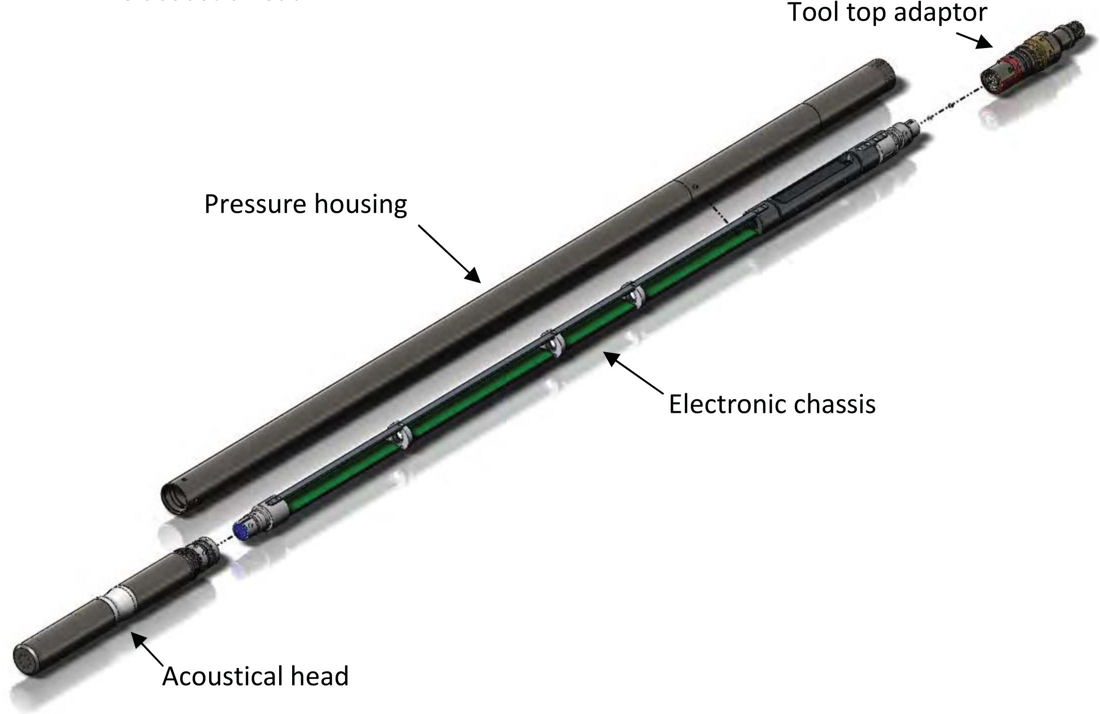


Figure 6-1 *ABI and tool top, exploded view*

Should it become necessary to open the tool, the tool parts must be separated in the following sequence:

1. Remove the tool top adapter
2. Remove the acoustic head
3. Remove the pressure housing

Disassembly of the electronic chassis from the pressure housing should never be attempted in the field.

6.1 Tool Top Adapter

The tool top adapter provides the connection between wireline cable head and chassis electronics and can be provided to suit 7 conductors, 4 conductors, mono or special wireline configurations. The adapter is fixed by the means of a threaded ring screwed in the pressure housing. To remove the tool top adapter, use the correct C spanners provided with the tool - see picture below (Figure 6-2).

Figure 6-2 *Removing the tool top*

The wireline cable head socket and tool top adapter connector pins should be checked for cleanliness before each use of the tool. The pin inserts, whether 4 or 7 pin, have a locating mark indicating WL1 or A that should line up with the slot mating with the cable head.

Check O-Ring seals and apply silicon grease before re-assembly. Silicon grease of a similar type to RS Components Ref 494-124 is suitable for this and other O-Ring seals.
(Rem: O-Ring reference for tool top and for the quick link 40 is AS215 26,57 x 3,53 Viton Shore 75)

Figure 6-3 *QL40-GO4 Tool top adaptor*

Figure 6-4 *QL40-GO7 tool top adaptor*

Figure 6-5 *QL40-GO1 tool top adaptor*

6.2 Acoustic head

Warning: The televiewer acoustic head is extremely delicate and must be treated gently at all times. Any laterally applied force on the end of the head is liable to cause damage!

The acoustic head is attached to the electronic chassis of the sonde by three 2.5mm hex set screws. To remove the entire televiewer head the tool top and pressure housing must first be removed as described below. Slacken off the fixing screws and slide the televiewer head off the connector. The connector has a keyway to locate the head with the correct orientation.

Figure 6-6 *Acoustical head*

Re-assembly is the same procedure in reverse order, but taking care not to force the head on to the connector. This will result in bent or broken connector pins! Check all “O” ring seals (Orings AS215, 26.57x3.53, viton, shore 75) and apply silicon grease to them.

The acoustic head needs to be properly maintained to give the best image results.
Note the following points:

- Check that there are no air bubbles visible in the acoustic window. Air can separate out of the oil filling the head, notably after airfreight at low pressure, and can also work its way out of the inner parts of the motor. The presence of air in the head is indicated by a spotty image or streaking. These effects may come and go as the orientation of the tool is changed.
- Check that there is not excessive lateral movement on the end of the head. The bellows cap must be screwed up against the acoustic window but not excessively tight.
- If the acoustic signal is lost, check for isolation between pins A&B in the acoustic head. The most common reason for loss of signal is the cutting of the signal coax to the transducer in the head. This happens when the window is rotated relative to the head body. Check with a gentle twisting motion that the window does not rotate more than a degree or two relative to the tool body.

- At very low temperatures the oil in the acoustic head becomes viscous and this may prevent the mirror from rotating. In this case keep the tool and head warm before use.

6.2.1 Cleaning the acoustic head bottom section

The bottom section of the televiewer assembly houses a pressure compensating bellows that must be free to move. For this reason the bellows cover is removable to allow cleaning of the exterior of the bellows. The interior of the bellows and main body of the televiewer head is oil filled. Both, the end of the bellows cover and its side wall, have holes to allow pressure equalization, and these holes must be kept clear. The bellows cover is threaded at the top end and held by a screw thread on the main body below the nylon window. The cover should only be **hand tightened**.

Keep the bellows section clean. This will prevent the deterioration of glue seals and the bellows itself. Grit lodged in the folds of the bellows can cause perforation if left over a period of time.

When removing the cover, it is important to **hold the nylon mirror section only,** which is locked integrally with the main tool, while unscrewing the cover. Wrenches must **NOT** be used (Figure 6-7 and Figure 6-8).

Warning: Any Rotation of the nylon section relative to the main tool pressure housing will result in damage to the head and probable tool failure.

The necessity for cleaning will depend on the borehole fluid and borehole conditions. The bellows should only be cleaned when the sonde was used in heavily contaminated fluids, i.e. heavy muds or sediments, or when the fluid is known to be corrosive. In this case it is important to clean deposits off the bellows where it is glued to the flanges at either end. The bellows wall is thin and can become perforated if allowed to corrode.

Figure 6-7 *Unscrewing the bellows cover*

Figure 6-8 *Bellows cover removed*

6.3 Pressure Housing

The main pressure housing is locked on to the televiewer head by four 2.5mm hex cap screws. After removal of the tool top, the pressure housing can be removed after undoing these screws. When separating the two parts, place the tool on suitable stands, grip the pressure housing with one hand and the acoustic head close to the joint with the other and apply a straight pull. During re-assembly extreme care should be taken not to over tighten the fixing screws which may shear off if overloaded!

The outside of the pressure housing is marked with a Y symbol to indicate the position of the Y axis vertical and upward. The purpose of this is to simplify tool checking.

When re-assembling the pressure housing make sure that the reference mark is correctly aligned with the upper side of the deviation sensor.

6.4 Upgrading ABI firmware

In accordance with the ALT policy of continuous development the ABI has been designed to allow firmware upgrades. The current version of firmware installed in a tool may be verified in the Tool Details window opened from the Tool Settings dialogue box.

Firmware upgrade procedure is as follows:
1. Checking the communication is valid.
2. Upgrading firmware

6.4.1 Checking the communication

1. Connect the ABI tool to your acquisition system.
2. Start ALTLog/Matrix software.
3. In the **Tool** panel select the appropriate tool and turn on the power.
4. In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-9 or Figure 6-10).

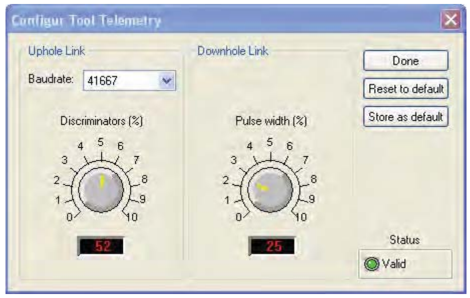


Figure 6-9 *Tool communication settings - ALTLog*

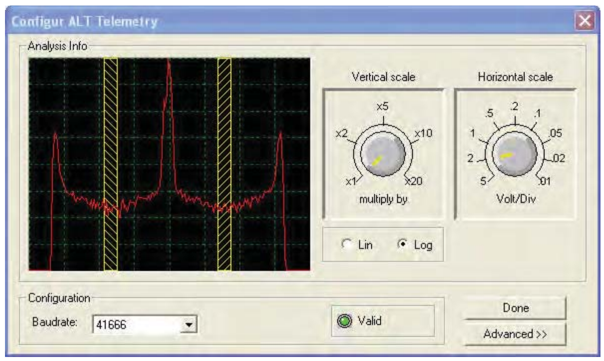


Figure 6-10 *Tool communication settings - Matrix*

Warning: Telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.4.2 Upgrading the firmware

In the **Tool** panel, select **Tool settings/commands**. Check that the communication status is valid (Figure 6-11).

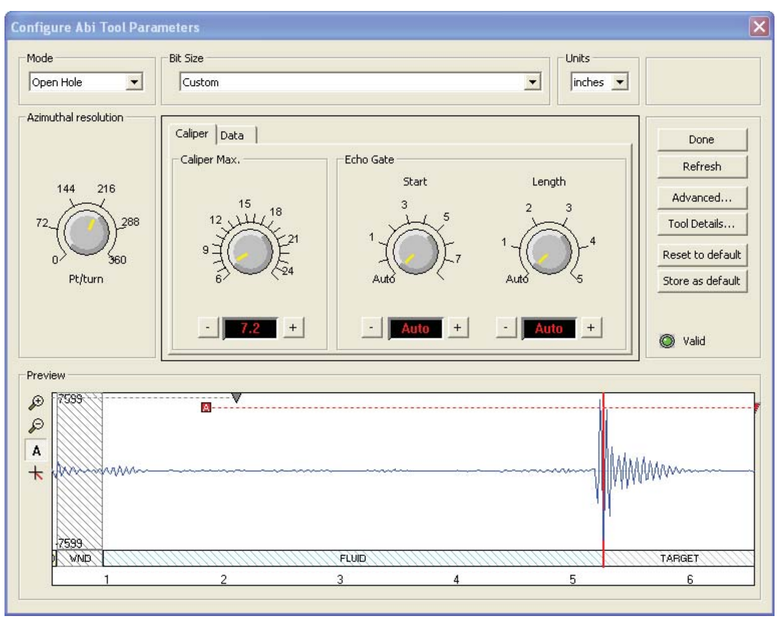


Figure 6-11 *Tool settings dialog box*

1. Click on **Tool Details**. Note that the firmware version currently in use is displayed in the firmware box. Click on the **Upgrade** button (Figure 6-12).

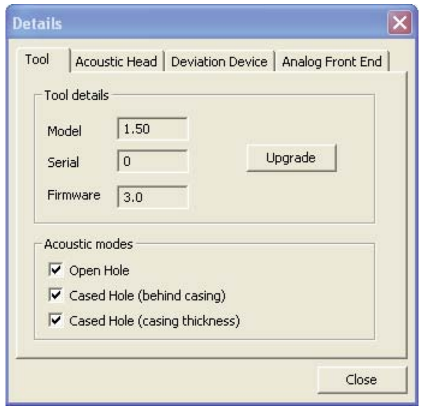


Figure 6-12 *Tool Details dialog box*

2. The following message will appear (Figure 6-13). Click **Yes** to validate your choice.

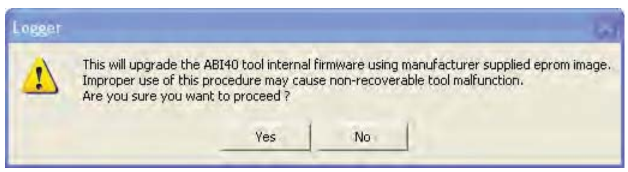


Figure 6-13 *Warning Message during firmware upload*

3. Select and open the appropriate **.hex** file provided (Figure 6-14). The upgrade will start.

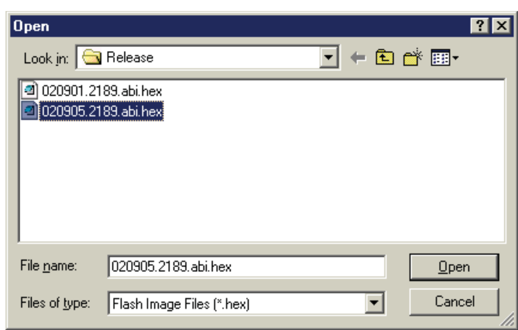


Figure 6-14 *Select firmware upgrade*

4. During the upgrade procedure, the following message is displayed:

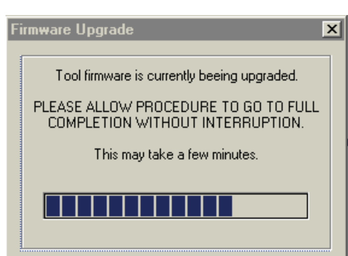


Figure 6-15 *Firmware upgrade progress window*

5. Once the upgrade has been successfully completed (Figure 6-16), click on **OK** to turn off the tool.

Figure 6-16 *Successful upgrade*

6. Power on the tool to start the upgraded firmware. Check in **Tool settings/commands** and **Tool details** that the firmware version has been changed with the new one.

Note that this error message (Figure 6-17) will appear at end of the procedure when the tool firmware upgrade has failed or has been aborted. Check tool communication settings.

Figure 6-17 *Error message*

7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been copied into the …/Tools folder (refer to MATRIX or ALTLog manual about details of the directory structure)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.3 or 4.4) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible short-circuit (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a short-circuit. - If the above shows no issues, use test cable to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.3 or 4.4).
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.3 or 4.4). - Check bandwidth usage and telemetry error status.

Observation	To Do
Permanent No Sync message and red led status in MChNum browser. *Motor stalled and increase of current drawn by the tool.*	**! Immediately switch off the tool !** - Stepper motor and mirror synchronization issue. Contact ALT for Acoustic Head service.
WellCADimport : acoustic images not imported	- Check your WellCAD version (please refer to 1.3 Technical Specifications chapter).
WellCAD import : Magnetic North and High Side orientation options not available	- Check your WellCAD version (please refer to 1.3 Technical Specifications chapter).

8 Notes on Data Processing

The processing of data acquired with the QL40 ABI and the ABI 40 tools is usually performed using the WellCAD software. We would like to refer the user to the WellCAD user guides for a detailed description of the software's functionality. In particular *Book 3 - Image & Structure Module* should be of help when processing image data.
The following paragraphs will focus on three processes to process traveltime data for which the input of correct units and parameters is crucial in order to obtain accurate results.

8.1 Estimation of Fluid Velocity

The procedure described below outlines the estimation of the borehole fluid velocity which can be used as input for the computation of caliper data described hereafter.

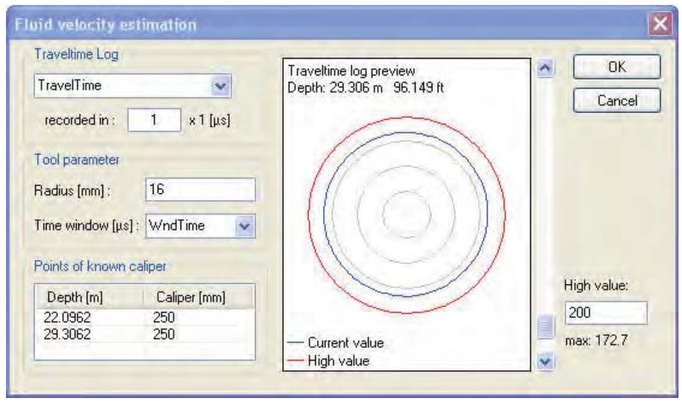
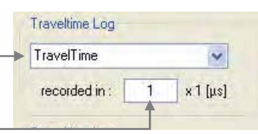


Figure 8-1 *Fluid velocity estimation dialog box*

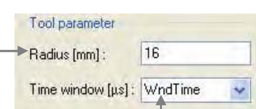
1. From the **Process > Image Module > Image Logs** menu in WellCAD select the **Estimate Fluid Velocity** entry. The corresponding options dialog box will open (Figure 8-1).

2. Select the TravelTime log from the corresponding drop down list in the dialog box.



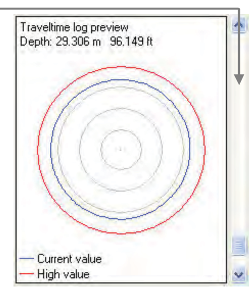
3. Set the unit the traveltime has been recorded in. For the QL40 ABI or ABI40 tool this manual refers to the unit is 1 µs. (Older tools measured in 0.1 µs. You can find out by double left clicking on the log title of the TravelTime log. The unit should show *µs*. If no unit is shown the measurement was made on *0.1 µs.*)

4. Enter the radius of the acoustic head at the measurement point into the corresponding edit box. For the ABI tools described here a value of 16 mm is appropriate.

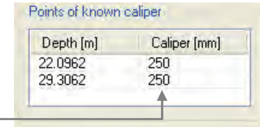


5. Select the Time window channel *WndTime* which contains the traveltimes from transducer to the acoustic head window and back (has been recorded by your tool along with the other measurements).

6. Use the scroll bar next to the preview of the cross sections generated from the traveltime data and find a depth at which the caliper of the pipe or borehole is known and best reflected by the measurement (for example the nominal internal diameter of casing or the bit size).



7. Right click into **Points of known caliper** list and add a new row for a reference point. The depth value will automatically set to the depth of the preview. Enter the known caliper value in [mm].



8. Try to set a least a reference point at or near the top and base of the well. Click **OK** when finished. A new log containing the estimated velocity profile will be created.

8.2 Computation of Caliper Data

The following steps summarize the steps to compute radius and caliper data from the acoustic traveltime recorded with your ABI tool:

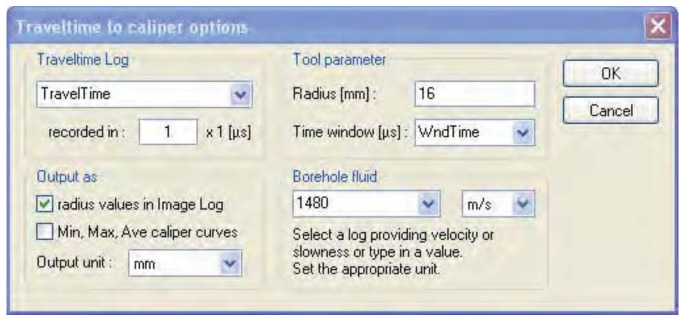
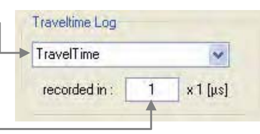


Figure 8-2 *Traveltime to caliper conversion dialog box*

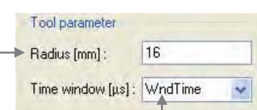
1. Select the **Calculate Caliper** process from the **Process > Image Module > Image Logs** menu. The options dialog box (Figure 8-2) will open.

2. Select the TravelTime log from the corresponding drop down list in the dialog box.



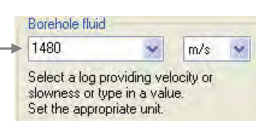
3. Set the unit the traveltime has been recorded in. For the QL40 ABI or ABI40 tool this manual refers to the unit must be set to 1 µs. (Older tools measured in 0.1 µs. You can find out by double left clicking on the log title of the TravelTime log. The unit should show *µs*. If no unit is shown the measurement was made on *0.1 µs.*)

4. Enter the radius of the acoustic head at the measurement point into the corresponding edit box. For the ABI tools described here a value of 16 mm is appropriate.

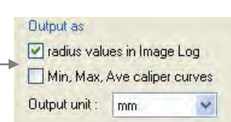


5. Select the Time window channel *WndTime* which contains the traveltimes from transducer to the acoustic head window and back (has been recorded by your tool along with the other measurements).

6. If you estimated a fluid velocity as described in the paragraph above or have measured values extend the drop down list and select the corresponding log. You can also enter a textbook value manually. Ensure the correct unit has been selected.



7. Select the output options and unit. You can create a new Image Log containing a radius value for each traveltime measurement. In addition you can create Min, Max and Average caliper curves.



8. Click on **OK** to close the dialog box ad start the computation.

8.3 Calculation of Casing Thickness

If you made measurements in cased hole mode you will get a log containing the traveltime within the steel casing (thickness travel time). The procedure described below summarizes the conversion of the thickness traveltime into a true thickness value.

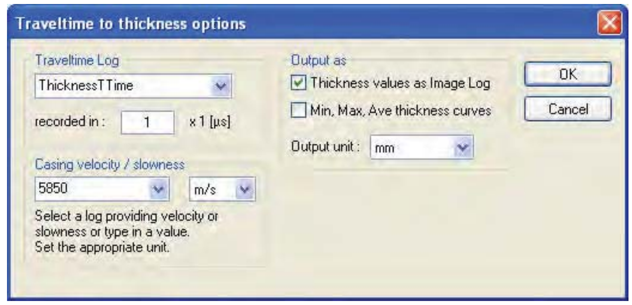


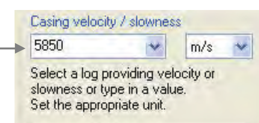
Figure 8-3 *Traveltime to casing thickness conversion dialog box*

1. From the **Process > Image Module > Image Logs** menu in WellCAD select the Calculate Thickness… entry. The corresponding options dialog box will open (Figure 8-3).

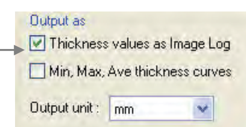
2. Select the ThicknessTTime log from the corresponding drop down list in the dialog box.

3. Set the unit the thickness traveltime has been recorded in. For the QL40 ABI or ABI40 tool this manual refers to the unit must be set to 1 µs. (Older tools measured in 0.01 µs. You can find out by double left clicking on the log title of the ThicknessTTime log. The unit should show *µs*. If no unit is shown the measurement was made on *0.01 µs.*)

4. Enter the velocity of sound in steel into the corresponding edit box. A typical value for steel is 5850 m/s. If you have a velocity profile available in a log extend the drop down list and select the corresponding channel.



5. Choose the output option and unit. The thickness values can be given as a Image Log with on thickness value for each traveltime thickness measurement and as curve of the minimum, maximum and average thickness determined.



6. Click on **OK** to close the dialog box ad start the computation.

9 Appendix

9.1 Parts list

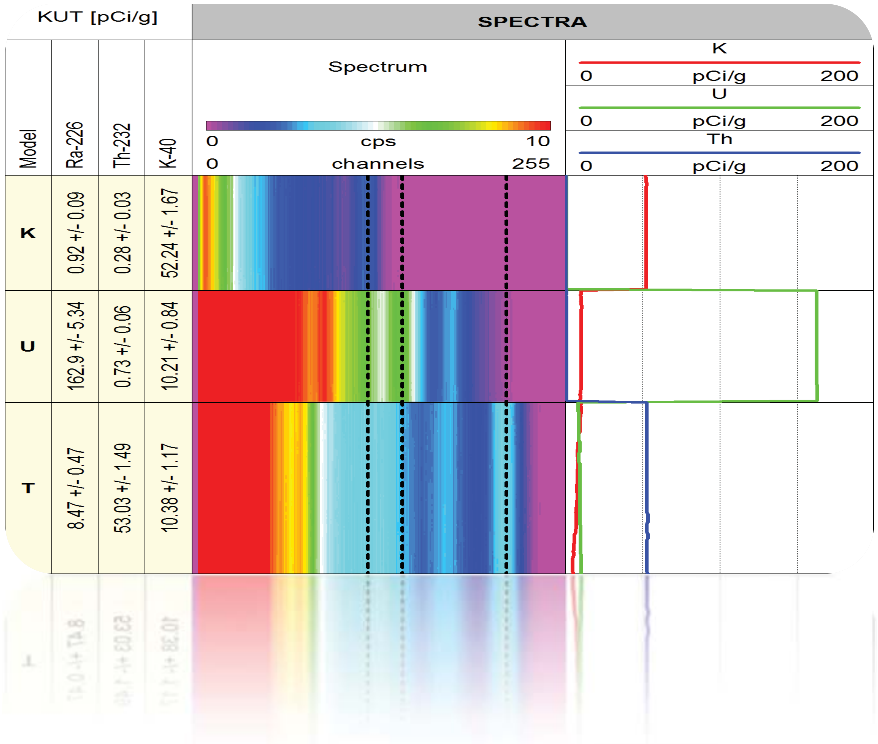
Detailed part numbers and descriptions are available for tool delivery and spare part kits.

9.2 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- Wiring Diagram.

Index



User Guide

QL40 SGR – Spectral Gamma Ray Probe

MOUNT SOPRIS INSTRUMENTS

Advanced Logic Technology

V17.03.03

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1 General Information

The **QL40-SGR** tool measures the energy of the gamma emissions occurring naturally within the formations crossed by a borehole and counts the number of gamma emissions associated with each energy level. A scintillation Sodium Iodide crystal (or a BGO crystal) is used to detect the gamma rays. Gamma rays are produced mainly by isotopes of potassium, thorium, uranium and their decay products. The gamma ray log is widely used in the mining and oil industry for the identification of lithology, correlation between boreholes and clay content analyses.

The tool is supplied as an inline sub of the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a stand alone tool.
The QL40 SGR operates with the ALTLogger and Matrix logging systems and can be run on any standard wireline (mono, 4 or 7 conductor, coax).

1.1 Dimensions

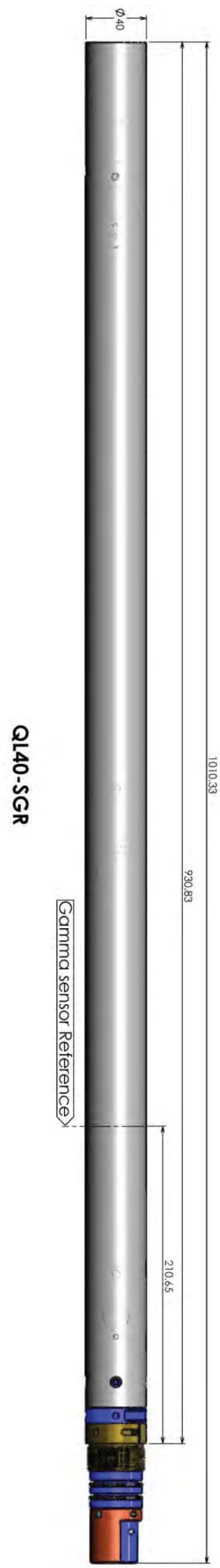


Figure 1-1 *QL40 SGR Dimensions*

1.2 Technical Specification

Tool

Diameter:	40 mm (1.6”)
Length:	0.93 m (36.6”)
Measurement point:	0.210 m (8.29”) from bottom
Weight:	6 kg (13 lbs)
Max. Temp:	70 °C (158 °F)
Max.Pressure:	200 bar (2900 psi)

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – ABOX – Matrix

Sensors:

Scintillation NaI(Tl) crystal:	2.22 cm x 10.16 cm (0.875” x 4.00”)
BGO crystal	2.22 cm x 10.16 cm (0.875” x 4.00”)

2 Measurement Principle

The **tool** is equipped with a scintillation Thallium doped Sodium Iodide crystal - NaI(Tl) or by a BGO, which, when struck by gamma rays, emits pulses of light. These pulses of light are amplified by a photo multiplier tube and are then converted into electrical pulses. The number of pulses are counted, digitized and transmitted up the wireline to the surface acquisition system.
In addition to the "total natural gamma counts" the tool records the energy spectrum of the gamma radiation emitted by the formations. A real time process on the energy spectrum is applied and computes the concentration of the three main radioisotopes K, Th and U.

Figure 2-1 shows a data set acquired with the tool in a test pit.

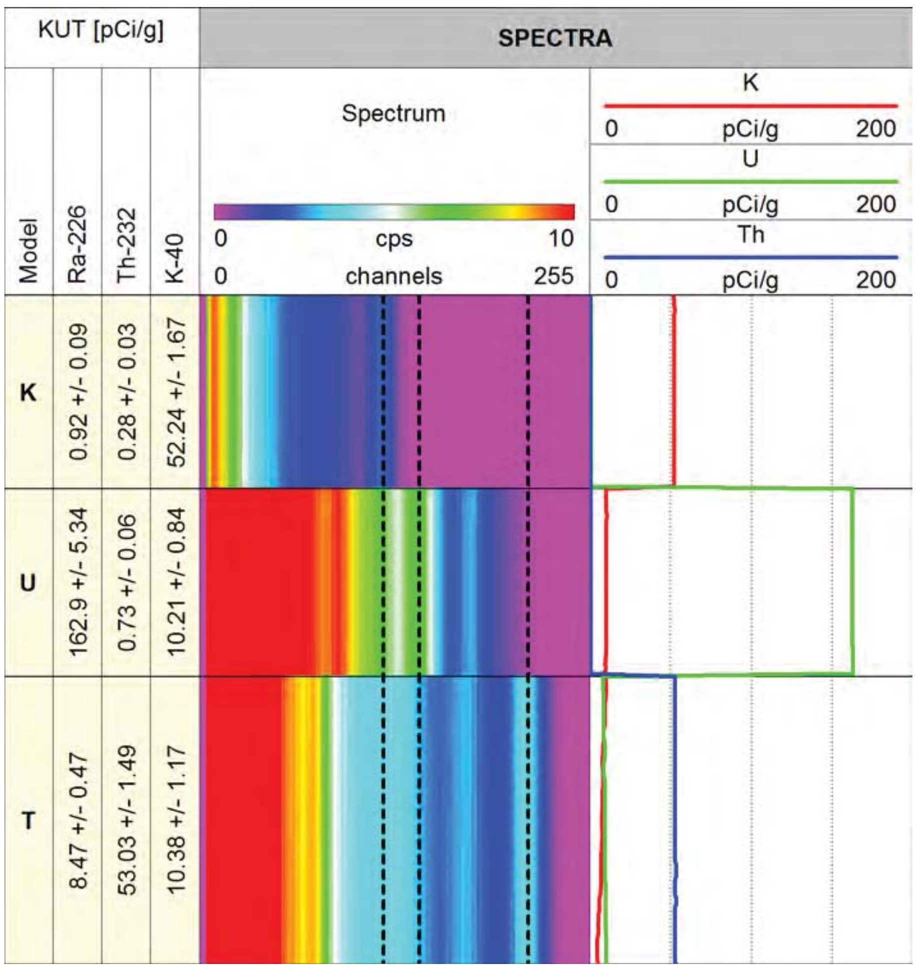


Figure 2-1

3 Notes on QL tool assembly

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

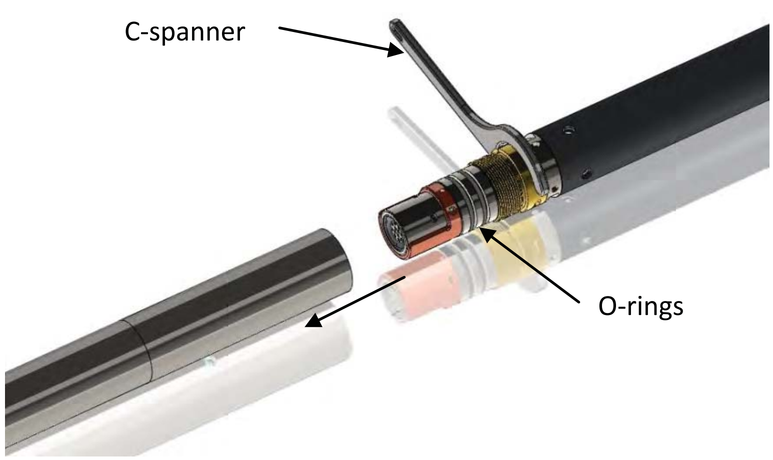


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-SGR and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-SGR sub stand-alone.

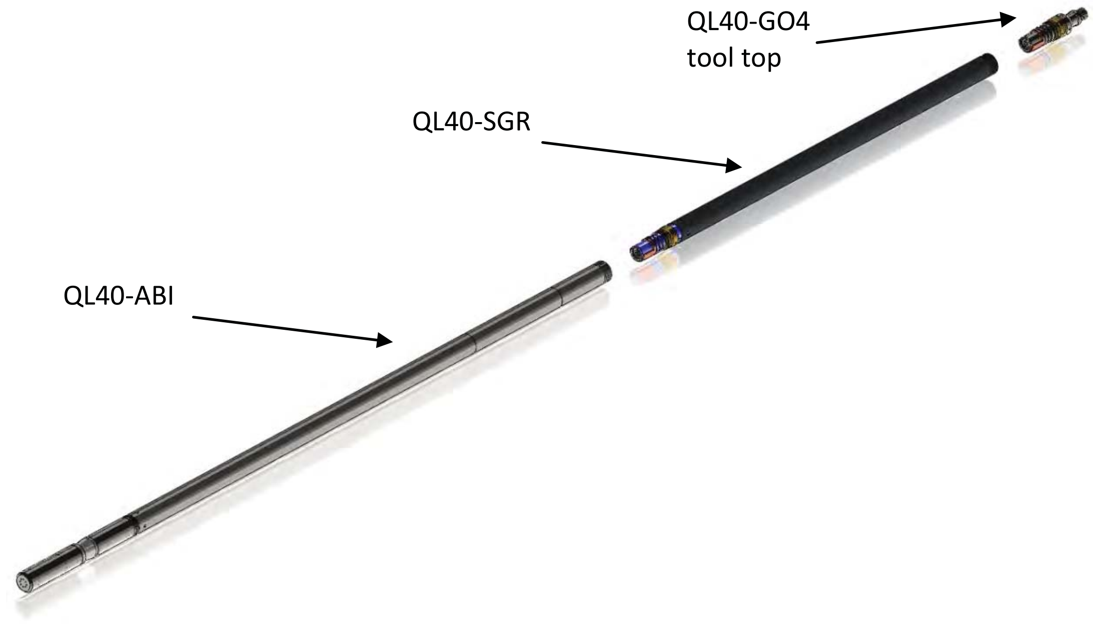


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

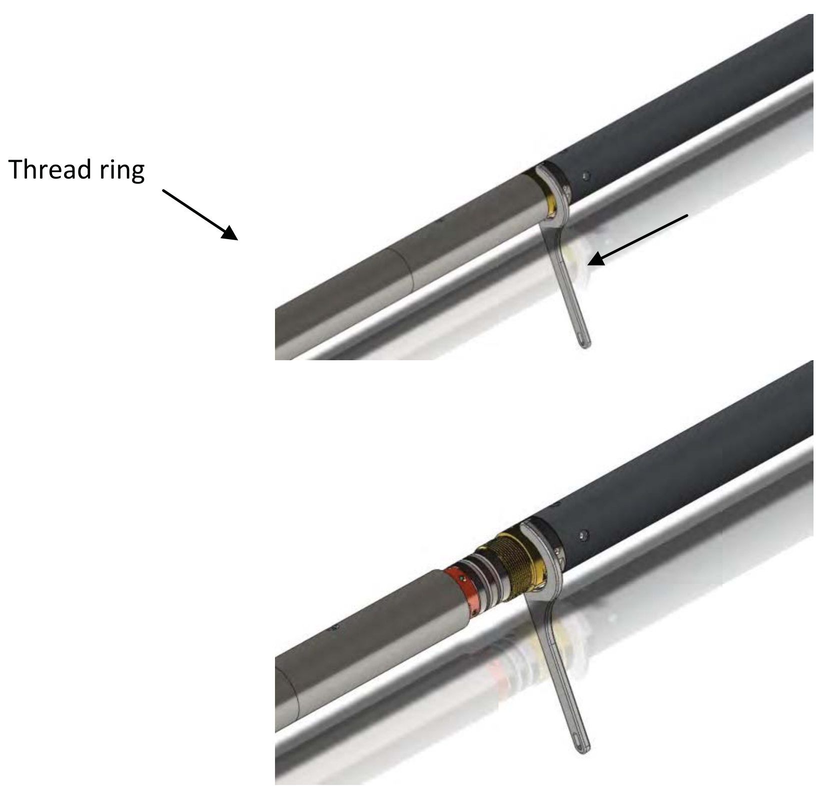


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

Figure 3-4 *Attaching the QL40-Plug*

The QL40-SGR can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-SGR mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in the sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant QL40 SGR tool from the drop down list (Figure 4-1) in the software's **Tool** panel (if your tool is not listed check that your tool configuration file is stored in the designated folder on your computer).

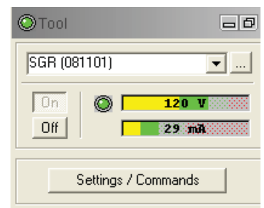


Figure 4-1 *Tool panel*

3. In the **Tool** panel, switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in chapter **4.2** if error message is displayed.)

4. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button to configure your tool (see chapter **4.5** for details).

Figure 4-2 *Acquisition panel*

5. In the **Acquisition** panel (Figure 4-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

6. Press the **Record** button in the **Acquisition** panel (Figure 4-2), specify a file name and start the logging.

7. During logging observe the controls in the **Telemetry** panel (Figure 4-3):
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

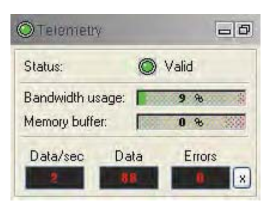


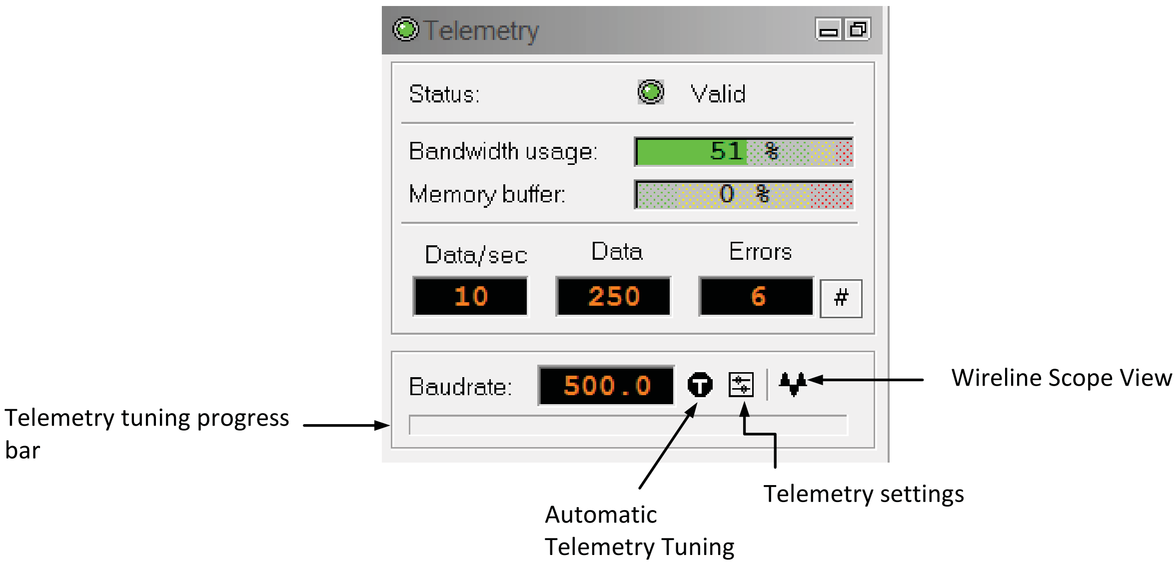
Figure 4-3 *Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

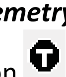
4.2 Tool Communication with OPAL/SCOUT (ALT MODEM)

The telemetry provided through the **OPAL-SCOUT** systems implementing the **ALT MODEM** controls and configures **AUTOMATICALLY** the telemetry settings for any wireline. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

The Tune button  resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.

A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

Refer to **Appendix** at the end of this manual for more information on the **advanced telemetry settings**.

4.3 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.

- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

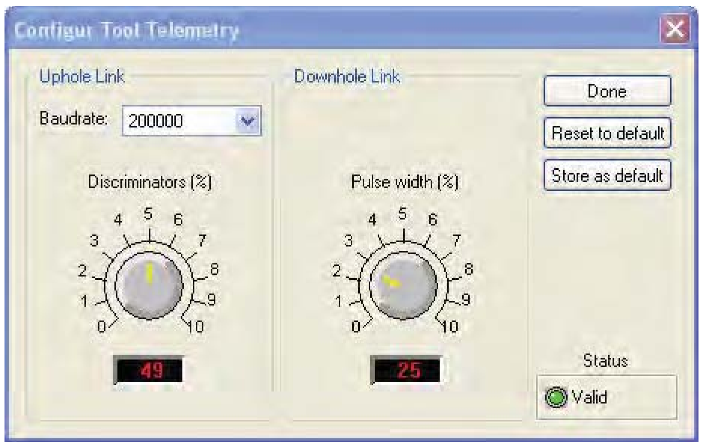


Figure 4-4 *Tool communication settings*

4.4 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-5) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased

(long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

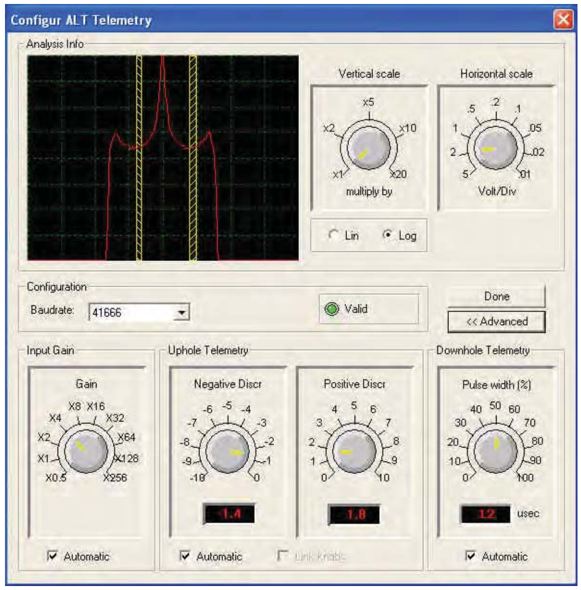


Figure 4-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in "Valid" status the next time the power is turned on.

4.5 Configuring Tool Parameters

The QL40 SGR has the following configuration options.

The "Spectra" page allows you to choose whether or not to enable recording of the instant and stacked spectrum. The stack size can be adjusted with the corresponding control knob.

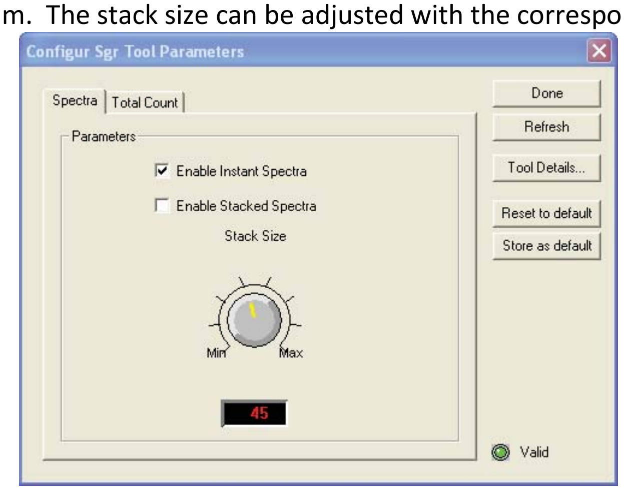


Figure 4-6 *Tool configuration - Spectra*

The second page "Total Count" allows the user to adjust the energy capture limit for the lower part of the spectrum.

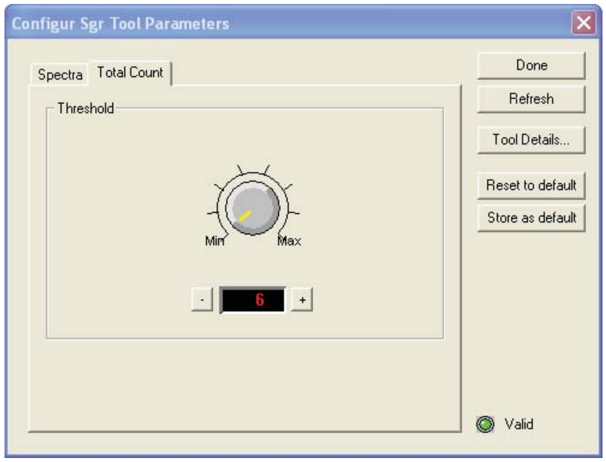


Figure 4-7 *Tool configuration – Total Count*

The tool details (serial number, firmware version,…) are listed in the dialog box displayed when clicking on the "Tool Details…" button. This dialog allows also the tool firmware upgrade (See Appendix)

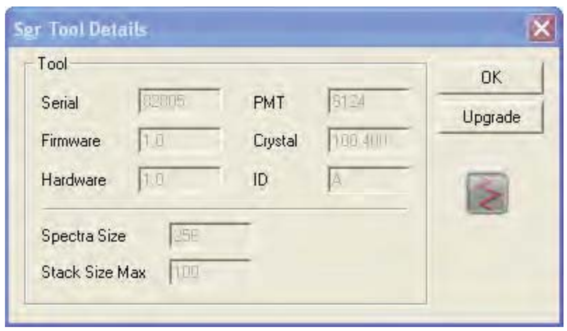


Figure 4-8 *Tool details*

4.6 Recorded Parameters, Processors and Browsers

4.6.1 Recorded parameters

The following data channels are recorded by the QL40 SGR tool.

Temperature	Temperature at CPU board in °C
Counts	Raw gamma ray counts
Time	Sampling time in seconds
Stack Counts	Stacked raw gamma ray counts
Stack Time	Stacked sampling time in seconds
EHT	High voltage [V]
Instant Spectrun	256 samples spectrum
Stacked Spectrum	Stacked 256 samples spectrum

The total GR is computed by the MChProc processor

GR	Total Gamma ray in cps or API

Additional channels are computed and produced by the SgrProc processor – See below.

4.6.2 SgrProc Processor

The SgrProc processor processes the spectra acquired by the tool in two different ways according to the tool configuration file :

- Standard : Window counts mode
- Full Spectrum Analysis (Medusa)

In its standard configuration, only the number of counts related to user-defined windows are computed.

The second configuration applies the gain shift correction and a full spectrum analysis to compute the concentrations in Bq/kg of the nuclide elements. This process requires a master calibration file provided by the Medusa company.

In both configurations, the channels produced by the processor are listed in the About dialog box displayed when selecting "About SgrProc…" from the context menu.

4.6.2.1 Standard Process

The configuration of the processor is done by right-clicking on its window title and by selecting "Parameters" from the context menu.

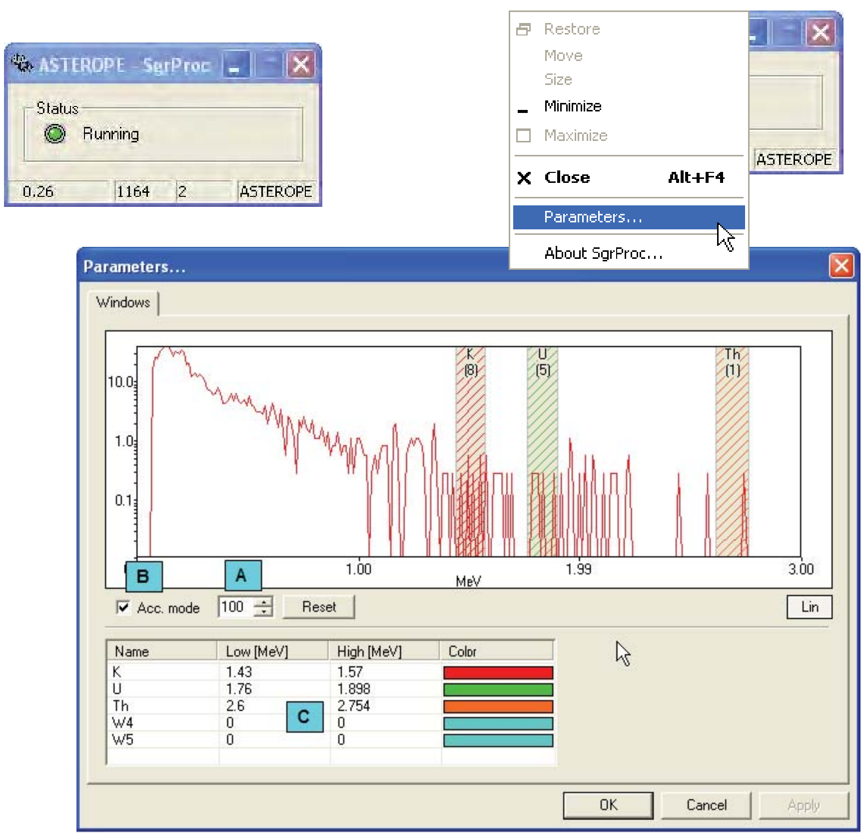


Figure 4-9 *SgrProc configuration*

Raw spectra acquired by the tool can be stacked for a user defined number of samples and averaged. The stack size can be adjusted with the control A. Unchecking the control B (Acc. Mode) will deactivate the stacking operation. At any moment, the stack can be reset by clicking on the Reset button.

Up to five windows can be set. Their tanges may be adjusted from the list (C). The processor computes the number of counts of the stacked spectrum on each window.

K	Counts in K window [cps]
U	Counts in U window [cps]
Th	Counts in Th window [cps]
W4	Counts in the window W4 [cps]
W5	Counts in the window W5 [cps]

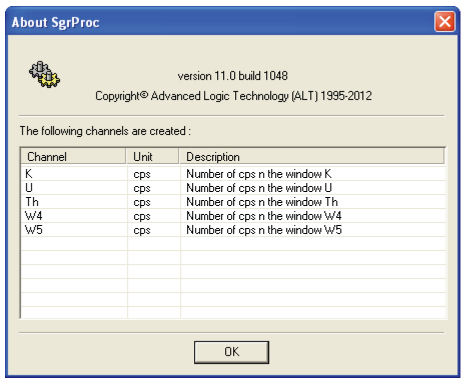


Figure 4-10 *SgrProc About dialog*

4.6.2.2 Full Spectrum Analysis Process – Medusa[1]

This process does the spectrum stabilization and computes the concentration of the nuclides. It's based on a calibration file delivered by the Medusa Company.

K	Concentration of K [Bq/kg]
U	Concentration of U [Bq/kg]
Th	Concentration of Th [Bq/kg]
K-Error	Concentration Error of K [Bq/kg]
U-Error	Concentration Error of U [Bq/kg]
Th-Error	Concentration Error of Th [Bq/kg]
A1	Spectrum Stabilization factor
Chi2	Spectrum Fitting Chi2
StabSpectrum	Energy Stabilized Spectrum

These are the most current channels. The list can be extended depending on the calibration file used by the processor (ex : Cs concentration, …)

[1] *Full-spectrum analysis of natural γ-ray spectra, PHGM Hendriks, J. Limburg, R.J> de Meijer Journal of Environmental Radioactivity 53 (2001) 365-380*

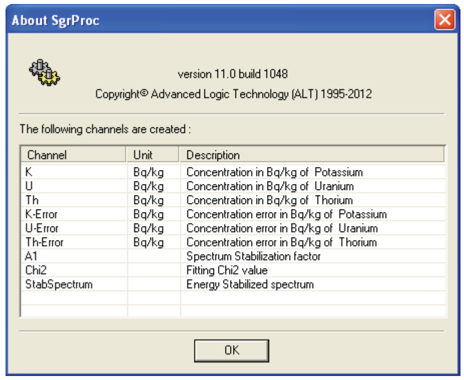


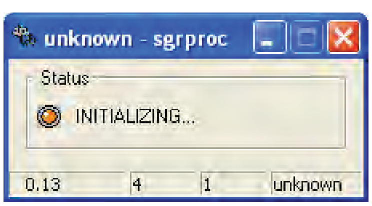
Figure 4-11 *SgrProc About dialog*

The values of the channels can be expressed in other units. This can be done by using the MChNum calibration pages. The following are the conversion factors (CalA) from Bq/kg to % and ppm

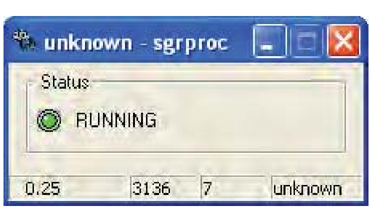
1 % K	= 315.99 Bq/kg K^{40}	1 Bq/kg K^{40}	= 0.0031645 %K
1 ppm U	= 12.35 Bq/kg U^{238}	1 Bq/kg U^{238}	= 0.081 %U
1 ppm Th	= 4.06 Bq/kg Th^{232}	1 Bq/kg Th^{232}	= 0.2457 % Th

How to log :

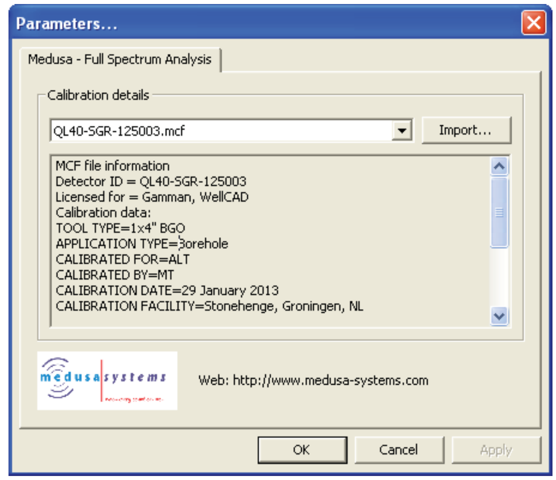
The processor should collect a certain number of spectra to initialize the stabilization process. During this period of time, no outputs are produced and the MChNum numerical displays corresponding to the nuclide concentrations remain black.



When this phase is completed, the real-time stabilization process is running and the concentration of the nuclides are computed and displayed in the MChNum browser.

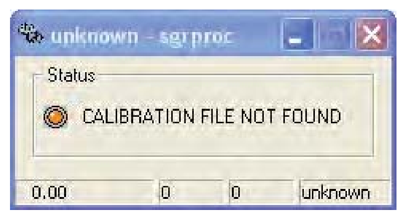


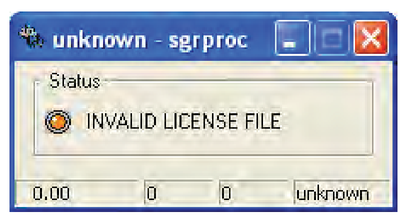
The calibration file details can be accessed from the "Parameters" entry of the menu displayed when right-clicking on the window title.



It is possible from this window to select another calibration file or to import a new one. Calibrations files are stored in the \Tools\Calibrations folder and are displayed in the list.

If the calibration file indicated in the sub file is not found, the corresponding error message is displayed. Select the right calibration file from the "Parameters" dialog box. If a calibration file is not provided, the system still collects the spectra from the tool but does not apply any process to them.
The calibration should be tagged to be used with LoggerSuite or WellCAD. If not, the following message Is displayed. The system still collects the spectra from the tool but does not apply any process to them.





4.6.3 SgrSpectra Browser

The SgrSpectra browser displays the instant spectrum acquired by the tool as well as the stacked spectra generated by the tool or by the browser itself (Settings menu entry). Windows and their related count rates, isotopes, … can be displayed by choosing the corresponding options in the menu.

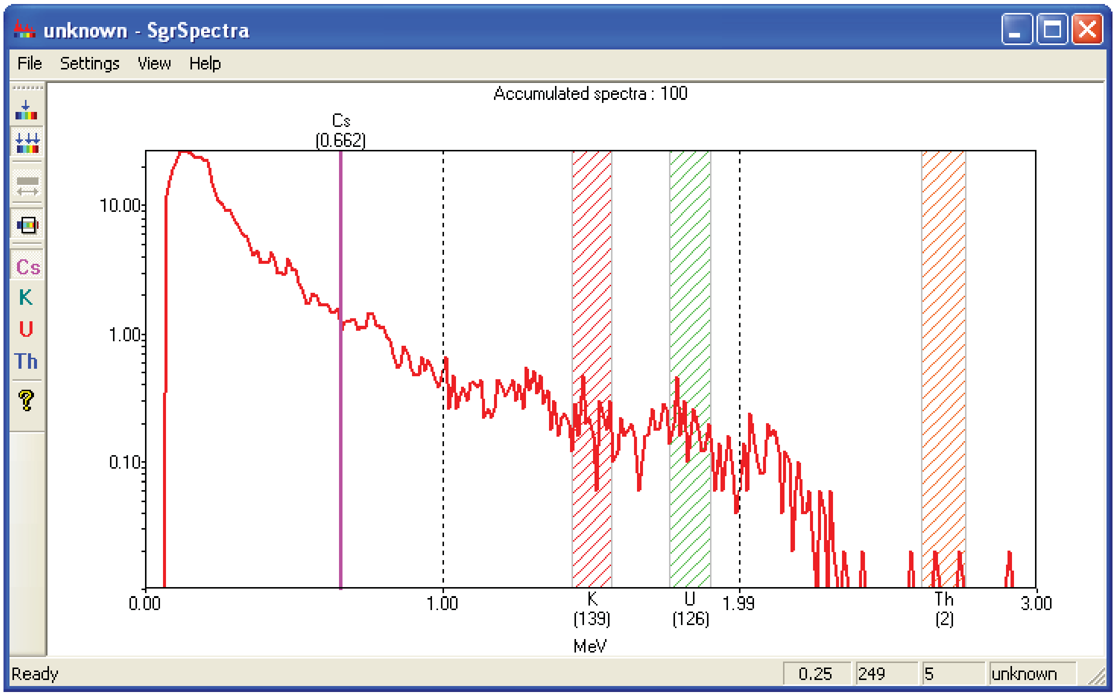
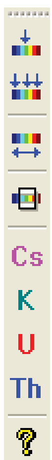


Figure 4-12 *SgrSpectra browser*



Show / hide the current spectrum

Show / hide the stacked spectrum

Show / hide the energy stabilized spectrum (if available) – see figure below

Show / hide windows

Show / hide the Cs energy peaks

Show / hide the K energy peaks

Show / hide the U energy peaks

Show / hide the Th energy peaks

Display the About dialog box

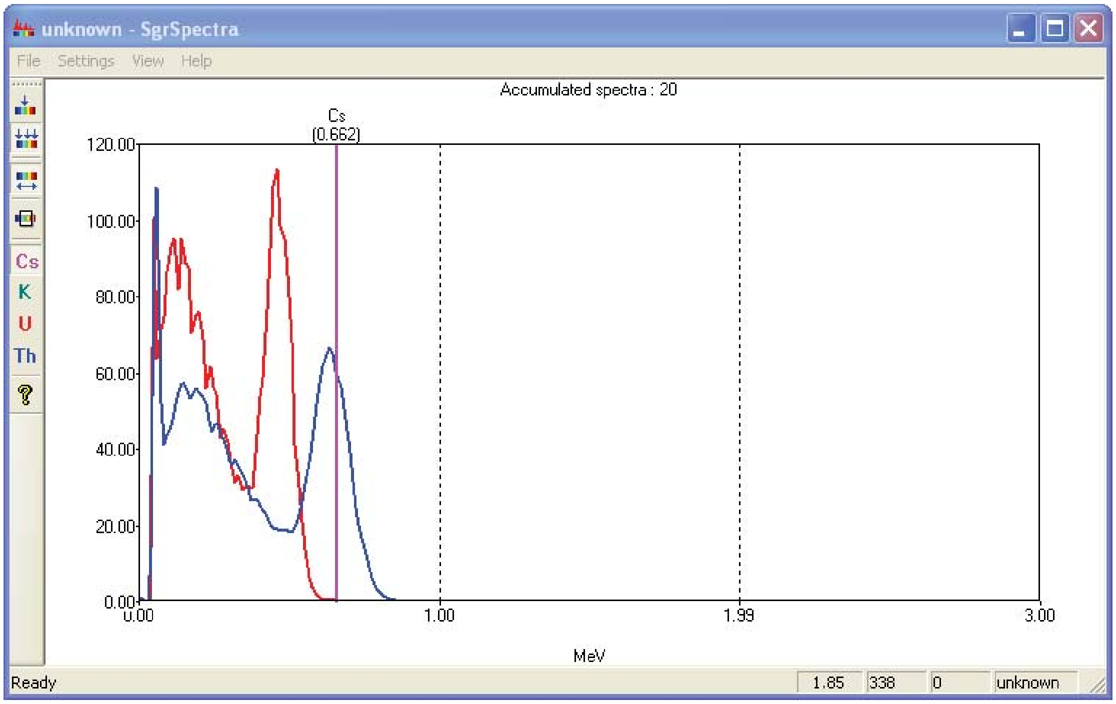
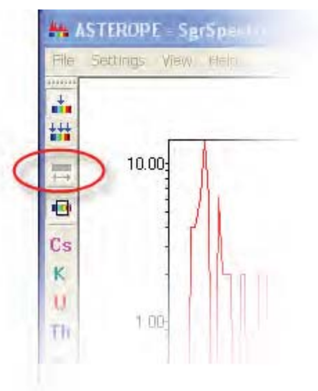


Figure 4-13 *SgrSpectra browser*

The “Stabilized Spectrum” button remains disabled until the processor has acquired enough spectra to stabilize the spectra.



4.6.4 MChNum Browser

The MChNum browser is used to display the numerical values of the channels. The list of channels that can be displayed depends on the process running with SgrProc.

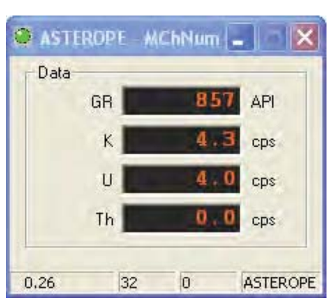
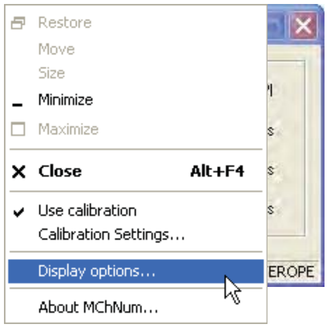
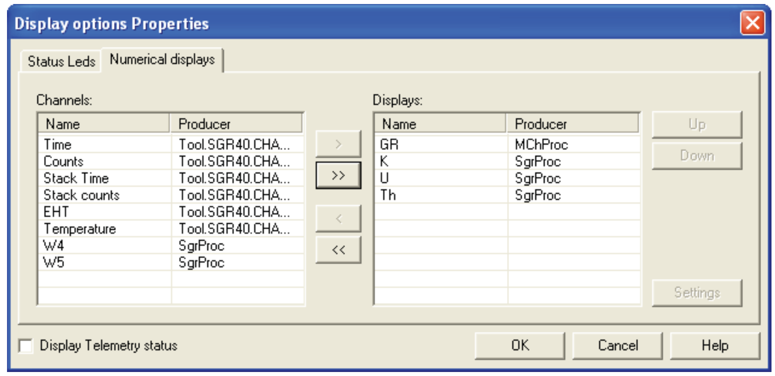


Figure 4-14 *MChNum Browser during operation*

Additional channels can be displayed by right-clicking on the window title and selecting "Display options…" from the context menu.





4.6.5 MChCurve Browser

The MChCurve browser displays the recorded parameters by means of curves in real time (Figure 4-7).

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, gridding,….)

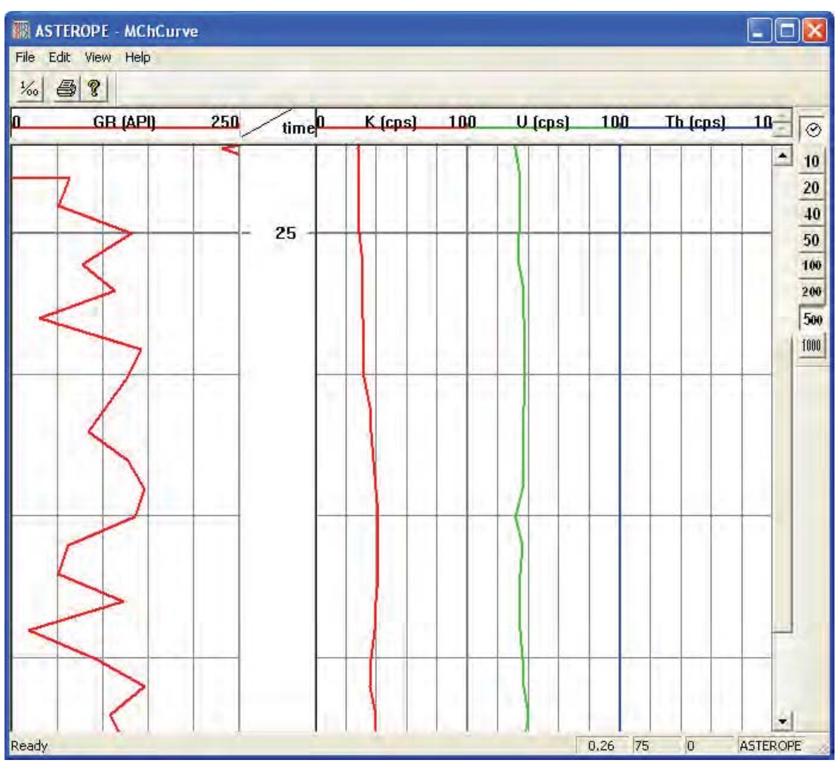


Figure 4-15 *QL40 SGR MChCurve Browser Window*

5 Performance Check & Calibration

Calibrations are performed at the factory and require a basic knowledge and understanding of the tool. Performance checks for the gamma measurement can be made on the surface before logging. With the tool powered on and viewing data on the computer screen a small source of natural gamma radiation can be placed in close proximity to the detector area about 21 cm above the bottom of the probe. An increase in gamma counts will then be observed in the MChNum and MChCurve window if the tool is working properly.

Prepare to Calibrate:

1. Assemble the tool sub(s) and connect to the wireline.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
3. In the **Acquisition Panel** select **Time** and turn it **On**.
4. Click the Green LED at the top left corner of the MCHNum Browser window or right click the top pane to display the MCHNum context menu (Figure 5-1).
5. Select **Calibration Settings**.

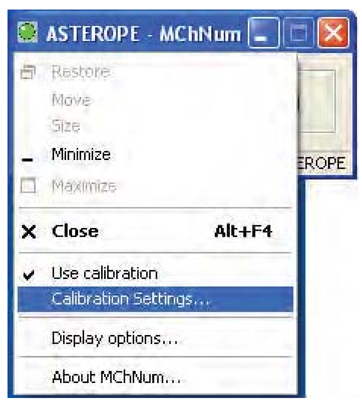


***Figure 5-1** MChNum context menu*

Calibration Settings

1. In order to measure the background radiation, place the tool away from any radioactive material at least 1.5m above the ground or, if available, place the tool in a water tank.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
3. In the **Calibration Settings** dialog box (Figure 5-2) click on **Sample** in the **Background Only** section and wait until an average value has been determined. The corresponding **Value** will be updated automatically. (The number of samples taken can be changed under **Options**.)

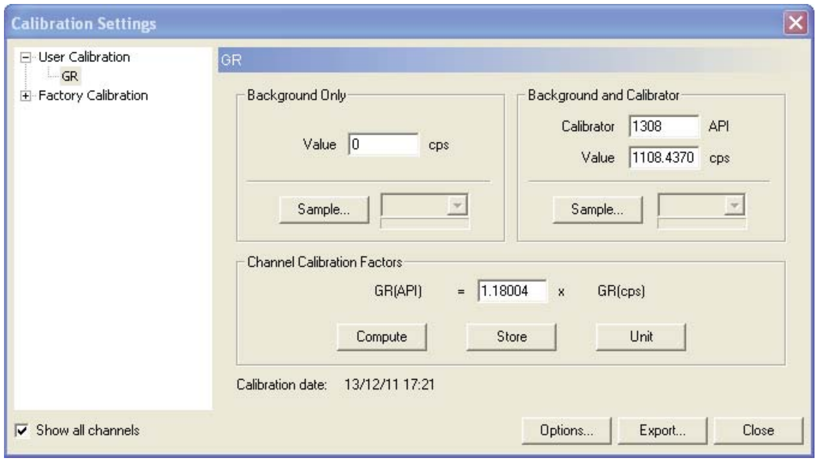


Figure 5-2 *Calibration Settings dialog box*

4. Place the calibrator on top of the sensor or lower the tool into the test pit.
5. Enter the known source strength into the **Calibrator** edit box. If necessary change the units by clicking on the **Unit** button.
6. Click on **Sample** in the **Background and** Calibrator section to determine an average value. The corresponding **Value** will be updated automatically. Click on **Compute** in order to compute the calibration factor.
7. **Store** the new calibration settings in the sub file by clicking on the corresponding button.

On the **Browsers & processors** panel click **Close All** then **Start All** to refresh the other Browsers and Processors. This must be done as they only read the calibration constants from the sub file once when they start.

6 Maintenance

6.1 Upgrading firmware

In accordance with the ALT policy of continuous development the tool has been designed to allow firmware upgrades.

Firmware upgrade procedure is as follows:

1. Checking the communication is valid.
2. Upgrading firmware

6.1.1 Checking the communication

- Connect the tool to your acquisition system.
- Start the data acquisition software.
- In the **Tool** panel select the appropriate tool and turn the power on.
- In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-1 or Figure 6-2).

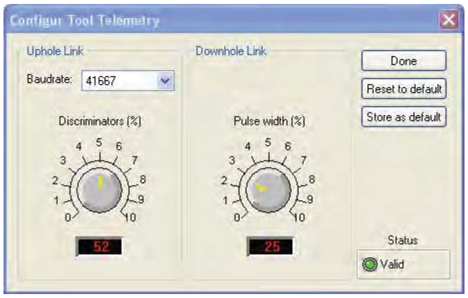


***Figure 6-1** Tool communication settings - ALTLog*

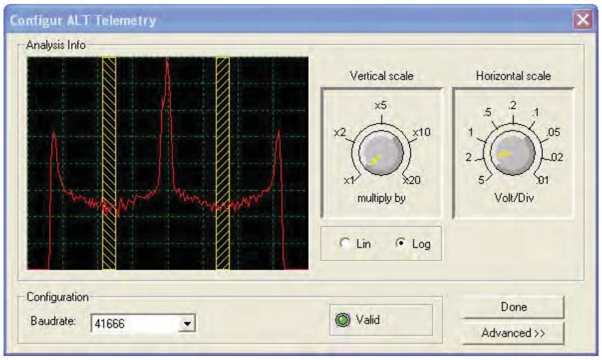


***Figure 6-2** Tool communication settings - Matrix*

Warning: The telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.1.2 Upgrading the firmware

Check that the communication status is valid. **Click** on the “Settings/Commands” button and on the the “Tool Details” button in the dalog. **Click on Upgrade** (Figure 6-3).

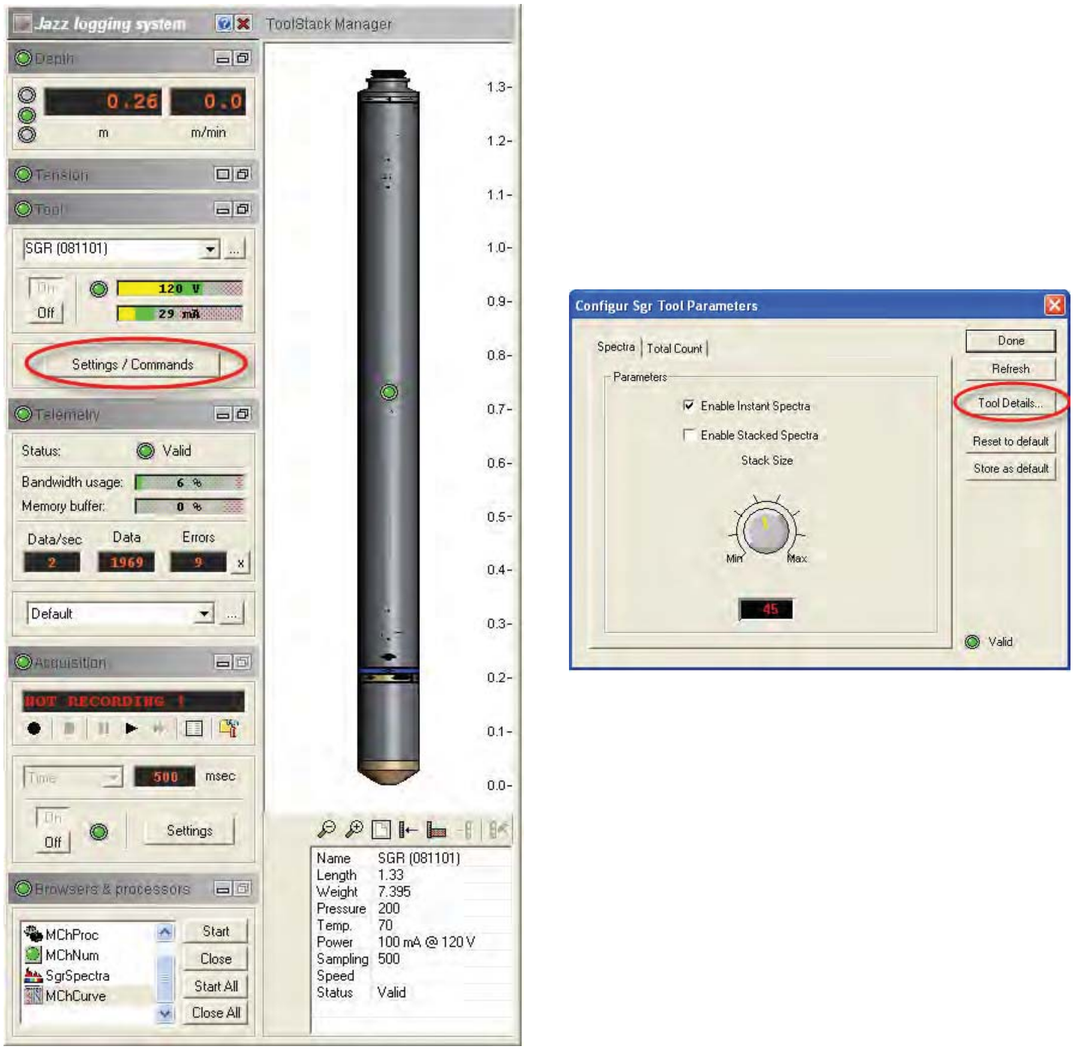


Figure 6-3 *Click on the “Settings/Commands” buttonand on the “Tool Details” button*

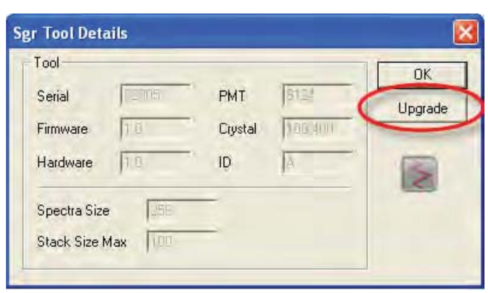


Figure 6-4 *Click Upgrade*

- By clicking on the “Upgrade” button, the following message will appear (Figure 6-4). Click **Yes** to validate your selection.

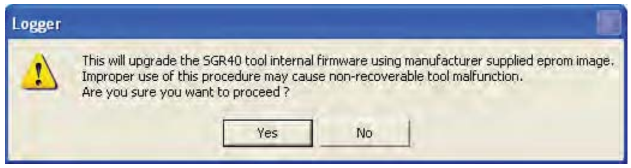


Figure 6-4 *Warning Message during firmware upload*

- Select and open the appropriate **.hex** file provided. The upgrade will start.
- During the upgrade procedure, the following message is displayed:

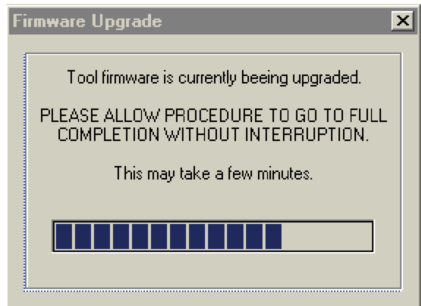


Figure 6-5 *Firmware upgrade progress window*

- Once the upgrade has been successfully completed (Figure 6-6), click on **OK** to turn the tool off.

Figure 6-6 *Successful upgrade*

- Power the tool on to start the upgraded firmware.

Note that the following error message (Figure 6-7) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 6-7 *Error message*

6.2 General Tool Maintenance

The QL40-SGR tool should require no maintenance other than a few salient points.

- Keep the probe and the tool top/bottom connectors clean.
- When the probe is transported, it needs to be contained in a vibration damped container to minimize stress on the sensors.
- The probe top/bottom connector should be periodically cleaned with oil free contact cleaning solvent.

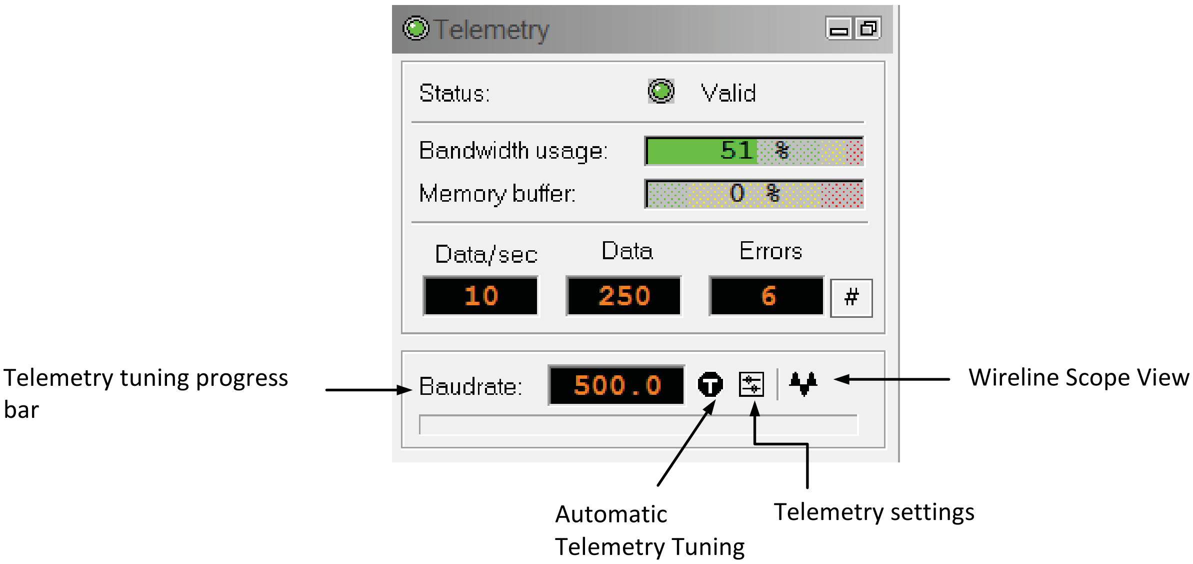
7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been imported using the Logger Settings application (refer to the corresponding manual)? - Did you configure a stack for your tool (at least top, tool body and bottom plug)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use test cable provided by ALT to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu .
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Tool Communication with OPAL/SCOUT

The telemetry provided through the OPAL-SCOUT systems implementing the ALT MODEM adapter is self-tuning. In case communication status is not valid the user has different options to adjust manually the telemetry settings from the telemetry panel of the dashboard:



Baud rate:
Indicates the default baud rate or optimal baud rate in kbps found by the system for the selected winch/telemetry scheme

Automatic Telemetry Tuning:

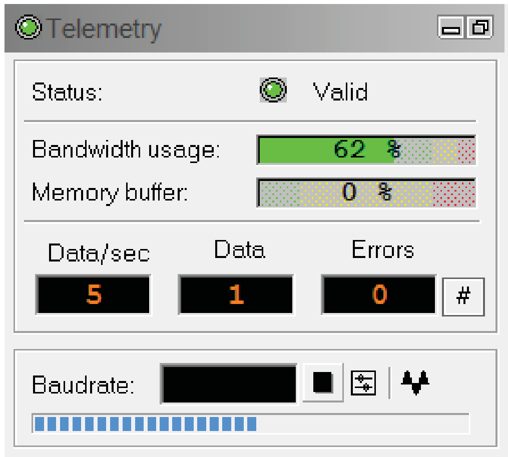
The Tune button resets the telemetry tuning automatically. This process defines:

- the optimum baud rate for the winch configuration selected
- a transfer function and a filter to re-construct at the surface the shape of the pulse trains distorted by the wireline.[2] Refer to the **Equalizer** paragraph for more details.

The Automatic Tuning is very useful on wireline over 1000m length to optimize the telemetry performance and logging speed.

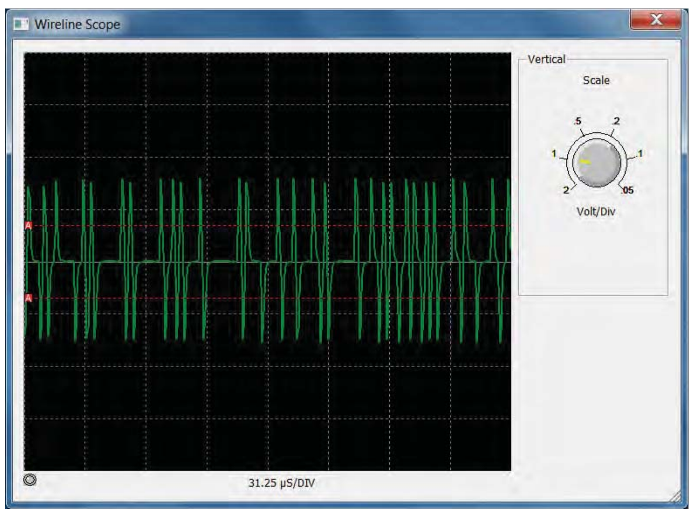
A **progress bar** at the bottom of the telemetry window shows the progression of the telemetry tuning. At the end of the process the baud rate display is refreshed with the optimal baud rate value.

[2] The transfer function and filter concept are only valid for tools implementing the latest generation of ALT MODEM telemetry board (i.e. QL40-ABI2G, ABI-GR-2G, QL40-OBI2G, OBI-GR-2G, QL43-ABI2G,…)



Scope:

Pressing the scope button on the **Telemetry Panel** brings up a **Wireline Scope** view (Figure x), which displays the pulse strings transmitted through the wireline and received by the system at the surface.



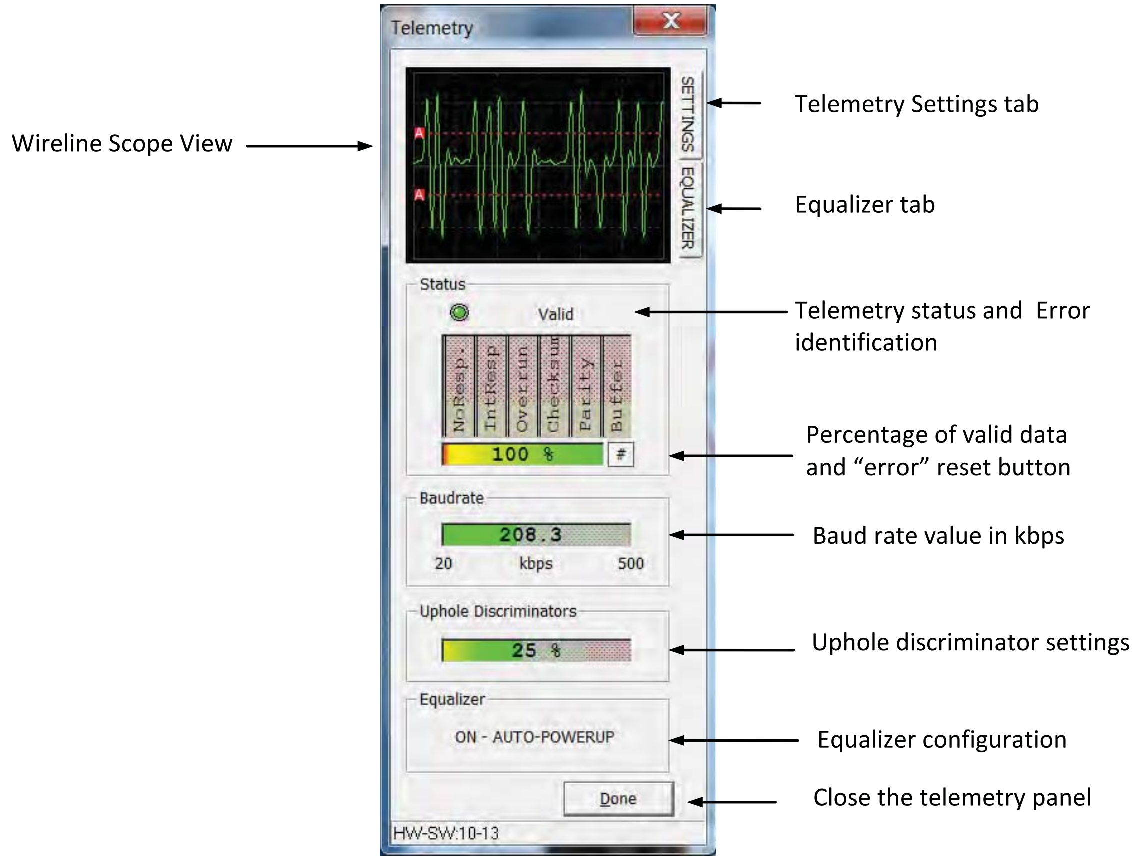
The two red-dashed horizontal lines help to visualize the position of the discriminator levels set for detecting the pulses at the surface. Discriminator levels can be tuned in the **Telemetry Settings** dialog – refer to section 3.6.1 for more information.

The Scale knob can be adjusted to show more or less vertical details. This view has no effect on the communications and is a visual aid only.

Telemetry Settings:

The Telemetry Settings button opens a **Telemetry** control panel summarizing the telemetry status and configuration.

If the system cannot establish a stable communication with the tool, the **Settings and Equalizer tabs** allow the user to modify the telemetry settings and to apply a telemetry filter (Equalizer option)

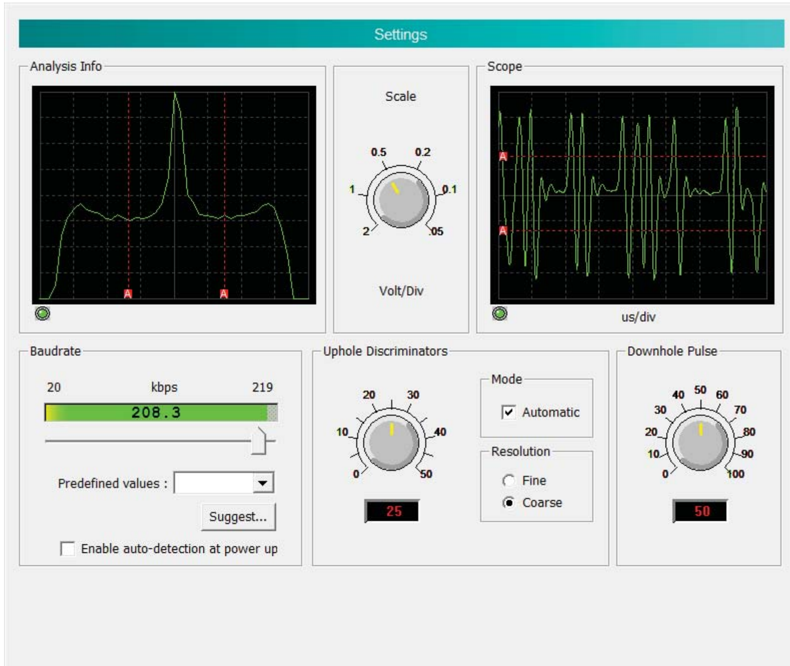


Adjusting the Telemetry Settings:

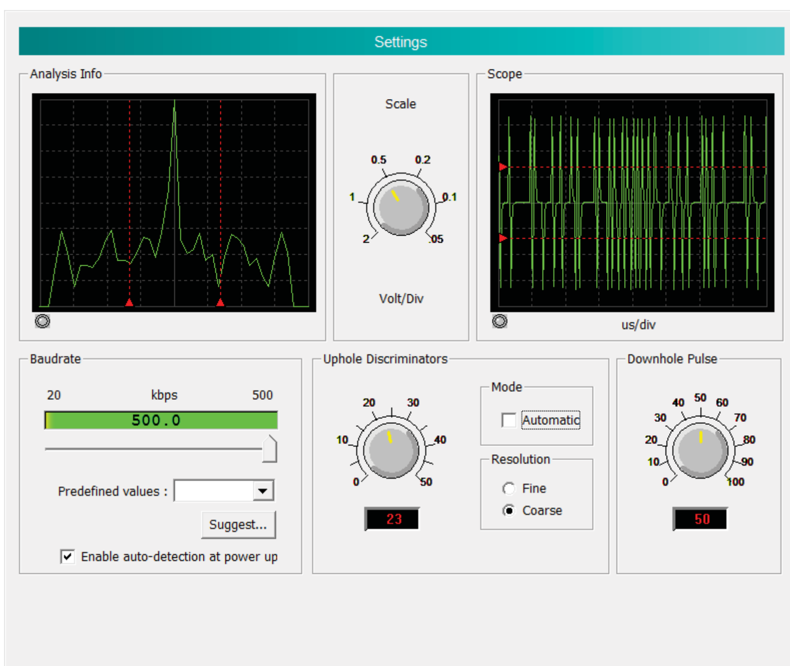
By default the telemetry settings are set to Automatic mode and should stay in this configuration. When more advanced tuning is required (i.e. long wirelines having a limited bandwidth) the manual mode can be activated.

In Automatic mode the uphole discriminators are set automatically to detect the pulse strings.
The position of the discriminator levels are visible on the Scope and Analysis views and are represented by two red dashed lines – one for the positive pulses and the other for the negative pulses.
The "A" letter on the red square means that the discriminators are set in automatic mode.
The **Scale knob** controls the scale for the Analysis and Scope displays.

Position of the discriminator lines should be set as illustrated below.



When the automatic mode is unchecked user has the option to adjust manually the uphole discriminators using either the discriminator knob or by moving interactively the red dashed lines in the Analysis and Scope displays. The red triangles located at the extremities of the red dashed lines refer to manual mode. For fine tuning of the discriminators the **Fine resolution** can be chosen.



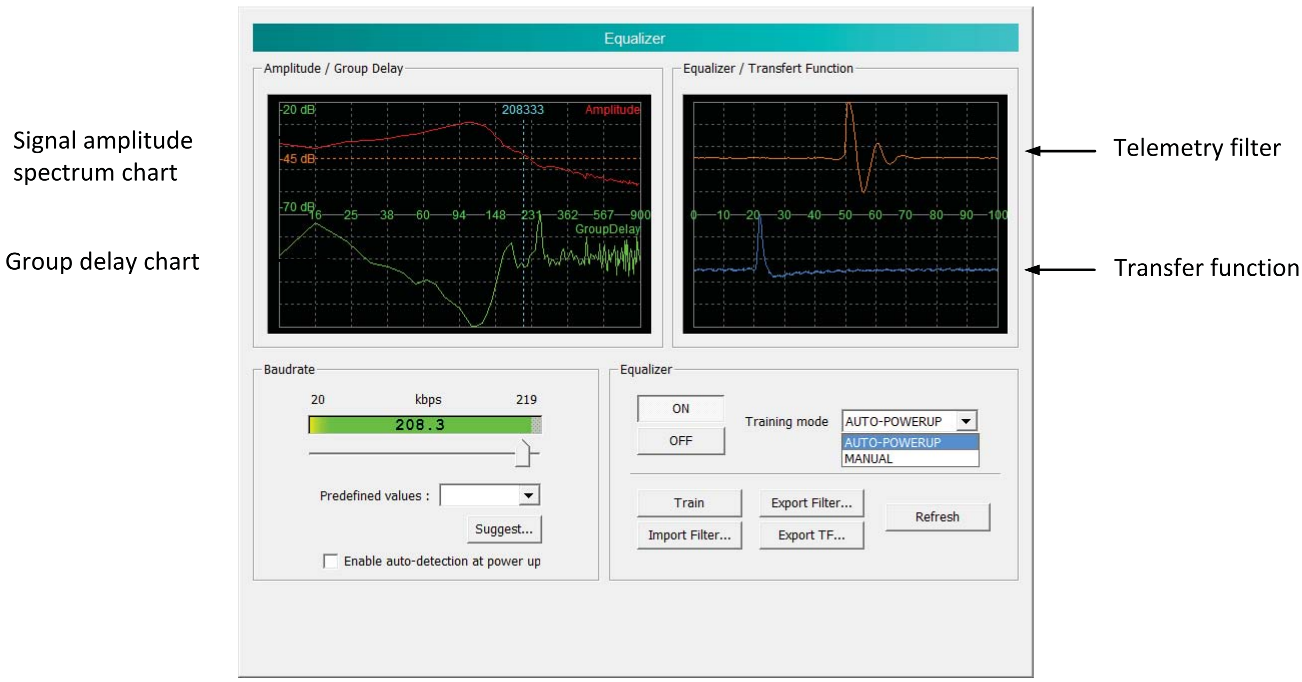
The **Downhole Pulse knob** controls the width of the pulse commands sent to the tool. It is set on 50 as a default value. This value is the preferred one and is suitable for a wide range of wirelines. For long wireline increasing the pulse width could help to stabilize the communication. The reverse for short wireline.

The **Baudrate** is generally set to the maximum value for which the communication status stays valid in order to optimize the logging speed for the wireline configuration.
The baudrate can be adjusted by moving the cursor below the baudrate bar meter or by selecting a predefined baudrate value from the select box.

When clicking the **Suggest** button the system is searching for the optimum baudrate value and keeps this value for the data transmission.

The **Enable auto-detection at power-up** configures the system such a way that the baudrate is reset to its optimum value each time a tool is powered up.

Applying the Equalizer



The **Equalizer** dialog provides some advanced telemetry settings described hereafter.

- The **Train** button computes the transfer function of a wireline - refer to the blue signal.
  When clicking on Train the tool sends a pilot pulse frame to the surface. The received signal at the surface is compared with the original pilot pulse frame to measure the distortion of the signal through the wireline. The result of this process is the definition of a transfer function specific to the wireline used.

  A filter is then derived from the transfer function - refer to the orange signal. The filter will be applied on the telemetry signal to counteract the distortion of the pulse strings through the wireline.
  Applying the filter will thus improve the telemetry performance of the system and logging speed on wirelines with unfavorable band width.

- The **Equalizer ON/OFF** buttons enables or disables the filter. The activation of the equalizer can be configured to **MANUAL** mode or to **AUTO-POWERUP**.

The AUTO-POWERUP feature applies the telemetry filter upon tool power-up.

- The **Export TF** option exports the **Transfer Function** defined by the wireline training process in a ASCII file format
- The **Export Filter** option exports the **Filter** derived from the transfer function in a ASCII format
- The **Import Filter** option loads a saved filter configuration
- The **refresh** button is refreshing the Equalizer/transfer function display

The **Amplitude/Group Delay** charts are mostly used by ALT developers for telemetry signal and performance analysis.

The Equalizer dialog repeats the **Baudrate** settings already discussed in the previous paragraph “Adjusting telemetry settings”.

8.2 Parts list

8.2.1 Spare parts

Item No.	Qty	Part No.	Description
1	1	1673840	Molykote 111 compound
2	2	55459	DIN1810B 40-42 Hook wrench w.pin
3	6	AS215-V-75	O-ring Viton 51414 26.57X3.53 -75°
4	1	L0034-086	Grease Lubriplate

8.2.2 Other parts

Item No.	Part No.	Description
1	QL40GO1	QL40-GO1 tool top
2	QL40GO4	QL40-GO4 tool top
3	QL40GO7	QL40-GO7 tool top
4	QL40MS1	QL40-MSI tool top
5	QL40BOT	QL40 bottom plug

8.3 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- QL40-SGR Wiring Diagram

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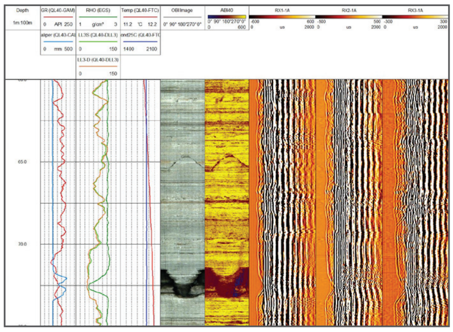
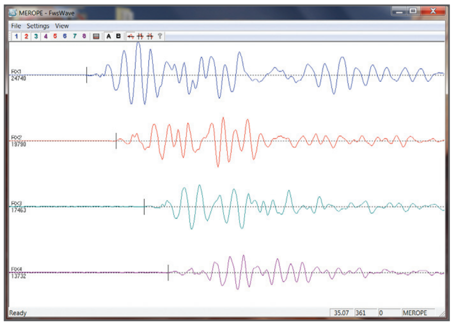
QL40 FWSS Full Wave Form Sonic

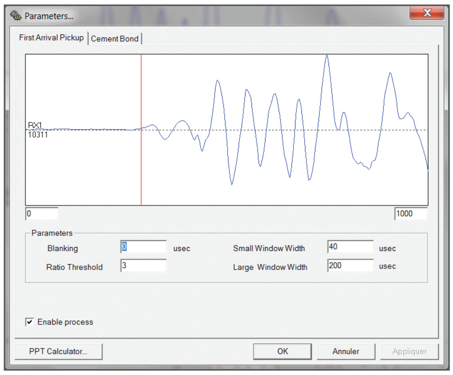
The ALT QL40 full waveform sonic tool - QL40 FWSS - is mainly dedicated for the water, mining and geotechnical industries. Its specification makes it ideal for cased-hole, open-hole applications and also to carry out fractures identification.
Sonic logs are widely used, often in combination with other logs, to provide porosity, permeability and geomechanical properties of the rocks. Under suitable borehole conditions and formations, compressional (P), shear (S), stoneley and tube wave arrivals can be detected.

The QL40 FWSS tool is optimized for such purpose. It implements a high energy source generated by a ceramic-piezoelectric transducer which excites the formations. Real time display and analysis of the recorded full wave forms are performed by the tool.
The QL40 FWSS is supplied as a **bottom sub** of the Quick link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a standalone tool.

The tool can only be operated in a fluid-filled hole. Logging speed depends on tool configuration and acquisition parameters.







Application

· Cased-hole :
  - Cement bond logging (CBL)

· Open-hole :
  - Porosity evaluation
  - Permeability
  - Lithology identification
  - Variation of rock strength
  - Calculation of rock mechanical properties (elastic moduli, poisson's ratio, shear modulus, young modulus, bulk modulus and compressibility)
  - Identification and hydraulic characterization of fractures

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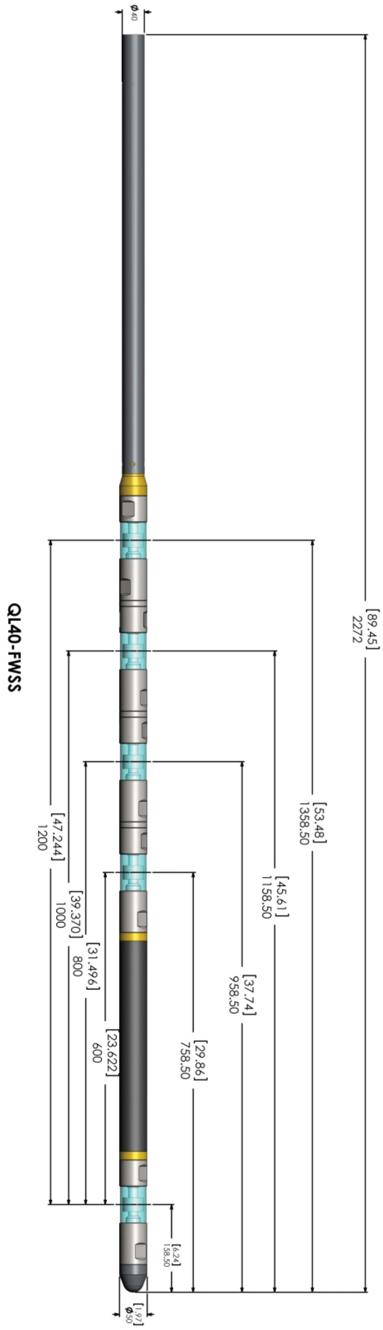
QL40 FWSS Full Wave Form Sonic



Principle of measurement

During logging, a series of high frequency sonic impulses are emitted by the tool. Following their passage through the borehole fluid and formations, they are detected by receivers at various distances from the transmitter. At each receiver the arriving waveform is digitally sampled according to a set of predefined tool configuration parameters (sample rate, sampling period).
The digitized waveforms are subsequently transmitted to the surface acquisition and recording system.

Measurements/derived parameters

· Full waveform per receiver
· Real time p-wave velocity or slowness
· Real time CBL processing
· Additional post processing module available in WellCAD

Operating Conditions

· Fluid filled borehole
· Minimum borehole diameter 60mm
· Centralizers recommended for CBL application

Technical Specifications

Tool

· Diameter: max 50mm
· Length: standard configuration: 2.27m (89.45”) 1TX – 4RX with 0.2m (7.87”) RX separation
· Measurement point: transmitter location
· Max Temp.: 70°C (158°F)
· Max. Pressure: 200bar (2900psi)

Cable

· Cable type: mono, coaxial, 4 or 7 conductor
· Digital data transmission: up to 500 Kbits per second depending on wireline
· Compatibility: ALTLogger – BBOX – Matrix

Sensors

· Transducers: ceramic piezoelectric with 15 KHz resonant frequency
· Sonic Wave Sampling Rate:
Normal Mode: 4 µs
Extended Mode: 20 µs
· Sonic Wave Dynamic Range: 16 bits
· Sonic Wave Sample Length:
Normal Mode: up to 4 ms
Extended Mode: up to 16 ms

The specifications are not contractual and are subject to modification without notice.

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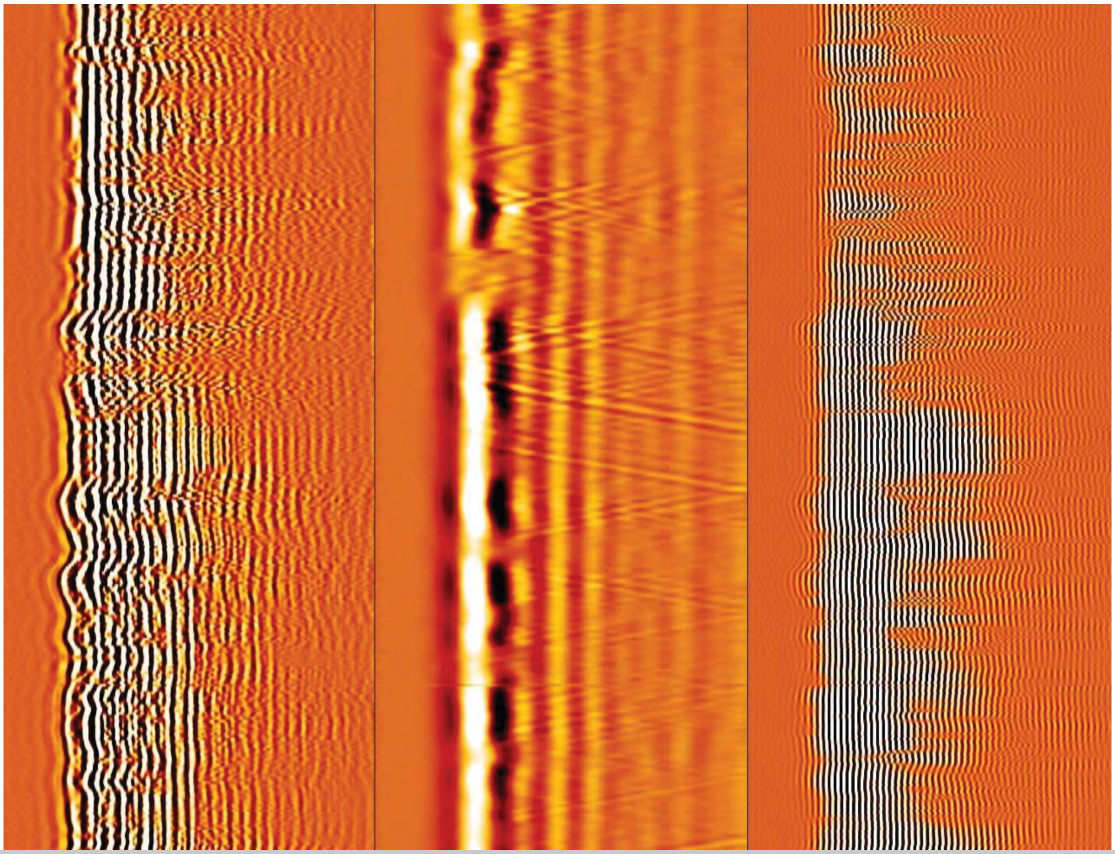
36th Floor, Menara Maxis | Kuala Lumpur City Centre | 50088 Kuala Lumpur | **Malaysia** | Tel. +60 3 2615 7261 | www.alt.lu



User Guide

QL40 FWS-M Broad Band Full Waveform Sonic

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V.19.03.2020

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Table of Contents

1 General Information

The ALT QL40-full waveform sonic tool is mainly dedicated for the water, mining and geo-technical industries. Its specification makes it ideal for cased-hole and open-hole applications and to carry out fractures identification.

Sonic logs are widely used, often in combination with other logs, to provide porosity, permeability and geo-mechanical properties of the rocks. Under suitable borehole conditions and formations, Compressional (P), Shear (S), Stoneley and Tube waves arrivals can be detected.

The QL40-FWS tool is optimized for such purpose. It implements a high energy source generated by a ceramic-piezoelectric transducer which excites the formations in such a way that waves of different frequencies are developed and propagated. Real time analysis and process of the full wave form are performed by the tool to enhance the picking of the different wave propagation modes.

The tool can only be operated in a fluid-filled hole. Logging speed depends on tool configuration and acquisition parameters.

Applications:

- Cased-hole:
  - Cement bond logging (CBL)
- Open-hole:
  - Porosity and permeability
  - Lithology identification
  - Variation of rock strength
  - Elastic moduli
  - Indication of fractures and formation permeability in hard rocks

1.1 Dimensions

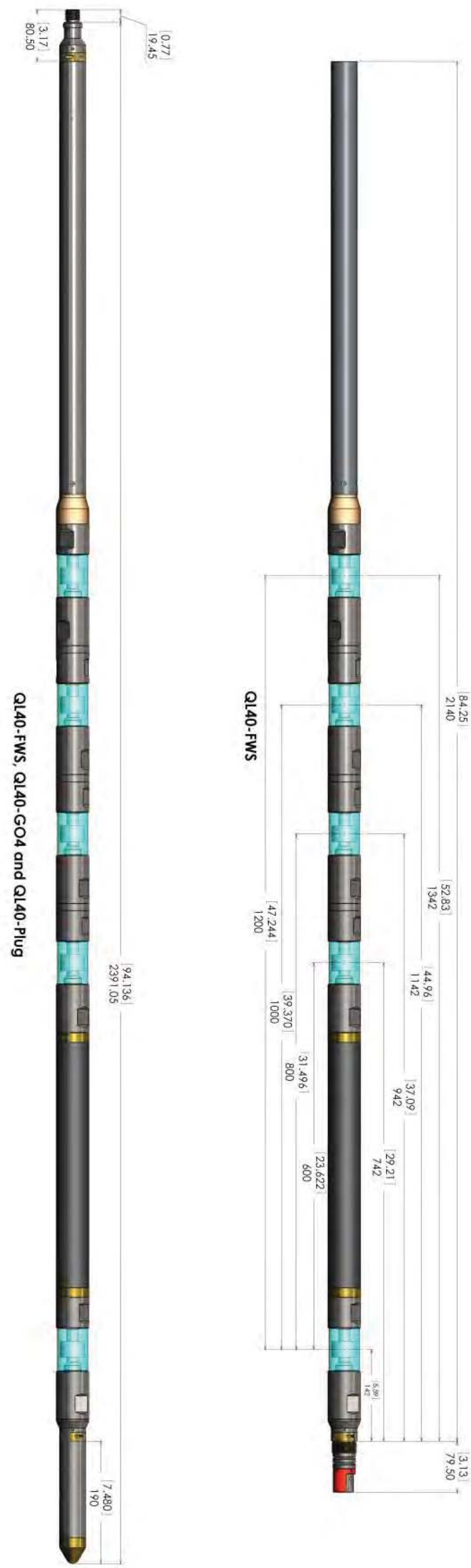


Figure 1-1 *QL40-FWS dimensions*

1.2 Technical Specification

Tool

Diameter:	Max 50mm
Length:	Standard configuration: 1TX – 4RX @ 0.2m RX separation : 2.14m
Measurement point:	Transmitter location
Max. Temp:	70°C
Max.Pressure:	200bar
Operating frequency:	Broad band

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTLogger – Matrix - BBOX – SCOUT – SCOUT PRO - OPAL

Sensors:

Transducers:	Ceramic piezoelectric with 6 KHz resonant frequency
Sonic Wave Sampling Rate:	Normal Mode: 4 µs Extended Mode: 20 µs
Sonic Wave Dynamic Range:	16 bits
Sonic Wave Sample Length:	Normal Mode: up to 4 ms Extended Mode: up to 16 ms

2 Measurement Principle

The QL40-FWS tool measures the time it takes for a sound pulse to travel from a piezo electric transmitter to a receiver at a defined distance. Transmitter and receiver are mounted on the same tool. The acoustic pulse generated by the transducer travels through borehole fluid and rock in various different forms while undergoing dispersion and attenuation.

When part of the energy of the emitted sound pulse arrives at a receiver it does so at different times in form of different types of waves (**Figure 2-1**).

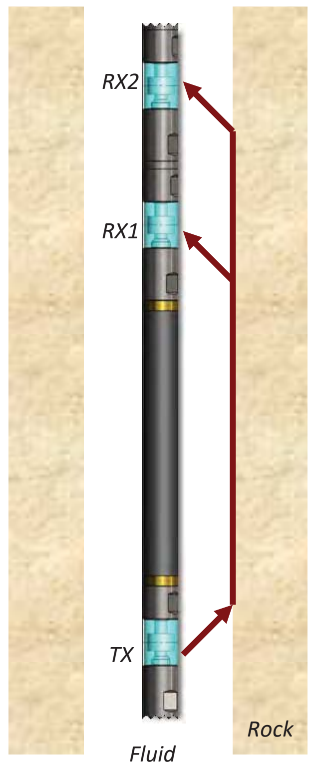


Figure 2-1 *Typical wave path for a 1 transmitter and 2 receiver tool*

Usually it is the compressional wave (P-wave) that travelled through the rock (or pipe) that arrives first followed by shear waves (S-wave), Rayleigh, Stoneley and mud waves. **Figure 2-2** shows a typical sonic trace with received wave forms.

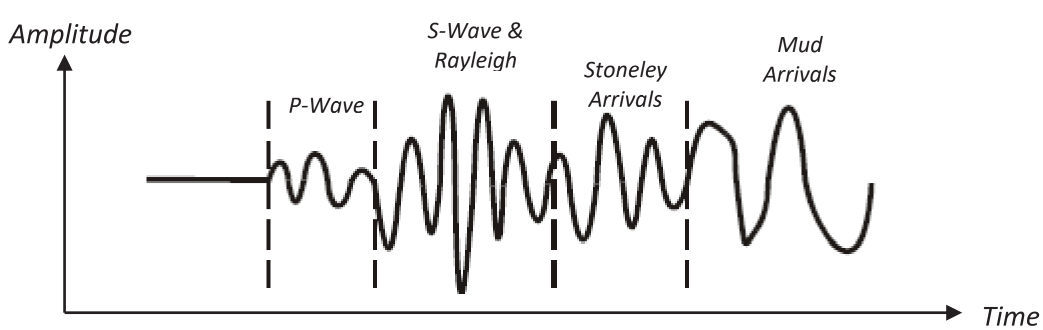


Figure 2-2 *Typical sonic trace with wave form arrivals*

The P-wave is usually the fastest wave but has small amplitudes. The next wave to arrive is the S-wave, which is slower than the P-wave but usually has higher amplitudes. After them come Rayleigh and Stoneley waves, which are associated with energy moving along the borehole wall. The last arrival (mud wave) is a pressure wave that travels through the borehole fluid in the borehole. They can be of high amplitude but always arrive after the two main waves – P- and S-wave.

In cased wells, common application of the sonic tool is the measurement of the degree of cementation of steel casing. It is generally called “Cement Bond Logging”.
It is often important to know how much cement is present in the annulus between casing and formation. The sonic tool is used to measure whether there is cement in contact with the outside of the casing and whether that cement is in contact with the formation.
This can be achieved by measuring the amplitude of the first compressional arrival. Just one transmitter and one receiver is needed for this. The amplitude of the first arrival is linked to the amount of cement bonded to the casing. If there is no cement outside the casing, the sonic wave will travel almost entirely through the casing and return to the receiver with a high amplitude. If there is good, solid cement outside the casing, a large proportion of the sonic wave will be refracted into the cement and formation. The amount of energy returning to the receiver will be less and is corresponding to a low amplitude of the first compressional arrival.

3 Operating Procedure

3.1 Tool setup and handling

<u>Note on centralisers :</u> Tool centralization is mandatory for Cement Bond application. For open hole application, tool centralization is strongly recommended as it helps the detection of the different wave propagation modes.

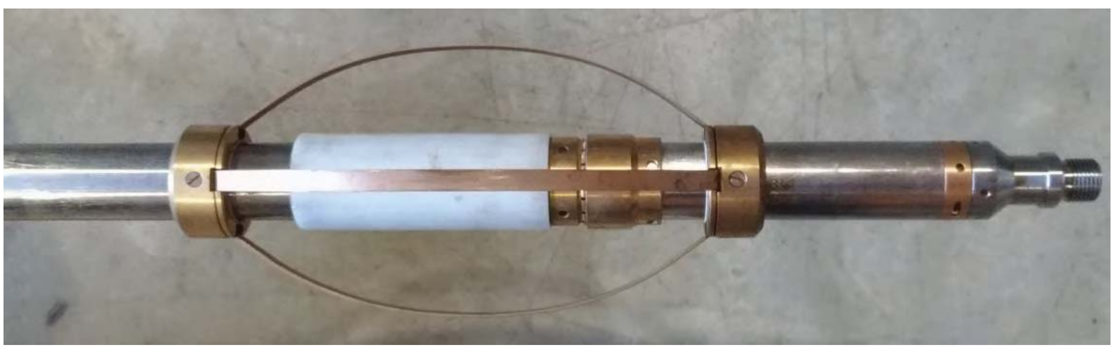
One set of slip over centralisers (ALT26705) is supplied with the tool.

The standard assembly comprises upper and lower mounting rings with sets of bowsprings for different borehole diameters, a locking ring and sleeve. The mounting rings are equipped with a teflon ring in order to eliminate the road noise caused by the friction of the centralisers against the borehole wall.

Two C spanners are also provided for tightening the locking ring.

<u>The following points relating to the use of centralisers should be considered:</u>

The top centraliser should be fitted before mating the tool with the wireline cable head. One centraliser should be placed at the top of the tool and the second one on the tool sub located at the bottom of the QL40-FWS. An aluminum extension bar can also be supplied upon request for this purpose.



Top centraliser assembly

Bottom centraliser assembly

Use the C spanner to fasten the locking ring but take care not to cross thread or over tighten them.

(The weak point of the bowsprings is the welded bearing pin. Take care during assembly as the weld can be broken by reverse bending.)

<u>Note on tool handling :</u> when the QL40-FWS is stacked with other subs, special care should be taken when handling the tool string. On the rig site, it is recommended to lift the tool string using the logging wireline. During this operation, care should be taken and operator must avoid to apply too much flexion on the spacer section of the QL40-FWS.

3.2 Quick Start

Note: Parts of the topics discussed in these sections below assume that the user is familiar with the LoggerSuite acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

1. Connect the QL40 FWS to your wireline and start the data acquisition software.

2. Select the relevant QL40 FWS tool from the drop down list (**Figure 3-1**) in the software's **Tool** panel (if your tool is not listed check that your tool configuration file is stored in the designated folder on your computer).

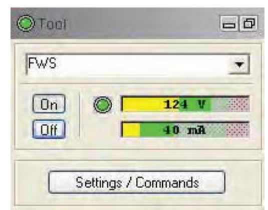


***Figure 3-1** Tool panel*

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings. The configuration returned by the tool is also checked during this procedure.
   Setup tool communication as explained in chapter **3.2** and **3.3** if error message is displayed)

4. On the **Tool** panel (**Figure 3-1**) click the **Settings / Commands** button to configure your tool. (see chapter **3.4** for details).

5. In the **Acquisition** panel (**Figure 3-2**) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

***Figure 3-2** Acquisition panel*

6. Press the **Record** button in the **Acquisition** panel (**Figure 3-3**), specify a file name and start the logging.

7. During logging observe the controls in the **Telemetry** panel:
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

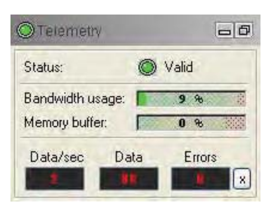


***Figure 3-3** Telemetry panel*

8. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

9. In the **Tool** panel power off the tool.

3.3 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (**Figure 3-4**).

A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialization sequence the next time it is turned on.

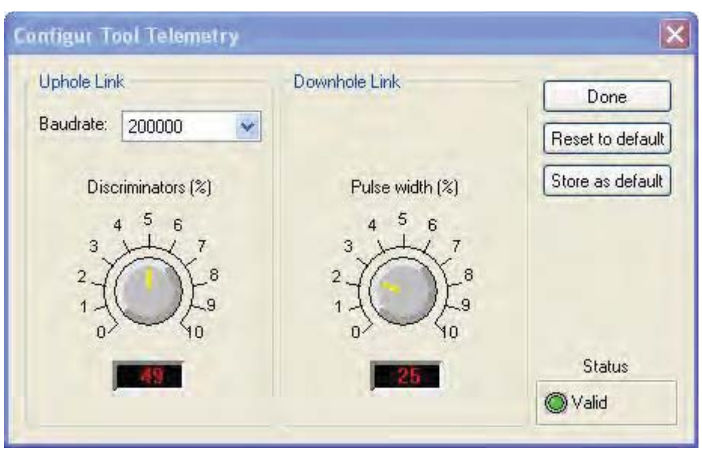


Figure 3-4 *Tool communication settings*

3.4 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (**Figure 3-5**) providing various controls to adjust the telemetry settings and monitor its current status.

The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see **Figure 3-5**) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

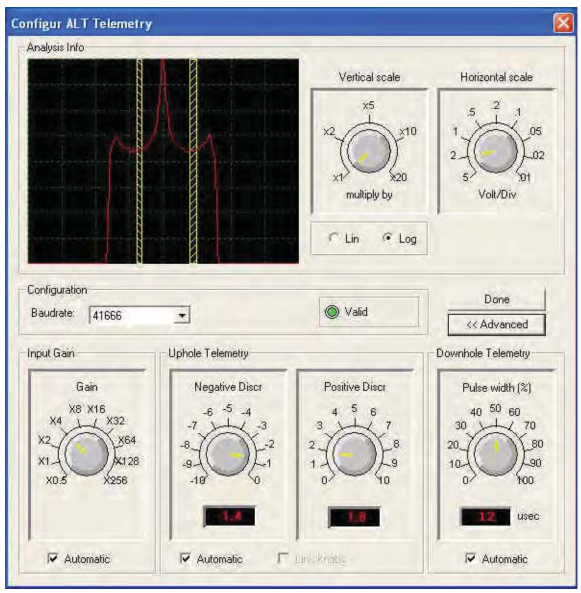


Figure 3-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in “Valid” status the next time the power is turned on.

3.5 Configuring Tool Parameters

The **Configure FWS Tool Parameters** dialog box (**Figure 3-6**) can be accessed by clicking on the **Settings / Command** button on the dashboard's **Tool** panel (**Figure 3-1**).

3.5.1 Transmitter Selection

If your FWS tool is fitted with two transmitters you can choose to operate only one transmitter or both by turning the Transmitter Mode knob (**Figure 3-6**). Turn it to position A or B to operate only a single transmitter or set it to A & B to fire both transmitters in alternance. Transmitter A is the one located closest to the bottom of the tool.

3.5.2 Receiver Selection

The Configure FWS Tool dialog box provides two tabs – TXA and TXB - to choose the receivers to be used with each transmitter. With each transmitter the maximum number of receivers available on the tool can be used.

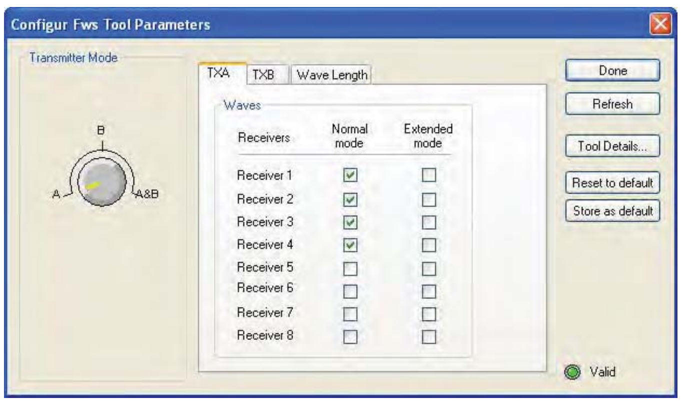


***Figure 3-6** Receiver Selection per transmitter*

Receivers can be operated in different modes:
Normal Mode: A receiver in **Normal** mode samples the received sonic signal in 4 µs steps up to the maximum recording time specified in the Wave Length tab (see section 3.4.3).

Extended Mode: One receiver can be chosen to operate in **Extended** mode. The selected receiver will sample the sonic trace in 20 µs steps up to the maximum recording length. This might be useful when looking for reflected tube waves.

Note: Only one receiver can be chosen for transmitter A and B to operate in **Extended** mode.

3.5.3 Selecting the recording time

The third tab in the Configure FWS Tool dialog box – Wave Length (**Figure 3-7**) – allows the user to set the maximum recording time and hence the length of the recorded full waveform trace in Normal and Extended mode. A maximum length of 16 ms is possible in Extended mode.

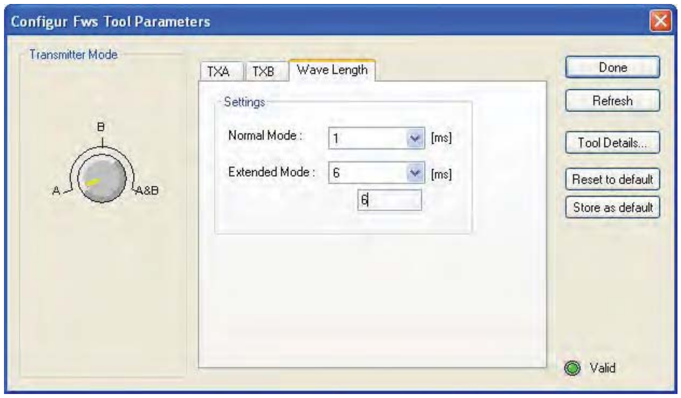


__Figure 3-7__ Definition of recording time

Click on the **Store as default** button to save the new settings into the internal memory of the tool and make the default for future measurements.

3.5.4 Tool Details

Click the **Tool Details** button in the **Configure FWS Tool** dialog box to display a dialog box showing the tool's serial number, firmware and hardware versions, and the transmitter-receiver configuration (**Figure 3-8**). None of the items shown is editable.

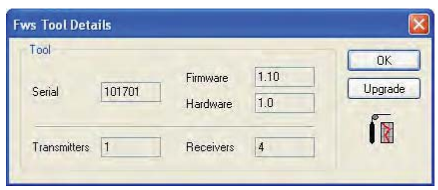


__Figure 3-8__ Tool Details displayed

3.6 Recorded Parameters, Processors and Browsers

The QL40-FWS in combination with the **FwsProc** processor provide in real time three different "Full Wave Form" and "Variable Density Log" outputs corresponding to four operating modes listed hereafter:

- **"Wide Band" -** is the preferred wave output for picking the first arrival of the compressional and shear waves. It will be used preferentially for velocity analysis, Cement Bond analysis, porosity evaluation, rock mechanical properties and lithology identification.

- **"Chevron" -** is the preferred wave output for performing fractures analysis. It is used to help User to detect the fractures in the borehole, to evaluate their extension and hydraulic properties.

- **"Tube" -** this wave output could be used as a permeability index and may help also for the lithology identification. Amplitude should be function of the permeability.

3.6.1 Recorded parameters

For each operating mode, the following data channels are recorded by the tool. Depending on the number of transmitters and receivers used and the chosen receiver mode the number and naming of the recorded data channels may vary.

RX1-1A-Wide Band	Amplitudes of the sonic trace recorded at transmitter A and recorded at receiver 1 (Normal mode) with the Wide Band recording mode
RX2-1A-Wide Band	Amplitudes of the sonic trace recorded at transmitter A and recorded at receiver 2 (Normal mode) with the Wide Band recording mode
RX1-1B-Wide Band	Amplitudes of the sonic trace recorded at transmitter B and recorded at receiver 1 (Normal mode) with the Wide Band recording mode
RX1-2A-Wide Band	Amplitudes of the sonic trace recorded at transmitter A and recorded at receiver 1 (Extended mode) with the Wide Band recording mode

…

The naming convention for the data channels is:

RX*n-mT- operating mode*

where ***n*** is the receiver number, ***m*** defines the receiver mode (1 : normal, 2 : extended) and ***T*** defines the transmitter which generated the wave (A or B).

Please note that additional data channels can be produced by the FwsProc processor. Please refer to the following chapter.

Note: None of the data channels recorded has been shifted in depth. The transmitter location is considered as measurement point.

3.6.2 FwsProc Processor

Processors perform real time operations on the recorded data. For the QL40 FWS tool two processes are supported: picking of the First Arrival and Cement Bond log processing. The FwsProc window (**Figure 3-9**) informs about the running status of the processes.

***Warning!* The FwsProc window must always be active when operating the QL40-FWS. Closing the FwsProc window will stop the record of the full wave forms and will stop all associated real time operations. No data will be recorded!**

If the processor window is not started automatically choose the **FwsProc** entry from the **Browser & processors** panel (**Figure 3-10**) and click on the **Start** button.

Figure 3-9 *FwsProc window*

Figure 3-10 *Start the processor from the Browser & processors panel*

To start or stop a process right click on the title bar of the FwsProc window and select the **Parameters** option from the context menu.
The **Parameters** dialog box will open providing a tab to adjust the processing parameters for each process (**Figure 3-11** and **Figure 3-13**).

First Arrival Pickup

To start the **First Arrival Pickup** process, check the corresponding box in the lower left edge of the dialog box.
User must also select from the drop down list the **full wave form output** (Wide Band, Chevron or Tube) on which the first arrival picking should be applied.

The preview window shows the recorded trace at the first receiver and the determined first arrival pick (red vertical line). The number displayed at the beginning of the trace is the maximum amplitude span found in the actual trace.
The first arrival time will be picked for each selected receiver and output as a data channel. The resulting data channels can be used in formulas to compute P-wave slowness and velocities.

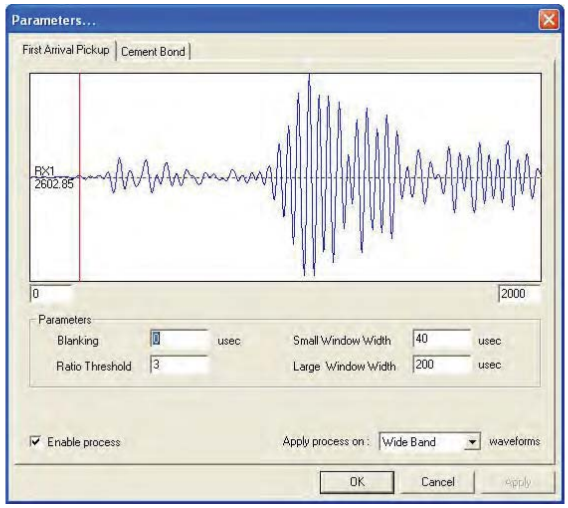


Figure 3-11 *First Arrival Pickup process options*

The process iterates through each trace in the time dimension. For each data point the average of the data values in a time window centered on the actual data point (Small Window = signal window) will be calculated. Another average value will be calculated from the data points falling into a time window preceding the actual data sample (Large Window = noise window). The ratio of small window average and large window average (signal to noise) will be compared against a user specified threshold value. The first time sample for which the computed signal to noise ratio exceeds the threshold will be considered as first arrival intercept.

$$\frac{Small\ Window\ Average}{Large\ Window\ Average} > Ratio\ Threshold$$

Blanking

In the edit box, enter the time period in micro-seconds for which the first arrival detection will be skipped. Using this option, you can blank out noise occurring in the beginning of the traces.

Small Window Width

In the edit box, enter the Small Window time width in micro-seconds.

Large Window Width

In the edit box, enter the Large Window time width in micro-seconds.

Ratio Threshold

In the edit box, enter the Ratio Threshold value.

The following additional data channels will be created by the first arrival pickup process:

RX1-1A - dt	First arrival pick (in µs) at receiver 1
RX2-1A - dt	First arrival pick (in µs) at receiver 2
RX3-1A - dt	First arrival pick (in µs) at receiver 3
RX4-1A - dt	First arrival pick (in µs) at receiver 4

Cement Bond

To start the Cement Bond process, check the corresponding box in the lower left edge of the dialog box.
If a FWS tool is run in borehole with cemented casing, the quality of the bond from casing to cement can be evaluated. The emitted acoustic signal travels through the casing, cement and formation before it reaches the receivers. The sonic waves travelling along the casing are attenuated when energy is lost to the environment behind the casing due to conversion of P- to S-waves, i.e. when the bond is good. As the compressional wave travelling through the casing is generally the first one to reach the near receiver, the Cement Bond Log is the recording of the amplitude of the first arrival of energy on the near receiver.
The first three peaks of the signal at the receiver are traditionally labeled E_1, E_2 and E_3 (**Figure 3-12**).

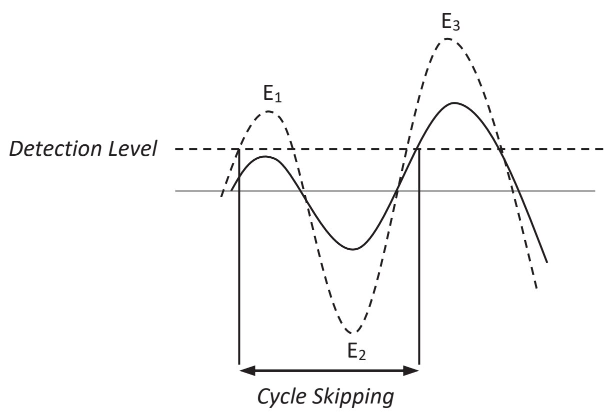


Figure 3-12 *Naming of signal peaks and principle of cycle skipping*

It is the goal of the Cement Bond processing to extract the amplitude of the E1 peak, which leads to judgment of the cement bond quality (low amplitude = good bond, high amplitude = bad bond).
In the case when the bond leads to amplitudes of E_1 so low that they are below the detection level, the first arrival pick would be triggered by E3 instead of E1. This is referred to as cycle skipping (**Figure 3-12**).

Two processes (**Fixed** and **Floating Gate**) will be run in parallel to extract the desired amplitude. In general the maximum amplitude within a time window (also referred to as gate) will be determined. The gate can be opened always at the same fixed time for all traces (**Fixed Gate**) or it can be opened at the time provided by a first arrival pick log (**Floating Gate**) – in the last case the starting time varies from trace to trace. If cycle skipping occurs the Fixed Gate method would return small amplitudes and the Floating Gate method high amplitudes, altogether indicating a very good bond (the E_1 amplitude was so low that the higher E_3 amplitude was detected by the Floating Gate method; **Figure 3-12**).

The Cement Bond options dialog box shows a preview of the sonic trace seen by the first receiver (**Figure 3-13**). The upper part of the preview shows the first receiver trace with the fixed gate start position and width as defined in the corresponding edit boxes. The lower part of the preview shows the trace with the Floating Gate configuration.

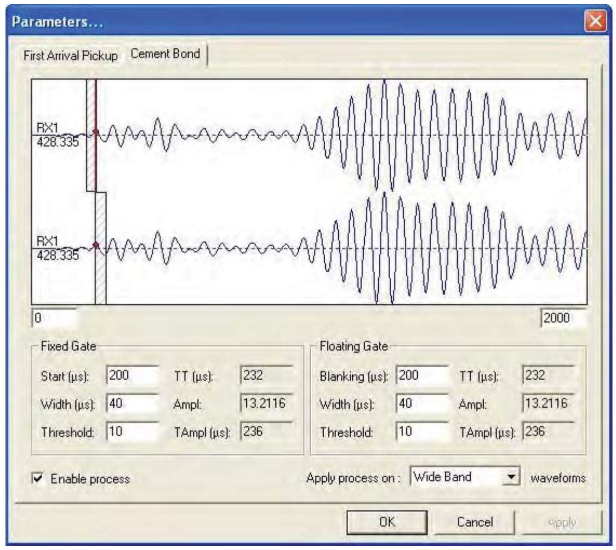


Figure 3-13 *Cement Bond processing option*

From the drop down list, User must first select the **WideBand** wave form output on which the gates and first arrival picking will be applied.

For the Fixed Gate configuration you can enter:

Start(µs): Starting point of the detection gate.
Width(µs): Width of the gate.
Threshold: Amplitude of detection level.

Only signal amplitudes within the gate limits and above the defined detection level will be extracted and recorded.

For the Floating Gate configuration you can adjust the following parameters:

Blanking(µs): Only first arrival times beyond the blanking period are considered as valid starting point for the gate.
Width(µs): Width of the gate.
Threshold: Amplitude of detection level.

For each gate the gate starting time (**TT(µs)**), extracted amplitude (**Ampl**) and intercept time of the amplitude (**TAmpl(µs)**) are displayed.
The following additional data channels will be created by the cement bond process:

TT0	Start time of fixed gate (in µs)
TAmpl0	Time at which fixed gate amplitude was derived (in µs)
Ampl0	Amplitude from fixed gate
TTX	Start time of floating gate (in µs)
TAmplX	Time at which floating gate amplitude was derived (in µs)
AmplX	Amplitude from floating gate

About FwsProc
When right clicking on the FwsProc window title bar the **About FwsProc** dialog box can be opened.

The dialog box provides information about the software version and the names of the recorded data channels.

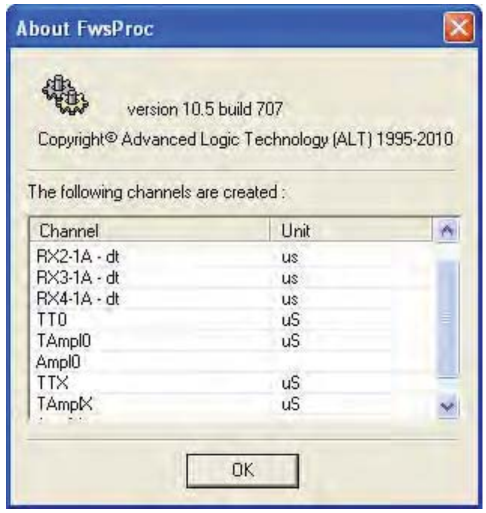


Figure 3-14 *FwsProc version and channels produced*

3.6.3 FwsWave Browser

The FwsWave browser displays the waves acquired on each receiver in real time. The **1**, **2**, … **8** toolbar buttons allow selection of the waves detected by the different receivers to be displayed. The **A** and **B** toolbar buttons allow display of the received waves fired by the transmitter **A** or **B** respectively. The Extended Wave is displayed in the bottom part of the window.
User can also choose between one of the four full wave form output (Wide Band, Chevron or Tube).

All these options are either available from the toolbar or from the menu.

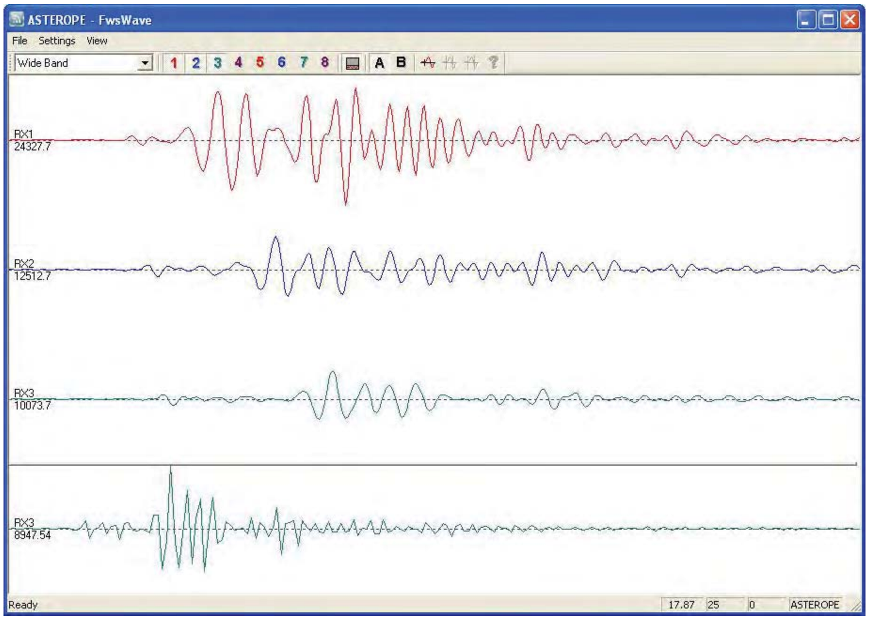


Figure 3-15 *FwsWave browser - Receivers 1 to 3 from Transmitter A – Extended mode on Rx3 – "**Wide Band" wave output***

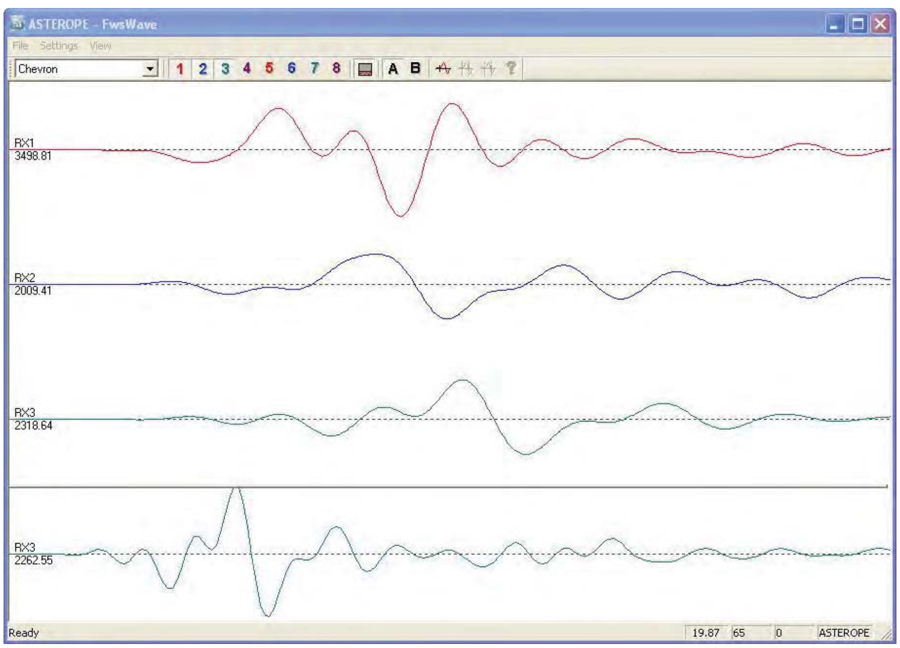


Figure 3-16 *FwsWave browser - Receivers 1 to 3 from Transmitter A – Extended mode on Rx3 – "**Chevron" wave output***

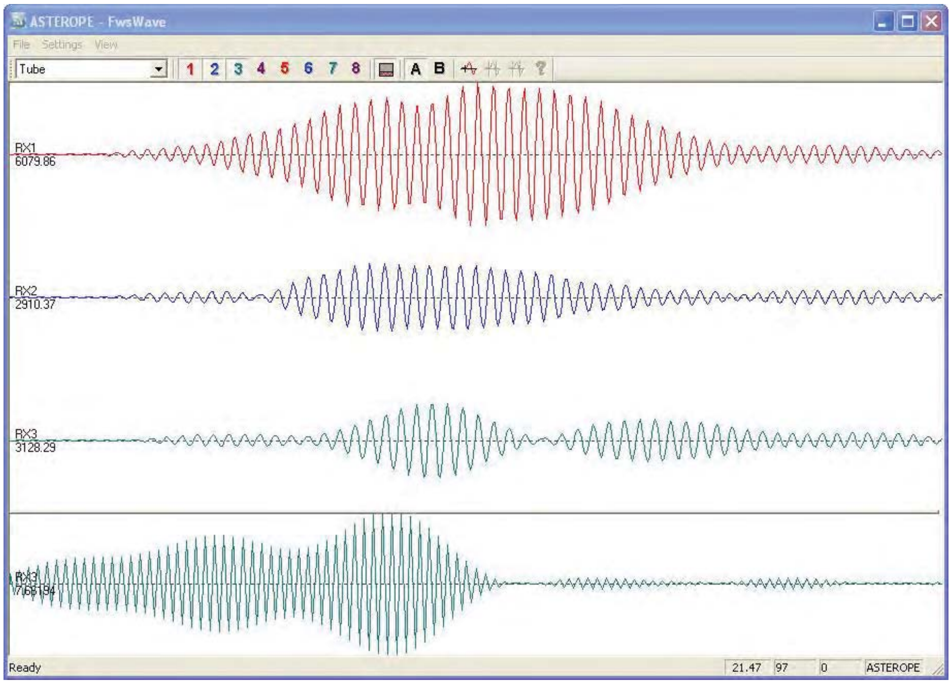


Figure 3-17 *FwsWave browser - Receivers 1 to 3 from Transmitter A – Extended mode on Rx3 – **"Tube" wave output***

3.6.2 MChNum Browser

Figure 3-18 and ***Figure 3-19*** show a typical example of the numerical values displayed in the MChNum browser window during logging. The display can be modified by right-clicking on the browser window and selecting the **Display options** entry.
From the **Display options properties** dialog box add or remove the channels to display.
It is also possible to change the format of decimal digits displayed for a channel. Select the channel and click on "Settings" to configure the number of digits after the period.

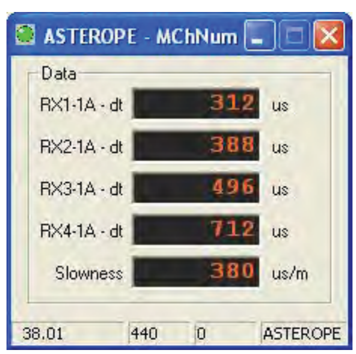


Figure 3-18 *MChNum browser (OpenHole display)*

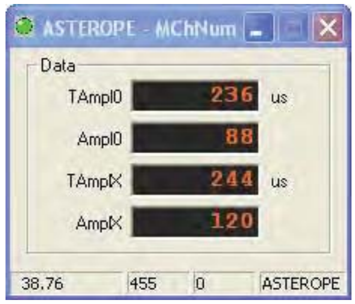


Figure 3-19 *MChNum browser (Cement Bond display)*

3.6.3 WellCad Browser

The **WellCAD Browser** is an add-on module allowing WellCAD software to be connected to ALT acquisition systems. While logging, WellCAD borehole documents will receive the data stream in real time offering the operator all WellCAD data edition capabilities for preprocess or quality check operations. Data can be saved, additional data loaded and templates can be applied.

More specifically when operating the QL40-FWS tool, WellCad browser offers the possibility to display in real time the full wave forms recorded by each receiver as "**Variable Density Logs" – Figure 3-20**.

In addition, when combined with **WellCad Full wave sonic module**, User can access to various Full wave sonic process options.

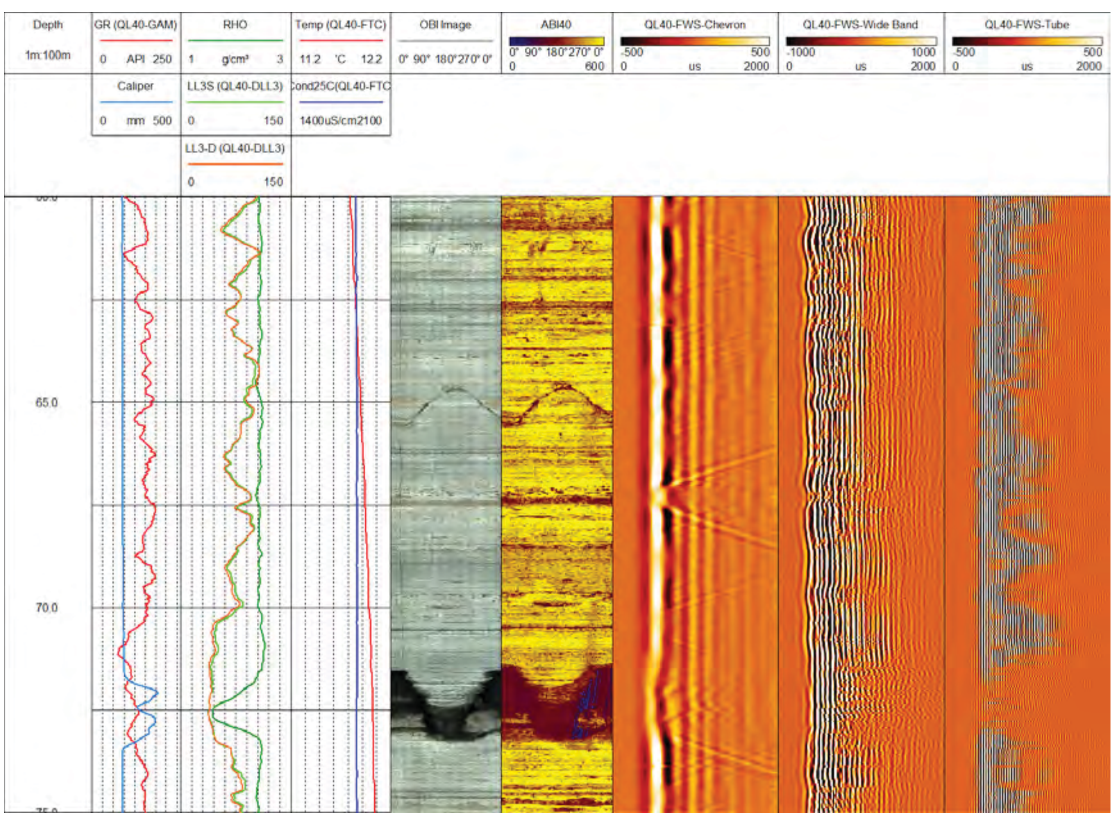


Figure 3-20 *Example of WellCad browser display*

4 Performance Check & Calibration

There is no specific performance check or calibration procedure recommended by ALT. When starting the sampling after powering on the tool the firing of the transmitter pulse should be heard even in air. A test borehole or water filled pipe could be used to check the correct operation of the tool over time. Reported slowness when the tool is centered in water-filled steel pipe is 183 – 190 uS/m or 56 – 58 uSec/ft.

5 Maintenance

Warning: Removing the electronic chassis from pressure housing without prior consultation with ALT will void the tool warranty.

5.1 Upgrading QL40 FWS firmware

In accordance with the ALT policy of continuous development the QL40-FWS has been designed to allow firmware upgrades. The current version of firmware installed in a tool may be verified in the **Tool Details** window opened from the **Tool Settings** dialogue box.

Firmware upgrade procedure is as follows:

1. ***Checking the communication is valid.***
2. ***Upgrading firmware***

5.1.1 Checking the communication

1. Connect the QL40 FWS tool to your acquisition system.
2. Start LoggerSuite software.
3. In the **Tool** panel select the appropriate tool and turn on the power.
4. In the Communication panel, select Settings. Check baud rate is set to 41666 and communication status is valid.

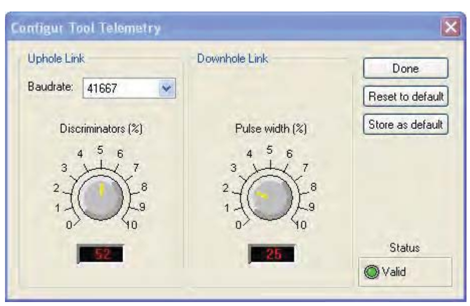


Figure 5-1*Tool communication settings - ALTLog*

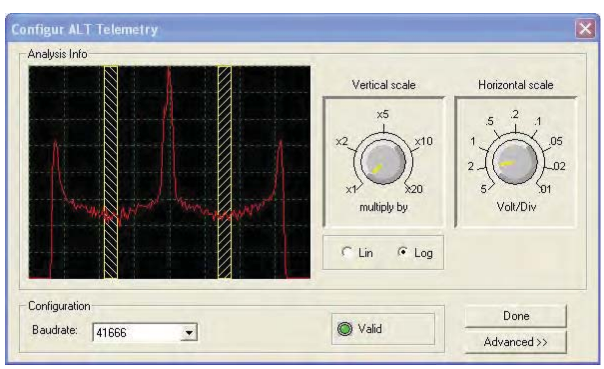


Figure 5-2 *Tool communication settings - Matrix*

Warning: Telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

5.1.2 Upgrading the firmware

In the **Tool** panel, select **Tool settings/commands**. Check that the communication status is valid.

1. Click on **Tool Details**. Note that the firmware version currently in use is displayed in the firmware box. Click on the **Upgrade** button.
2. The following message will appear. Click **Yes** to validate your choice.

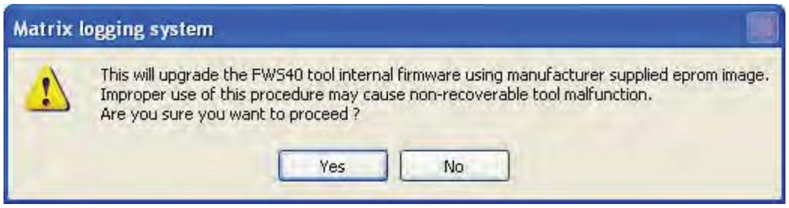


Figure 5-3 *Warning Message during firmware upload*

3. Select and open the appropriate **.hex** file provided. The upgrade will start.
4. During the upgrade procedure, the following message is displayed:

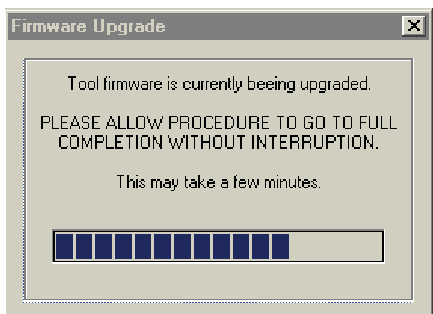


Figure 5-4 *Firmware upgrade progress window*

5. Once the upgrade has been successfully completed, click on **OK** to turn off the tool.

Figure 5-5 *Successful upgrade*

6. Power on the tool to initialize the upgraded firmware. Check in **Tool settings/commands** and **Tool details** that the firmware version has been changed with the new one.

Note that the following error message will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 5-6 *Error message*

6 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a tool configuration file? - Has the tool configuration file been copied into the correct folder? Refer to LoggerSuite manual about details of the directory structure.
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 3.2 or 3.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 3.4).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V for ALT tools).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use the test cable provided by ALT to verify the tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 3.2 or 3.3). - If problem cannot be resolved contact support@alt.lu .
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease tool resolution, adjust tool parameters and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 3.2 or 3.3). - Check bandwidth usage and telemetry error status.

7 Appendix

7.1 Parts list

7.1.1 Tool delivery kit QL40-xxx (ref. 209-016)

Item No.	Qty	Part No.	Description
1	1	210-002	Silicone grease Molykote111
2	2	211-004	C-spanner 40-42 (QL40-43)
3	6	AS215-V-75°	Oring-V 26.57 x 3.53 75°
4	1	210-003	Grease Lubriplate L0034-086

7.2 Technical drawings

The following technical drawings are available on request:

- Acquisition system wiring diagram.
- QL40 FWS Wiring Diagram.

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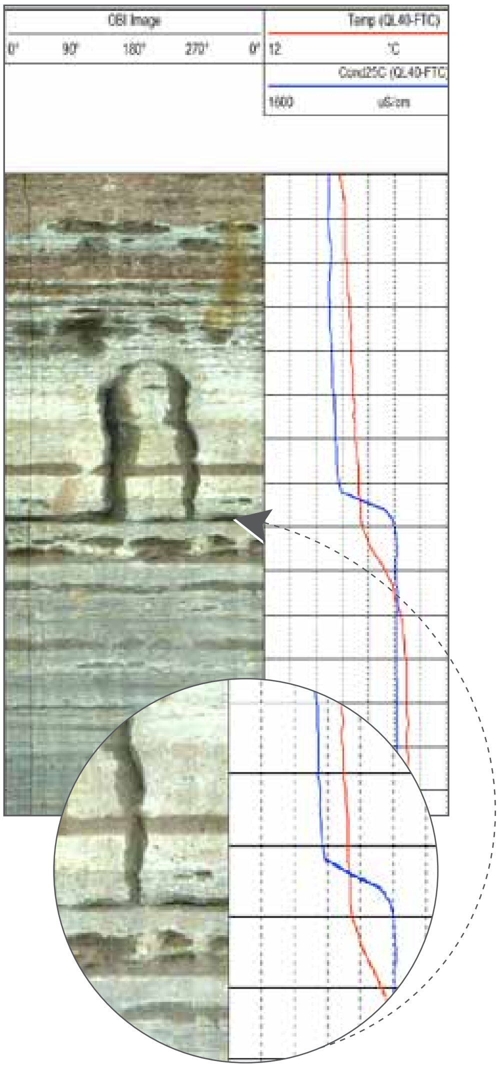
QL40-FTC Fluid Temperature and Conductivity probe

The QL40-FTC sub provides borehole temperature and fluid conductivity measurements. In comparison with tools from competitors, the QL40-FTC is capable of recording a wide range of conductivity from fresh to highly saturated water.
The borehole fluid temperature measurement is helpful to detect anomalies caused by events such as fluid flow into the borehole. It is also used to normalize the conductivity measurement which is temperature dependent and so allowing comparisons between boreholes.

The borehole fluid conductivity is directly proportional to the concentration of dissolved minerals. It is generally used in hydrogeology to determine the concentration of dissolved ions in the aquifers and to locate the fluid flows occurring in the borehole.

The QL40-FTC is supplied as a bottom sub. It can be combined with other logging tools of the QL (Quick Link) product line or can be operated as a standalone tool. It is compatible with Matrix, BBOX and ALTlogger acquisition systems.



Application

- Fluid conductivity – salinity
- Salt-water intrusion studies
- Identification of fluid flow in open/cased hole
- Localisation of the water table
- Localisation of water intervals of different quality
- Water-well monitoring
- Geothermal gradient logging
- Often used in the implementation of temperature compensation equations for other logs

Advanced Logic Technology

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QL40-FTC Fluid Temperature and Conductivity probe

Principle of measurement

Borehole temperature is measured with a sensor based on a fast response semiconductor device whose output voltage changes linearly with temperature. The temperature sensor is located in a stinger at the top of the sensor body in the center of the three exit ports where the borehole fluid returns to the well bore.

Borehole fluid conductivity is measured using a seven electrode mirrored Wenner array. The conductivity array is an internal cylindrical array open at the bottom of the probe. Borehole fluid passes by the array as the probe is lowered in the hole. The array is completely shielded from the outside borehole, so that only fluid conductivity is measured.

Measurements / Features

· Fluid temperature in °C
· Fluid conductivity in µS/cm or mS/cm
· Compensated conductivity at 25°C in µS/cm or mS/cm

Operating Conditions

· Open or cased hole
· Temperature measurement: dry or water filled borehole
· Conductivity measurement: water filled borehole
· Always run downwards as the first log in order to minimize the fluid disturbance
· Compatible with Matrix, BBOX and ALTlogger systems
· Can be combined with other QL subs

Technical Specifications

Tool

· Diameter: max 42.3mm (1.67”)
· Length: 0.78m (30.7”)
· Weight: 3.35kg (7.2lbs)
· Operating Temp.: 0 - 70°C (32 - 158°F)
· Max. Pressure: 200bar (2900psi)

Measurement point

· Temperature: 0.09m up from bottom
· Conductivity: 0.06m up from bottom

Power

· DC voltage at probe top: Min 80 VDC
Max 160 VDC
Nominal 120 VDC
· Current: Nominal 25mA

Temperature measurement

· Range: -20 to 80°C
· Accuracy: < 1%
· Resolution: 0.004°C

Conductivity measurement

· Range: 5µS/cm to 2.5 x 10^5 µS/cm
· Accuracy: 1% (500 – 2.5 x 10^5 µS/cm)

The specifications are not contractual and are subject to modification without notice.

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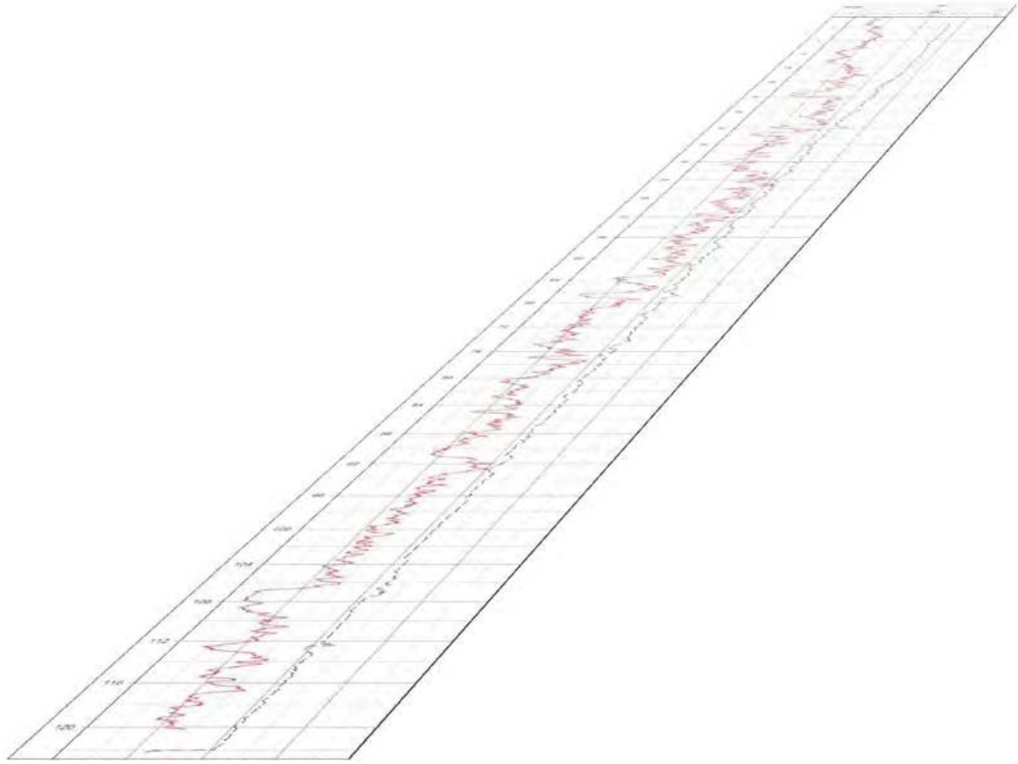

User Guide

QL40 FTC and **40FTC** Fluid Temperature and Conductivity Probe

MOUNT SOPRIS INSTRUMENTS

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Table of Contents

1 General Information

The QL40 FTC and 40FTC logging tools provide borehole temperature and fluid conductivity measurements. In comparison with tools from competitors, the QL40-FTC / 40FTC is capable of recording a wide range of conductivity from fresh to highly saturated water.

The borehole fluid temperature measurement is helpful to detect anomalies caused by events such as fluid flow into or out of the borehole. It is also used to normalize the conductivity measurement which is temperature dependent and so allowing comparisons between
boreholes.

The borehole fluid conductivity is directly proportional to the concentration of dissolved minerals. It is generally used in hydrogeology to determine the concentration of dissolved ions in the aquifers and to locate the fluid flows occurring in the borehole.

The QL40 FTC tool is supplied as a bottom sub of the Quick Link (QL) product line and can be combined with other QL40 tools to form a tool string or it can be run as a stand alone tool. The 40FTC is the standalone - non stackable – version.
The tools are fully downhole digital and operate with the ALTLogger and Matrix logging systems. They can be run on any standard wireline (mono, 4 or 7 conductor, coax).

1.1 Dimensions

Figure 1-1 *QL40 FTC Dimensions (bottom sub)*

1.2 Technical Specification

Tool	
Diameter:	Max 40mm (1.57”)
Length:	0.78m (30.7”)
Measurement point:	
Temperature:	0.09m up from bottom
Conductivity:	0.063m up from bottom
Weight:	3.35kg (7.2lbs)
Operating Temp.:	0 - 70°C (32 - 158°F)
Max. Pressure:	200bar (2900psi)
Cable:	
Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – BBOX – Matrix
Temperature measurement:	
Range:	-20 to 80°C
Accuracy:	< 1%
Resolution:	0.004°C
Conductivity measurement:	
Range:	5µS/cm to 2.5 x 10^5 µS/cm
Accuracy:	1% (500 – 2.5 x 10^5 µS/cm)
Power:	
DC voltage at probe top:	Min 80 VDC
	Max 160 VDC
	Nominal 120 VDC
Current:	Nominal 25mA

2 Measurement Principle

The FTC probe measures simultaneously borehole fluid temperature and conductivity.

2.1 Temperature

Borehole temperature is measured with a sensor based on a fast response semiconductor device whose output current changes proportionally to absolute temperature. The temperature sensor is located in a stinger at the top of the sensor body in the center of the three exit ports where the borehole fluid returns to the well bore.

2.2 Fluid Conductivity

Borehole fluid conductivity is measured using a seven electrode mirrored Wenner array. The conductivity array is an internal cylindrical array open at the bottom of the probe. Borehole fluid passes by the array as the probe is lowered in the hole. The array is completely shielded from the outside borehole, so that only fluid conductivity is measured.
The following table provides an overview of typical water categories and associated conductivities.

Drinking water	Up to 500 uS/cm
Fresh water rivers	30 – 500 uS/cm
Marginal river water	500 – 1500 uS/cm
Brakish water	1500 – 5000 uS/cm
Industrial waters	100 – 10000 uS/cm
Sea water	50000 - … uS/cm

Note: Logging in downward direction may result in a better flow of the fluid through the sensor cell!

3 Notes on QL tool assembly

The following explanations are only valid for the QL40 FTC tool. 40FTC users can skip this chapter.

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family. The QL40 FTC is a bottom sub.

Bottom Sub definition
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

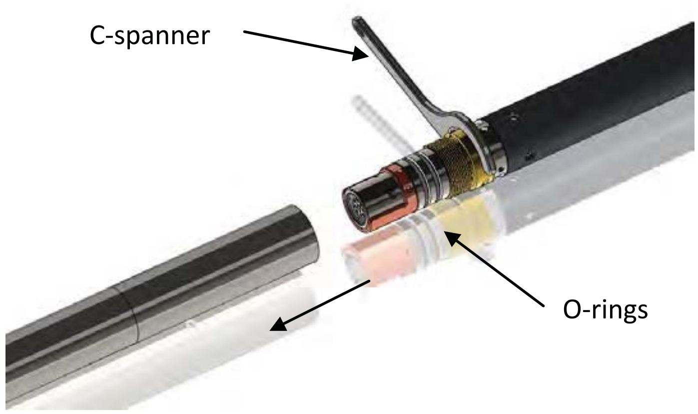


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GR and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GR sub stand-alone.

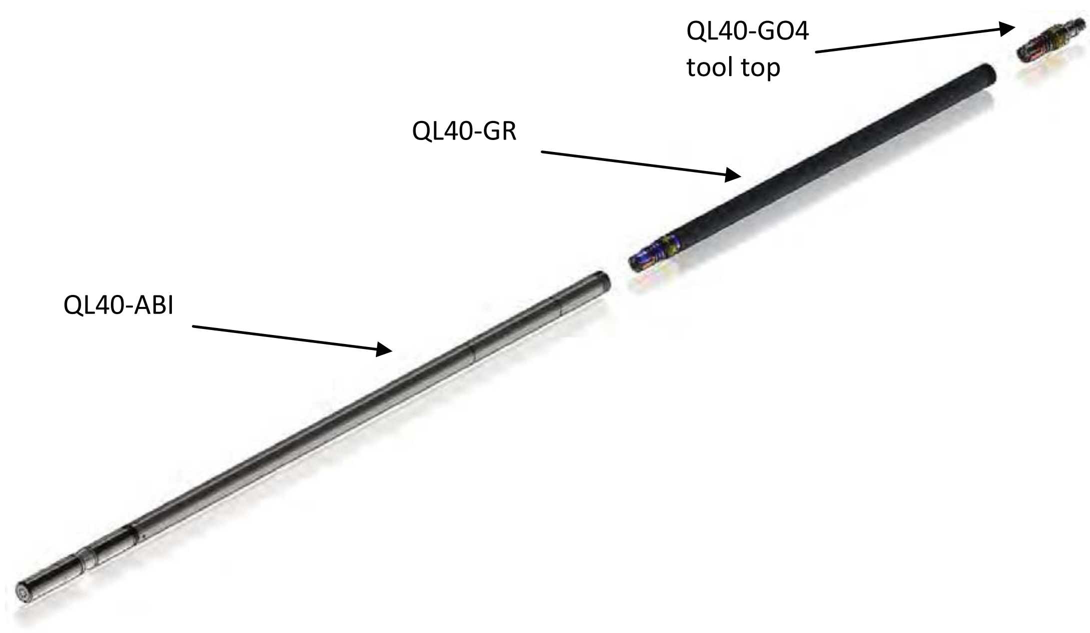


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

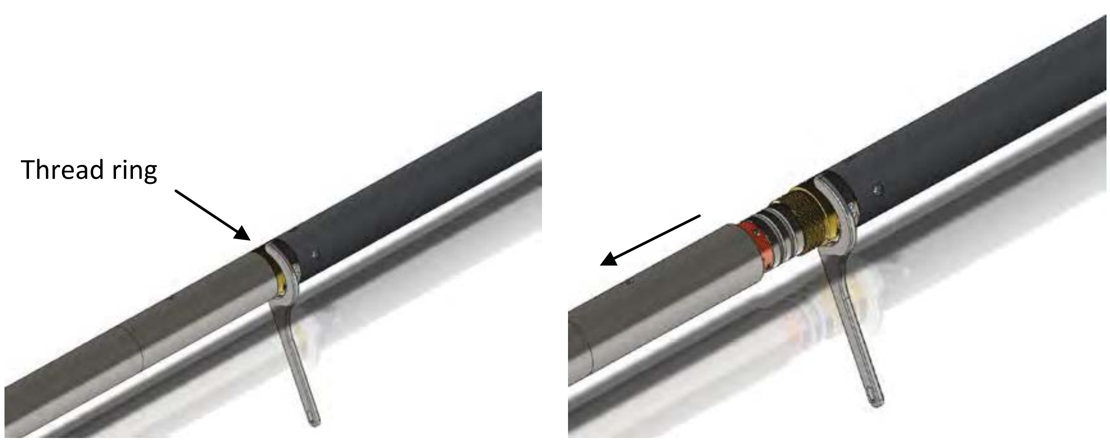


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

Figure 3-4 *Attaching the QL40-Plug*

The QL40-GR can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-GR mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in the sections below assume that the user is familiar with the data acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the tool to your wireline and start the data acquisition software.

2. Select the relevant FTC tool from the drop down list (Figure 4-1) in the software's **Tool** panel. *If your tool is not listed check that the tool configuration files (.sub and .stack files) are properly installed. Tool configuration files may be found on the installation or separate CDROM. The files should be installed using LoggerSettings.exe utility program supplied with the software installation. See LoggerSettings.doc for detailed instructions.*

Figure 4-1 *Tool panel*

3. Once the tool is properly positioned to the depth reference level, click the button in the upper right of the Depth panel and press "Zero Tool".

4. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level. The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in chapter **4.2** if error message is displayed.)

5. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button to configure your tool (see chapter **4.5** for details).

6. In the **Acquisition** panel (Figure 4-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

7. Press the **Record** button in the **Acquisition** panel (Figure 4-2), specify a file name and start the logging.

Figure 4-2 *Acquisition panel*

8. During logging observe the controls in the **Telemetry** panel (Figure 4-3):
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

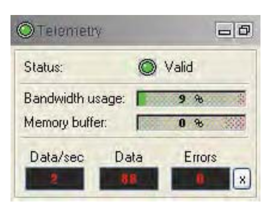


Figure 4-3 *Telemetry panel*

9. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

10. In the **Tool** panel power off the tool.

4.2 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4). A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

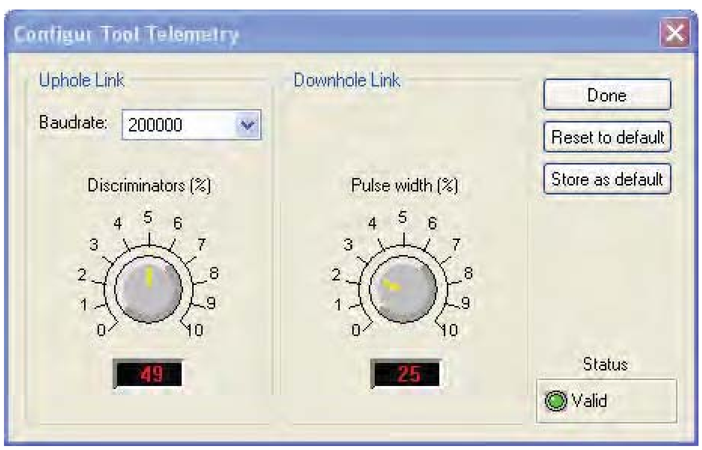


Figure 4-4 *Tool communication settings*

4.3 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (Figure 4-5) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.

The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5) for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

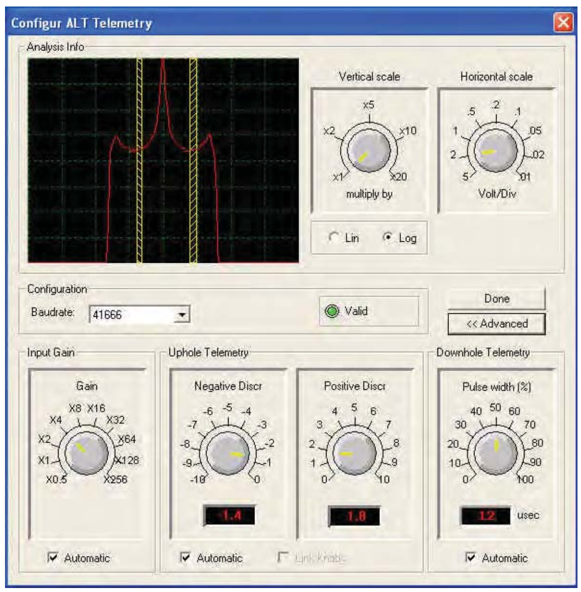


Figure 4-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in “Valid” status the next time the power is turned on.

4.4 Configuring Tool Parameters

The FTC probe does not have any configuration options.

4.5 Recorded Parameters, Processors and Browsers

4.5.1 Recorded parameters

The following data channels are recorded by the FTC tool.

VInj	*For internal use only*
IInj	*For internal use only*
DV1	*For internal use only*
DV2	*For internal use only*
Temp	Fluid temperature in °C
Cond	Measured fluid conductivity at temperature Temp

4.5.2 MChNum Browser

Figure 4-6 shows a typical example of the numerical values displayed in the MChNum browser window during operation.

Temp	Fluid temperature in °C
Cond	Measured fluid conductivity
Cond25C	Fluid conductivity corrected to 25 °C (Temperature corr. Factor: 2 %/°C)

As mentioned before, conductivity measurements are temperature dependent. The degree to which temperature affects conductivity varies from solution to solution and can be calculated using the following formula:

$$Cond_{Tcal} = Cond / (1 + alpha * (T - Tcal))$$

where
$Cond_{Tcal}$ = conductivity at reference temperature,
Tcal = reference temperature (e.g. 25°C),
Cond = measured conductivity,
T = measured temperature,
alpha = correction factor.

The Cond25C channel is calculated with an alpha of 2% per °C, which corresponds approximately to NaCl solutions at 25 °C

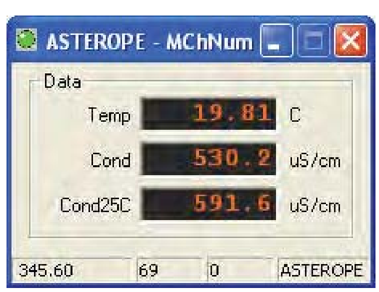


Figure 4-6 *MChNum Browser during operation*

4.5.3 MCHCurve Browser Window

The MChCurve browser displays the recorded parameters by means of curves in real time (Figure 4-7).

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, grids,….)

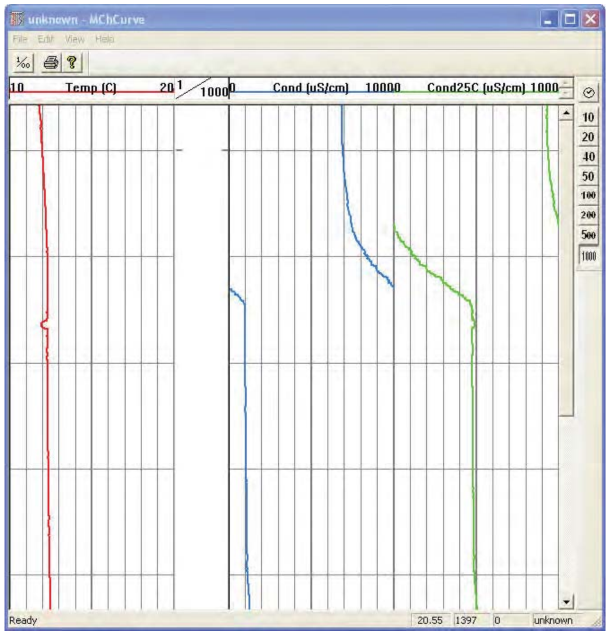


Figure 4-7 *MCHCurve Browser Window*

5 Performance Check & Calibration

Calibrations are performed at the factory and ensure stable readings for a long period of time. However, good practice requires regular validation of the measurements. This can be achieved by comparison of tool readings and measurements made with a conductivity-meter in solutions of known conductivity. Solutions should be constantly stirred during the procedure (mainly for high conductivity measurements, above 10000 uS/cm) and measurements should be made for a sufficiently long time.

Prepare to Calibrate:

1. Assemble the tool and connect to the wireline.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn the tool power **On**;
3. In the **Acquisition Panel** select **Time** and turn it **On**.
4. Click the Green LED at the top left corner of the MCHNum Browser window or right click the top pane to display the MCHNum context menu (Figure 5-1).
5. Select **Calibration Settings** (see Figure 5-2).

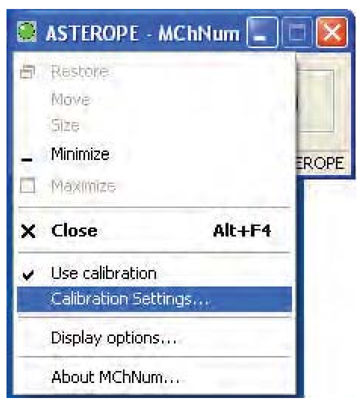


Figure 5-1 *MCHNum context menu*

5.1.1 Conductivity

Calibration Settings

1. Place the sensor body in the reference solution. Ensure the reference solution is above the three exit holes on the probe. In the **First Point Reference edit box of the Calibration Settings dialog box** (Figure 5-2) enter the ***non-compensated*** low calibration value read from the conductivity-meter. If necessary change the units by clicking on the **Unit** button.
2. Click **Sample**. When the average sampling is complete the value read from the tool will be displayed in the **First Point Value** box. (The number of samples taken can be changed under **Options**.)
3. Place the sub into a high value reference solution.

4. In the **Second Point Reference** enter the ***non-compensated*** high calibration value as read from the conductivity-meter.
5. Click Sample. When the average sampling is complete the value read from the tool will be displayed in the **Second Point Value** box.
6. Click **Compute** to determine the calibration coefficients.
7. Click **Store** to update the sub file with the new calibration settings.
8. Click Close to leave the calibration settings.

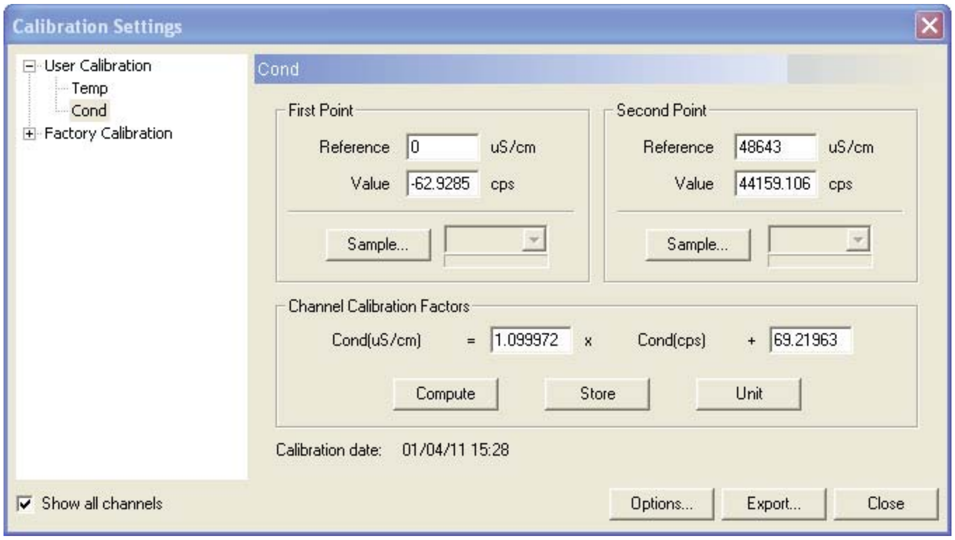


Figure 5-2 *Calibration Settings dialog box (Conductivity page)*

On the **Browsers & processors** panel click **Close All** then **Start All** to refresh the other Browsers and Processors. This must be done as they only read the calibration constants from the configuration file when they start.

5.1.2 Temperature

The tool is using a measurement circuit that measures the temperature to a very high accuracy that most of common thermometers can not measure. Therefore the factory calibration should be kept. However, if it is necessary to recalibrate the tool the 2 points calibration can be achieved from the dedicated page of the calibration dialog box (Figure 5-3) in a similar manner as the conductivity calibration described above.
It is unlikely that any problems will occur with the temperature measurement. If a problem occurs, it is recommended to return the probe.

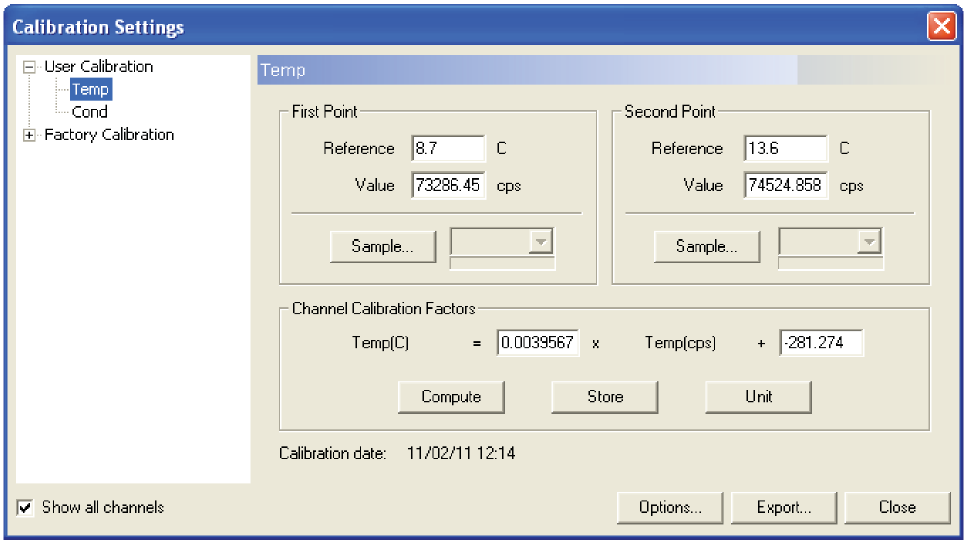


Figure 5-3 *Calibration Settings dialog box (Temperature page)*

6 Maintenance

Warning: Removing the electronic chassis from pressure housing without prior consultation with ALT or Mount Sopris Instruments will void the tool warranty.

6.1 Fluid Resistivity Cell Maintenance

Wash the cell with clean tap water and scrub the surface of the ring assembly with a bottle brush or a similar tool to remove any surface contaminants. Be careful not to damage the Temperature stinger located at the top of the cell. Mild soap and water may help remove oil, grease or other contaminants. Ensure you rinse the sensors carefully after using soap.

6.2 Upgrading firmware

In accordance with the ALT policy of continuous development the FTC has been designed to allow firmware upgrades. The current version of firmware installed in a tool may be verified in the **Tool Details** window opened from the **Tool Settings** dialogue box.

Firmware upgrade procedure is as follows:

1. Checking the communication is valid.
2. Upgrading firmware

6.2.1 Checking the communication

1. Connect the FTC tool to your acquisition system.
2. Start ALTLog/Matrix software.
3. In the **Tool** panel select the appropriate tool and turn the power on.

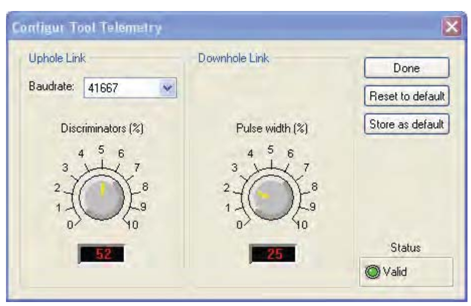


Figure 6-1 *Tool communication settings - ALTLog*

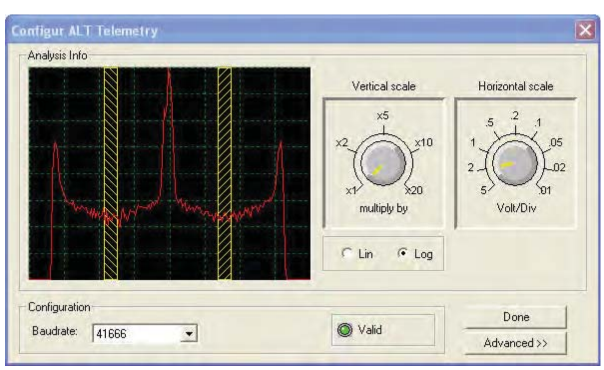


Figure 6-2 *Tool communication settings - Matrix*

Warning: The telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.2.2 Upgrading the firmware

In the **Tool** panel, select **Tool settings/commands**. Check that the communication status is valid.

1. Click on **Tool Details**. Note that the firmware version currently in use is displayed in the firmware box. Click on the **Upgrade** button.
2. The following message will appear (Figure 6-3). Click **Yes** to validate your choice.

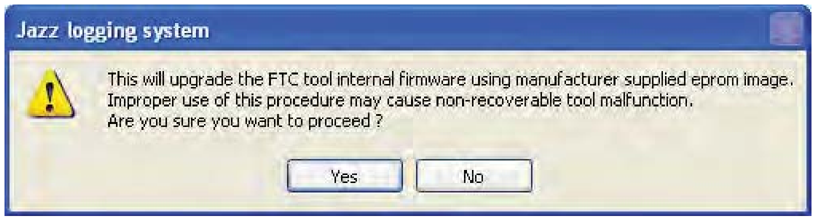


Figure 6-3 *Warning Message during firmware upload*

3. Select and open the appropriate **.hex** file provided. The upgrade will start.
4. During the upgrade procedure, the following message is displayed:

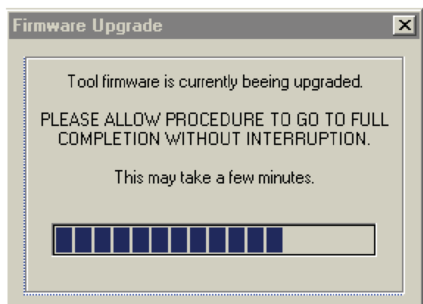


Figure 6-4 *Firmware upgrade progress window*

5. Once the upgrade has been successfully completed, click on **OK** to turn off the tool.

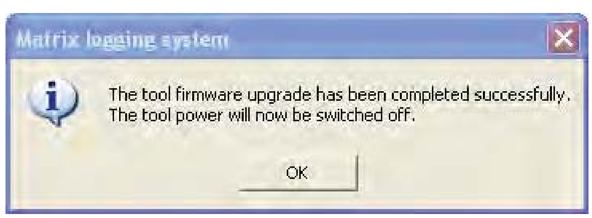


Figure 6-5 *Successful upgrade*

6. Power on the tool to start the upgraded firmware. Check in **Tool settings/commands** and **Tool details** that the firmware version has been changed with the new one.

Note that the following error message (Figure 6-6) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 6-6 *Error message*

6.3 General Tool Maintenance

The FTC tool should require no maintenance other than a few salient points.

- Keep the probe and the tool top/bottom connectors clean.
- When the probe is transported, it needs to be contained in a vibration damped container to minimize stress on the sensors.
- The probe top/bottom connector should be periodically cleaned with oil free contact cleaning solvent.
- Fluid resistivity cell maintenance:

  Wash the cell with clean tap water and scrub the surface of the ring assembly with a bottle brush or something similar to remove any surface contaminants. Be careful not to damage the Temperature stinger located at the top of the cell. Mild soap and water may help remove oil, grease or other contaminants.

7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been imported using the Logger Settings application (refer to the corresponding manual)? - Did you configure a stack for your tool (at least probe top and tool body)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.5).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use the optional ALT/MSI test cable to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu or tech.support@mountsopris.com.
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed, decrease azimuthal resolution and/or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Parts list

8.1.1 Recommended spare parts

Item No.	Qty	ALT Part No.	MSI Part No.	Description
1	1	1673840	-	Molykote111 compound
2	2	55459	-	DIN1810B 40-42 Hook wrench w.pin
3	6	AS215-V-75°	-	O-ring Viton 51414 26.57X3.53 -75°
4	1	L0034-086	-	Grease Lubriplate
5	1	-	504-101-921	1” Bristle brush
6	1	ALT26306	-	QL40 Male plug

8.1.2 Other parts

Item No.	ALT Part No.	MSI Part No.	Description
1	QL40-GO1	17-202-092	QL40-GO1 tool top
2	QL40-GO4	Q40GO4-1000	QL40-GO4 tool top
3	QL40-GO7	17-202-079	QL40-GO7 tool top
4	QL40-MSI1	Q40MS1-1000	QL40-MSI single conductor tool top
5	QL40-BOT	Q40BOT-1000	QL40 bottom plug

8.2 Technical drawings

The following technical drawings are available on request:

- QL40 FTC or 40FTC Wiring Diagram.

Index

QL40-SFM

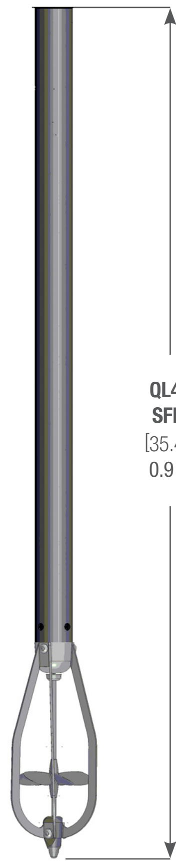
Bi-directional spinner flowmeter

This QL40-SFM measures impeller rotation caused by fluid flow in the borehole. It uses a magnetically coupled pick-up which drives a low friction, high resolution encoder located inside the lower pressure housing. The encoder produces 256 pulses per shaft rotation. It has quadrature sensing electronics that instantaneously detect flow rate direction and changes.

The QL40-SFM is a bottom sub, and can be combined with other logging tools in the QL (Quick Link) product line or operated as a stand alone tool. Weight bars with centralizers are recommended to improve log response and repeatability in large boreholes or low flow environments.

Application

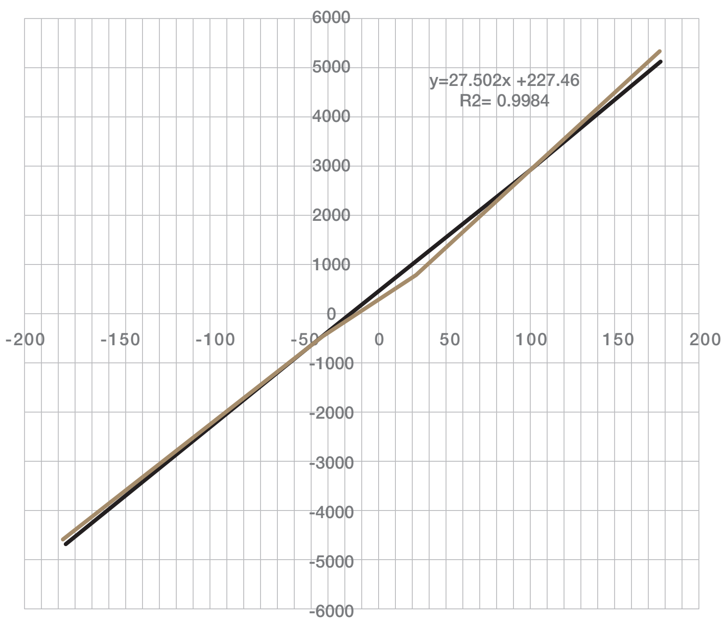
- Pumping flow profiles in screened or perforated cased holes
- Identification of hydrostratigraphic units
- Confirmation of predicted transmissive zones in open hole



TOOL	
Diameter	40mm (1.6")
Length	0.9m (35.4")
Weight	3.2kg (7.05 lbs)
Temp	0 - 70°C (32 - 158°F)
Max. Pressure	200bar (2900psi)

SENSOR	
Pickup sensor	3000 RPM max.
Accuracy	> 1%
Resolution	256 pulses/revolution
Output	Counts/second
Standard cage/impeller assembly	3" (76.2mm) or 4" (101.6 mm)

OPERATING CONDITIONS	
Cable type	Mono, multi-conductor, coax
Compatibility	Scout Pro / Opal (Scout / Bbox / Matrix)
Digital data transmission Telemetry	Variable baudrate telemetry according to cable length/type & surface system
Logging	Static/dynamic or dynamic while pumping
Centralisation	Recommended
Borehole conditions	Fluid-filled borehole Open borehole or perforated screen casing



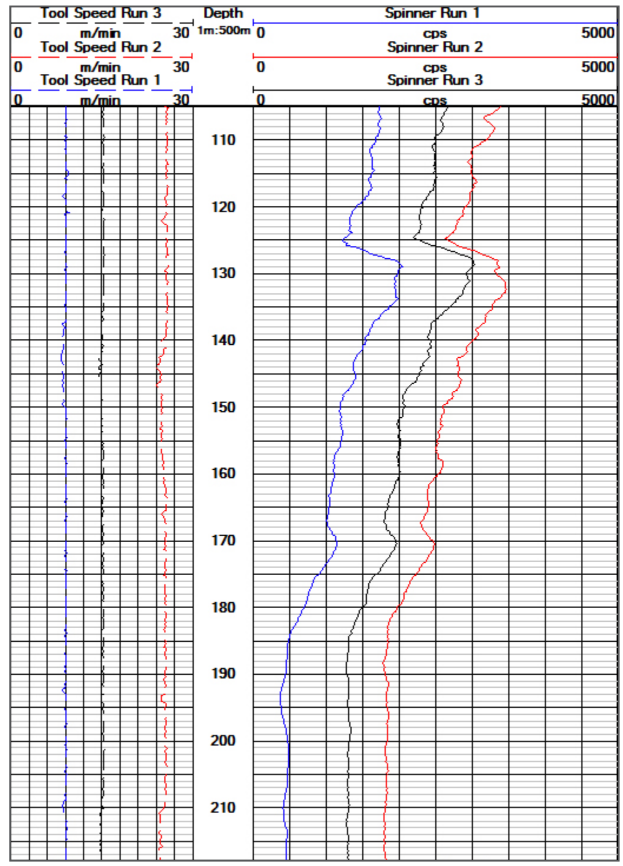
Typical flow response curve for up and down runs in 6" casing
(Flow rate in gpm vs. spinner speed in cps)

Principle of measurement

A bouyant impeller mounted on a hollow stainless steel shaft is suspended between two precision ground ceramic bearings. A balanced transfer bulkhead fitted with magnets couples motion and direction from the impeller through a sealed sensor body inside the probe. A low friction high resolution encoder detects this information and transfers it digitally to a counter circuit that sends the information by wireline modem to the surface.

Measurements features

. Spinner up in CPS
. Spinner down in CPS
. Tool speed in m/min

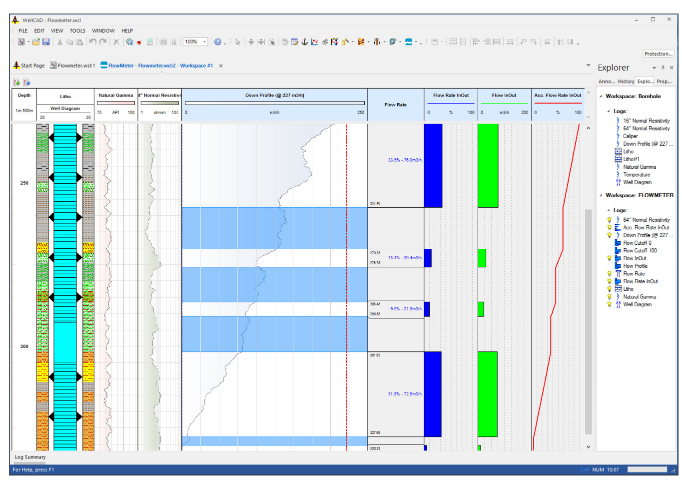


Flowmeter data processing available in WellCAD® 5.3

After initializing the workspace the user can interactively pick identified No Flow zones. The contribution of the flow zones will automatically be computed and displayed as percentage, absolute and cumulated values in text as well as in graphic form.

Additional data such as geophysical logs, lithology columns or well sketches can be added as reference logs to the workspace aiding the interpretation.

Templates can be saved and applied when initializing a new workspace to save valuable time.



Flowmeter Workspace with reference logs (left), flowmeter curve (center) and interval flow answer products (right)

User Guide

QL40 SFM – Spinner Flow Meter

V08.09.15

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Table of Contents

1 General Information

The QL40 SFM measures impeller rotation caused by fluid flow in the borehole. It uses a magnetically coupled pick-up which drives a low friction, high resolution encoder located inside the lower pressure housing. The encoder produces 256 pulses per shaft rotation. It has quadrature sensing electronics that instantaneously detect flow direction changes.

The probe comes standard with a 3 inch cage and impeller assembly. If a larger cage and impeller assembly are required it can be ordered. The part number for a 4 inch cage and impeller assembly is a Q40SFM-1200. This assembly includes the 4 inch cage pieces and entire impeller assembly to be attached to the bottom of the QL40-SFM probe in place of the 3 inch version supplied with the probe.

The QL40 SFM is a bottom sub, and can be combined with other logging tools in the QL (Quick Link) product line or operated as a standalone tool. Weight bars with centralizers are recommended to improve log response and repeatability in large boreholes or low flow environments.

- **Applications**

  - Pumping flow profiles in screened or perforated cased holes
  - Identification of hydrostratigraphic units
  - Confirmation of predicted transmissive zones in open hole

- **Operating conditions**

  - Open or cased borehole
  - Water filled
  - Centralization recommended

1.1 Dimensions

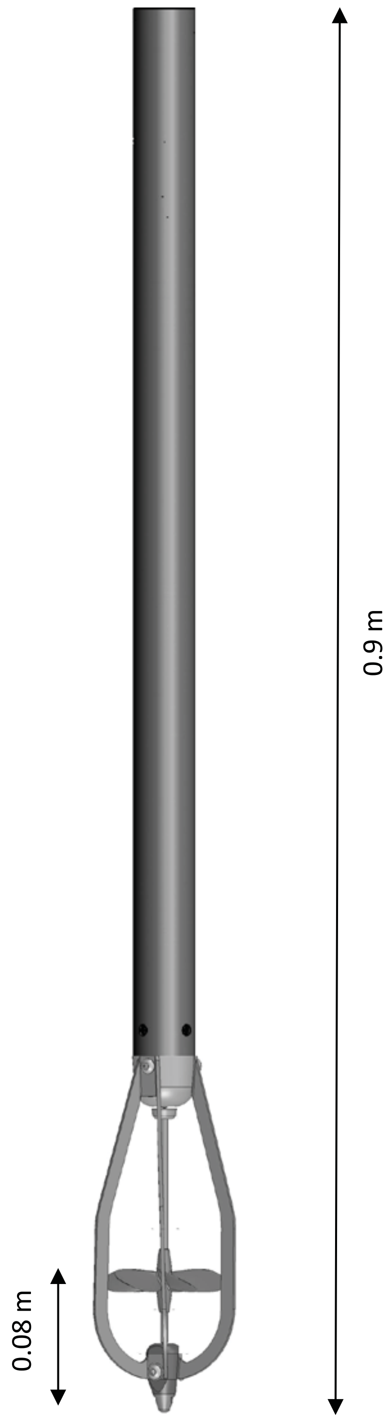


Figure 1-1 *QL40 SFM dimensions with a 3" impeller cage*

1.2 Technical Specifications

Tool

Diameter:	Max 40mm (1.57”) excluding cage
Standard impeller cage:	76.2mm (3.0”)
Bigger impeller cage:	101.6mm (4.0”)
Length:	0.9m (35.4”)
Measurement point:	0.08m up from bottom of impeller cage
Weight:	3.2kg (7lbs)
Max. Temp:	70°C (158°F)
Max.Pressure:	200bar (2900psi)

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – BBOX – Matrix

Measurements:

Range:	Pickup sensor 3000 RPM Max
Accuracy:	Better than 1%
Resolution:	256 pulses per revolution
Output:	Counts Per second (cps)

Power:

DC voltage at probe top:	Min 80 VDC
	Max 160 VDC
	Nominal 120 VDC
Current:	Nominal 38mA

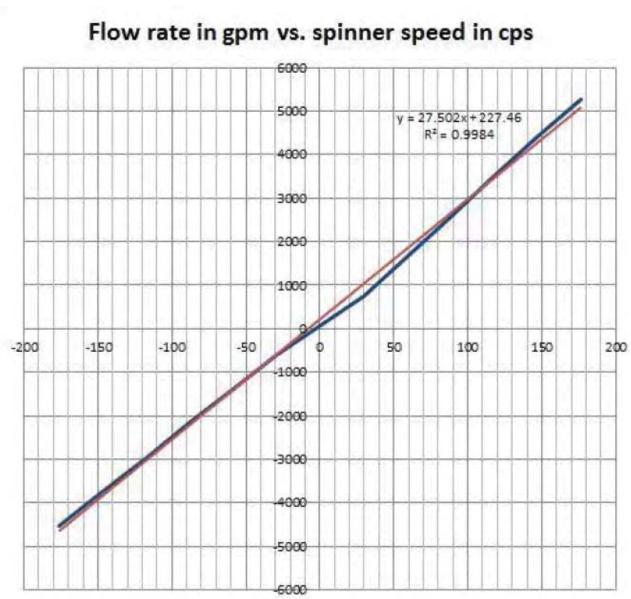


***Figure 1-2** Typical flow response curve for up and down runs in 6” casing*

2 Measurement Principle

Borehole flow measurements are made either in a trolling mode or a static mode depending upon flow rates and desired pump configurations. The probe is capable of determining the direction of flow based upon the direction of the spinning motion of the impeller. The impeller assembly uses a point and cup system much the same as a jeweled bearing to reduce friction and allow for smooth spinning of the impeller assembly. These bearings are made from a hard material and should last for many runs in boreholes given the impeller assembly is properly set up. Proper adjustment of the impeller is required for the smoothest operation of the impeller. A discussion of this set up will be covered in this manual in the Installation section.

- **Principle**

  A buoyant impeller mounted on a hollow stainless steel shaft is suspended between two precision ground ceramic bearings. A balanced transfer bulkhead fitted with magnets couples motion and direction from the impeller through a sealed sensor body inside the probe. A low friction high resolution encoder detects this information and transfers it digitally to a counter circuit that sends the information by wireline modem to the surface.

3 Installation of the impeller and cage assembly

Installation tools required: *3mm allen wrench, flat blade screw driver, small crescent wrench*

This section covers instructions on how to properly install the impeller and cage assemblies supported by the Q40SFM Spinner Flow Meter. Failure to read and or follow these instructions may result in damage to the impeller assembly and rendering the probe non operational. Take the time to read and understand this portion of the document so the sensitivity of the impeller assemblies can be properly set and optimum performance from the probe be realized. The Q40SFM comes standard with the 3” cage and associated impeller assembly. An optional 4” cage and impeller assembly can or may be purchased. One or both assemblies will be located in the small box provided with the probe in the shipping case.

To begin remove the probe from the case and the desired cage assembly you wish to log with. This can be either the 3” or the 4” cage version. If purchased with both cage options the probe will be delivered with a smaller and larger impeller assembly. The probe was designed to be run with the smaller impeller inside the 3” cage and the larger impeller to be run inside the 4” cage.

Find the lower Cage Tip and (3) of the same size Impeller Cage pieces. Attach the Cage Tip with only two of the Impeller Cage pieces to the brass main body of the lower portion of the probe as shown below.

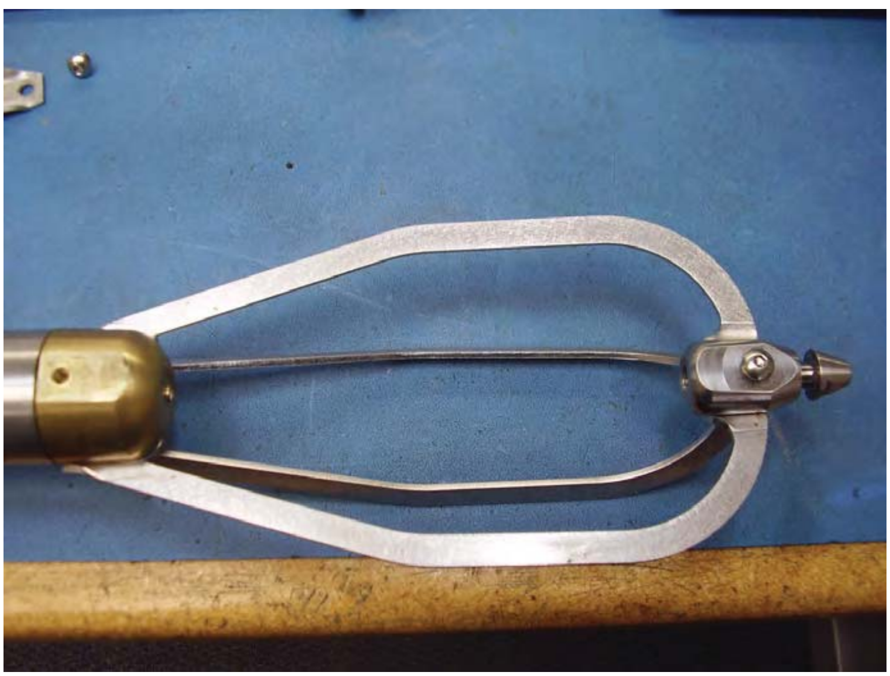


Figure 3-1 *Cage tip mounted with two of the impeller cage pieces*

Tighten the screws down but do not fully tighten them until the impeller and final cage piece have been installed. Remove the cone piece from the Cage Tip and set aside.

Inside the Cage Tip is an adjustable screw that will tighten and loosen the impeller axle assembly into the bearings. The picture below shows the cup the impeller axle bearing will ride in. The other end of the brass portion of the probe also has one of these cups for the axle to ride in but it is not adjustable but fixed in place.

Figure 3-2 *Cup detailed picture of the cup for the impeller axle bearing*

You will need a small flat blade screw driver to make the required adjustments to the screw inside the Cage Tip when mounting the axle of the impeller assembly. Take the screw driver and back the screw inside the Cage Tip out some so you can insert the entire axle into the cage and probe assembly .

You will not want to force in any way when inserting this axle and impeller assembly. Make certain there is plenty of room by adjusting the screw in the Cage Tip if needed. The points on the Axle Tips are rugged but if forced can be broken off or damaged. You should be able to move the axle assembly inside the cage back and forth with ease at this point. Installation of the axle assembly is such that the impeller end is closer to the bottom of the probe and the axle end with the small disk at one end goes closer towards the brass end of the main probe body as shown on the next picture.

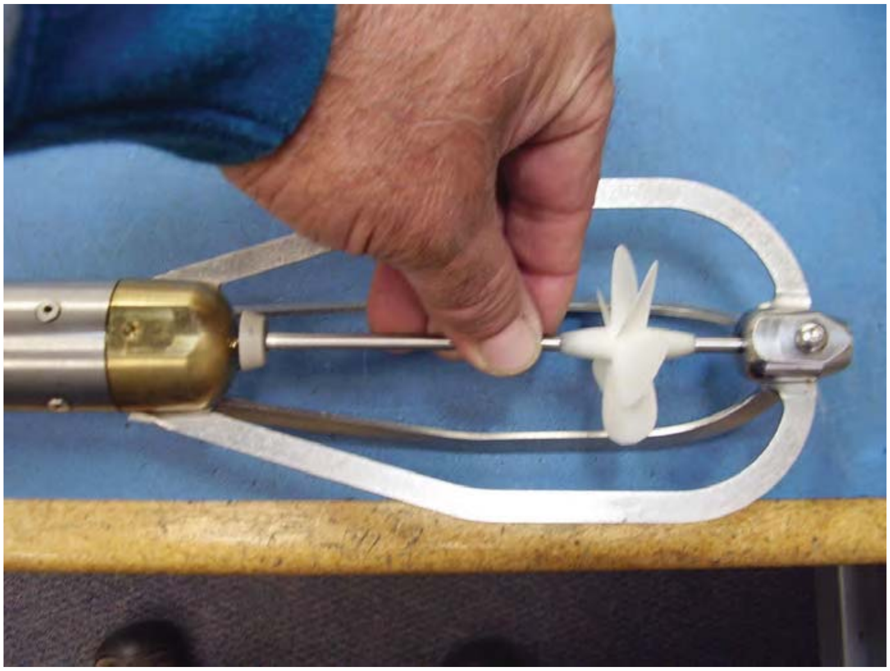


Figure 3-3 *Mounting the axle of the impeller assembly*

Locate the tip of the Axle inside the lower cup in the adjustment screw you will be adjusting in the Cage Tip and begin to turn the screw inward to push the entire assembly towards the cup located in the brass section of the probe. Watch carefully that you are in fact inserting the point of the axle into the actual cup and not off to the side while adjusting the screw. Once the screw is adjusted to where the axle is supported in the cups stop adjusting.
DO NOT adjust the screw so tight that it can smash or damage the ends of the axle or the cup bearings.
Final setting of this adjustment must not be done until the cage is fully assembled and tightened as it may change overall setting for the axle adjustment screw.

At this time you will want to install the final or third piece of the cage you will be running the probe with. Tighten all screws on cage pieces down at both ends. With the three cage pieces firmly attached you can now adjust and tune the impeller adjustment screw in the Cage Tip for optimum operating tension. The proper amount of screw adjustment will result in the impeller being able to move freely but not be so loose that it will come out of the two end cups. A small amount of movement back and forth, between the cups is okay. This adjustment will take some feeling to get use to but the idea is to allow it to float with as little friction inside the cups as possible but not be so tight that it inhibits free movement of the impeller and axle assembly. By simply blowing on the impeller or spinning the axle with your finger tip you can tell if the proper setting and adjustment of the lower screw is correct.

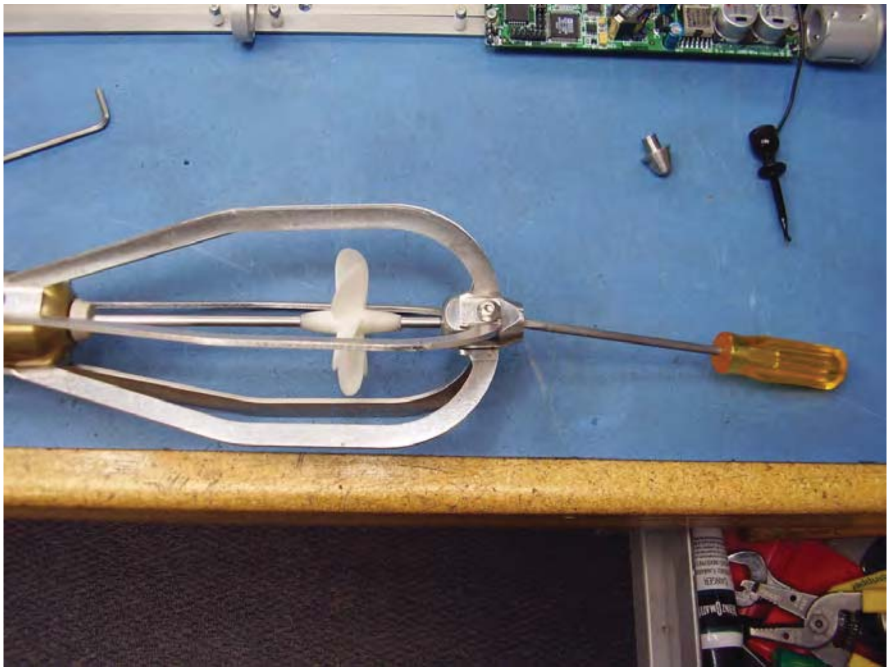


Figure 3-4 *Fine tuning the installation of the impeller*

Install the lower cone onto the Cage Tip and the probe is ready to have a probe top installed. Place the probe in a vertical position and again blow on the impeller and or check the operation of the impeller assembly in this position. The cages for the Q40SFM are rugged enough for what would be considered normal spinner boreholes but not so rugged that they can encounter objects and or blockage in the borehole. Any damage to the cage by running at fast rates into the borehole and hitting something or forcing it past an obstruction in the borehole may result in damage to the cage and improper adjustment changes to the impeller axle setting.

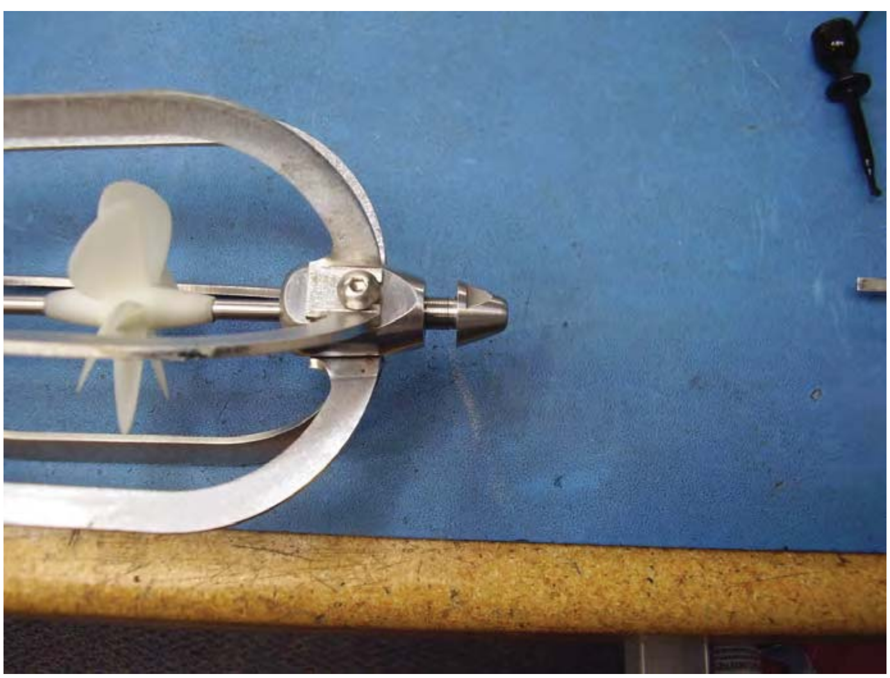


Figure 3-5 *Installation of the lower cone and final check*

4 Notes on QL tool assembly

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

4.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

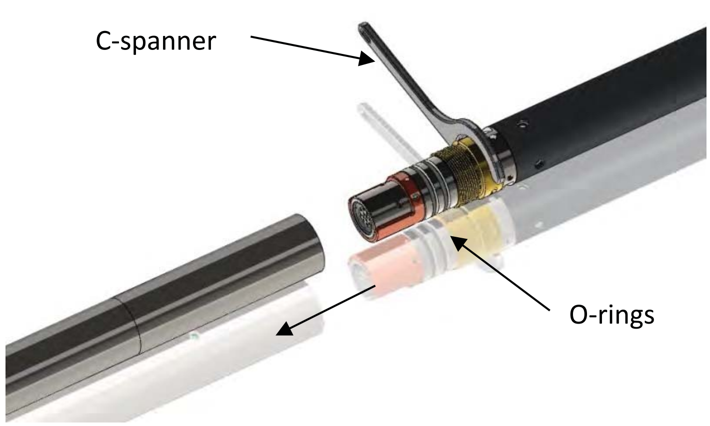


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GAM and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GAM sub stand-alone.

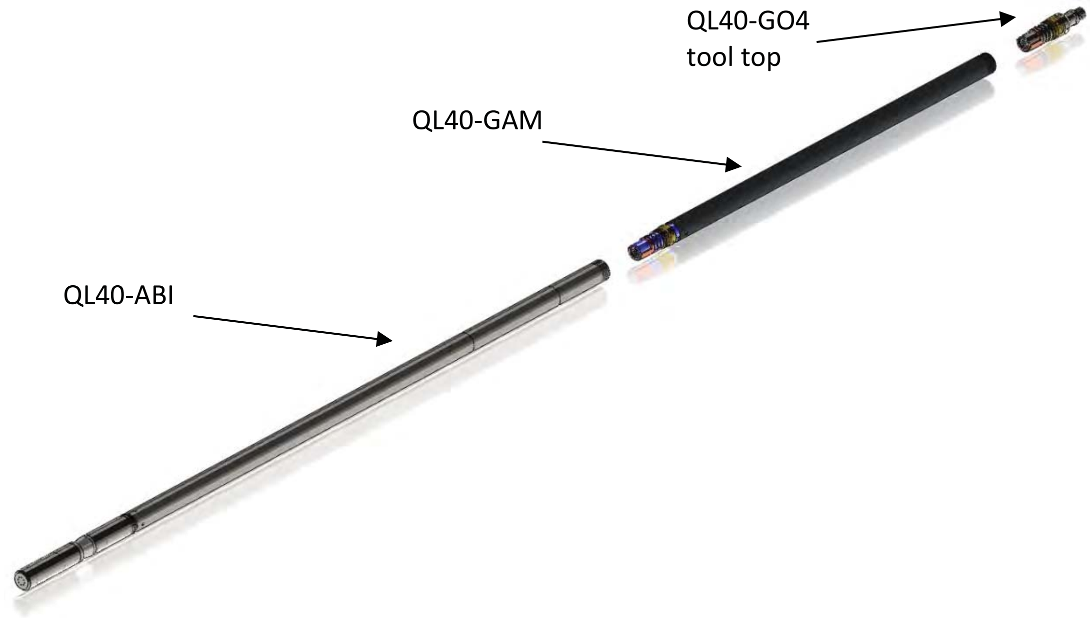


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

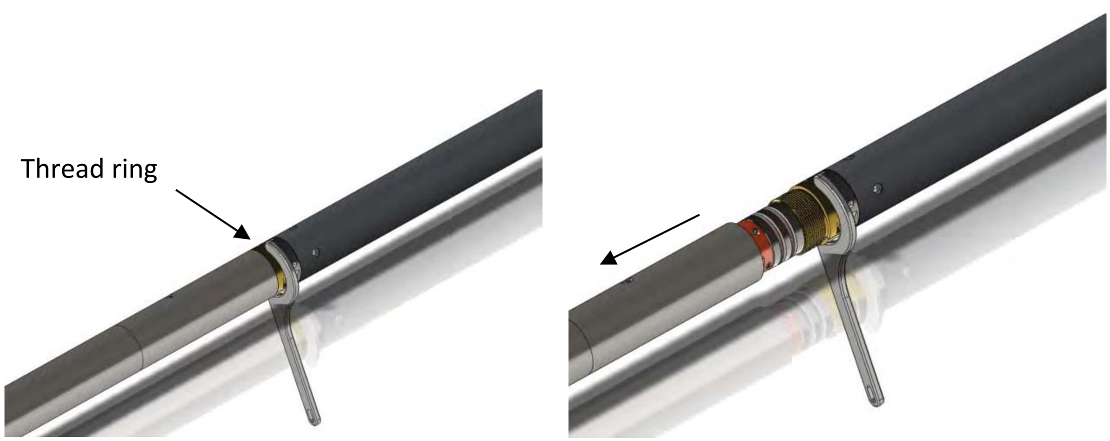


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

Figure 3-4 *Attaching the QL40-Plug*

The QL40-GAM can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-GAM mid sub with tool top and bottom plug*

5 Operating Procedure

Note: Parts of the topics discussed in these sections below assume that the user is familiar with the ALTLog or MATRIX acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

5.1 Quick Start

1. Connect the QL40 SFM to your wireline and start the data acquisition software.

2. Select the relevant QL40 SFM tool/stack from the drop down list (Figure 5-1) in the software's **Tool** panel (if your tool is not listed check that your tool configuration file is stored in the designated folder on your computer using the *LoggerSettings* application).

Figure 5-1 *Tool panel*

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level.
   The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in Chapter 5.2 if an error message is displayed.)

4. In the **Acquisition** panel (Figure 5-2) select the sampling mode (depth or time). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling (click the **ON** button).

Figure 5-2 *Acquisition panel*

5. Press the **Record** button in the **Acquisition** panel (Figure 5-2), specify a file name and start the logging.

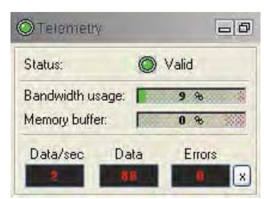


Figure 5-3 *Telemetry panel*

6. During logging observe the controls in the **Telemetry** panel:
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.

7. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

8. In the **Tool** panel power off the tool.

5.2 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4**Error! Reference source not found.**).
A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

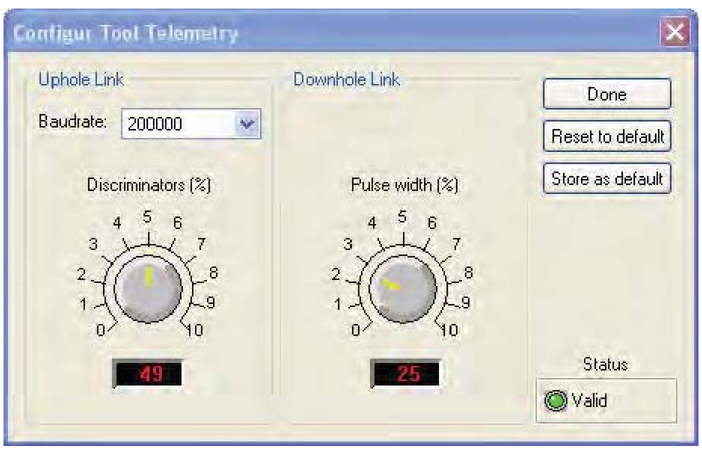


Figure 5-4 *Tool communication settings*

5.3 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (***Figure 3-5***) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.

The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5 for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

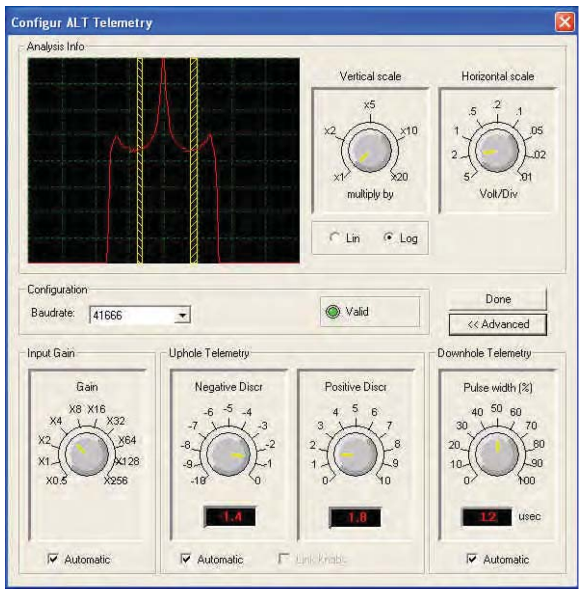


Figure 5-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in "Valid" status the next time the power is turned on.

5.4 Recorded Parameters, Processors and Browsers

5.4.1 Recorded parameters

The following data channels are recorded by the QL40 SFM tool.

Temperature	*Temperature recorded on CPU board in °C*
Time	*Sampling time in seconds*
Count Up	*Spinner counts in up direction*
Count Dn	*Spinner counts in down direction*
Spinner Up	**Spinner count rate in up direction (cps)**
Spinner Dn	**Spinner count rate in down direction (cps)**
Speed	**Logging speed in m/min**

5.4.2 MChCurve Browser

The MChCurve browser displays the recorded parameters by means of curves in real time (Figure 5-6).

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, gridding,….)

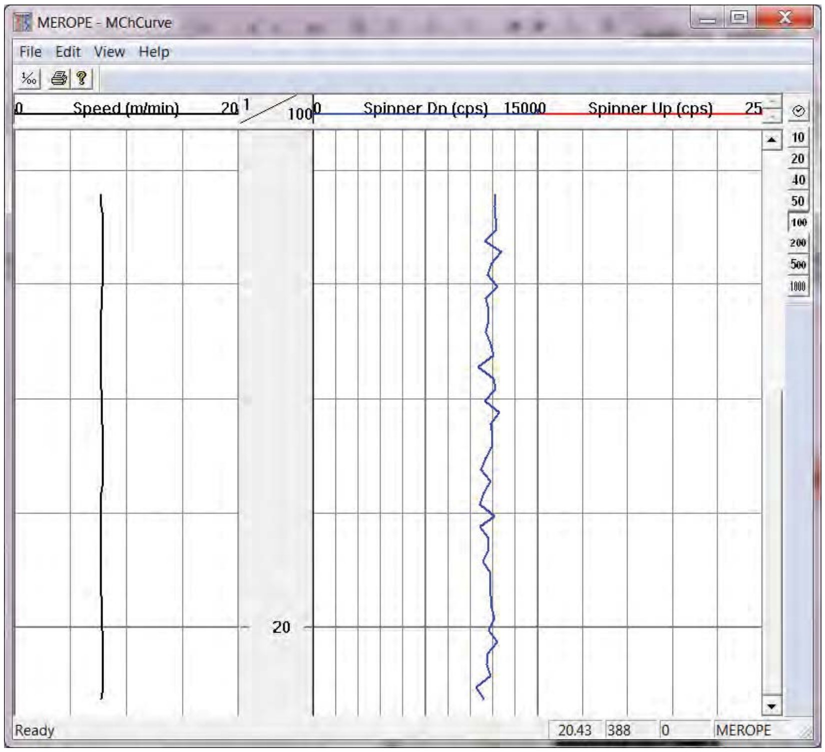
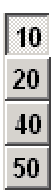


Figure 5-6 *MChCurve browser window displaying Spinner and Speed curves*

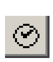
The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter, gridding,….)

Vertical scales and grids:



Depth mode display and pre-defined depth scales

Operator defined depth scales, interval spacing and settings



Time mode display

5.4.2 MChNum Browser

Figure 5-7 shows a typical example of the numerical values displayed in the MChNum browser.

Spinner Up	Spinner count rate in up direction (cps)
Spinner Dn	Spinner count rate in down direction (cps)
Speed	Logging speed in m/min

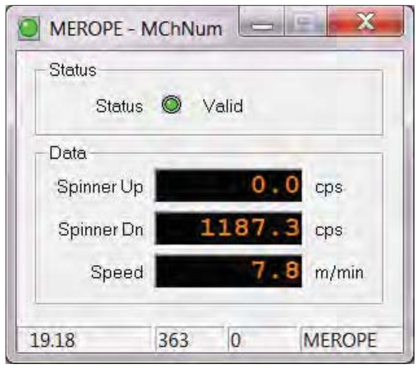


Figure 5-7 *MChNum browser window during logging*

6 Maintenance

6.1 Preventive maintenance

The QL40 series tools require some maintenance. Make sure the threads on the brass nut on the toll joints are free of sand mud or other dirt. A thin layer of anti-seize is recommended. When disassembling the sub string dry the joint as it is separated to prevent fluid from entering the sub top and getting into the Lemo electrical connector inside.

Before probe is removed from cable head it is good to wash the probe off after each use if at all possible. Wash the probe with clean tap water and remove any sediments or grime that may have lodged itself where the impeller bearings are located. Mild soap and water may help remove oil, grease or other contaminants. You may scrub the surface of the housing with a brush or something similar to remove any surface contaminants. Be careful not to damage the impeller blades as they are fragile.

Inspect O-rings occasionally when breaking tool joint apart and keep the threads on both ends of the probe clean, to minimize problems in the future.

Never take the probe apart. This probe is very difficult to disassemble and requires special steps to be taken in order to gain access to the inside of the probe without damaging the electronics. If you have read this after attempting to disassemble the probe chances are the probe has experienced damage and will need to be sent to the factory to be repaired.

Tools required:
1.5mm Allen wrench
2 ea 40-42mm spanner wrench
Paper towels or clean rags

Replacement Parts:
ALT26005, Large Threaded Ring, Qty 2
28-174-995 M2x8 SHCS, Qty 2

Disassembly:
Unscrew and remove the two M2x8 socket head cap screws and separate the two halves. Four guide pins align the two ring halves and tend to hold them together after the screws are removed.
To pry the halves apart you can use a pair of spanner wrenches inserted into the wrench holes on opposite sides of the ring mating surfaces to pull them apart slightly.
Do this carefully to prevent bending the guide pins.

Figure 6-1 *Disassembly of the treaded ring*

Place something small in the opening and move the spanners to the other side and pry it open slightly.
This should be enough to release the two rings as below.

Figure 6-2 *Halves rings when pulled apart*

6.2 Upgrading firmware

In accordance with the ALT policy of continuous development the tool has been designed to allow firmware upgrades.

Firmware upgrade procedure is as follows:

1. Checking the communication is valid.
2. Upgrading firmware

6.2.1 Checking the communication

1. Connect the tool to your acquisition system.
2. Start ALTLog/Matrix software.
3. In the **Tool** panel select the appropriate tool and turn on the power.
4. In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-3 or Figure 6-4).

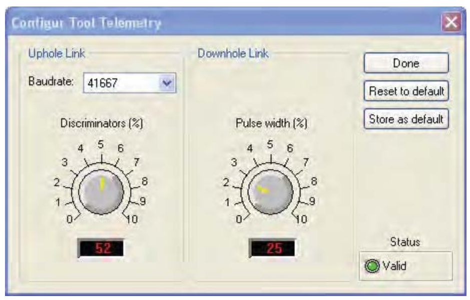


Figure 6-3*Tool communication settings - ALTLog*

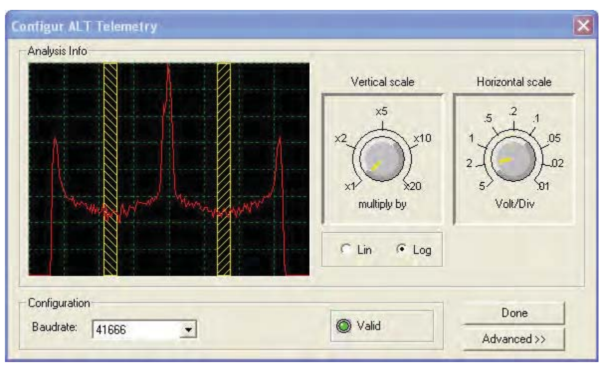
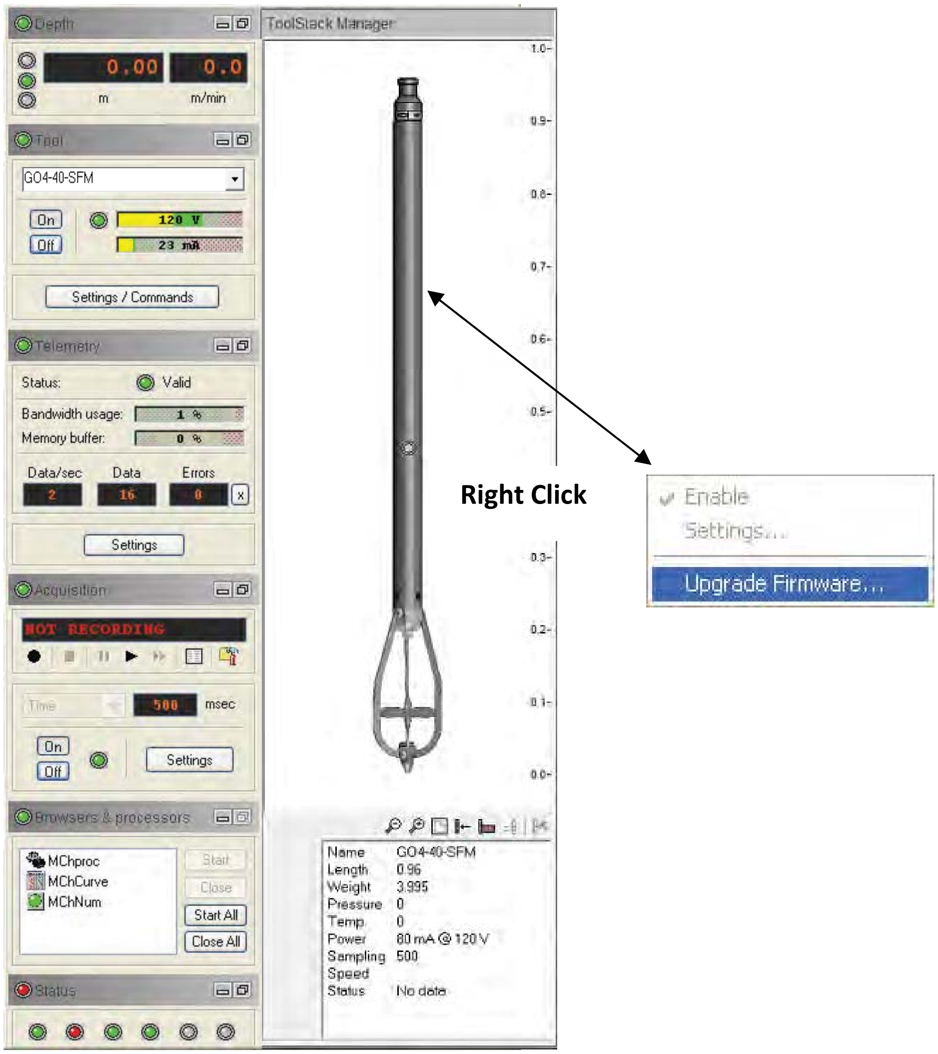


Figure 6-4 *Tool communication settings - Matrix*

Warning: Telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.2.2 Upgrading the firmware

1. **Right Click** on the tool preview in the **ToolStack Manager** view and select **Upgrade Firmware** from the context menu.



2. The following message will appear (Figure 6-3). Click **Yes** to validate your choice.

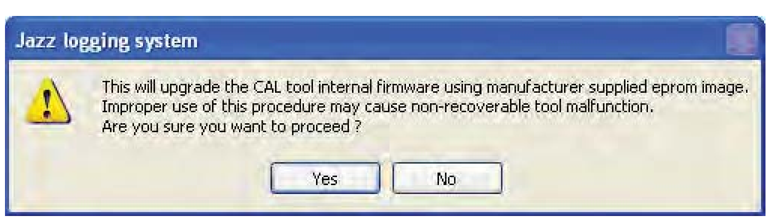


Figure 6-5 *Warning Message during firmware upload*

3. Select and open the appropriate **.hex** file provided. The upgrade will start.
4. During the upgrade procedure, the following message is displayed:

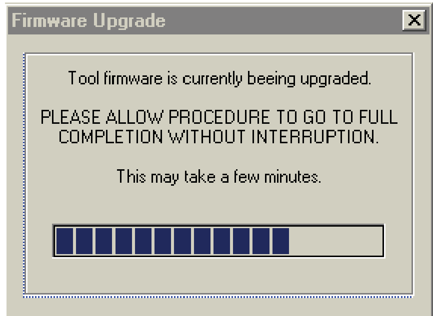


Figure 6-6 *Firmware upgrade progress window*

5. Once the upgrade has been successfully completed (Figure 6-5), click on **OK** to turn off the tool.

Figure 6-7 *Successful upgrade*

6. Power on the tool to start the upgraded firmware.

Note that the following error message (Figure 6-6) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 6-8 *Error message*

7 Troubleshooting

In the event the tool develops a problem, follow the troubleshooting procedure listed below.
WARNING: ***NEVER DIS-ASSEMBLE THE PROBE WITHOUT KNOWLEDGE OF PROCEDURE***

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been installed with the LoggerSettings application (refer to LoggerSettings and LoggerSuite manuals for more information)
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 5.2 or 5.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 5.4).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage low, current high): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of the short circuit. - If the above shows no issues, use test cable provided by ALT to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 5.2 or 5.3). - If problem cannot be resolved contact support@alt.lu or tech.support@mountsopris.com
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 5.2 or 5.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Parts list

Detailed part numbers and descriptions are available for tool delivery and spare part kits. Please contact support@alt.lu or tech.support@mountsopris.com for further details.

8.2 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- Wiring Diagram.

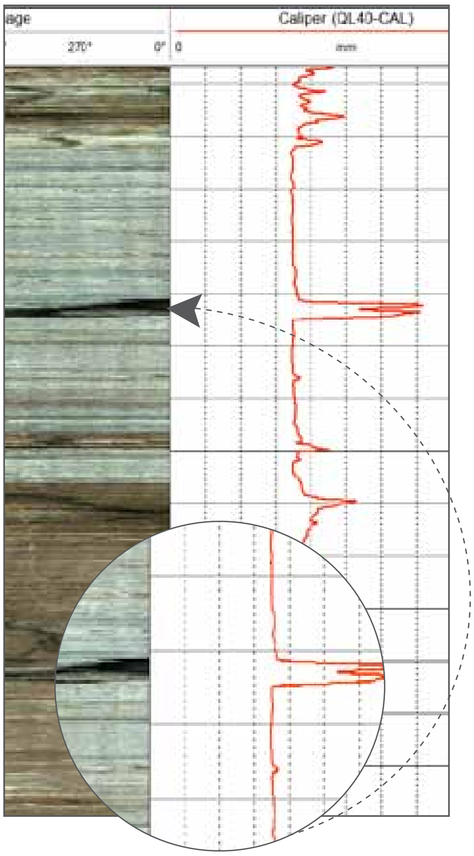
Index

QL40-CAL 3 Arm Caliper

The QL40-CAL sub records a single continuous borehole diameter log by means of three mechanically coupled arms in contact with the borehole wall. The 3 arm caliper measurement is a useful first log to determine the borehole condition before running other probes.

The QL40 CAL is supplied with two sets of arms. The standard arms are suitable for a borehole diameter ranging from 57 mm to 406 mm. The extension arms are suitable for borehole diameters up to 736mm. The caliper arms can be unscrewed from their short pivot arms and may be replaced with ones of different length. The hardened arm wear tips can be unscrewed and are easily replaced.
Opening and closing of the caliper arms is surface controlled from the LoggerSuite application allowing the probe to be run into the borehole with the arms closed. Once positioned at the bottom of the borehole, and caliper arms opened, the spring-loaded arms respond to borehole diameter variations as the probe is moved up the borehole.

The QL40-CAL sub can be combined with other logging tools of the QL (Quick Link) product line or can be operated as a standalone tool. It is compatible with Matrix, BBOX and ALTlogger acquisition systems.

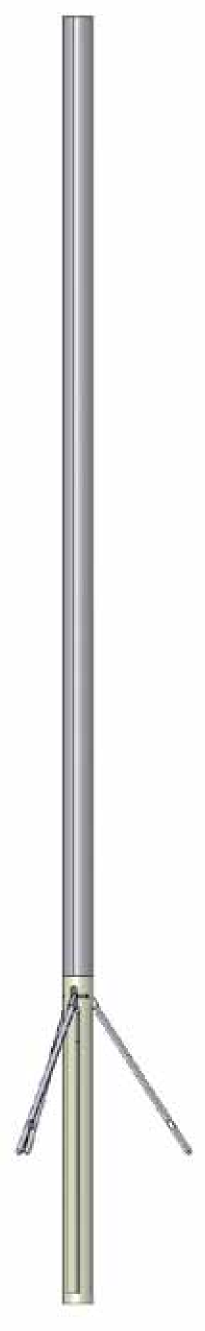


Application

- Borehole diameter measurement
- Borehole volume calculation before borehole completion, cementation
- Fractures and cavities localisation
- Rock integrity evaluation
- Often used in the implementation of environmental correction equations for other logs

Advanced Logic Technology

MOUNT SOPRIS INSTRUMENTS



QL40-CAL 3 Arm Caliper

Principle of measurement

The caliper measurement is made with three arms attached to a mechanical assembly which drives a linear potentiometer. The DC output voltage from the wiper of the potentiometer is converted to a frequency linearly related to the borehole diameter. Digital control commands for opening and closing the arms are made via the LoggerSuite acquisition software interface. The caliper measurement can be scaled and calibrated in inches, centimeters or millimeters.

Measurements / Features

- Calibrated measurement of borehole diameter in inches, centimeters or millimeters
- Easy exchangeable caliper arms and wear tips

Operating Conditions

- Dry or fluid filled borehole
- Compatible with Matrix, BBOX and ALTlogger systems
- Can be combined with other QL subs

Technical Specifications

Tool

- Diameter: Max 42.3mm (1.67”)
- Length: 1.785m (70.28”)
- Weight: 10kg (22lbs)
- Max. Temp: 70°C (158°F)
- Max. Pressure: 200bar (2900psi)

Power

- DC voltage at probe top: Min 80 VDC
  Max 160 VDC
  Nominal 120 VDC
- Current: Nominal 25mA

Measurement

- Standard arms: 50mm to 406mm (2” to 16”)
- Extended arms: up to 736mm (up to 29”)
- Accuracy: 1mm
- Resolution: 0.5mm

The specifications are not contractual and are subject to modification without notice.

MOUNT SOPRIS INSTRUMENTS
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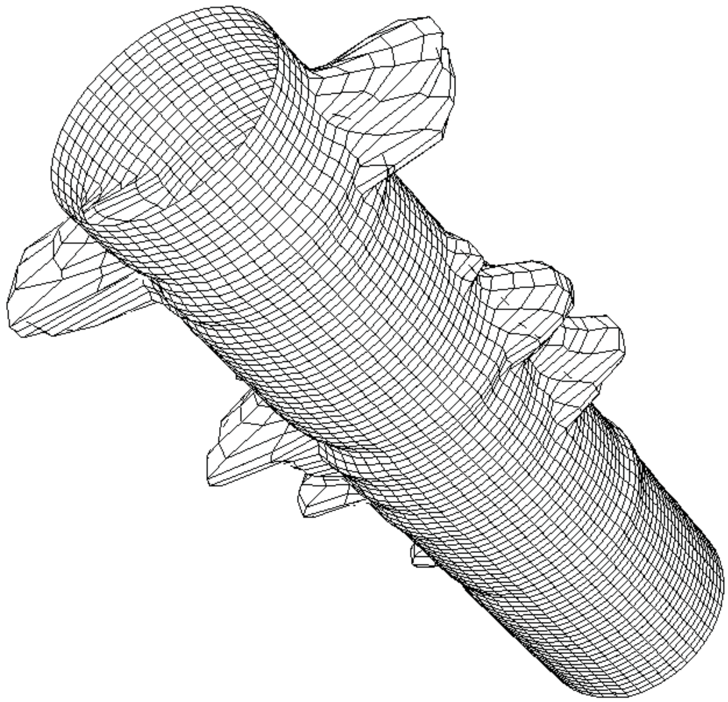

User Guide

QL40 CAL – 3 Arm Caliper

MOUNT SOPRIS INSTRUMENTS

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v12.12.13

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Table of Contents

1 General Information

The QL40-CAL sub records a single continuous borehole diameter log by means of three mechanically coupled arms in contact with the borehole wall. The 3 arm caliper measurement is a useful first log to determine the borehole condition before running other probes.

QL stands for Quick Link and describes the latest line of stackable logging tools. This development is a joint venture of Mount Sopris Instruments (MSI) and Advanced Logic Technology (ALT). Innovative connections between tool elements (subs) allow users to build their own tool strings in the field.
The Tool Stack Factory – a sophisticated extension of the acquisition software – provides a convenient way to configure tool strings for operation.
Each sub has a Telemetry and Power supply element, the TelePSU, allowing them to operate individually without a separate telemetry sub. The GenCPU card in each measurement handles Analog to Digital conversion and/or counting of the measurement signal and formatting of the data for transmission up hole.
The QL40-CAL sub can be operated as a stand-alone probe or can be stacked above or below another sub on a MATRIX logging system.

1.1 Dimensions

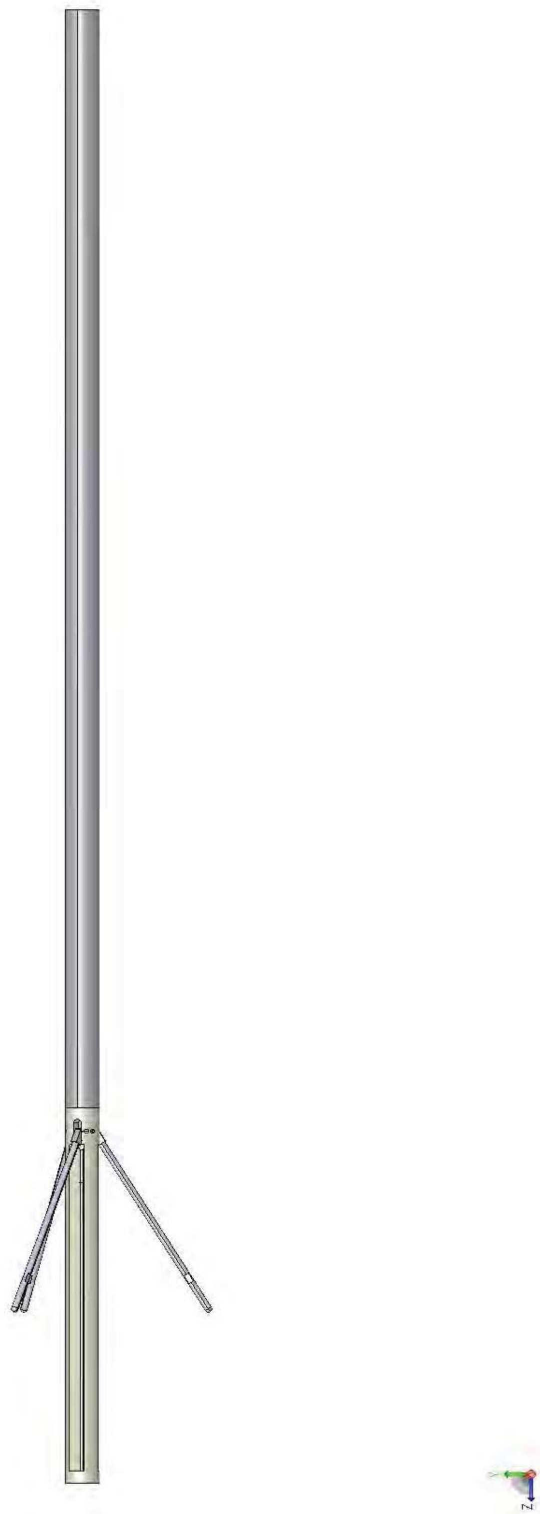


Figure 1-1 *QL40 CAL Dimensions*

1.2 Technical Specification

Tool

Diameter:	Max 42.3mm (1.67")
Length:	1.785m (70.28")
Measurement point:	0.2m up from bottom of locking ring at the tip of the closed, short caliper arms
Weight:	10kg (22lbs)
Max. Temp:	70°C (158°F)
Max.Pressure:	200bar (2900psi)

Cable:

Cable type:	Mono, Coaxial, 4 or 7 conductor
Digital data transmission:	Up to 500 Kbits per second depending on wireline
Compatibility:	ALTlogger – BBOX – Matrix

Measurement:

Standard arms:	57.2mm to 406mm 2.25" to 16"
Extended arms:	300mm to 736mm 12" to 30"

Power:

DC voltage at probe top:	Min 80 VDC Max 160 VDC Nominal 120 VDC
Current:	Nominal 25mA

Figure 1-2 *QL40 CAL 3-arm caliper probe*

2 Measurement Principle

The caliper measurement is made with three arms attached to a mechanical assembly which drives a linear potentiometer. The DC output voltage from the wiper of the potentiometer is converted to a frequency linearly related to the borehole diameter. The 3 Arm Caliper data can be scaled and calibrated in inches or in centimeters.
Opening and closing of the caliper arms is surface controlled from the LoggerSuite application allowing the probe to be run into the borehole with the arms closed. Once positioned at the bottom of the borehole, and caliper arms opened, the spring-loaded arms respond to borehole diameter variations as the probe is moved up the borehole.

The QL40 CAL is supplied with two sets of arms. The standard arms are suitable for a borehole diameter ranging from 57 mm to 406 mm. The extension arms are suitable for borehole diameters up to 736mm. The caliper arms can be unscrewed from their short pivot arms and may be replaced with ones of different length. The hardened arm wear tips can be unscrewed and are easily replaced.

3 Notes on QL tool assembly

QL stands for **Q**uick **L**ink and describes an innovative connection between logging tools (subs) allowing to build custom tool stacks. QL40 describes a specific family of logging tools. Each sub is equipped with its own Telemetry board, Power supply element and A/D converter allowing an operation as stand-alone tool or as a stack in combination with other subs of the QL product family.
The QL40 probe line deals with two types of subs - Bottom Subs and Mid Subs.

Bottom Sub
A bottom sub is a tool that must have one or more sensors located at the bottom. It can be operated in combination with other QL subs connected to the top but it is not possible to connect another sub below. When used in stand-alone mode the bottom sub only needs a QL40 tool top adaptor, which fits the cable head.

Mid Sub
A mid sub is a tool that can be integrated anywhere within a stack of tools. When used at the bottom of a tool string a QL40 bottom plug must be used to terminate the string. If the mid sub is used as a stand-alone tool it needs a QL40 bottom plug at the lower end and a QL40 tool top adaptor at the top.

3.1 QL40 stack assembly

QL40 tool stacks are terminated by either a QL40 bottom sub or a QL40 bottom plug. At the top of the stack a QL40 tool top is required to connect the tool string to the cable head. Several tool tops are already available, special ones can be made on request.

To assemble and disassemble the subs the C-spanner delivered with the tool must be used (Figure 3-1). It is recommended that before each assembly the integrity of the O-rings (AS216 Viton shore 75) is verified. Prime the O-rings with the silicon grease that was supplied with the subs.

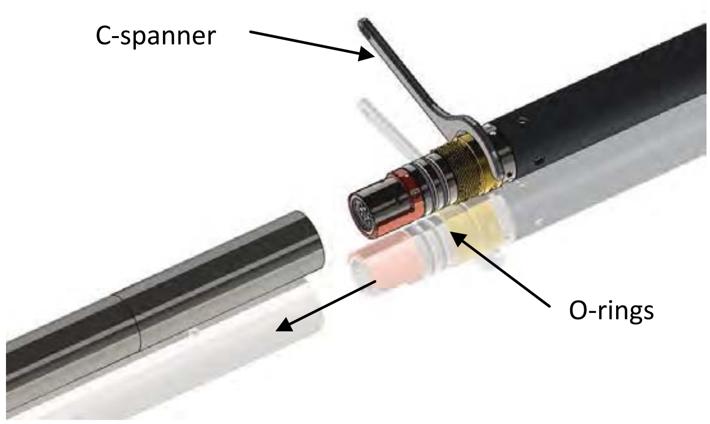


Figure 3-1 *C-spanner and O-rings of QL connection*

The following example of a QL40-ABI, QL40-GAM and QL40-GO4 (Figure 3-2) describes how to replace the QL40-ABI with a QL40-Plug in order to run the QL40-GAM sub stand-alone.

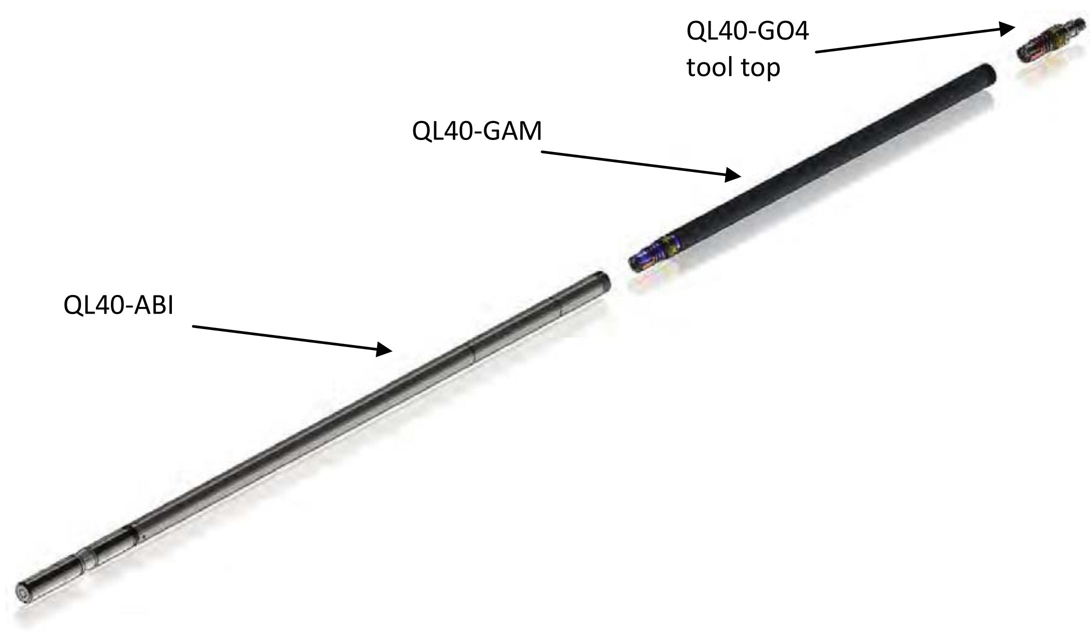


Figure 3-2 *Tool stack example*

To remove the QL40-ABI bottom sub attach the C-spanner to the thread ring as shown in Figure 3-3, unscrew the thread ring and remove the QL40-ABI bottom sub.

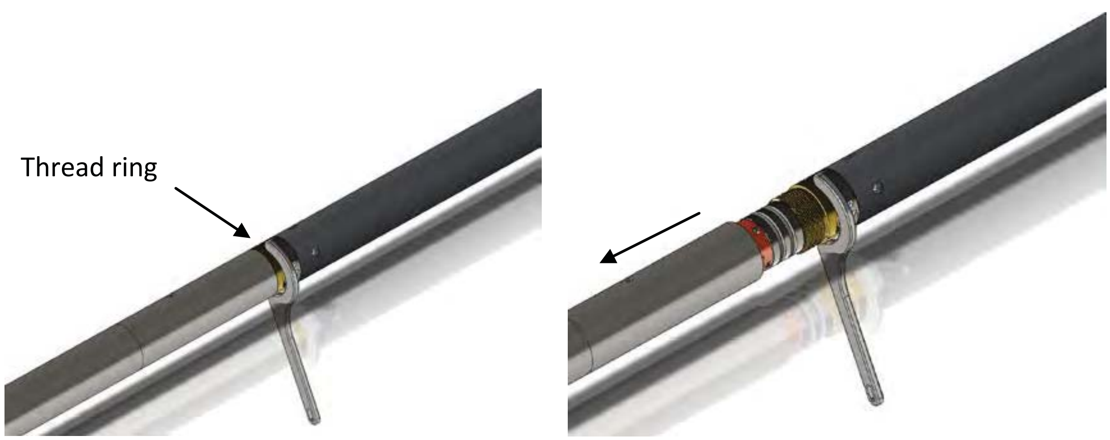


Figure 3-3 *Unscrewing the thread ring and removing the bottom sub*

After checking the O-ring integrity slip the QL40-Plug over the exposed QL connector (Figure 3-4) attach the C-spanner and screw the thread ring until the plug fits tight.

Figure 3-4 *Attaching the QL40-Plug*

The QL40-GAM can now be run stand-alone (Figure 3-5).

Figure 3-5 *QL40-GAM mid sub with tool top and bottom plug*

4 Operating Procedure

Note: Parts of the topics discussed in these sections below assume that the user is familiar with the ALTLog or MATRIX acquisition software. Refer to the corresponding operator manuals for more details. Information about assembly and configuration of tool stacks can be found in the same manuals.

4.1 Quick Start

1. Connect the QL40 CAL to your wireline and start the data acquisition software.

2. Select the relevant QL40 CAL tool/stack from the drop down list (Figure 4-1) in the software's **Tool** panel (if your tool is not listed check that your tool configurations file is stored in the designated folder on your computer using the *LoggerSettings* application).

Figure 4-1 *Tool panel*

3. In the **Tool** panel switch on the tool (click **On** button) and verify that the power indicator shows a valid (green) level.
The system goes through a short initialization sequence which sets the default parameters and communication settings held in the tool configuration file. The configuration returned by the tool is also checked during this procedure. (Setup tool communication as explained in Chapter 4.2 if an error message is displayed.)

4. In the **Acquisition** panel (Figure 4-1**Error! Reference source not found.**) select the time sampling mode. Switch on the sampling (click the **ON** button). The process of opening the caliper arm can now be monitored in the MChNum window.

Figure 4-2 *Acquisition panel*

5. On the **Tool** panel (Figure 4-1) click the **Settings / Commands** button and open the caliper arms from the **Caliper operations** dialog box.

6. Once the caliper arms are open (Caliper Operating progress bar disappeared) turn the sampling **Off,** select the final sampling mode (depth or time) from the **Acquisition** panel (Figure 4-3). Click on **Settings** and specify the corresponding sampling rate. Switch on the sampling again (click the **ON** button).

7. Press the **Record** button in the **Acquisition** panel (Figure 4-2**Error! Reference source not found.**), specify a file name and start the logging.

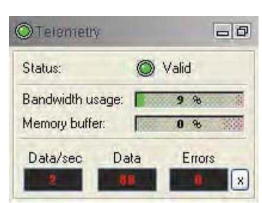


Figure 4-3 *Telemetry panel*

8. During logging observe the controls in the **Telemetry** panel:
   - Status must be valid (green light);
   - Bandwidth usage in green range;
   - Memory buffer should be 0%;
   - Number of **Data** increases and number of **Error**s negligible.
   - Verify motor status (synchronization) in MChNum browser is valid.

9. To end the logging procedure press the **Stop** button in the **Acquisition** panel and turn off the sampling (click **OFF** button).

10. In the **Tool** panel power off the tool.

4.2 Tool Communication with ALT Logger

The telemetry provided through the ALTLogger is self-tuning**.** In case communication status is not valid the user can manually adjust the settings. In the **Telemetry** panel of the dashboard click on **Settings** to display the **Configure Tool Telemetry** dialog box (Figure 4-4**Error! Reference source not found.**).
A procedure to achieve valid communication is given below:

- Change the **Baudrate** to 41666 kbps.
- Verify that the **Downhole Pulse width** knob is set on 20 (default value). This value is the preferred one and is suitable for a wide range of wirelines. For long wireline (over 2000m), increasing the pulse width could help to stabilize the communication. The reverse for short wireline (less than 500m).
- Set the **Uphole** discriminators in the middle of the range for which the communication status stays valid.
- Increase the **Baudrate**, check the communication status stays valid and the **Bandwidth usage** (in **Telemetry** panel of the dashboard) is below the critical level.
- When **Uphole** discriminators are properly set, store the new configuration as default. The tool should go through the initialisation sequence the next time it is turned on.

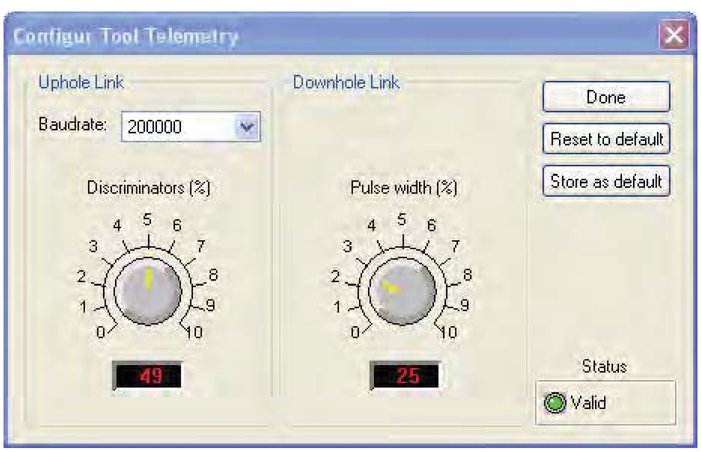


***Figure 4-4** Tool communication settings*

4.3 Tool Communication with MATRIX

The tool telemetry can be configured through the **Telemetry** panel of the Matrix dashboard. By clicking on **Settings**, the operator has access to the **Configure ALT Telemetry** dialog box (***Figure 3-5***) providing various controls to adjust the telemetry settings and monitor its current status.
The **Analysis View** displays the current discriminator levels (vertical yellow lines) and a histogram of the up-hole data signal. The scales of the **Analysis View** can be adjusted using the **Vertical Scale** and **Horizontal Scale** knobs and the **lin**ear / **log**arithmic scale buttons.
The status of the configuration should be flagged as Valid (indicated by the LED being green). In any other case (LED red) the telemetry should be adjusted (we assume a pulse signal is displayed in the analysis view). Click on the **Advanced** button to display additional controls to tune the telemetry.
The Automatic settings option is the preferred mode and should allow the telemetry to be configured for a wide range of wirelines without operator input. For wirelines with a more limited bandwidth, the operator might need to turn off the automatic mode and adjust the telemetry settings manually.
For each wireline configuration, the discriminators (vertical yellow lines) for the **positive** and **negative** pulses must be adjusted in order to obtain a valid communication status (see Figure 4-5 for an example of a suitable discriminator position). There is also the option to alter the **baudrate** in order to optimize the logging speed. The input **gain** can be increased (long wirelines) or decreased (short wirelines) in order to set up the discriminator levels correctly.

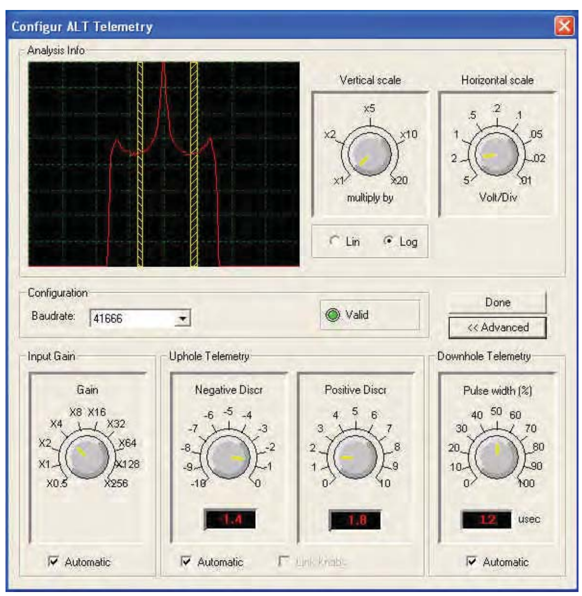


Figure 4-5 *Matrix telemetry settings*

Once the telemetry is correctly set, store the new settings as default. The tool should go through the initialization sequence in "Valid" status the next time the power is turned on.

4.4 Operating the Tool

Warning: *Never lower the tool down the hole with caliper arms open*!

Once the tool has been lowered down to the start position in the hole it is recommended to turn on the sampling in time mode first before opening the caliper arms. This will display the MChNum browser window and allows monitoring of the caliper arm opening process.
To do so:

- Ensure the tool is powered on.
- Select **Acquisition Panel > Time.**
- Start the sampling (**Acquisition Panel > On**). The MChNum browser window (Figure 4-8***Error! Reference source not found.***) will open.

Now open the caliper arms using **Tool Panel > Settings / Commands > Caliper Operation > Open** (Figure 4-6).

Figure 4-6 *Caliper operation dialog to open/close the calliper arms*

During the process of opening/closing the caliper arms the status bar shown in Figure 4-7 will be displayed. In addition the MChNum browser window (Figure 4-8) provides status information (i.e. **Arm** and **Motor** LEDs) and the **Caliper** data field should increase/decrease during opening/closing the caliper arms.

Figure 4-7 *Caliper Operating progress bar*

Figure 4-8 *MChNum window to monitor the calliper opening process*

During operation of the motor to open/close the caliper arms increased power consumption can be observed in the **Tool Panel** (Figure 4-9).

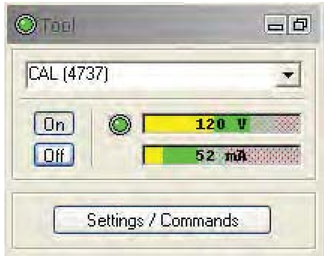


Figure 4-9 *Increased power consumption during opening and closing*

One should wait until the caliper arms are fully opened before commencing the logging operation. This is the case when the **Caliper Operating** status bar (Figure 4-7) has disappeared and the MChNum window status indicators show **Arm – Open** and **Motor – Idle** as shown in Figure 4-10.

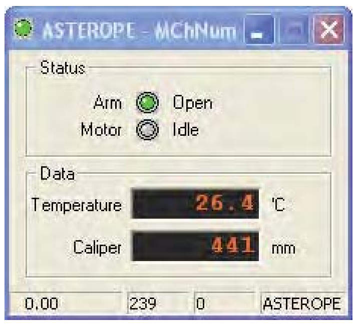


Figure 4-10 *MChNum window indicates arms fully opened*

For fully closed caliper arms the MChNum window status indicators will show **Arm – Closed** and **Motor – Idle** (Figure 4-11).

Figure 4-11 *MChNum window display for arm fully closed*

After the motor stopped moving the caliper arms in or out the power consumption should fall back to the nominal value (Figure 4-12).

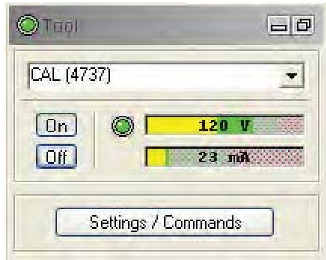


Figure 4-12 *Nominal power consumption when calliper motor does not operate*

4.5 Recorded Parameters, Processors and Browsers

4.5.1 Recorded parameters

The following data channels are recorded by the QL40 CAL tool.

Temperature	**(recorded on CPU board) in °C**
Caliper	**In units specified in the calibration settings**
Motor	*Motor status (Operating (<100), Idle (>100))*
CAL In	*Caliper in raw units*
Open	*Status byte*
Close	*Status byte*
Arm	*Arm status (Open (< -0.5), Close (>0.5), HalfWay ([-0.5, 0.5])*
Time	*Sampling time (s)*

4.5.2 MChCurve Browser

The 3 arm caliper tool produces a single caliper channel which is displayed as curve in the MChCurve browser window (Figure 4-13).

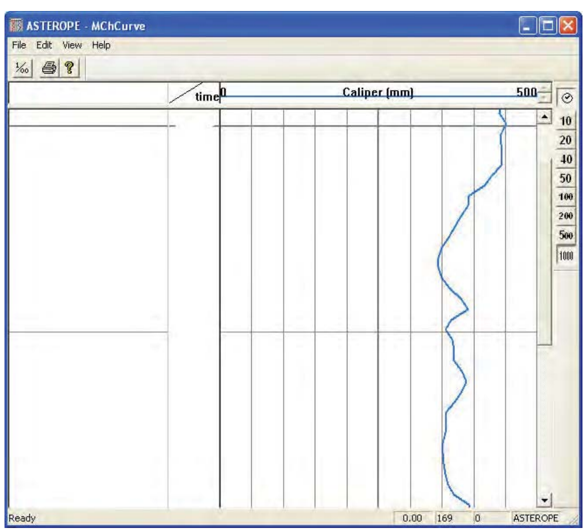


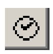
Figure 4-13 *MChCurve browser window displaying Caliper curve*

The user is allowed to modify the curve presentation by double clicking on the log title (colours, column position, scale, filter,gridding,….)

Vertical scales and grids:

Depth mode display and pre-defined depth scales


Operator defined depth scales, interval spacing and settings


Time mode display

4.5.2 MChNum Browser

Figure 4-14 shows a typical example of the numerical values displayed in the MChNum browser.

Temperature:	Temperature recorded on CPU board - °C
Caliper:	Caliper in units defined in the calibration settings

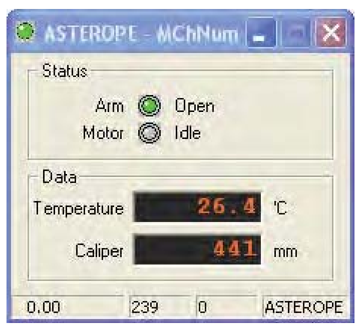


Figure 4-14 *MChNum browser window during logging*

5 Performance Check & Calibration

5.1 Calibration

Calibrations are performed using calibration rings of known diameter over the opened arms (Figure 5-1).

Figure 5-1 *3 Arm Caliper, calibration Jig shown with one arm folded for ease of packaging*

Prepare to Calibrate:

1. Assemble the tool sub(s) and connect to the wireline.
2. In the **Tool Panel**:
   Select the proper tool/stack;
   Turn tool power **On**;
   Click Tool Panel **Settings/Commands** button and open the caliper arms from the dialog.
3. Rotate the Jig arms into place and secure with Socket Flat Head Screws.
4. Slide the Jig over the body of the tool from the bottom and place one arm into each of the desired small set of holes (Figure 5-1).
5. In the **Acquisition Panel** select **Time** and turn it **On**.
6. When the arms are open the Open Status Led in the MCHNum Browser window will turn green. Calibrated measurements will be display in the **Caliper** box.
7. Click the Green LED at the top left corner of the MCHNum Browser window or right click the top pane to display the MCHNum context menu (Figure 5-2).
8. Select **Calibration Settings**.

Figure 5-2 *MCHNum context menu*

Calibration Settings

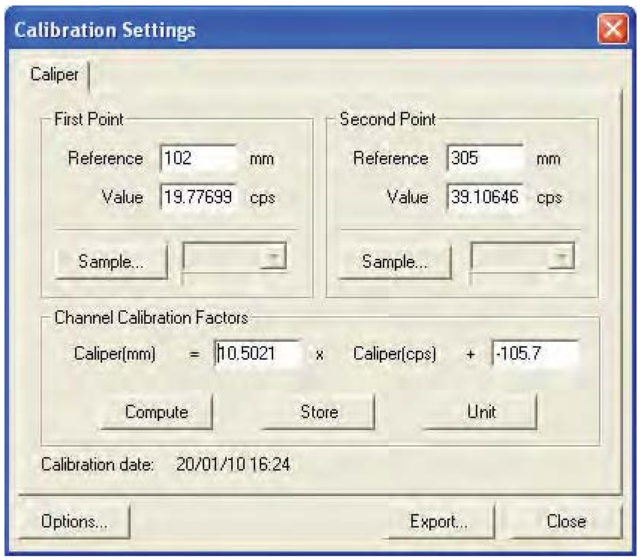


Figure 5-3 *Calibration Settings*

1. In the **First Point** reference enter the diameter of the small calibration value.
2. Click **Sample**. Wait until the sampling is complete and an average value has been determined. It will be displayed in the **First Point Value** box. (The number of samples taken can be changed under **Options**.)
3. Place the caliper arms into a large value calibration Jig hole.
4. In the **Second Point** reference enter the diameter of the large calibration value.
5. Click **Sample**. When average sampling is complete the value read from the tool will display in the **Second Point Value** box.
6. Click **Compute** to determine the calibration coefficients.
7. Set the desired units by clicking on the **Unit** button.
8. Click **Store** to update the corresponding sub files followed by **Close**.
9. On the **Browsers & processors** panel click **Close All** then **Start All** to refresh the other Browsers and Processors. This must be done as they only read the calibration constants from the sub file once when they start.

6 Maintenance

Warning: Removing the electronic chassis from pressure housing without prior consultation with ALT will void the tool warranty.

6.1 Upgrading firmware

In accordance with the ALT policy of continuous development the tool has been designed to allow firmware upgrades.

Firmware upgrade procedure is as follows:
1. Checking the communication is valid.
2. Upgrading firmware

6.1.1 Checking the communication

1. Connect the tool to your acquisition system.
2. Start ALTLog/Matrix software.
3. In the **Tool** panel select the appropriate tool and turn on the power.
4. In the **Communication** panel, select **Settings**. Check **baud rate** is set to **41666** and **communication status** is **valid** (Figure 6-1 or Figure 6-2).

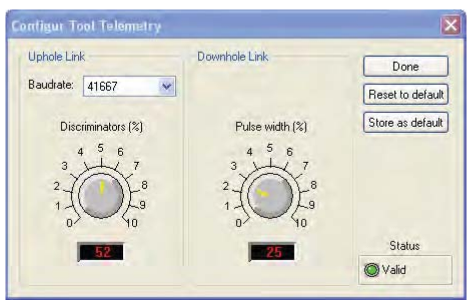


Figure 6-1*Tool communication settings - ALTLog*

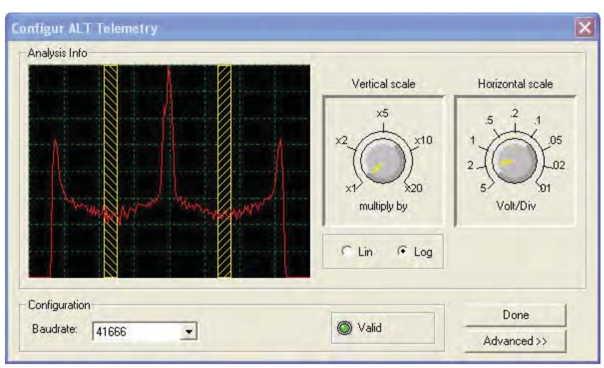
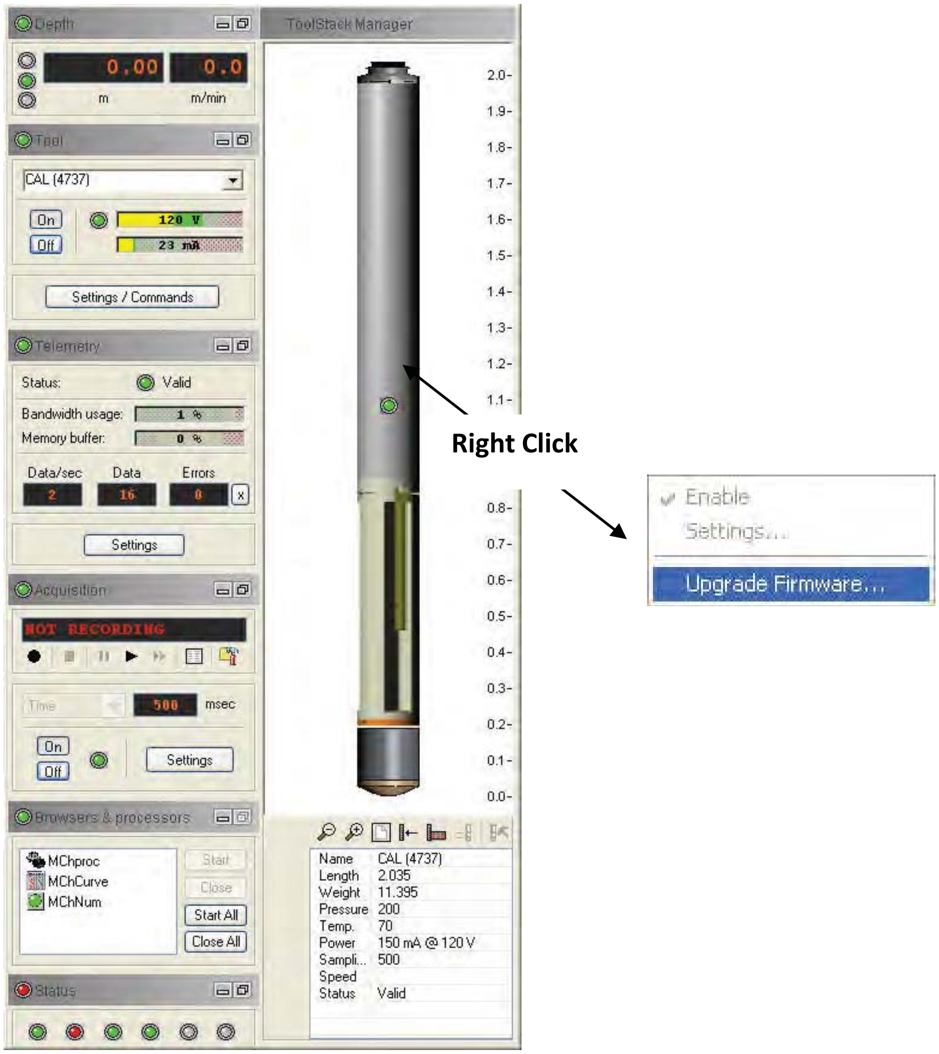


Figure 6-2 *Tool communication settings - Matrix*

Warning: Telemetry must be tuned properly. Bad communication may abort the upgrade of the firmware!

6.1.2 Upgrading the firmware

1. **Right Click** on the tool preview in the **ToolStack Manager** view and select **Upgrade Firmware** from the context menu.



2. The following message will appear (Figure 6-3). Click **Yes** to validate your choice.

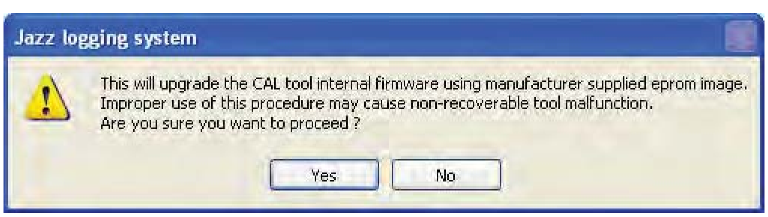


Figure 6-3 *Warning Message during firmware upload*

3. Select and open the appropriate **.hex** file provided. The upgrade will start.
4. During the upgrade procedure, the following message is displayed:

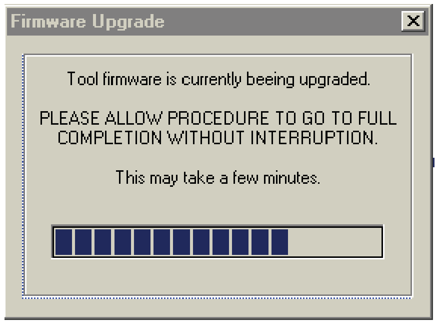


Figure 6-4 *Firmware upgrade progress window*

5. Once the upgrade has been successfully completed (Figure 6-5), click on **OK** to turn off the tool.

Figure 6-5 *Successful upgrade*

6. Power on the tool to start the upgraded firmware.

Note that the following error message (Figure 6-6) will appear at the end of the procedure when the tool firmware upgrade has failed or has been aborted. Verify the tool communication settings in this case.

Figure 6-6 *Error message*

7 Troubleshooting

Observation	To Do
Tool not listed in Tool panel drop down list.	- Do you have a configuration file? - Has the configuration file been copied into the …/Tools folder (refer to MATRIX or ALTLog manual about details of the directory structure)?
Tool configuration error message when powering on the tool.	- Check all connections. - Adjust the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3) and store the new settings as default. Apply the appropriate tool settings for your logging run (see chapter 4.4).
Tool panel - No current.	- Verify that the wireline armour is connected to the logging system. Test your interface cable between winch and data acquisition system. - Verify cable head integrity. - Verify voltage output at the cable head (it should be 120V).
Tool panel - Too much current (red area).	**! Immediately switch off the tool !** **-**Possible shortcut (voltage down, current up): Check for water ingress and cable head integrity - wireline continuity. - Verify the interface cable between winch slip ring and data acquisition system is not loose at the connectors. Check for possible source of a shortcut. - If the above shows no issues, use test cable provided by ALT to verify tool functionality. - If the problem still occurs, please contact service centre.
Telemetry panel - status shows red.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - If problem cannot be resolved contact support@alt.lu .
Telemetry panel - memory buffer shows 100%.	- Indicates that the systems internal memory buffer is full. PC can't receive incoming data streams fast enough. Ensure your PC has enough resources available.
Telemetry panel – bandwidth usage shows 100%. *(Overrun error message.)*	- Set the baudrate to highest value allowed by your wireline configuration. - Reduce logging speed or increase vertical sample step.
Telemetry panel - large number of errors.	- Verify the telemetry settings for your wireline configuration (see chapter 4.2 or 4.3). - Check bandwidth usage and telemetry error status.

8 Appendix

8.1 Parts list

Detailed part numbers and descriptions are available for tool delivery and spare part kits. Please contact support@alt.lu for further details.

8.2 Technical drawings

The following technical drawings are available on request:

- 19” Rack connection diagram.
- Wiring Diagram.

Index

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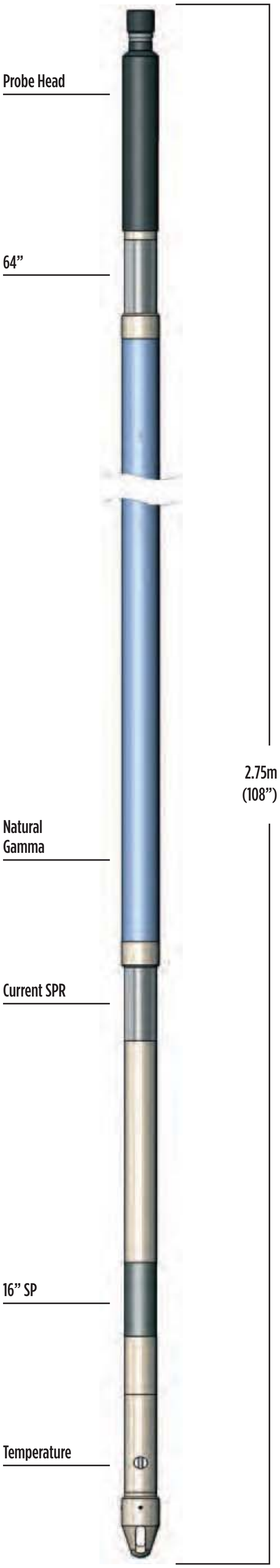


Electric Log Probe

The classic water-well combination probe combining shallow, medium and deep penetrating resistivity measurements with Self-Potential (SP).

Principle of Measurement:

A low-frequency bi-directional electric current from a source electrode on the probe returns through the formation to the cable armour above an insulated bridle. Potentials due to this current flow are measured on various sense electrodes on the probe with respect to a voltage reference 'fish' normally located at the surface. These measurements are converted to apparent formation resistivities within the probe and transmitted to the surface.

SPECIFICATION:

Features

- Digital down-hole measurement avoids errors due to cable effects
- Constant-power down-hole current source

Measurements

- 16" Normal resistivity
- 64" Normal resistivity
- Single-point resistance
- Self-Potential (SP)
- Natural-gamma
- Fluid Temperature
- Optional 8" and 32" Normal resistivity

Applications

- Water
- Determination of water quality
- Indication of permeable zones and porosity
- Minerals/Engineering
- Bed-boundary positions
- Strata correlation between boreholes
- Fracturing Indication

Operating Conditions

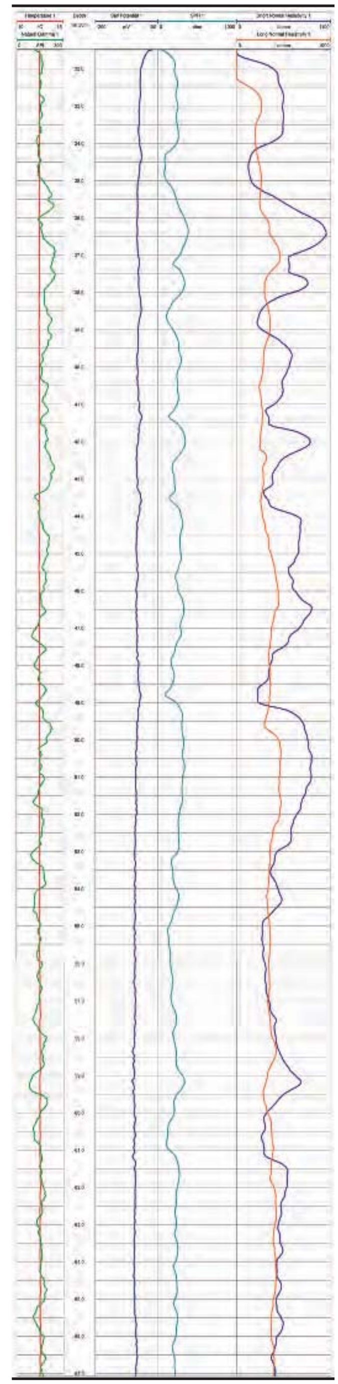
Borehole type:	open-hole, water-filled
Recommended Logging Speed:	4m per min

Specifications

Diameter:	45mm
Length:	2.75m or 3.16m (with 8" and 32" option)
Weight:	11kg
Temperature:	0-70°C (extended ranges available)
Max. pressure:	20MPa
Resistivity range:	1 to 10,000 ohm-m

Part Numbers

I002072	Electric Log probe with natural gamma and temperature
I002111	- including 8" and 32" normal resistivity



Example of logging data

Scan the QR code to go directly to www.robertson-geo.com

ELECTRIC LOG SONDE (Extended Range)
ELXG (WinLogger)

Log Applications:

- Bed boundary identification
- Porosity determination
- Strata correlation between boreholes
- Strata geometry and type (shale indication)
- Formation water quality and temperature
- Temperature compensation of other logs

Measurements made by this sonde:

Channel number	Description of sonde measurement	Channel mnemonic	Measurement Offset (cms)
1	Short normal resistivity (16")	SH N	36
2	Long normal resistivity (64")	LO N	137
3	Natural Gamma	NGAM	76
4	NULL	-	-
5	Self Potential	SP	15
6	Single-point resistance	SPR	56

Operating ranges:

- Self Potential -1 volt to +1 volt
- Resistivity 1 to 10000 ohm metres
- Resistance 1 to 10000 ohms

Physical specifications:

- Length 2.50 metres (12.50 m with bridle)
- Diameter 44 millimetres
- Pressure rating 3000 psi
- Temperature rating 70 celsius
- Power Supply 60-100 V DC, 100mA

Safety Notice:

This equipment is energised at up to 100 Volts by the surface system. Ensure that sonde power is switched off before attaching or detaching the logging cable. Opening the sonde by removing the outer tube should only be attempted by trained personnel.

Hazardous voltages (up to 2 kV) may be present inside this equipment when powered from the surface system.

If the sonde is used in a manner not specified by the manufacturer or his agent, the protection provided by the equipment may be impaired.

Sales Information:

Sondes

26 055 000	Electric Log sonde with earth stake
26 056 000	Electric Log sonde, Including Gamma, with earth stake

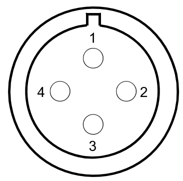
Accessories

20 072 000	Natural Gamma Calibrator, excluding source.
20 100 000	Test Box
30 010 000	100μCi Cs-137 radioctive source for Natural Gamma calibration.

Sonde Connections:

The sonde head connector carries the following signals from the surface system:

Pin Number	Monocable Communications	Four-wire Communications
1	Power and communication	Uphole communication
2	Not connected	Downhole communication
3	Voltage reference	Voltage reference
4	Not connected	Sonde power



Notes:
Pin 1 is adjacent to the polarising keyway, 2, 3 & 4 are numbered clockwise when looking down from above.

Operating principles:

- Resistivity: The sonde operates by driving an alternating current into the formation from the central SPR/DRIVE electrode. The current returns via the logging cable armour. To ensure adequate penetration of the formation the logging cable is insulated for approximately 10 metres from the cablehead, or more if the optional bridle is used. Voltages are measured between the 16" and 64" electrodes and the remote earth connection at surface. Alternatively, the sonde may be configured for a bridle with a lead voltage reference at the top. After attaching the ELOG sonde, it is necessary to complete the insulation between the cable armour and the sonde body with self-amalgamating tape, covering the exposed metal of the sondehead and cablehead - including the bridle connections where appropriate (***do not cover the lead bridle electrode***).

- Single Point Resistance: The current flowing to the cable armour is measured along with the voltage at the SPR electrode. Voltage divided by current gives resistance.

- Self Potential: This is the DC bias of the 16" electrode with respect to the voltage return at surface (earth stake). Normally this conductor carries caliper power at 90 volts. **Use the switch on the winch to isolate this conductor from the surface system before the sonde is energised. Failure to do so may destroy the sonde.**

- Natural Gamma: All rocks contain small quantities of radioactive material. Certain minerals contain trace amounts of Uranium and Thorium, Potassium-bearing minerals will include traces of a radioactive isotope of Potassium. All of these emit gamma radiation as they decay with an extremely long half-life. This radiation is detected by scintillation - the production of a tiny flash of light when gamma rays strike a crystal of Sodium Iodide. The light is converted into an electrical pulse by a photomultiplier tube - pulses above a threshold value of 60 KeV are counted by the sonde's microprocessor. The measurement is useful because the radioactive elements are concentrated in certain rock types e.g. clay or shales, and depleted in others e.g. sandstone or coal.

Log quality depends upon good earthing at the surface. This is achieved with a 'fish' in the mud-pit or with a metal stake. Drive the stake at least 0.5 metres into ground which has been copiously wetted. The stake or 'fish' is then bonded to the identified connection at the winch.

It is not possible to make electrical logs in dry holes.

Calibration:

- RESISTIVITY , SP and SPR

This sonde measures real units downhole, so there is no calibration procedure to be followed for these channels.

For increased precision the values measured downhole are scaled for transmission to the surface. There is a fixed conversion between the sonde response and real units as follows :

Long / Short normal resistivity	: 5 per ohm metre
Single point resistance	: 5 per ohm
Spontaneous Potential	: 10 per millivolt

Note that Spontaneous Potential can read positive or negative. The data format does not permit the transmission of negative numbers, so the count rate is biased in the following way :

Spontaneous Potential : 0 volts = 10,000 cps

- NATURAL GAMMA:

It is possible to calibrate the response of the sonde in API gamma ray units. The procedure falls into two parts, the primary calibration is performed in a test pit at RG during manufacture, and the secondary can be performed in the field using the optional calibration fixture.

The primary calibration uses a test pit manafactured from Uranium-doped concrete which has a known API activity. An identical pit made with the same concrete mix, but without the Uranium additive, is used as a background. The increase in count rate above the background is measured, and this is used to calculate a multiplier which relates the raw count rate to the API count rate.

Once this primary calibration has been performed, it is possible to create a secondary standard which will give a convenient count rate such as 200 API. This is done by mounting a small source on a rod which can be clamped over the detector, and then moving the source in or out along the rod until the activity reaches the required value. At this point the a small detent is made in the rod at the correct position, and the jig is stamped with the API value. If an optional API calibrator is specified by the customer, all the above procedures will be performed by RG.

Click on ***Tools|Calibration***, and you will be invited to select the sonde which you intend to calibrate. The dialogue box is the same as that used on entry to the Sonde Database, and can be used in the same way. ***Please note that you may not change the serial number of the sonde in this dialogue*** - to do that, go to the ***Tools|Sonde Database*** dialogue, select the GLOG and click OK to enter the database editor. Then you may modify the serial number and save the changed data. The sonde mnemonic and serial number will be combined to make a filename unique to that sonde (e.g. GLOG1956.CAL), which you will select later when preparing to make the log.

Secondary calibration is achieved through the ***Tools|Calibration*** menu. Select the ***NGAM*** channel and you will be asked to establish *background* conditions. Place the sonde horizontally on stands about 1 metre above the ground. Start acquisition by clicking ***Continue***, which will proceed for 5 minutes (300 seconds). At the end of the first period, attach the calibrator jig to the sonde tube, taking care that the base of the rod is exactly centred over the detector crystal. This can be determined experimentally by 'peaking' the count rate in a separate time mode log, or by measurement from the base of the sonde. Start the second acquisition period. After 5 minutes counting, you will be asked for the activity of the calibration source (see below). The calibration coefficients will then be computed and written to file together with the count rates and timestamp. Previous data will be transferred to the 'history' file for reference.

The date of calibration is important because the API value will change as the source decays. The API value at any time in the future is given by :

$$API_t = API_0 \cdot \exp(-t \cdot \ln(2) / T_{1/2})$$

where :

t = time (years) since the original API calibration.
API_t = API value at time t.
API_0 = original API value.
$T_{1/2}$ = half-life of isotope.

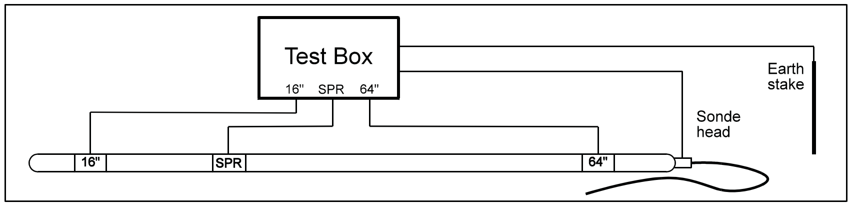
The half-life of ^{137}Cs is approximately **28 years**. In a four year period, a ^{137}Cs source will decay to approximately 90% of its original value, and to 80% after 10 years.

Testing sonde functions:

A test box can be supplied separately for checking sonde operation. It is not a calibration jig.

Select ELOG operation on the winch switch box to isolate the voltage return connection from the surface system. Failure to do so may destroy the sonde.

Connect the earth stake or 'fish' to the winch box. Connect the sonde to the logging cable, but do not put tape on the cablehead yet. ***Note that a sonde may be configured for use with a bridle electrode - if so configured, it can not be used without a bridle unless its configuration is changed internally.*** Connect the test box as shown below. The sockets on the test box are labelled with the names of the electrodes. Two return wires are permanently attached to the test box. They are interchangeable. Connect one to the metal sonde head and the other to the earth stake.



Start the WinLogger software and choose the menu item ***Tools|SondeTest*** or use the toolbar icon to start the utility. Choose ***Standard Six Channel*** from the sonde type selection box, then click on ***Start Test***. Power will be applied to the sonde. Select the ***Normal*** data display mode, and then click ***Show Data***.

With the rotary switch on the test box select resistivity ranges and observe the sonde response. Channels 1,2 and 6 should read close to 5 times the range value selected, although it will not be exact due to component tolerances.

Pressing the push button on the test box which is marked **'SP'** will connect a battery into the circuit. You should be able to see an increase in the SP reading on channel 5 corresponding to 100 millivolts or 1000 cps.

The Natural Gamma section (when fitted) will normally give a small count rate at the surface due to the radioactive background. Otherwise a small test source of gamma rays can be utilised e.g. 10 μCi ^{137}Cs.

If all is well you can proceed to make a log.

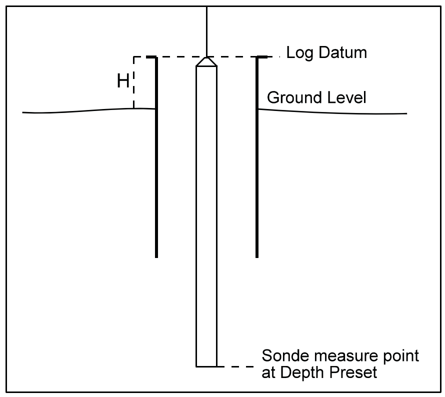
Logging Procedure:

These instructions should be used in conjunction with the full, or quick reference guide to logging with your surface system. First, ensure that Sonde Power is OFF.

Isolate the voltage return from the surface system by selecting ELOG position on the winch switch box. Failure to do so may destroy the sonde.

Attach the sonde to the logging cable. ***Note that a sonde may be configured for use with a bridle electrode - if so configured, it can not be used without a bridle unless its configuration is changed internally.*** Insulate the sonde head by wrapping all exposed metal of the cablehead and sondehead with self-amalgamating insulation tape between the cable sleeving and the insulated sonde body. ***Do not insulate the lead electrode if a bridle is fitted.*** Check for damage to the insulating sleeve on the logging cable.

Drive the earth stake firmly into the ground. Soak the area with water if necessary to achieve good contact. Connect the stake to the socket on the winch switch box.



Lower the sonde into the borehole. Use the winch to align the top of the sonde with your logging datum. Set the depth preset. For logging uphole this will be 2.50 metres, or 12.50 metres if the bridle is fitted. If you wish to use ground level for your datum you must subtract the height H from the above preset. Lower the sonde to the bottom of the zone of interest. Once the sonde has passed any casing in the borehole it is a good idea to use the ***Tools | Sonde Test*** dialogue to monitor the operation of the sonde.

If you wish to produce a log with real electrical units you should check the ***Calibration*** option on the ***Data Processing*** tab of the Log Settings profile sheet when you go to start the new log, then browse for the appropriate file. The calibration file will contain the fixed conversion for the resistivity (and may also contain API gamma calibration).

Observe the data as the tool ascends. The sonde will operate correctly at up to 10 metres/minute, but the ideal is around 5 m/min. Resolution from Natural Gamma, when fitted, will be improved at lower speeds. When the uninsulated section of the logging cable leaves the water, the log should be terminated as the sonde will not function any further.

Remove the sonde from the borehole. Remove insulating tape from the sonde head and detach the sonde from the cable. Clean the sonde with fresh water and dry it off. Stow it securely to prevent damage. Reset the switch on the winch box for normal operation if you will be using other types of sonde.

DUAL FOCUSSED INDUCTION | ULTRA-SLIM INDUCTION

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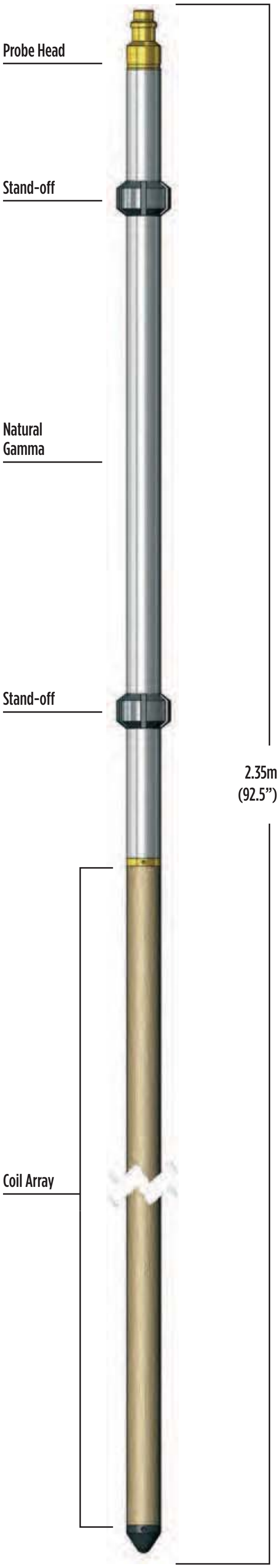


Dual Focussed Induction Probe

The Dual Focussed Induction probe provides two simultaneous conductivity logs, corresponding to "medium" and "deep" radii of investigation into the formation.

The two depths of penetration are useful in porous, permeable formations where displacement of formation fluids by drilling mud creates an "invasion zone" with different electrical properties. The 1" focussed induction probe produces a single medium penetration conductivity log. It finds particular application in small-diameter dry or plastic-lined boreholes used for mineral exploration and for conductivity/resistivity in dry holes.

Principle of Measurement:

An oscillating high-frequency magnetic field from a transmitter coil within the probe induces an alternating electrical current within the surrounding conductive formation. This current, in turn, induces voltages within receiver coils proportional to the formation conductivity. The transmitter-receiver spacings determine the depth of investigation of the measurements. Additional focussing coils minimise the contribution of the borehole signal.

SPECIFICATION:

Features

- Formation conductivity measurement in wet/dry boreholes or through plastic casing
- Separate deep and medium penetrating measurements give information on invaded zone
- Focussed measurements for minimum borehole signal PSD (phase-sensitive detector) discriminates between magnetic susceptibility and conductivity signals

Measurements

- Deep formation conductivity
- Medium formation conductivity
- Natural Gamma

Applications

Water
- Indicator of permeable zones and porosity
- Formation water salinity
- Long-term well monitoring

Mineral/Engineering
- Ore identification and quality
- Correlation

Other
- Indication of hydrocarbons

Operating Conditions

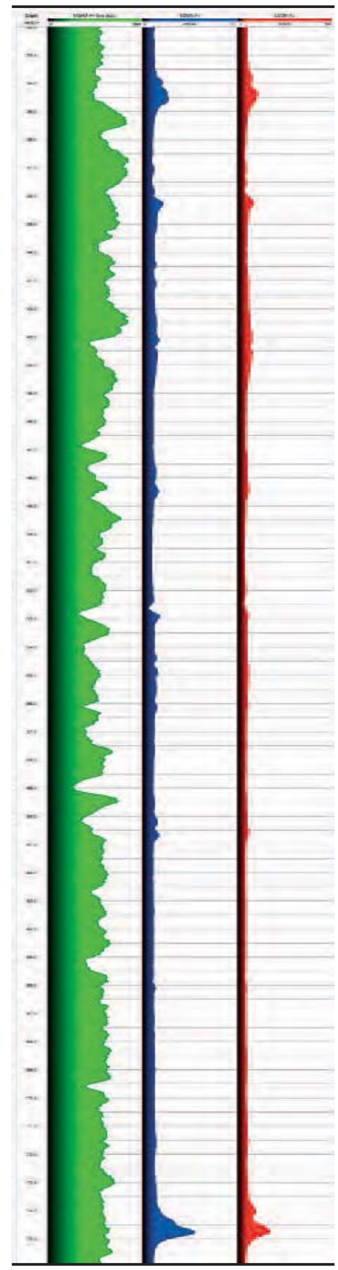
Borehole type:	open/plastic or grp cased, air/water-filled
Recommended Logging Speed:	5m/min

Specifications

Diameter:	38mm/25mm
Length:	2.35m/1.95m
Weight:	6kg
Temperature:	0-70°C (extended ranges available)
Max. pressure:	20MPa
Number of coils:	Dual Induction 7, Ultra-slim 4
TX-RX spacings:	ILM 50cm (20"), ILD 81cm (32")
Conductivity range:	3 to 3300mS/m

Part Numbers

I002087	Dual Focussed Induction probe with natural gamma
I002091	Ultra-Slim Induction probe with natural gamma



Example of logging data

Scan the QR code to go directly to www.robertson-geo.com

DUAL-SPACING INDUCTION SONDE
DIND (WinLogger)

Log Applications:

- Water quality
- Bed boundaries
- Correlation

Measurements made by this sonde:

- Formation conductivity
- Natural Gamma
- Formation Resistivity (Computed from conductivity measurement)

Channel number	Description of sonde measurement	Channel mnemonic	Measurement Offset (cms)
1	No measurement	NULL	-
2	Natural Gamma ❶	NGAM	229
3	Conductivity (Long Spacing)	LCON	113
4	No measurement	NULL	-
5	Conductivity (Short Spacing)	SCON	92
6	No measurement	NULL	-

❶ Only present on sondes specified for Natural Gamma measurement

Operating ranges:

- Conductivity 3 - 3,000 mS/m (0.3 - 300 Ohm-Metres)

Physical specifications:

- Length 2.42 metres
- Diameter 42 millimetres
- Pressure rating 3,000 psi
- Temperature rating0-50 Degrees Celsius
- Weight 8.5 Kg
- Power Supply 60-100 V DC, 100mA

Safety Notice:

This equipment is energised at up to 100 Volts by the surface system. Ensure that sonde power is switched off before attaching or detaching the logging cable. Opening the sonde by removing the outer tube should only be attempted by trained personnel.

Hazardous voltages (up to 2 kV) may be present inside this equipment when powered from the surface system.

If the sonde is used in a manner not specified by the manufacturer or his agent, the protection provided by the equipment may be impaired.

Sales Information:

Sondes

26 062 000	Dual Focussed Induction Sonde with calibrator
26 063 000	As above, including Natural Gamma measurement

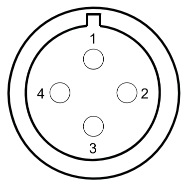
Accessories

23 001 000	Fin stand-off
20 072 000	Natural Gamma Calibrator, excluding source.
30 010 000	100μCi ^{137}Cs radioctive source for Natural Gamma calibration.

Sonde Connections:

The sonde head connector carries the following signals from the surface system:

Pin Number	Monocable Communications	Four-wire Communications
1	Power and communication	Uphole communication
2	Not connected	Downhole communication
3	Not connected	Not connected
4	Not connected	Sonde power



Notes:
Pin 1 is adjacent to the polarising keyway, 2, 3 & 4 are numbered clockwise when looking down from above.

Operating principles:

- INDUCTION

  The induction sonde uses a coil array: one transmitter, one receiver and a number of focussing coils. The sonde's coil spacing is optimised to achieve high vertical resolution and a deep radius of investigation. In this instrument the focussing action is arranged to give two different depths of investigation, 24 inches (60cm) and 32 inches (80cm).

  The transmitter coil is supplied with a sine wave drive. The alternating magnetic field induces a circular current flow around the axis of the sonde in a toroidal zone shaped by the focussing coils. The current flow sets up an alternating magnetic field of its own. The induced magnetic field sets up an out-of-phase EMF in the receiver coil which is amplified by the measurement circuit. An EMF is also produced from the direct magnetic coupling between the transmitter and receiver coils.

  The conductivity information is contained in the received out-of-phase EMF. The in-phase component due to the direct coupling is unwanted and removed by a phase sensitive detector in the measurement circuit.

  The induction method is unique because it is the only conductivity/resistivity measurement which will operate in dry holes, oil based muds or plastic-cased boreholes.

- NATURAL GAMMA
  All rocks contain small quantities of radioactive material. Certain minerals contain trace amounts of Uranium and Thorium. Potassium-bearing minerals will include traces of a radioactive isotope of Potassium. All of these emit gamma radiation as they decay with an extremely long half-life. This radiation is detected by scintillation - the production of a tiny flash of light when gamma rays strike a crystal of Sodium Iodide. The light is converted into an electrical pulse by a photomultiplier tube - pulses above a threshold value are counted by the sonde's microprocessor. The measurement is useful because the radioactive elements are concentrated in certain rock types e.g. clay or shales, and depleted in others e.g. sandstone or coal. It is an ideal method for correlation, since the activity profile will remain constant on human timescales.

Units

The dual induction sonde measures conductivity in units of milliSiemens per metre. The User Function performs the following conversion to produce resistivity measured in Ohm-metres:

Resistivity = 1000 / Conductivity from sonde measurement

Calibration:

Click on ***Tools|Calibration***, and you will be invited to select the sonde which you intend to calibrate. The dialogue box is the same as that used on entry to the Sonde Database, and can be used in the same way. ***Please note that you may not change the serial number of the sonde in this dialogue*** - to do that, go to the ***Tools|Sonde Database*** dialogue, select the Induction Sonde (DIND) and click OK to enter the database editor. Then you may modify the serial number and save the changed data. The sonde mnemonic and serial number will be combined to make a filename unique to that sonde (e.g. DIND1202.CAL), which you will select later when preparing to make a log.

When the sonde has been identified, you will be given the choice of which channel to calibrate. Only channels nominated for calibration may be selected - and with each will be associated a calibration scenario which must be followed for correct operation.

NATURAL GAMMA It is possible to calibrate the response of the Natural Gamma detector in API gamma ray units. The procedure falls into two parts, the primary calibration is performed in a test pit at RG during manafacture, and the secondary calibration, which can be performed in the field using the optional calibration fixture.

The PRIMARY calibration uses a test pit manafactured from Uranium-doped concrete which has a known API activity. An identical pit made with the same concrete mix, but without the Uranium additive, is used as a background. The increase in count rate above the background is measured, and this is used to calculate a multiplier which relates the raw count rate to the API count rate.

Once this primary calibration has been performed, it is possible to create a SECONDARY standard which will give a convenient count rate such as 200 API. This is done by mounting a small gamma ray source on a rod which can be clamped over the detector, and then moving the source in or out along the rod until the activity reaches the required value. At this point a small detent is made in the rod at the correct position, and the jig is stamped with the date and API value. The detent allows the correct position for the source holder to be determined.

If an optional API calibrator is specified by the customer, all the above procedures will be performed by RG. Secondary calibration is achieved through the ***Tools|Calibration*** menu - as explained for the caliper section previously. Select the ***NGAM*** channel and you will be asked to establish *background* conditions. Place the sonde horizontally on stands about 1 metre above the ground. Start acquisition by clicking ***Continue***, which will proceed for 5 minutes (300 seconds). At the end of the first period, attach the calibrator jig to the sonde tube, taking care that the base of the rod is exactly centred over the detector crystal. This can be determined experimentally by 'peaking' the count rate in a separate time mode log, or by measurement from the base of the sonde (taking into account the fact that the gamma-gamma source holder will not be attached at this stage). Start the second acquisition period. After 5 minutes counting, you will be asked for the activity of the calibration source (see below). The calibration coefficients will then be computed and written to file together with the count rates and timestamp. Previous data will be transferred to the 'history' file for reference.

The date of calibration is important because the API value will change as the source decays. The API value at any time in the future is given by :

$$API_t = API_0 \cdot \exp(-t \cdot \ln(2) / T_{1/2})$$

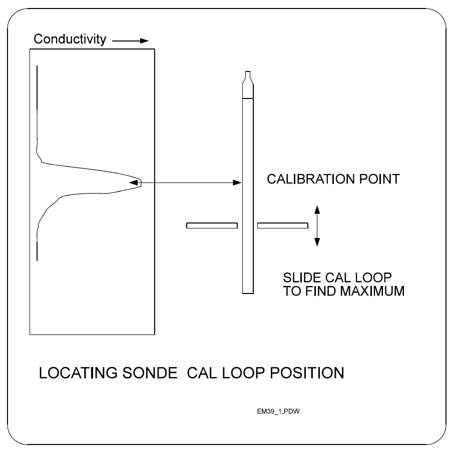
where :

- t = time (years) since the original API calibration.
- API_t = API value at time t.
- API_0 = original API value.
- $T_{1/2}$ = half life of isotope.

The half life of ^{137}Cs is approximately **28 years**. In a four year period, a ^{137}Cs source will decay to approximately 90% of its original value, and to 80% in ten years. The value for the activity of the calibration source must therefore be adjusted on at least an annual basis.

INDUCTION Before attempting this procedure, select the DIND sonde and turn on the sonde power, allowing the sonde several minutes to come to a stable operating temperature. The sonde must be supported on non-conducting stands, at least 1.5 metres above the ground, wooden tripod stands are ideal. A calibration loop is provided with the sonde, which gives three switch-selected values of apparent conductivity.

Before calibration starts, the exact calibration positions on the sonde need to be established. This is achieved by putting the calibration loop over the sonde and sliding it up the sonde while logging in TIME mode. The position of maximum response is indicated in the sketch below. Put the range selection switch on the cal loop in the maximum conductivity position. Note that it is not required to have the sonde calibrated for this operation, since all that is required is the position of the peak response. Use scales from 32000 to 64000 CPS to get a good display. The correct positions of the sonde calibration loop will be around 92 and 113cm from the bottom of the sonde. It is recommended that these points be marked with insulating tape (**do not use any metal-based tape**).



With the calibration loop is in the lower position, perform the first calibration process. Select the **DIND** sonde and click on **Tools|Calibration**, then select the **SCON** channel from the list box. You will be required to establish three different conductivity settings, for each you must set the switch on the calibration ring, enter the conductivity value and click **Continue** to perform counting for about 10 seconds. The use of all three calibration points is compulsory, including the zero conductivity point. Coefficients will be stored in the correct format when you click **Save**.

Repeat the process with the calibration loop in the upper position, selecting the **LCON** channel.

Finally, check your results with a time mode log in the jig before proceeding.

Testing sonde functions:

Use the calibration loop, and make a calibrated log in TIME mode. The conductivity ranges of the calibration loop should be read out correctly on the logging system when it is positioned at the focus points of the sonde.

Cal Loop Apparent Conductivity & Resistivity

Loop Resistance (Ω)	Apparent Conductivity (mS/m) Short Spacing	Apparent Conductivity (mS/m) Long Spacing
1	3339	2263
10	331	225
∞	0	0

User Function:

The ***calibrated*** conductivity data from the sonde must be manipulated by a process running on the logging system in order to compute the formation resistivity. The User Function should be shipped with the sonde, but in case of non-availability, and for explanantion, the code is presented below.

```
/************ Dual Induction Sonde **********/
/* Copy Natural Gamma unchanged */
OUT1 = IN2;
/*Deep - check conductivity to prevent maths error */
TMP3 = fabs(IN3);
if (TMP3 > 0.5)
  OUT2 = 1000 / TMP3;
else
  OUT2 = 2000;
/* Shallow - check conductivity to prevent maths error */
TMP5 = fabs(IN5);
if (TMP5 > 0.5)
  OUT3 = 1000 / TMP5;
else
  OUT3 = 2000;
```

IN2 is Natural Gamma. IN3 is the calibrated long-spacing (deep) conductivity measured by the sonde, IN5 is the calibrated short-spacing (shallow) conductivity.

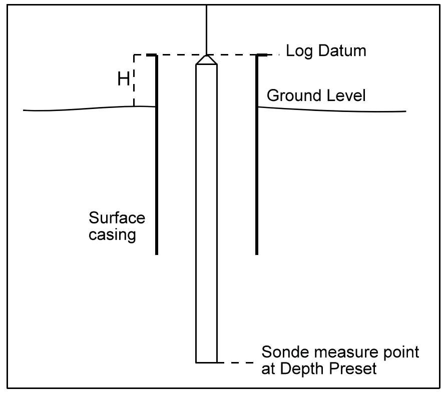
The computation is simple, since it only performs the reciprocal of the conductivity, with appropriate conversion of units. The maths is protected against a divide-by-zero error by checking that the conductivity is greater than 0.5 milliSiemens per metre, at which point the resistivity output is clamped. N.B. This version of the user function also checks to see that calibration has not introduced small negative values for conductivity. These are ‘rectified’ to prevent large negative anomalous values for resistivity being produced.

For more information regarding implementation of User Functions please refer to the Logging Software Manual.

Logging Procedure:

These instructions should be used in conjunction with the full, or quick reference guide to logging with your surface system.

Attach the sonde to the logging cable. Select the INDS sonde from the drop-down list on the toolbar. Place the sonde into the borehole and level the sonde off with the datum, then set the depth preset - this will be 2.42 metres for an uphole log. If you wish to use ground level for your datum you must subtract the height H from the preset (see sketch).



While running in steel casing, it is recommended that the sonde power be switched off. It is OK to log up into casing for a short distance with the sonde power on, at the end of the logging run, but extensive operation in casing should be avoided.

Run into the hole until the bottom of the required section is reached. Use the ***Test Sonde*** facility to monitor the operation of the sonde and allow it time to warm up to a stable operating temperature. Avoid resting the tool in the mud at the bottom of the borehole.

Use ***File|New Log*** from the menu, or click on the toolbar icon to intialise the log. The log mode will be set to uphole by default. The log should be run with calibration on, this is selected through a check-box on the ***Data Processing*** tab of the log initialisation dialogue. Use the ***Browse*** facility to select the calibration file which you created in the previous steps described above. The User Function should also be enabled for a log of resistivity.

When the log is initialised, pull up at a steady speed. This log can be run at speeds up to 10m/min, but when Natural Gamma is fitted, the log should be run more slowly for improved resolution, at up to 6 m/min. Pull up until the end of the required section. See the note above regarding steel cased sections. Close the log file and turn OFF sonde power.

Remove the sonde from the borehole and detach it from the cable. Clean it with fresh water and dry it off. Stow it securely to prevent damage.

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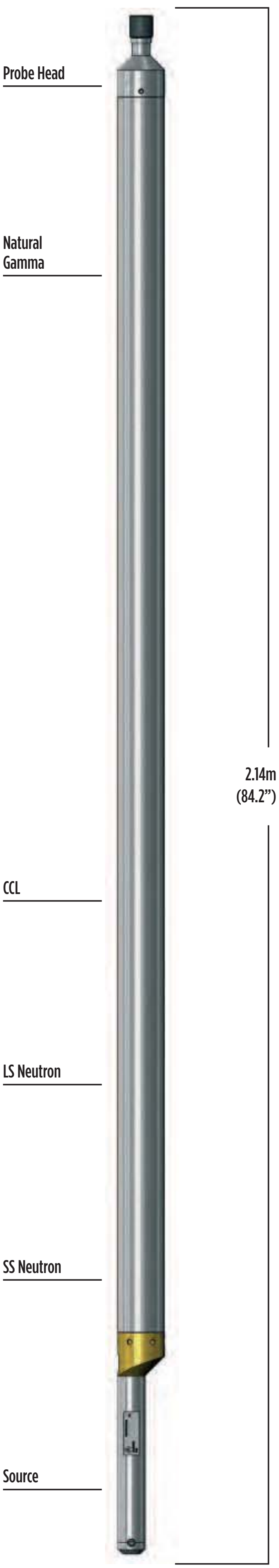


Dual Neutron Probe

The Dual Neutron probe provides a calibrated borehole-compensated neutron porosity measurement in mud-filled open holes.

It is the probe of choice for quantitative formation-fluid studies.

A single-detector neutron probe is also available for qualitative porosity logging under most borehole conditions including through steel or plastic casing and drill-pipe.

Principle of Measurement:

The Dual Neutron measurement uses two ^{3}He proportional detectors and a detachable, sealed ^{241}Am-Be neutron source. Fast neutrons emitted by the source are scattered and slowed to thermal levels, principally by hydrogen in the formation. The ratio of the neutron flux reaching the near and far detectors depends on the hydrogen index and porosity. Use of dual detectors and a ratio method provides a porosity measurement compensated for borehole diameter but not independent of it.

SPECIFICATION:

Features

- Real-time porosity measurement
- Compensation for borehole diameter

Measurements

- Compensated porosity
- Neutron (raw counts)
- Natural gamma
- Option: Casing-collar locator (CCL)

Applications

Minerals / Water / Engineering

- Lithology identification
- Location of aquifer and aquitard
- Fracture analysis in coals
- Correlation between open and cased-hole logs
- Strata correlation between wells

Operating Conditions

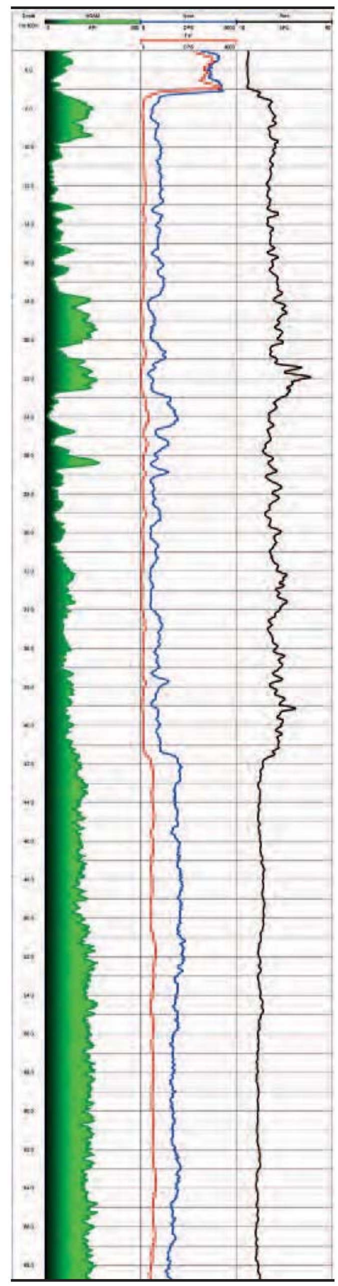
Borehole type:	open/cased, water-filled
Centralisation:	ex-centralised with bowspring
Recommended Logging Speed:	4m/min

Specifications

Diameter:	65mm
Length:	2.14m
Weight:	19.5kg
Temperature:	0-70°C (0-125°C optional)
Max. pressure:	20MPa
Range:	15 to 45% Limestone Porosity Units (LPU)

Part Numbers

I002029	Dual Neutron probe with natural gamma
I002030	- includes CCL



Examples of logging data

Scan the QR code to go directly to www.robertson-geo.com

DUAL-SPACING EPITHERMAL NEUTRON SONDES
DNNS (WinLogger)

Log Applications:

- Measurement of formation porosity
- Lithology identification
- Strata correlation between boreholes
- Correlation between logs in cased and uncased boreholes
- Fracture analysis in coal seams

Measurements made by this sonde:

Channel number	Description of sonde measurement	Channel mnemonic	Measurement Offset (cms)
1	Near Detector Count Rate	NEAR	25
2	Far Detector Count Rate	FAR	40
3	No Measurement	-	-
4	No Measurement	-	-
5	Casing Collar Locator ✸	CCL	78
6	Natural Gamma Radiation ✸	NGAM	199

✸ These measurements are optional

Operating ranges:

- Neutron -15% to 45% Limestone Porosity

Physical specifications:

- Length 1.925 metres + 0.230 metres with the source
- Diameter 63.5 millimetres
- Pressure rating 2,000 psi
- Temperature rating0-70 celsius
- Power Supply 60-100 V DC, 100mA

Safety Notice:

This equipment is energised at up to 100 Volts by the surface system. Ensure that sonde power is switched off before attaching or detaching the logging cable. Opening the sonde by removing the outer tube should only be attempted by trained personnel.

Hazardous voltages (up to 2 kV) may be present inside this equipment when powered from the surface system.

If the sonde is used in a manner not specified by the manufacturer or his agent, the protection provided by the equipment may be impaired.

Sales Information:

Sondes

25 019 000	Dual Neutron - Neutron (Thermal) Sonde with source holder and transport container.
25 020 000	As 25 019 000, including Natural Gamma measurement.
25 021 000	As 25 019 000, including Natural Gamma and CCL measurements.

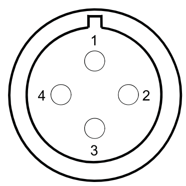
Accessories

30 006 000	3 Ci Neutron source, Americium-Beryllium.
30 010 000	100μCi ^{137}Cs source for Natural Gamma calibration.
20 274 000	Natural Gamma Calibrator, excluding source.
20 091 000	Neutron Calibrator.
22 020 000	Bowspring excentraliser (90 - 180 mm)
22 021 000	Bowspring excentraliser (180 - 260 mm)
22 022 000	Bowspring excentraliser (260 - 342 mm)
22 023 000	Bowspring excentraliser (342 - 472 mm)

Sonde Connections:

The sonde head connector carries the following signals from the surface system:

Pin Number	Monocable Communications	Four-wire Communications
1	Power and communication	Uphole communication
2	Not connected	Downhole communication
3	Not connected	Not connected
4	Not connected	Sonde power



Notes:
Pin 1 is adjacent to the polarising keyway, 2, 3 & 4 are numbered clockwise when looking down from above.

Detectors:

- Neutron: ^3He proportional counters. Two detector spacings.
  Source - Americium/Beryllium.
- Natural Gamma: Sodium Iodide (Thallium doped) scintillation crystal.
  Dead-time 4 microseconds.

Precautions when using radioactive sources:

The sonde uses a demountable, closed, chemical source of neutrons.

The following precautions are of a purely advisory nature and do not replace legislation relevant in any place of use. Local regulations on the use of radiation must be followed at all times. All personnel involved in the handling of radioactive sources must be properly trained and wear appropriate dosemeter badges.

When attaching the source to the sonde and transferring the assembly into the borehole it is essential that exposure to radiation is minimised by working swiftly and utilising the correct tools at all times. Radiation monitors should be used to confirm that the source has been transferred safely from and to the transport container.

Only sound boreholes should be logged with a radioactive source attached. If there is doubt about constrictions, make a trial run into the hole without the source holder attached.

Check the condition of the cable head. Badly made, or damaged cable heads could fail, leaving the sonde and radioactive source in the borehole.

Attaching the source holder to the sonde:

This procedure should not be undertaken with the sonde attached to the logging cable, since there is the possibility of unscrewing the sonde-head assembly, and subsequently losing the sonde in the borehole.

Carry the source holder to the borehole in its transport container. The source holder attaches to the sonde by screw thread at the base. Ensure that the screw threads are not damaged or filled with debris.

Unlock the transport container and hinge back the retaining strap. This will uncover the top of the source holder. Lower the sonde base into the threaded top of the holder and rotate to engage the screw thread. The source holder is prevented from rotating within the transport container by a key that fits a slot in the base. Continue to screw the sonde base home to the full extent. Do not overtighten. Attach the logging cable to the sonde head.

Lift the sonde with attached source holder swiftly from the transport container and lower it into the borehole. Once the sonde is completely below ground there is no further risk to personnel.

When the log is complete remove the sonde from the borehole and transfer the source holder to the transport container as quickly as possible. Note that the key in the transport holder must engage the slot in the source holder. Otherwise, it will probably prove impossible to unscrew the source holder.

Removing the source holder is then the reverse of the above procedure. Ensure that the transport container is locked shut at all times when the source is not in use.

Operating principles:

- NEUTRON: Neutrons are generated in an isotopic source pellet in the separate holder which attaches to the sonde when in use. Alpha-particles are emitted as the Americium isotope decays, but cannot escape from the steel enclosure. The alpha-particles interact with the Beryllium in the pellet which emits large numbers of fast neutrons, which can escape.

  Fast neutrons entering the formation lose energy as they collide with atomic nucleii, this process is called moderation. Energy loss is greatest when the collision is with light nucleii - Hydrogen is the lightest and most effective element. After many collisions the energy reduces to 'thermal' levels comparable with the vibrational energy of atoms in thermal equilibrium in the formation. The 'thermalisation' occurs over a distance from the source which is dependent upon the Hydrogen content of the formation - principally in water in pore spaces. The detectors are positioned beyond the radius of thermalisation, in the zone where thermal neutrons are diffusing and being captured by nucleii in the formation. If the moderating power of the formation is lower, i.e. lower porosity, then the radius of thermalisation will increase and the density of thermal neutrons will increase at the detectors. Clearly the neutron flux at the far detector is lower than that at the near detector. The ratio of count rates is characteristic of the radius of thermalisation of neutrons in the formation, i.e. porosity or Hydrogen Index.

  The detector also works by thermal neutron capture. It is filled with ^{3}Helium at high pressure. Neutrons are captured by ^{3}He nucleii which then decay and emit alpha-particles. These cause ionisation in the detector tube and pulses of current, which are detected electronically. Fast neutrons, which have not been moderated by the formation are not detected.

  The dual-detector sonde represents a considerable advance over single-detector sondes because it considerably reduces borehole effects. The following factors are significant :

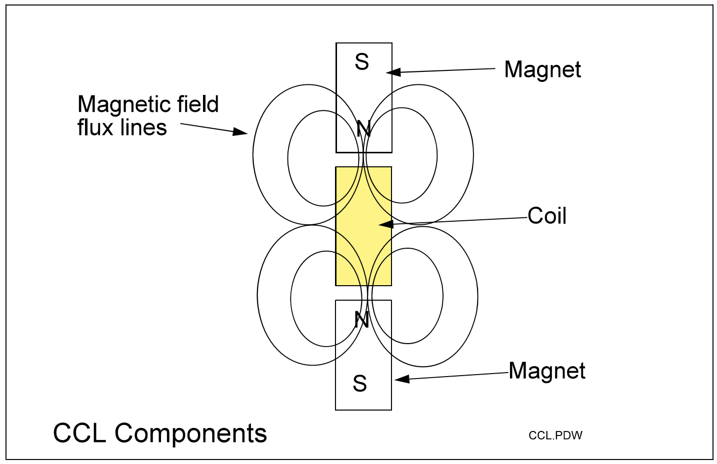
Formation type :	Limestone, sandstone, shales
Borehole fluid :	Salinity (Chlorine displaces Hydrogen)
Borehole size :	Diameter, mudcake, rugosity

  The reduction in borehole effects is due to the technique of using the ratio of count rates between the two detectors, which is much less affected than a single-detector count-rate. Borehole effects are further reduced by pressing the sonde against the wall with an excentralising bowspring.

  Note that results in shaly formations will show anomalously high porosity due to the water which is bound in the structure and not filling a pore space.

- NATURAL GAMMA: All rocks contain small quantities of radioactive material. Certain minerals contain trace amounts of Uranium and Thorium, Potassium-bearing minerals will include traces of a radioactive isotope of Potassium. All of these emit gamma radiation as they decay with an extremely long half-life. This radiation is detected by scintillation - the production of a tiny flash of light when gamma rays strike a crystal of Sodium Iodide. The light is converted into an electrical pulse by a photomultiplier tube - pulses above a threshold value of 60 KeV are counted by the sonde's microprocessor. The measurement is useful because the radioactive elements are concentrated in certain rock types e.g. clay or shales, and depleted in others e.g. sandstone or coal.

- CASING COLLAR LOCATOR: The CCL comprises two magnets aligned with a coil between them. This is shown schematically below.



The magnetic field is shown in a steady condition. While the magnetic flux lines are static no current will be induced in the coil.

If the magnetic field is disturbed then the magnetic flux change will induce a current in the coil. The induced current flows through a resistance and produces a changing voltage. The sonde electronics include a voltage to frequency converter, hence changing flux is reported as a variable count rate at the surface. A voltage offset is applied to give a nominal response of 10000 under static conditions.

In the presence of steel casing of uniform structure the magnetic field will be stable as the sonde is pulled up the pipe. If the structure of the pipe changes, then the magnetic field will change and the changing flux through the coil will be logged as a changing count rate at the surface.

In summary, the CCL responds to changes in structure of the surrounding ferromagnetic material. The CCL will not respond to plastic or aluminium alloy casing.

Calibration:

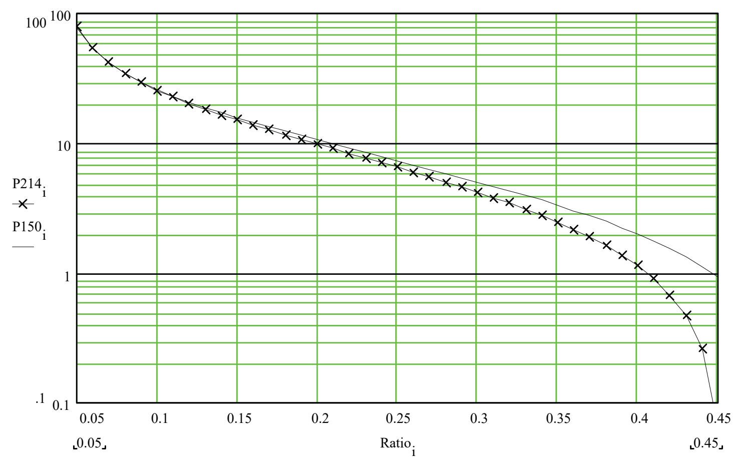
The Dual Neutron Sonde has two measurements which may be calibrated if the data are required in engineering units: Neutron Porosity and Natural Gamma. The Casing Collar Locator is never calibrated.

Click on ***Tools|Calibration***, and you will be invited to select the sonde which you intend to calibrate. The dialogue box is the same as that used on entry to the Sonde Database, and can be used in the same way. ***Please note that you may not change the serial number of the sonde in this dialogue*** - to do that, go to the ***Tools|Sonde Database*** dialogue, select the DNNS and click OK to enter the database editor. Then you may modify the serial number and save the changed data. The sonde mnemonic and serial number will be combined to make a filename unique to that sonde (e.g. DNNS2377.CAL), which you will select later when preparing to make the log.

When the sonde has been identified, you will be given the choice of which channel to calibrate. Only channels nominated for calibration may be selected - and with each will be associated a calibration scenario which must be followed for correct operation.

NEUTRON: The primary calibration of the Neutron-Neutron Sonde has been done by RG as part of the sonde development. Only calibration to secondary standards is required. The primary calibration was performed in the ELGI calibration facility in Budapest, Hungary. The results of this calibration generated a response as in the graph below.

The X axis is the ratio of the count rates (Far / Near) and is the basis of the calibration procedure. The Y axis is in porosity units, in a Limestone matrix, plotted on a logarithmic scale. Two curves are presented, for boreholes of diameter 150 mm (plain) and 214 mm (ornamented).



It is the ratio of the count rates that is converted to porosity, and not the actual count rates. The calibration was carried out in two hole sizes, 214mm and 150mm. For other values of borehole diameter, interpolation is performed to produce the required compensation. The conversion from a ratio to porosity is carried out by a user function The user function is presented in full below for reference.

The secondary standard used for this sonde is a plastic sleeve which produces a known count-rate ratio. Each calibration sleeve will have a slightly different value of ratio, and this number is stamped on the end of the sleeve, for example "RATIO = 0.24". The value 0.24 is typical of the RG sleeves, but the user must ensure that the correct value is taken from the sleeve in use.

The principle employed is the generation of a coefficient file which modifies the short spacing count rate so that the expected ratio of the calibration sleeve is achieved. Note that the strength of the source used does not influence the calibration results, as the ratio of the count rates is the important factor and not the actual count rates. It is permissible to calibrate with one source and log with a different source.

Prepare the sonde for calibration. Attach the neutron source to the sonde and insert the sonde fully into the calibration sleeve, which should be supported upon trestles at least 1.25 metres from the ground. Click on the ***Tools|Calibration*** menu - as explained for the caliper section previously. Select the ***NEAR*** channel and start acquisition by clicking ***Continue***. Counting will proceed for 5 minutes (300 seconds). At the end of this period you will be asked to enter the ratio value which is marked on the sleeve. The count rates for the near and far channels will then be examined and the appropriate scaling factor will be computed and written to file.

NATURAL GAMMA It is possible to calibrate the response of the Natural Gamma detector in API gamma ray units. The procedure falls into two parts, the primary calibration is performed in a test pit at RG during manafacture, and the secondary calibration, which can be performed in the field using the optional calibration fixture.

The PRIMARY calibration uses a test pit manafactured from Uranium-doped concrete which has a known API activity. An identical pit made with the same concrete mix, but without the Uranium additive, is used as a background. The increase in count rate above the background is measured, and this is used to calculate a multiplier which relates the raw count rate to the API count rate.

Once this primary calibration has been performed, it is possible to create a SECONDARY standard which will give a convenient count rate such as 200 API. This is done by mounting a small gamma ray source on a rod which can be clamped over the detector, and then moving the source in or out along the rod until the activity reaches the required value. At this point a small detent is made in the rod at the correct position, and the jig is stamped with the date and API value. The detent allows the correct position for the source holder to be determined.

If an optional API calibrator is specified by the customer, all the above procedures will be performed by RG. Secondary calibration is achieved through the ***Tools|Calibration*** menu - as explained for the caliper section previously. Select the ***NGAM*** channel and you will be asked to establish *background* conditions. Place the sonde horizontally on stands about 1 metre above the ground. Start acquisition by clicking ***Continue***, which will proceed for 5 minutes (300 seconds). At the end of the first period, attach the calibrator jig to the sonde tube, taking care that the base of the rod is exactly centred over the detector crystal. This can be determined experimentally by 'peaking' the count rate in a separate time mode log, or by measurement from the base of the sonde (taking into account the fact that the gamma-gamma source holder will not be attached at this stage). Start the second acquisition period. After 5 minutes counting, you will be asked for the activity of the calibration source (see below). The calibration coefficients will then be computed and written to file together with the count rates and timestamp. Previous data will be transferred to the 'history' file for reference.

The date of calibration is important because the API value will change as the source decays. The API value at any time in the future is given by :

$$API_t = API_0 \; . \; \exp(-t \; . \; \ln(2) \; / \; T_{1/2})$$

where :

t	= time (years) since the original API calibration.
API_t	= API value at time t.
API_0	= original API value.
$T_{1/2}$	= half life of isotope.

The half life of **Cs137** is approximately **28 years**. In a four year period, a Cs137 source will decay to approximately 90% of its original value, and to 80% in ten years. The value for the activity of the calibration source must therefore be adjusted on an annual basis.

User Function

```
/* RG Dual Epithermal Neutron - NOT RAYTHEON */
/* Default implementation, copy input to output */
OUT1 = IN1;
OUT2 = IN2;
OUT5 = IN5;
OUT6 = IN6;
/* Omit optional channels as appropriate */

/* Now for code - necessary to modify and COMPILE for different bitsize */
TMP1 = 150; /* Default bitsize, millimetres */

if (IN1 > 1) /* Protect against divide by zero */
   TMP2 = IN2 / IN1;
else
   TMP2 = 1;
TMP3 = TMP2 * TMP2; /* Square of ratio */
TMP4 = TMP3 * TMP2; /* Cube of ratio */
/* Calculate porosity at diameter 214mm */
TMP5 = 0.01080258/TMP4 -0.2344151/TMP3+4.779079/TMP2-9.517288;
/* Calculate porosity at diameter 150mm */
TMP6 = 0.01149102/TMP4 -0.25482/TMP3+4.85726/TMP2-8.734154;
/* Find slope of porosity against bitsize */
TMP7 = (TMP5 - TMP6) / 64;
/* And Intercept */
TMP8 = TMP6 - (TMP7 * 150);
/* Now plug in actual bitsize and read off porosity */
OUT5 = (TMP7 * TMP1) + TMP8;
```

Note: This function assumes that the coefficients have been applied to the count rates in order to standardise the count rate. See the section on field standardisation below.

The borehole size should be entered into the temporary variable TMP1 and the function recompiled by clicking on ***Compile and Implement*** in the user function implementation dialogue.

Note that further temporary variables are assigned values of the square and cube of the ratio value for efficiency in the body of the computation. The porosity at the two calibrated diameters, 214mm and 150mm, is calculated in TMP5 and TMP6 respectively. These equations are the equations of the curves presented in the graph above. This yields a pair of data values for porosity at different, borehole sizes. The straight line relationship (Y = Mx + C) between these values with slope M, and intercept C is then evaluated in this straight line equation to give the porosity at the actual borehole size.

Testing sonde functions:

Start the WinLogger software and choose the menu item ***Tools|SondeTest*** or use the toolbar icon to start the utility. Choose ***Standard Six Channel*** from the sonde type selection box, then click on ***Start Test***. Power will be applied to the sonde. Select the ***Normal*** data display mode, and then click ***Show Data***. Check that there is no communication error indicated.

With the source detached and the source container far away from the sonde the count rate observed should be very low, or zero. If this is not the case, then it may be that the sonde has some moisture inside. This can occur if the sonde has been opened in a damp atmosphere. If this is the case, it is necessary to remove the sonde tube (ensure power is off before opening) and heat the sonde chassis and housing to some 10 Degrees C above ambient before re-assembly. A domestic hair drier, fan heater or similar device can be used for the warming and drying - take great care not to overheat any of the components in the process. Check the ‘background’ count rate again.

The Neutron detectors can then be tested by moving the loaded source transport container close to the sonde and moving it past each detector in turn. Activity should be recorded at both detectors.

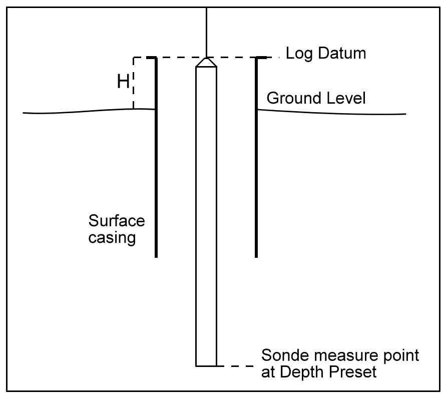
The Natural Gamma section will normally give a small count at the surface due to the radioactive background. It will also respond to the neutron source, since ^{241}Am also emits gamma rays.

The Casing Collar Locator can be tested by passing a small steel or iron object quickly along the side of the sonde tube. It may be better to make a log in time mode so that the impulse is recorded on paper.

Logging Procedure:

Run the sonde without its radioactive source first if there is any doubt about the condition of the borehole. Fit the dummy-end to protect the threaded section of the sonde. Neutron logs are always run uphole.

These instructions should be used in conjunction with the full, or quick reference guide to logging with your surface system.



Prepare the sonde for use as explained in the section 'Attaching the source holder'. Attach the sonde to the logging cable and lower the sonde into the borehole. Use the winch to align the top of the sonde with your logging datum. Set the depth preset - this will be 2.16 metres, i.e. the sonde length (including the source holder). If you wish to use ground level for your datum you must subtract the height H from the sonde length.

Run into the hole until the bottom of the required section is reached. Avoid resting the tool in the mud at the bottom of the borehole. When preparing to make the log, ensure that calibration and the user function are both applied if a log is required in engineering units. Winch uphole and observe the data, checking for correct operation. The maximum advisable speed is 5 metres per minute.

When at the surface turn OFF sonde power. Remove the sonde from the borehole and return the source holder to its transport container as described above. Clean the sonde with fresh water and dry it off. Stow it securely to prevent damage.

9339 Compensated Density – Photo Electric Logging Tool

Background Information
The 9339 Series Compensated Density logging tool uses the two focused density detectors to compute borehole compensated density real time while logging. No post processing required to produce CDL bulk density.
The Photo Electric density has been added to further define lithology from shale, sand, limestone and dolomite. Additionally, the tool also records natural gamma, caliper, and focused guard resistivity.

Features

Properties Measured (see diagram)		Tool Specifications
1. Natural Gamma: 2.2 x 10.16 cm (0.875 x4.0 in.) NAI Scintillation Offset: 21 cm (8.25 in.) **2. 3-Element Guard Resistivity:** 127.6 mm (50.25 in.) guard electrode Offset: 63.5 cm (25 in.) **3. Caliper:** Motorized, uphole actuated 35.6 cm (14 in.) or 20.3 cm (8 in.) Offset: 210.8 cm (83 in.)	**4. Far Density:** 2.2 x 10.16 cm (0.875 x4.0 in.) 35.8 cm (14.1 in.) spacing Offset: 243.3 cm (95.8 in.) **5. Near Density and Photo Electric:** 2.2 x 3.2 cm (0.875 x1.25 in.) 20 cm (7.9 in.) spacing Offset: 259.3 cm (102.1 in.) **6. Radioactive source:** 100-300 mCi Cesium 137 in bullplug Offset: 274.3 cm (108.0 in.)	**Length:**280.3 cm (110.35 in.) **Temperature:** 85 C (185 F) **Diameter:** 56 mm (2.2 in.) **Pressure:** 175 kg/cm^2 (2500 PSI) **Weight:** 32.7 kg (72 lb.) **Logging Speed:** 9 m/min. (30 ft./min.) **Tool Voltage Required:** 66 VDC

Sensor Response Ranges

Sensor	Response Limits	Accuracy
Natural Gamma (NG)	0-10,000 API units	+/-5%
Short or Long Arm Caliper (CAL)	0 to 35.6 cm (14 in.)	+/-0.635 cm (0.25 in.)
Near Density (ND) Photo Electric (PE)	0.9 to 3.5 g/cc (0.02 to 0.13 lbs/ci) 0 to 10 Barnes/Electron	+/-0.05 g/cc (0.001 lbs/ci) +/- 5%
Far Density (FD)	0.9 to 3.5 g/cc (0.02 to 0.13 lbs/ci)	+/-0.05 g/cc (0.001 lbs/ci)
Guard Resistivity (MG)	0 to 40,000 ohm meters	+/-5%

Tool Information

Item	Model #	Part #
Tool with NG, CAL, ND, FD, PE, MG	9339	320850
100-300 mCi Source w/Shield Cesium		please inquire
Source Handling Tool		101502
Calibration Gauge		212471
Guard Resistivity Calibration Box		335227

9339 Compensated Litho Density Calibration Procedure Using Delrin and Aluminum Standards

A. Introduction

This procedure will help you understand the calibration steps necessary to achieve accurate and repeatable density results for the 9339 compensated litho density logging tool. Although this presentation describes the calibration procedure for the 9339, the same basic principles can be applied to the 9239 model.

This calibration procedure assumes the user is familiar with Century's LOG software. Please refer to the **Calibration Menu** section of the **LOG HELP** manual for more information about calibration curves, calibration points, and integration.

B. Calibration Frequency

Century requires all density tools to be calibrated **at least one time every 30 days** or when one or more of the following occurs:

- Changing to a different source in the same tool.
- Changing to a new tool.
- Whenever any component of the tool has been changed, replaced, or repaired.

C. Accuracy & Repeatability

Century's goal is to provide customers density logs that are both repeatable and accurate using different density tools and different logging engineers.

Century requires all density logs to be **repeatable and accurate within .02 g/cc**.

D. Equipment Required to Calibrate Density

- Computer with LOG program installed
- System VI Box
- Drawworks or Bypass Cable
- Delrin Low-Density Standard
- Aluminum High-Density Standard
- Source handling tool
- Cs-137 Source
- Two Tool Stands
- 9339 Compensated Density Tool

E. Calibration Procedure

WARNING: Because this calibration procedure requires the use of a nuclear source, the user should be fully trained and experienced with the safe handling of radioactive source materials. All applicable federal, state, and local regulations must be followed.

IMPORTANT: Use two people to move the tool and follow recommended lifting practices to avoid back injury.

1. Place tool on stands with the collimator shoe plate **facing up** and collimator section hanging off edge of lower tool stand.

2. Thoroughly clean the collimator shoe plate and collimator section covering the detector windows (the internal windows face in the same direction as the shoe plate).

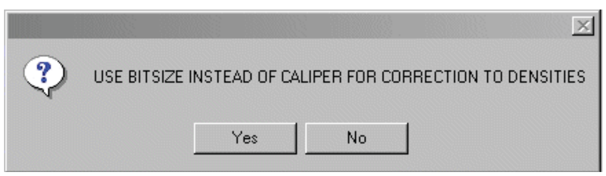
3. Thoroughly clean the contact grooves on both the Delrin and Aluminum standards.

4. Connect the cablehead or bypass cable to tool.

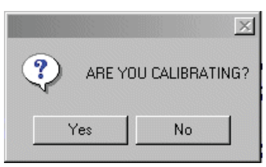
5. Turn on **Tool** power and **System** power on the System VI box. Start the **LOG** program, click on **LOG** on the Main Menu.

6. Click on **Configure Tool** on the **Control Menu**. Answer the following questions:

- Answer based on your tool's configuration.



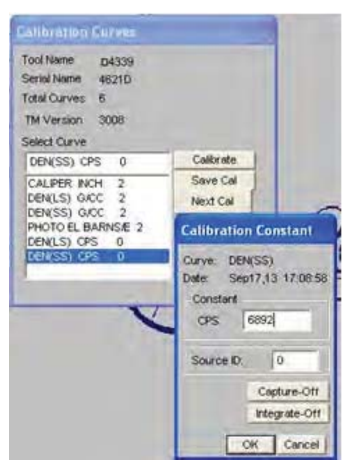
- Click on **No**.



- Click on **Yes**.

7. Allow the tool to warm up for **20 minutes**.

8. Before beginning calibration with Delrin and aluminum blocks, you must "subtract" out the pilot counts for the short spaced detector. This is done by placing the tool **far away from any radioactive materials** and integrating the CPS for **two minutes**. The value is entered in the CPS section of the DEN(SS) Calibration Constants (see right).



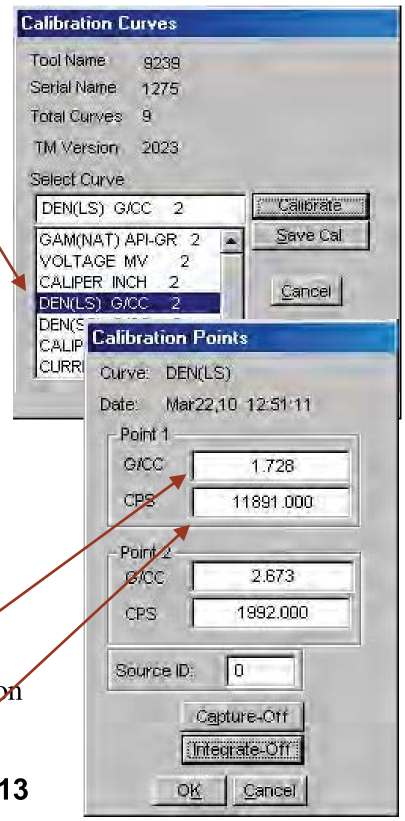
9. Using a source handling tool to maintain your distance, install Cs-137 source into the tool.

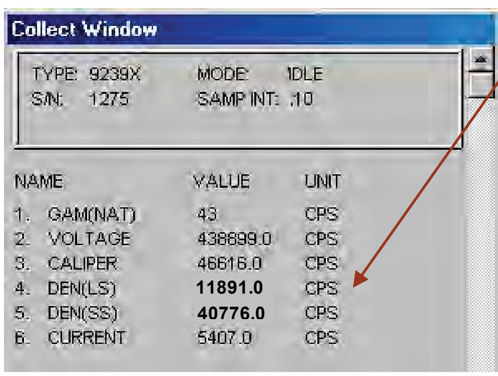
10. Double-check to ensure that the collimator shoe plate is still directly **face up** and perpendicular to the ground.

11. Place **Delrin** standard on tool with the collimator and collimator shoe plate completely covered by Delrin. The end of the standard should be flush with the end of the tool (not covering source bullplug).

12. In the **LOG** program, click on the **Cal** menu, select the **Tool** button and double-click on **DEN(LS)** in the Calibration Curves menu.

13. Turn **on** the **Integrate** function and wait approximately two minutes for CPS readings to stabilize in the collect window. Record both the **DEN(LS)**, **DEN(SS) and PE** readings.





14. Enter the **DEN(LS) Delrin** standard number in the **G/CC** section of **Point 1** of the **DEN(LS)** Calibration Points menu.

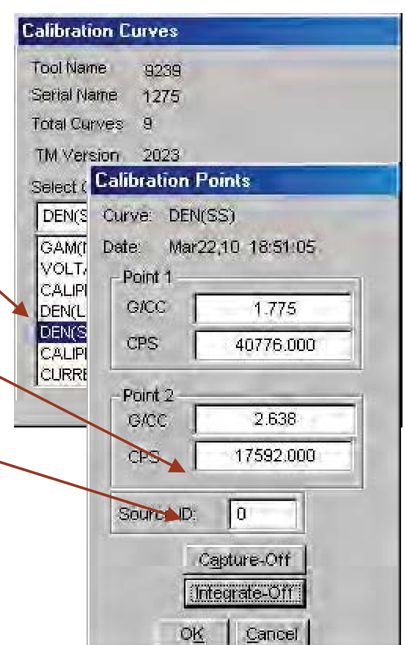
15. Enter the integrated **DEN(LS) CPS** value obtained from **step 13** in the **CPS** section of **Point 1** of the **DEN(LS)** Calibration Points menu.

16. Click on **OK** to exit the **DEN(LS)** Calibration Points menu.

17. Double-click on **DEN(SS)** in the Calibration Curves menu.

18. Enter the **DEN(SS) Delrin** standard number in the **G/CC** section of **Point 1** of the **DEN(SS)** Calibration Points menu.

19. Enter the integrated **DEN(SS) CPS** value obtained from **step 13** in the **CPS** section of **Point 1** of the **DEN(SS)** Calibration Points menu.

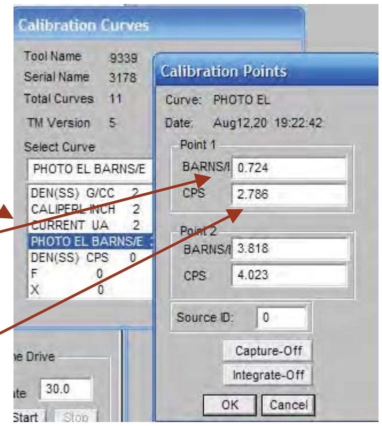


20. Click on **OK** to exit the **DEN(SS)** Calibration Points menu.

21. Double-click on **PHOTO EL** in the Calibration Curves menu

22. Enter the **PHOTO EL** Delrin standard number in the **BARNS** section of Point 1 of the **PHOTO EL** Calibration Points menu.

23. Enter the integrated **PHOTO EL** CPS value obtained from **step 13** in the CPS section of Point 1 of the **PHOTO EL** Calibration Points menu.

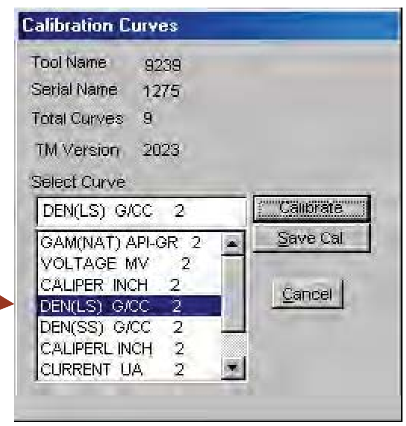


24. Click on **Save Cal** in the Calibration Curves menu. Exit all calibration menus of the LOG program.

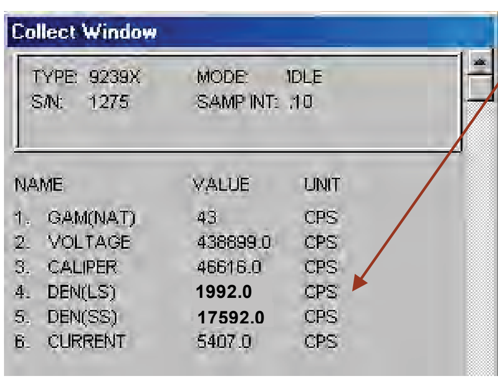
25. Remove the Delrin standard from tool and set aside.

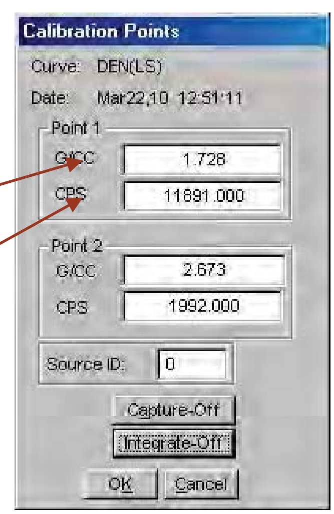
26. Place **Aluminum** standard on tool with the collimator and collimator shoe plate completely covered by Aluminum. The end of the standard should be flush with the end of the tool (not covering source bullplug).

27. In the **LOG** program, click on the **Cal** menu, select the **Tool** button and double-click on **DEN(LS)** in the Calibration Curves menu.



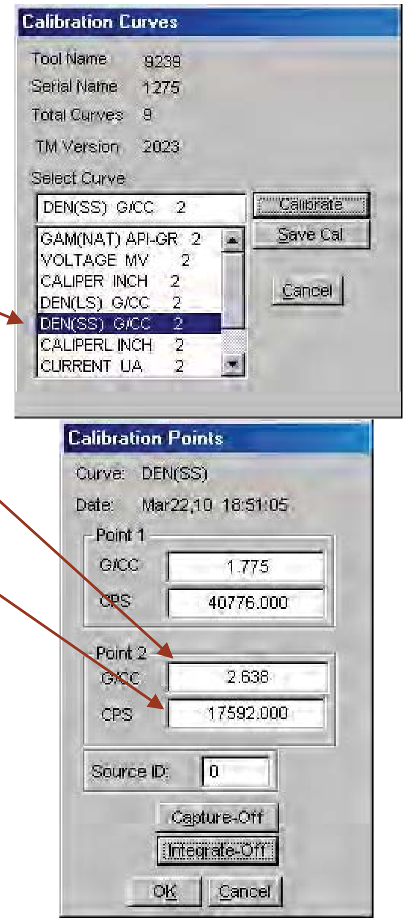
28. Turn **on** the **Integrate** function and wait approximately two minutes for CPS readings to stabilize in the collect window. Record both the **DEN(LS)**, **DEN(SS)** and **PE** readings.





29. Enter the **DEN(LS)** number marked on the side of the **Aluminum** standard in the **G/CC** section of **Point 2** of the **DEN(LS)** Calibration Points menu.

30. Enter the integrated **DEN(LS) CPS** value obtained from **step 28** in the **CPS** section of **Point 2** of the **DEN(LS)** Calibration Points menu.



31. Click on **OK** to exit the **DEN(LS)** Calibration Points menu.

32. Double-click on **DEN(SS)** in the Calibration Curves menu.

33. Enter the **DEN(SS)** number marked on the side of the **Aluminum** standard in the **G/CC** section of **Point 2** of the **DEN(SS)** Calibration Points menu.

34. Enter the integrated **DEN(SS) CPS** value obtained from **step 28** in the **CPS** section of **Point 2** of the **DEN(SS)** Calibration Points menu.

35. Click on **OK** to exit the **DEN(SS)** Calibration Points menu.

36. Double-click on **PHOTO EL** in the Calibration Curves menu

37. Enter the **PHOTO EL** Delrin standard number in the **BARNS** section of Point 2 of the **PHOTO EL** Calibration Points menu.

38. Enter the integrated **PHOTO EL** CPS value obtained from **step 28** in the CPS section of Point 2 of the **PHOTO EL** Calibration Points menu

39. Click on **Save Cal** in the Calibration Curves menu. Exit all calibration menus of the LOG program.

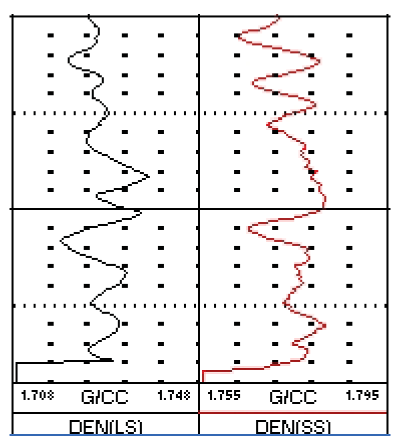
40. Remove the Aluminum standard from tool and set aside.

F. Density Accuracy Checks

This section assumes familiarity with the **Time Drive** function of the LOG program as well as the use of Century's **Display** program.

1. Place **Delrin** standard on tool with the collimator and collimator shoe plate completely covered by Delrin. The end of the standard should be flush with the end of the tool (not covering source bullplug).

2. On the LOG program **Control Menu**, click on the **Header** button and select **Last.hdr.** In the **Well** input box, enter the tool model, serial number, and a **Delrin** identifier (i.e., 9239-1275-DELRIN). Click **OK** to create the header file.



3. Click on the **Tool Position** button in the **Control Menu**, enter **5000**, and click **OK.**

4. Click on the **Start Recording** button in the **Control Menu** and click **Yes**.

5. In the **Time Drive** section of the **Control Menu**, enter in **30** in the **Rate** field and click on the **Start** button.

6. Allow the time drive to run for **2** minutes. Click on **Stop** in the **Time Drive** section of the **Control Menu**. Click on the

Stop Recording button and click **Yes**.

7. Open the time drive log in the **Display** program. Change the presentation to **9339 LS & SS Accuracy** (presentation may be downloaded from http://century-geo.com/support-index.html**).**

8. Adjust the **DEN(LS)** and **DEN(SS)** scales to where they read from **± .02 g/cc** of the density g/cc numbers marked on the side of the **Delrin** standard.

9. Inspect the log file. If either the **DEN(LS)** or **DEN(SS)** curves lie outside the boundary of the presentation (**± .02 g/cc**), then the tool must be recalibrated.

10. Remove the Delrin standard from tool and set aside.

11. Place **Aluminum** standard on tool with the collimator and collimator shoe plate completely covered by Aluminum. The end of the standard should be flush with the end of the tool (not covering source bullplug).

12. On the LOG program **Control Menu**, click on the **Header** button and select **Last.hdr.** In the **Well** input box, enter the tool model, serial number, and a **Aluminum** identifier (i.e., 9239-1275-ALUMINUM). Click **OK** to create the header file.

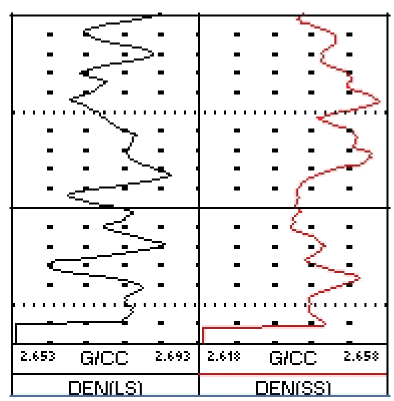
13. Click on the **Tool Position** button in the **Control Menu**, enter **5000**, and click **OK.**

14. Click on the **Start Recording** button in the **Control Menu** and click **Yes**.

15. In the **Time Drive** section of the **Control Menu**, enter in **30** in the **Rate** field and click on the **Start** button.

16. Allow the time drive to run for **2** minutes. Click on **Stop** in the **Time Drive** section of the **Control Menu**. Click on the **Stop Recording** button and click **Yes**.

17. Open the time drive log in the **Display** program. Change the presentation to **9339 LS & SS Accuracy** (presentation may be downloaded from http://century-geo.com/support-index.html**).**



18. Adjust the **DEN(LS)** and **DEN(SS)** scales to where they read from **± .02 g/cc** of the density g/cc numbers marked on the side of the **Aluminum** standard.

19. Inspect the log file. If either the **DEN(LS)** or **DEN(SS)** curves lie outside the boundary of the presentation (**± .02 g/cc**), then the tool must be recalibrated.

    NOTE: If after recalibration the curves still lie outside the boundary of the presentation, contact your supervisor or Century support personnel for further instructions.

G. Common Calibration Errors

The errors in calibrating may result from several factors. The 9339 density tool needs to have **Tool** power applied to it for **20 minutes** before calibrating. The **Tool** power allows the electronics tool to stabilize to operating temperature. If the tool is allowed too little time to warm up before calibrating, the data obtained may not be stable. Thus, measured density may be different from the true density.

Another factor is if the density standard was not properly positioned on the tool. The Calibration process and alignment are fairly forgiving when it comes to alignment. There is enough tolerance to allow ±1 inch of alignment error in terms of up or down positioning of the standard. Rotational alignment can vary several degrees in both directions without a significant difference.

Still, taking care to properly position the standards will ensure the least amount of variation. Also check that the two faces of contact on the standard and the collimator and shoe surface are clean and free from obstruction. Check the screws used for securing the collimator shoe pad for tightness. If it becomes loose and drilling mud migrates under the shoe the calibrations will change. Verify all data entries are correct.

H. Conclusion

By carefully following the steps of this procedure, the user will be able to produce good quality, reliable logs with which the customer can expect a high degree of accuracy and reliability.

APPENDIX A: CALIBRATION STANDARDS

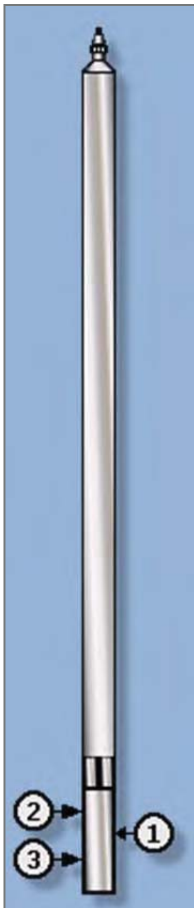
TOOL TYPE: 9339 (DUAL DETECTOR TOOLS)

DELRIN 8 INCH MODEL, SHORT SPACED DENSITY = 1.590 G/CC
DELRIN 8 INCH MODEL, LONG SPACED DENSITY = 1.620 G/CC
DELRIN 8 INCH MODEL, PHOTO EL = 0.726 BARNS/E

ALUMINUM 8 INCH MODEL, SHORT SPACED DENSITY = 2.580 G/CC
ALUMINUN 8 INCH MODEL, LONG SPACED DENSITY = 2.612 G/CC
ALUMINUN 8 INCH MODEL, PHOTO EL = 3.818 BARNES/E

The above standards are based on tool response in Century's standard test well in Tulsa. As you can see the values change from the tool type and the diameter of the calibration model being used. This is because the models are not "infinite" of which does not stop all the gamma rays coming from the source, and being returned to the detector.   So the larger the diameter of the standard, the closer it does become an infinite model, and closer to the "known density" of the material. For instance, the 8 inch model of aluminum is the best, and would have an actual value close to 2.612 g/cc.

9722 E-M Flowmeter



Background Information

The E-M Flowmeter tool is used in the environmental and hydrology industries to measure fluid movement in a borehole. The instrument measures flow rates using the principal of Faraday's Law of Induction. The downhole probe consists of an electromagnet and two electrodes located 180 degrees apart and 90 degrees to the magnetic field inside of a hollow cylinder. The voltage induced by a conductor moving at right angles through the magnetic field is directly proportional to the velocity of the conductor (water) through the field. The tool is capable of measuring low velocity flow rates down to less than 50 ml/min and increased flow rates to 40 liters/min, through the tool's 1 inch inside diameter sensor. When using the tool to measure low velocity flow rates a rubber skirt is attached to the outside of the sensor to block off the bore hole and force the fluid to pass through the 1 inch diameter opening inside the sensor coil. The Compu-View Software program is designed to allow the automatic collection of data at selected static stations in the borehole. When measuring faster flow rates the rubber skirt is typically removed and the tool is run in either the static station or dynamic mode. The tool has no moving parts.

Features	
Properties Measured (see diagram)	Tool Specifications
1. **Flowmeter:** Electromagnetic Offset: 139.7 cm (55.0 in.) 2. **Fluid Resistivity:** Offset: 139.7 cm (55.0 in.) 3. **Temperature & Delta Temperature :** Offset: 139.7 cm (55.0 in.)	**Length:** 142 cm (56.0 in.) **Temperature:** 60 C (140 F) **Diameter:** 41.3 mm (1.625 in.) **Sensor Housing:** 50.8 mm (2.0 in.) **Weight:** (13.5 lbs.) **Tool Voltage Required:** 64 VDC **PRESSURE**: 2500PSI

Sensor Response Ranges

Sensor	Response Limits	Accuracy
Flowmeter (EMF)	50 ml./min. to 40 liters./min.	+/-20 ml/min. (High Gain)
Temperature (TEMP)	0 C to 60 C (32 to 140 F)	+/-5%
Fluid Resistivity (FR)	0-100 ohm meters	+/-5%

Tool Information

Item	Model #	Part #
Tool with EMF, TEMP, FR	9722	300500A
(included) 6.5 in. Diameter Flow Diverter Skirt (modifiable for use in hole from 3.75 in. to 6.25 in. diameter)		
(included) Centralizer		
(included) Weighted Section		

E-M Flowmeter **User Guide**

BACKGROUND INFORMATION

The 9721 EM flowmeter is a full range instrument capable of measuring low flow rates of 50 milliliters per minute (0.01 gallons/min.) up to+/-40 liters per minute (10.6 gallons/min). It uses an electro -magnetic measuring electrode circuitry. The flowmeter uses Faraday's Law of Induction, which states that the voltage produced by a conductor moving at right angles through a magnetic field is directly proportional to the velocity. The flowing water then becomes the conductor, the electromagnet generates the magnetic field and the electrodes transmit the voltage proportional to the velocity of the water moving through the center of the flowmeter. As there are no moving parts associated with the flowmeter, mechanical problems associated with other types of flowmeters are eliminated. Precise calibration and proper operational procedures are critical to get accurate and quality results associated with very low flow rates.

Additionally, the tool measures temperature, delta temperature, and fluid resistivity in continuous logging mode.

TOOL STABILIZATION AND SENSOR OPERATION

To avoid damage to the EM sensor from overheating do not turn on tool power unless the flow sensor is in water.

Prior to calibration and logging, allow the tool to stabilize in a water filled hole or calibration device for at least 15 to 20 minutes.

Primary Calibration of The Tool

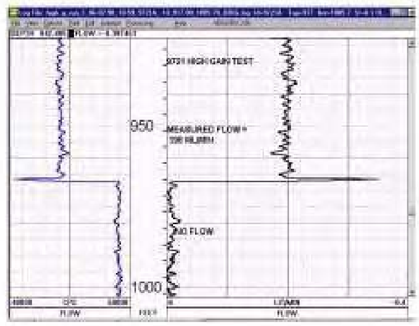
The EM flowmeter must be calibrated prior to use, with a known flow source. A simple calibration device consists of water filled PVC pipe of 6 inches in diameter and approximately 3 feet in length. A gate valve or small holes below the flow sensor is needed to generate the water flow. The borehole diverter must be located at approximately the middle of the sensor. This is very important both in calibration and in logging the tool to insure that the water is passing through the flowmeter sensor, and not going around the tool.

Two calibration points of the tool are measured using a graduated cylinder to plus or minus 5 ml / minute. These two reference points then become the standard response values. Usually in low flow situations, the calibration will be ZERO flow and 500 to 1000 ml / min flow ranges (conversion factor from Liters to Feet per Minute is 6.474). In holes with greater amounts of flow, calibration should be close to the amount of expected flows (if the borehole flows at 1 to 5 liters per minute, you should calibrate at approximately these flow rates).

To calibrate the tool, the PVC pipe must be filled with water, prior to placement of the tool inside. During calibration, the water level in the PVC calibration pipe must remain constant. Record the CPS values for the two desired calibration points, an example calibration would be as follows:

High Gain Standard	0 Ft/Min -6.21 Ft/Min
Response Limits	54,800 CPS 49,400 CPS
Low Gain Standard	0 Ft/Min -6.21 Ft/Min
Response Limits	54,720 CPS 53,400 CPS

Example Calibrated Flow Test



Calibration Ranges

Calibration Range	Standard	Response Limits
Temperature	50 Deg. F 80 Deg. F	9,500-0,500 CPS 5,000 - 5,400 CPS
Fluid Res.	0 Ohm/m 47.5 Ohm/m	1,000 CPS 48,500 CPS

Both sensors can be calibrated to known temperature and fluid resistivity values of a fluid filled bucket of water. A precise thermometer and fluid conductivity meter are used to measure the two different values of the water. Make sure the bucket is sufficiently large enough to cover the sensor being calibrated.

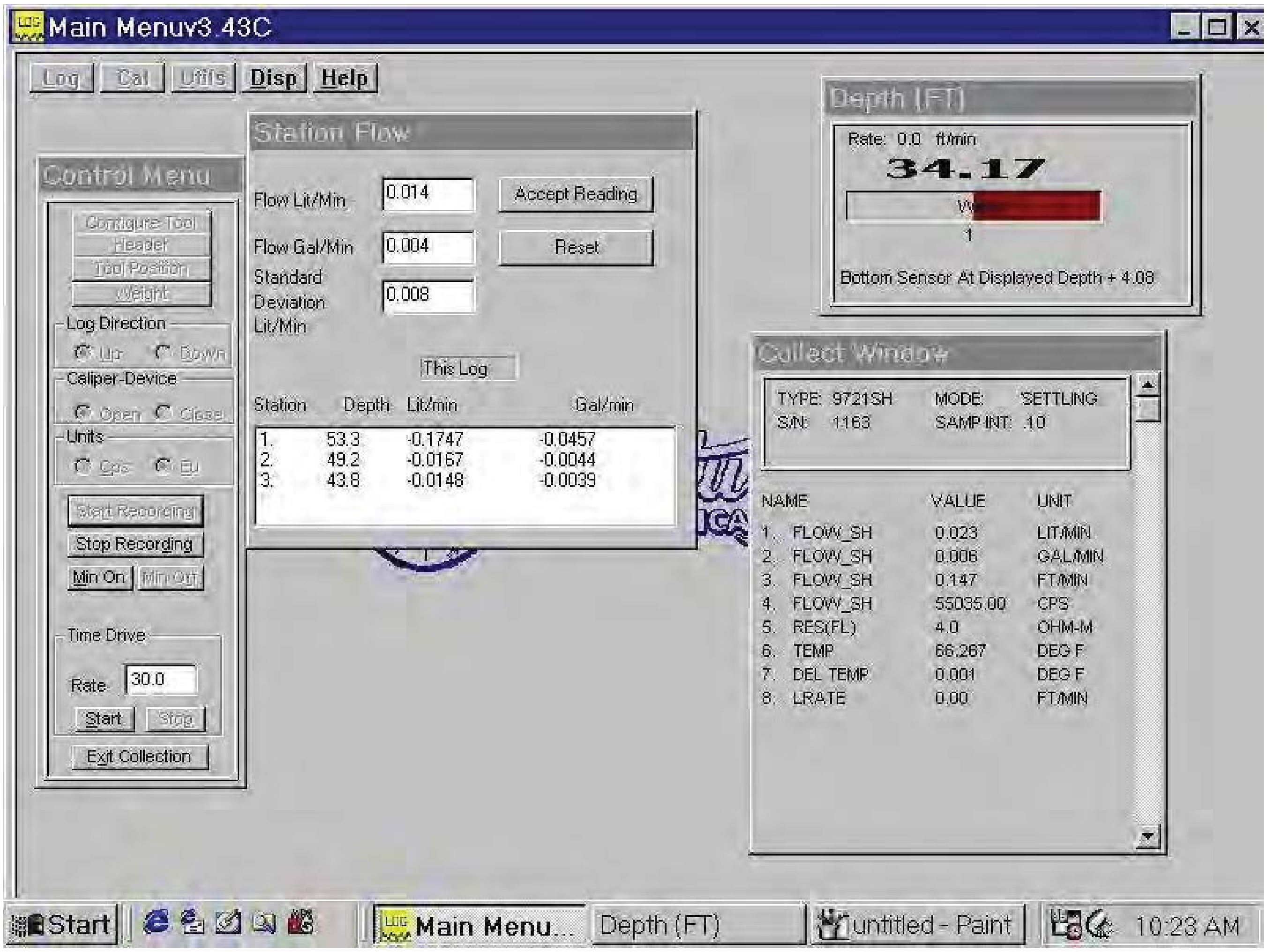
NOTES ON LOGGING THE 9721 TOOL

Two gain settings are available for use. The tool will default to low gain, and this should be used for recording high flow rates. To record low flow rates, the caliper open switch is toggled to change to the high gain setting. This gain setting is preferred in most applications requiring low flow measurements less than 10 liters per minute.

Logging procedures for the tool will vary with hole diameter, wall rugosity, and flow rates expected. Logging can be in boreholes with ambient flows to determine if there is any natural occurring flow due to pressure gradients, or with induced flow tests where water is either pumped from the well or injected into the well at a constant rate to determine the vertical distribution of the inflow or outflow.

Ambient flow tests are usually conducted first, with the flowmeter lowered to the bottom of the well. Acquisition of the data is similar to other logging tools with the Header, and Tool Position set prior to proceeding downhole. Upon reaching total depth of the borehole, select Start Recording and log to surface at a constant logging rate.

Stationary singular "depth stations" can also be recorded where the probe is allowed to "settle" and record the flow data. The sensor must be at the station for a minimum amount of time of at least be 2 minutes. When acquiring station data, you should watch both the "Station Flow" and the "Collect Window". The first readings in the station flow window will have bad values left over from moving the tool, therefore, you must hit the Reset button to start a new integration. After you are satisfied with the station, click on the "Accept Reading" prior to moving the probe to the next depth station. The probe is then raised the desired station length to the next station point.



Induced flow tests are also started at the probe on the well bottom. Water is pumped or injected from near the water surface at a low but constant rate to induce water to enter the well at the screened interval or through the natural fractures. Data is taken similarly as above with predetermined depth station intervals.

When using the flow diverter, it is best to pick a zone with concentric borehole wall so that the diverter works properly to isolate the zone. The borehole diverter must be slightly larger than (about 1/4") than the borehole size to assure proper isolation. This will require some customizing of the flow diverter for each borehole size.

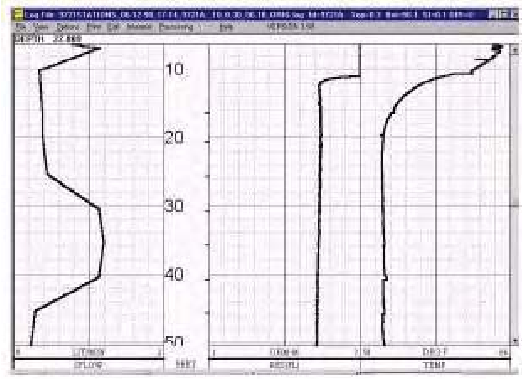
Additional logs such as the borehole televiewer, caliper, and conventional electric logs can help distinguish potential areas of flow.

Because the instrument measures voltage, it can be susceptible to ground currents from nearby underground cables. Depending upon the proximity, this can cause the signal to be noisy, but generally acceptable. Most of our applications have been at sites of contaminated groundwater at industrial facilities. Once we successfully conducted a test in downtown Los Angles, so the urban area does not necessarily cause any problem

DATA PRINTING

Flow station data is viewed and printed from the DISPLAY program. Select the log file similar to any other log file. To view the stations, from the VIEW menu button, select FLOW STATIONS. To print the data to the printer, from the PRINT menu button, select FLOW STATIONS.

Station data can also be viewed and printed in conventional chart form. From the Processing Menu in Display, select Add Flow Curve. This will take the stationary data and connect the data points to resemble a standard continuous log with the new curve called **SFLOW**



TOOL SPECIFICATIONS:

- Length: 56 Inches (142 cm)
- Temperature: 158 F (70 C)
- Diameter: 2.0 Inches (5.1 cm)
- Pressure: Not Yet Determined
- Weight: 13 Pounds (5.9 kg)
- Logging Speed: NA

SENSOR RESPONSE RANGES

Sensor	Sensor Response Limits	Accuracy
Flow	50 ml/min to+/-40 liter/min	+/-20 ml/min
Temp.	32 to 160 Deg.	+/-5%
Fluid R.	0 to 100 Ohm meters	+/-5%

Phone: 918-838-9811
Fax: 918-838-1532

Century Geophysical Corp.
1223 S. 71st E. Ave
Tulsa Oklahoma, 74112

sales@century-geo.com
www.century-geo.com

MAGNETIC SUSCEPTIBILITY SONDE

LOG APPLICATIONS

- Bed boundary identification
- Correlation
- Prospecting
- Definition of magnetic and mineralised zones

PHYSICAL SPECIFICATIONS

- Length 1.90 metres
- Diameter 43 mm
- Weight 6.8 Kg
- Pressure Rating 3000 PSI
- Temperature Rating 0 – 70 Deg Celsius
- Power Supply 60 – 100 V DC, 24mA
- Typical Logging speed 5 m/min

OPERATING RANGES

Magnetic Susceptibility:

- Range 1×10^{-5} to 1×10^{-1} cgs (Centimetre, Gram, Second)
- Resolution 25 mm F.W.H.M (Full Width Half Maximum)
- Sensitivity 1×10^{-5} cgs

MEASUREMENTS AND OFFSETS

Channel Number	Description of Sonde measurement	Channel Mnemonic	Measurement Offset (cm)
1	Magnetic Susceptibility	MSUS	16
2	Natural Gamma *	NGAM	80
3	No measurement	Null	-
4	No measurement	Null	-
5	No measurement	Null	-
6	No measurement	Null	-

Note: All Measurements are taken from bottom of sonde.

* Optional

SALES INFORMATION

SONDES

25 062 001 Magnetic Susceptibility (Bartington)

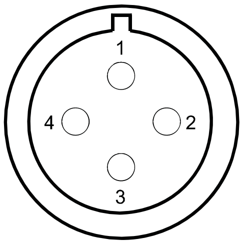
25 063 001 Magnetic Susceptibility (Bartington) + Natural Gamma

ACCESSORIES

20 070 000	Natural Gamma Test Jig without source
30 010 000	Natural Gamma Test source

SONDE CONNECTIONS

The sonde head connector carries the following signals from surface system:

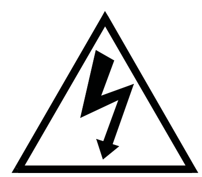


Pin Number	Monocable Communications	Four-wire Communications
1	Power & Comms	Uphole Comms
2	Not connected	Downhole Comms
3	Not connected	Not connected
4	Not connected	Sonde power

Note: Pin 1 as adjacent to the polarising keyway, 2, 3 & 4 are numbered clockwise when looking down from above.

SAFETY NOTICE

This equipment is energised at up to 100 Volts by the surface system. Ensure that sonde power is switched off before attaching or detaching the logging cable. Opening the sonde by removing the outer tube should only be attempted by trained personnel. Hazardous voltages up to 2KV may be present inside this equipment when powered from surface system



If the sonde is used in a manner not specified by the manufacturer or his agent, the protection provided by the equipment may be impaired.

OPERATING PRINCIPLES

MAGNETIC SUSCEPTIBILITY

The magnetic susceptibility sonde is intended to be used for prospection of magnetic minerals and stratigraphic correlation. The operating frequency is chosen to be sufficiently low to avoid interference from rock conductivities and the circuitry is temperature compensated to minimise thermally induced drift. The region of detection is situated 160mm from the tip of the pressure-equalised housing. The detector features a single focussed coil arrangement to achieve a single response to strata. The detection region has a full-width-half-maximum response of 25mm. The tool is calibrated for operation in 50mm diameter unclad boreholes. Larger diameter holes can be logged where the angle of the borehole assures de-centralisation. Correction factors for this and for linearity error correction are given.

NATURAL GAMMA (OPTIONAL)

All rocks contain small quantities of radioactive material. Certain minerals contain trace amounts of Uranium and Thorium; Potassium-bearing minerals will include traces of a radioactive isotope of Potassium. All of these emit gamma radiation as they decay with an extremely long half-life. This radiation is detected by scintillation - the production of a tiny flash of light when gamma rays strike a crystal of Sodium Iodide. The light is converted into an electrical pulse by a photomultiplier tube - pulses above a threshold value of 60 KeV are counted by the sonde's microprocessor. The measurement is useful because the radioactive elements are concentrated in certain rock types e.g. clay or shale's, and depleted in others e.g. sandstone or coal.

CALIBRATION

MAGNETIC SUSCEPTIBILITY

The system is scaled to a change of one least significant bit = $1x10^{-5}$ cgs units. (One measurement unit). A residual value of circa 1000 accommodates negative values and ageing effects. Each sonde can be supplied with a test block which is used to check for correct operation of the probe. Please note the block is a test; and may have an error of up to 10%. The calibration of the tool with time and temperature is assumed to be superior to the calibration test block. The test block should be fitted on the end of the probe centred at approximately 16cm from the bottom of the tool.   To convert to SI units multiply the cgs value by 4pi.

1 x 10e-5 cgs = 1.26 x 10e-4 SI

Note: this refers to volume susceptibility which is dimensionless.

Please note the probe is calibrated for use in a 50mm diameter borehole. The following table can be used to correct for other borehole ranges. (Values relative to 25mm layer normalised to a 50mm diameter borehole).

Borehole Diameter (mm)	Response Centralised	Response Decentralised
70	0.75	0.725
80	0.275	0.5
100	0.09	0.45

NATURAL GAMMA (OPTIONAL)

It is possible to calibrate the response of the sonde in API gamma ray units. The procedure falls into two parts, the primary calibration is performed in a test pit at RG during manufacture, and the secondary can be performed in the field using the optional calibration fixture.

The primary calibration uses a test pit manufactured from Uranium-doped concrete which has a known API activity. An identical pit made with the same concrete mix, but without the Uranium additive, is used as a background. The increase in count rate above the background is measured, and this is used to calculate a multiplier which relates the raw count rate to the API count rate.

Once this primary calibration has been performed, it is possible to create a secondary standard which will give a convenient count rate such as 200 API. This is done by mounting a small source on a rod which can be clamped over the detector, and then moving the source in or out along the rod until the activity reaches the required value. At this point a small detent is made in the rod at the correct position, and the jig is stamped with the API value. If an optional API calibrator is specified by the customer, all the above procedures will be performed by RG.

Secondary calibration is achieved through the ***Tools|Calibration*** menu. Select the ***NGAM*** channel and you will be asked to establish *background* conditions. Place the sonde horizontally on stands about 1 metre above the ground. Start acquisition by clicking ***Continue***, which will proceed for 5 minutes (300 seconds). At the end of the first period, attach the calibrator jig to the sonde tube, taking care that the base of the rod is exactly centred over the detector crystal. This can be determined experimentally by 'peaking' the count rate in a separate time mode log, or by measurement from the base of the sonde. Start the second acquisition period. After 5 minutes counting, you will be asked for the activity of the calibration source (see below). The calibration coefficients will then be computed and written to file together with the count rates and timestamp. Previous data will be transferred to the 'history' file for reference.

The date of calibration is important because the API value will change as the source decays. The API value at any time in the future is given by :

$$API_t = API_0 \ exp\left(\frac{-t.\ln(2)}{T_{\frac{1}{2}}}\right)$$

where :

t = time (years) since the original API calibration.

API_t = API value at time t.

API_0 = original API value as stamped on calibrator.

$T_{\frac{1}{2}}$ = half-life of isotope.

The half-life of ^{137}Cs is approximately 28 years. In a four year period, a ^{137}Cs source will decay to approximately 90% of its original value, and to 80% after 10 years.

BENCH TESTING SONDE FUNCTIONS

MAGNETIC SUSCEPTIBILITY

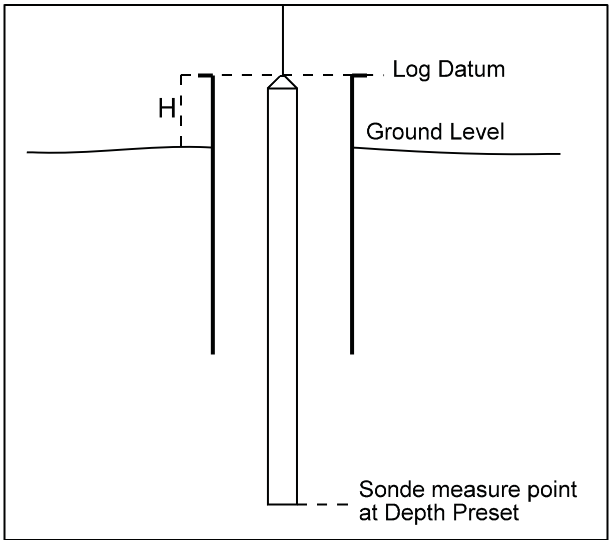
With the tool powered up on the bench select the menu item ***Tools*****/*****Test Sonde*** and monitor the data on channel 1 relating to magnetic susceptibility. With the tool in free air the reading should be approximately 1000 cps. If available place the test block on the sonde centred approximately 16cm from the bottom of the tool. The reading on channel 1 should increase by the amount stamped on the test block ±10%. If no test block is available simply move a steel item around the bottom section of the tool and look for a change in the magnetic susceptibility reading.

NATURAL GAMMA (OPTIONAL)

The Natural Gamma section can be observed on channel 2 and will normally give a small count rate at surface due to background radiation. Otherwise a small test source of gamma rays can be utilised, e.g. 10µCi^{137}Cs or a loaded source transport container.

OPERATING PROCEDURE

DEPTH SETUP



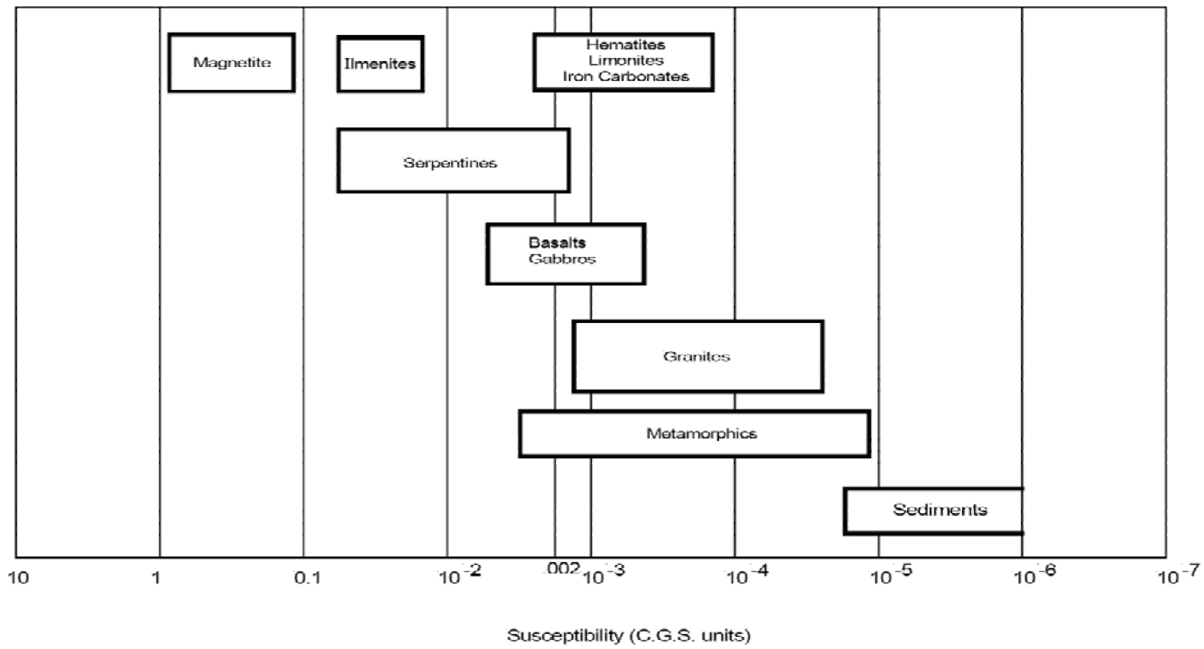
All sonde measurements are offset from the bottom of the tool. When performing an uplog if the top of the tool is aligned with your logging datum on surface you would initialize the depth to be the length of the tool. If performing a downlog then when the top of the tool is aligned with the logging datum then you would initialize the depth to be zero. Therefore if a downlog is performed from surface and then an uplog performed, the depth system must be changed once at the bottom by adding on the length of the tool. If you wish to use ground level for your datum then you must subtract the height H from the length of the tool. The preferred method of logging is to record in an upwards direction as this provides better depth control of the sonde.

Example: Tool length = 2.7m, Casing 50cm above ground. **Case 1.** Align top of tool with casing. Initialize depth to be -0.5m. Record down until depth reads 100m. Stop log, reset depth to 102.7m. Record uplog. **Case 2.** Align top of tool with casing. Initialize depth to be 2.2m run down to required depth and log up.

LOGGING PROCEDURE

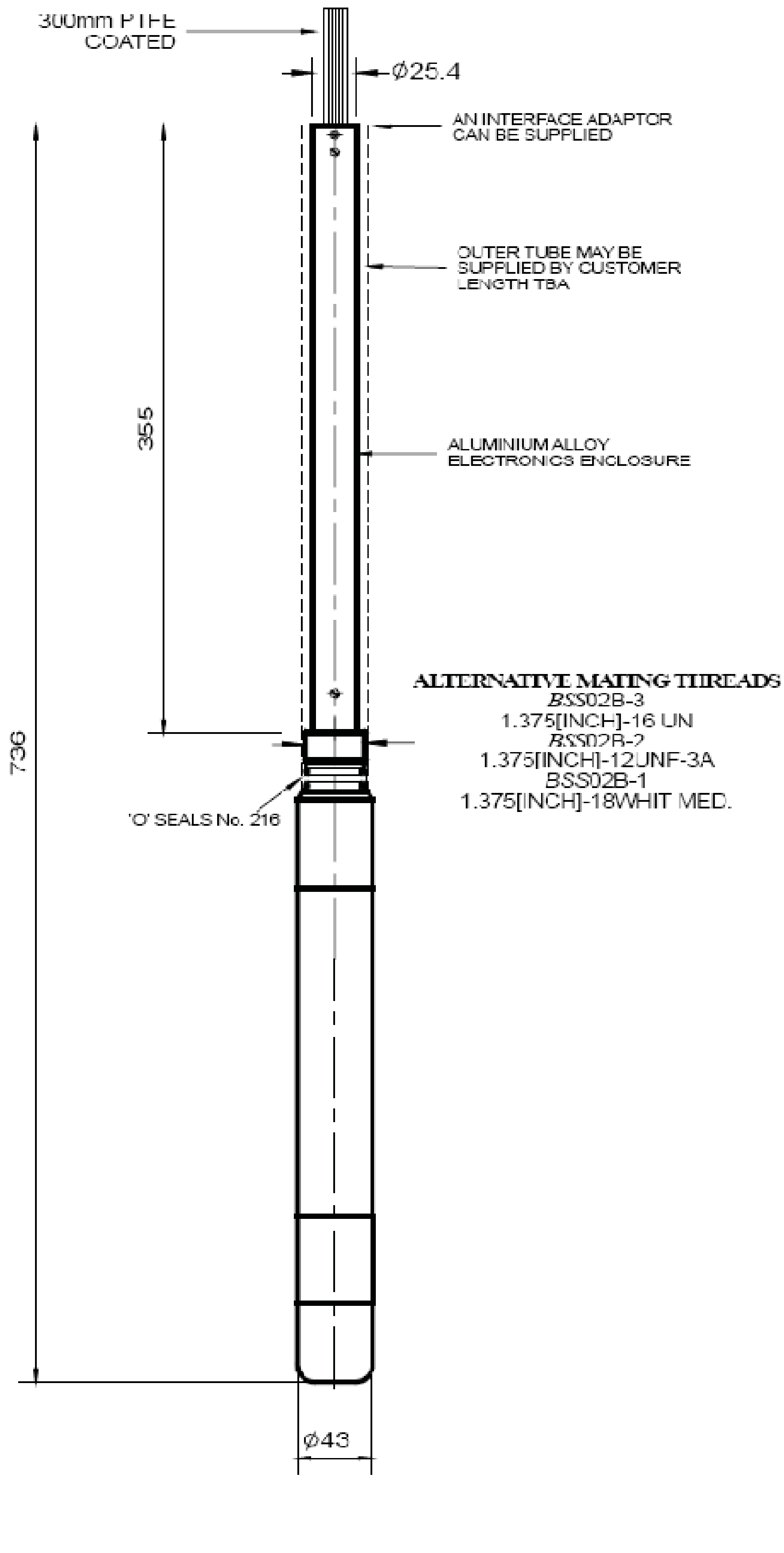
These instructions should be used in conjunction with the full or quick reference guide to logging with your surface system. **Ensure that sonde power is turned off**

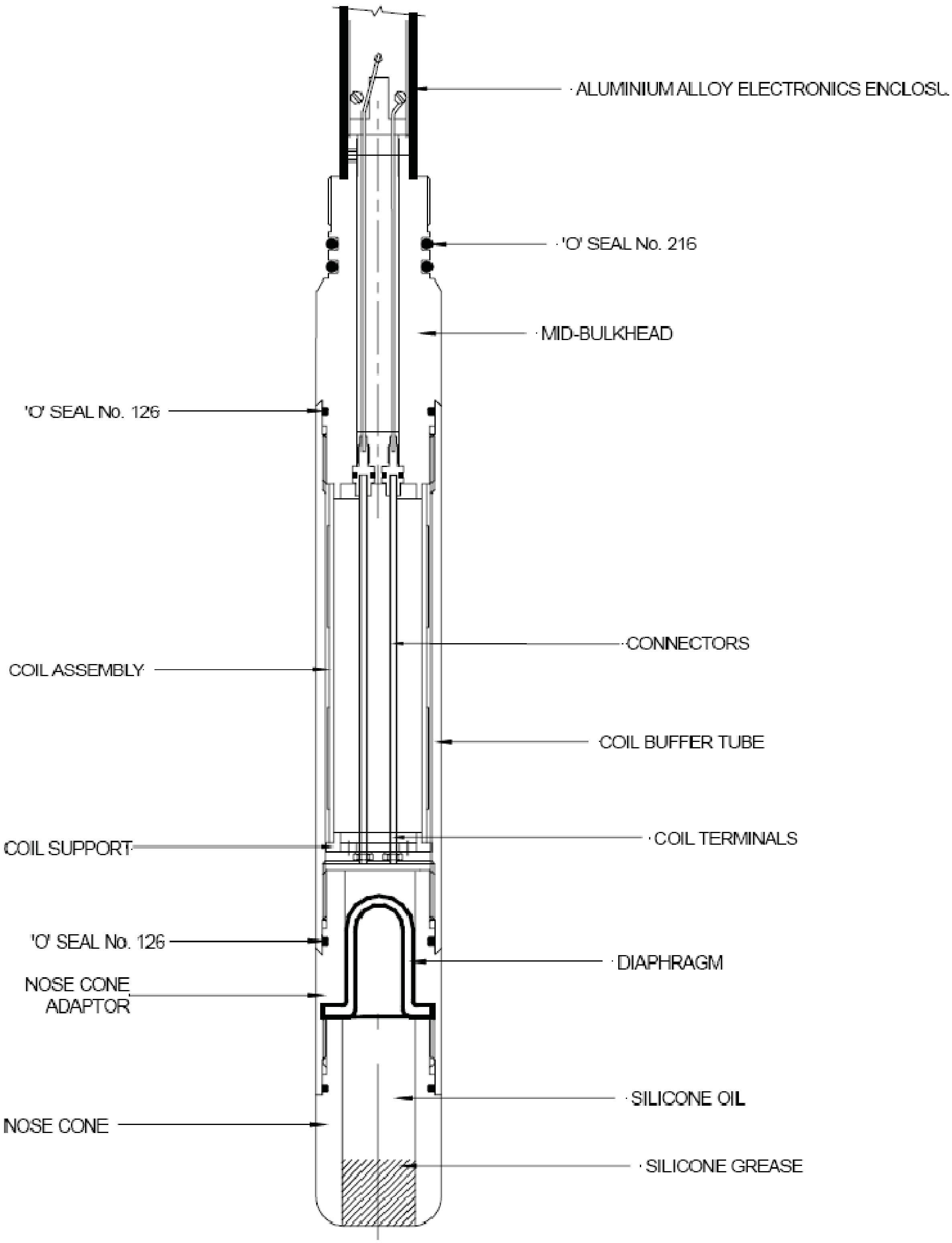
- Connect the sonde to the logging cable, power up the sonde.
- The initial offset can be removed from the magnetic susceptibility reading by selecting the 'Set baseline zero' command from within the WinLogger software. Ensure the probe is powered up and away from any metal objects if removing the offset.
- Measure the length of the tool from the bottom and also a reference point to use as a zero point for your logging datum.
- Lower the sonde into the borehole and ensure depth is incrementing in the correct direction and speed is correct. If not change the system settings by selecting menu item ***Tools / system settings***
- Run into the hole until the bottom of the required section is reached.
- Start the log ***File*** / ***New Log***.
- If you wish to produce a log with real electrical units and API gamma units ensure the correct calibration file is loaded in the ***Data Processing*** section of the new log window.
- Select logging direction and file name then complete the header information.
- Winch uphole and observe the data to ensure the sonde is operating correctly.
- Typical logging speeds are 5 m/min however Natural Gamma response is improved for slower speeds.
- When at surface turn off sonde power and remove sonde from the borehole. Clean the sonde with low-pressure fresh water.

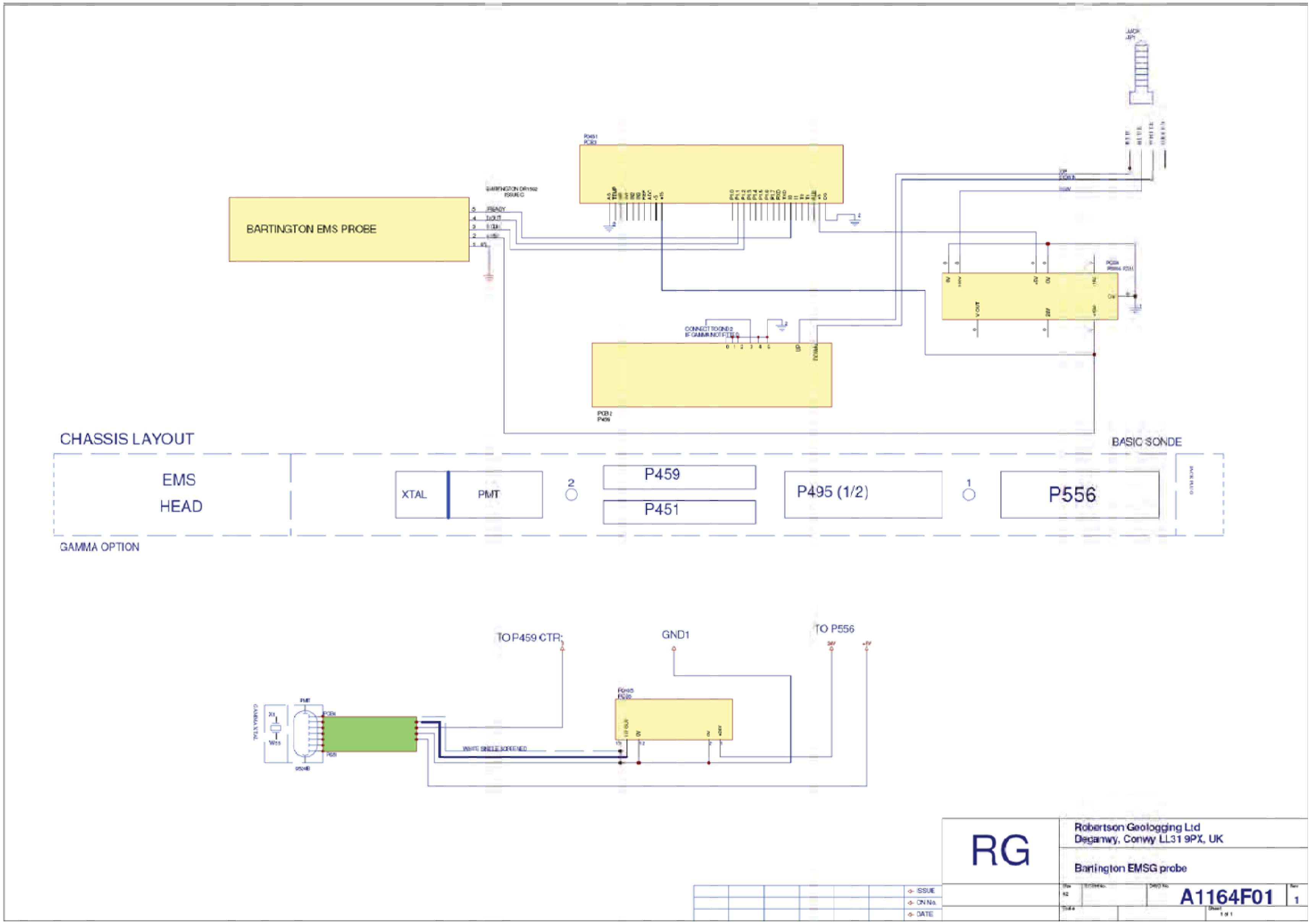


Magnetic susceptibility of common rocks

SONDE SCHEMATIC




ALUMINIUM ALLOY ELECTRONICS ENCLOSU
'O' SEAL No. 216
MID-BULKHEAD
'O' SEAL No. 126
CONNECTORS
COIL ASSEMBLY
COIL BUFFER TUBE
COIL TERMINALS
COIL SUPPORT
'O' SEAL No. 126
DIAPHRAGM
NOSE CONE
ADAPTOR
SILICONE OIL
NOSE CONE
SILICONE GREASE


BARTINGTON EMS PROBE
READY
DOUT
SCLK
CHASSIS LAYOUT
EMS
HEAD
GAMMA OPTION
XTAL
PMT
2
P459
P451
P495 (1/2)
1
P556
BASIC SONDE
TO P459 CTR
GND1
TO P556
WHITE SINGLE SCREENED
RG
Robertson Geologging Ltd
Deganwy, Conwy LL31 9PX, UK
Bartington EMSG probe
A1164F01
1
ISSUE
CN No.
DATE

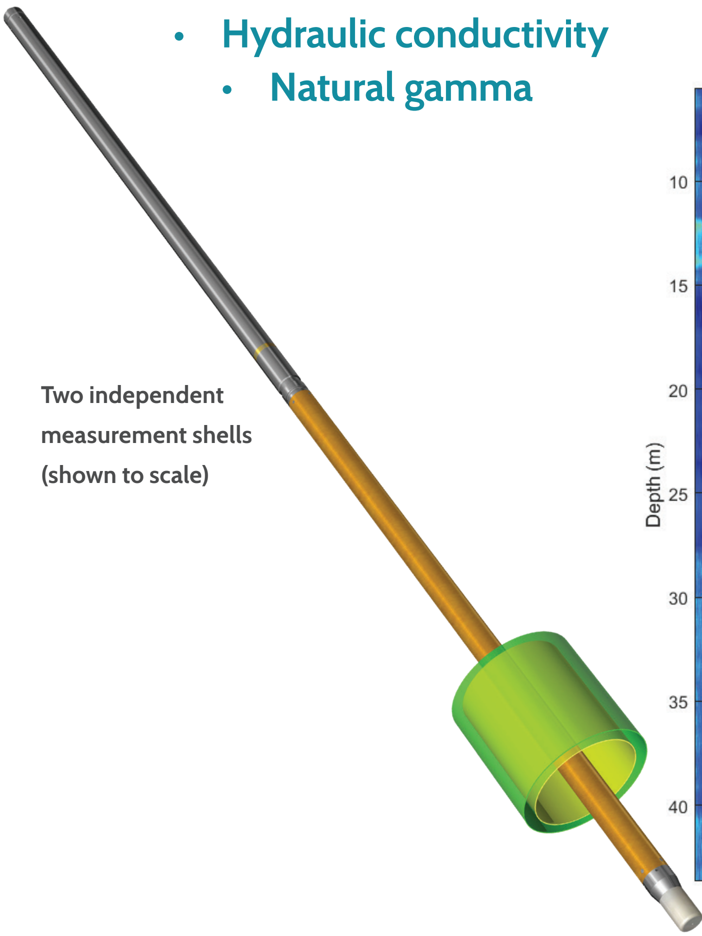
Javelin Wireline Slim

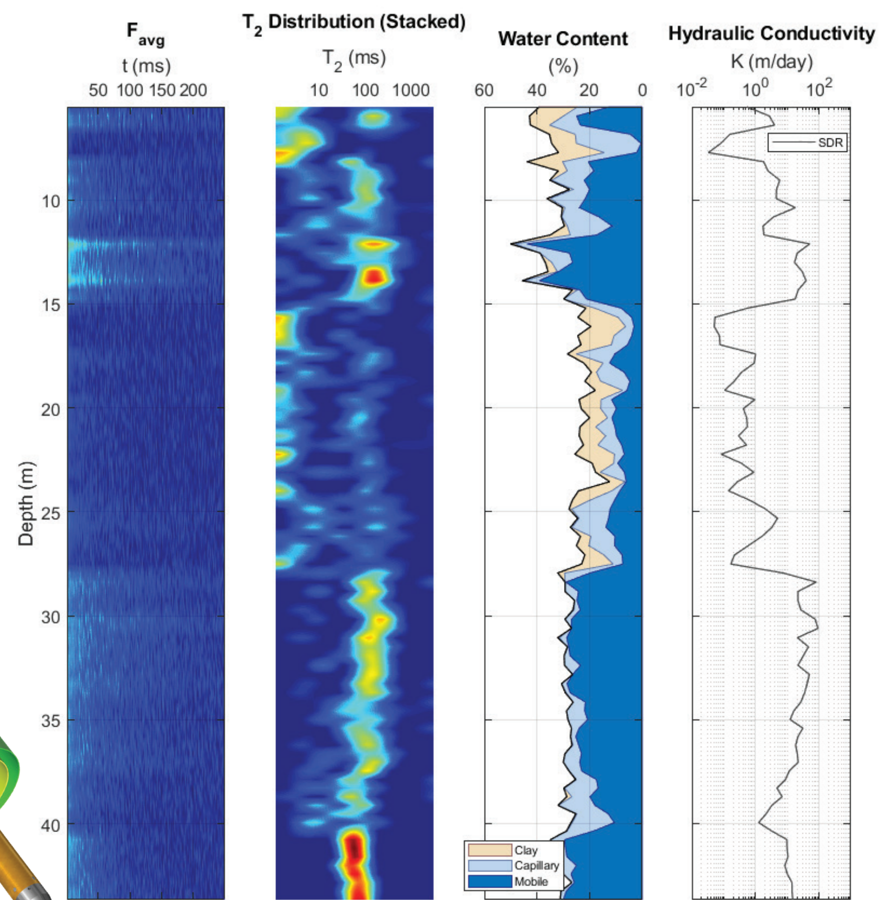
Small-Diameter Magnetic Resonance Wireline Logging Tool

For professional geophysical logging operators

The new Javelin® Wireline Slim provides high-resolution, continuous measurements of principal aquifer properties for groundwater and environmental investigations:

- **Porosity**
- **Bound and mobile water content**
- **Pore size distribution**
- **Hydraulic conductivity**
- **Natural gamma**





Applications

- Geotechnical site investigations
- Groundwater resource management
- Aquifer storage and recovery
- Environmental site characterization
- Mine water engineering
- Brine and leach mining

Javelin® Wireline Slim Magnetic Resonance Logging Tool

FEATURES

Interchangeable Probes

- 2.38in (60mm), 3.0in (76mm) and 3.5in (89mm) probes allow operation in a wide range of core holes and groundwater wells
- Integrated field joints for rapid and secure deployment

Widest Diameter of Investigation

- Largest Diameter of Investigation of any small or medium diameter magnetic resonance logging tool
- Measures properties of native formation past the disturbed zone

Multi-Frequency Logging

- Two independent measurement shells measured at different diameters of investigation during a single logging run
- Provides increased signal to noise ratio, ability to assess radial variability due to washout and mud invasion, and improved immunity to radiofrequency noise

Ultra-Short Echo Spacing

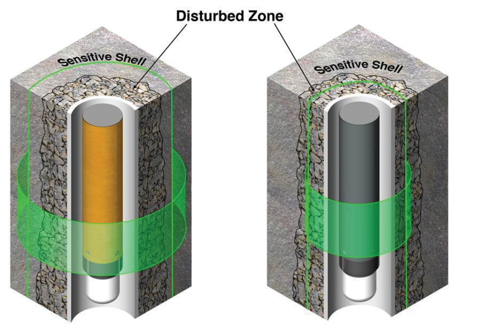
- Echo spacing as short as 450 microseconds ensures accurate measurement of clay-bound water content

Industry-Standard Wireline Compatibility

- Operation on 4-conductor or 7-conductor wireline cable ensures seamless integration with existing logging operations

Flexible Surface Station

- The Javelin® surface station provides tool power, tool control, telemetry, depth counter, tension display. and interface to PC. It works with all Javelin® Max, Slim and Micro tools.



Javelin deep-view sensitivity

Unusable data without deep-view

Surface Station is available as a rackmount unit (4U) or housed in a compact, shock-mounted case.

SPECIFICATIONS

Javelin Probes	JPY238	JPY300	JPY350
Diameter:	2.38in (60mm)	3.00in (76mm)	3.5in (89mm)
Length:	65in (165cm)	69in (175cm)	66in (167cm)
Weight:	25lb (11kg)	40lb (18kg)	53lb (24kg)
Pressure Rating:	2350 PSI	1700 PSI	1700 PSI
Sensitive Diameters:	F_1: 9in (23cm)	F_1: 13in (33cm)	F_1: 13in (33cm)
	F_2: 11in (28cm)	F_2: 15in (38cm)	F_2: 15in (38cm)
Vertical Resolution:	8in (20cm)	11in (28cm)	16in (41cm)
Echo Spacing:	500µs	600µs	600µs

Downhole Digital Module

Diameter: 2.38in (60mm)
Length: 69in (175cm)
Weight: 39lb. (18kg)
Length w/Gamma Sensor: 85in (216cm)
Weight w/Gamma Sensor: 53lb. (24kg)
Natural Gamma Sensor: Optional
Logging Speed: 100-500 ft/hr
Cable: 3/16 inch (or larger), 4-core or 7-core

CE Certified. FCC, CTick, CE Emissions Compliant
Protected by US Patents: US 10,162,026 B2; US 10,302,733 B2; US 8,816,684 B2; US 9,348,054 B2; US 9,588,068 B2; US 8,736,264 B2; US 10,113,982 B2

rev 2023-08-14

VISTACLARA INC.
NMR Geophysics

Sales, Rentals, and Services
www.vista-clara.com +1 425-493-8122

Javelin Wireline

Magnetic Resonance Well Logging System

Manual and Documentation

⚠ WARNING

Read this manual in its entirety before attempting to assemble or operate the Javelin instrument. Operation of the Javelin equipment by untrained or unqualified personnel can expose the operator and other persons to serious injury or death.

The Javelin Wireline magnetic resonance sensor has strong permanent magnets and generates current pulses up to 200 amps in the 200kHz – 2MHz frequency band. Permanent magnetic fields and those generated by current pulses could affect pacemakers, defibrillators, and other medical devices. Persons using any type of medical device must not operate the system and should remain at least 5 meters (15 feet) from all instrument components. Do not allow magnetic objects near the probes; magnetic objects and probes will be attracted and may become projectiles if not secured.

VISTACLARA INC.
21ST CENTURY GEOPHYSICS

12201 Cyrus Way, Suite 104,
Mukilteo, WA, USA 98275
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support@vista-clara.com
www.vista-clara.com

Revision 5, Dec. 2020

Published by Vista Clara, Inc.

12201 Cyrus Way, Suite 104

Mukilteo, WA, 98275 USA

Printed in the United States

Contents

1 Warranty and Certifications

Limited Warranty

Vista Clara Inc. guarantees the Javelin Wireline equipment and Javelin software for one year from the date of shipment when used according to our instructions, as described in the Javelin Wireline Manual and Documentation. Equipment or software which proves to be defective upon inspection by Vista Clara Inc. will be replaced or repaired free of charge, including freight and insurance charges to and from the customer. No allowance will be made for customer's labor or other expenses incurred by the customer in making exchanges, replacements or repairs. No equipment will be accepted for return without a return goods authorization. Any equipment failures due to accidents, accidental or intentional misuse of the equipment, damage caused by insufficient protection during transit, faulty installation, maintenance or repairs carried out by a person other than the vendor or his agent, or from alterations carried out without the Vista Clara's consent in writing, or normal wear and tear are excluded from the warranty. The Javelin Wireline equipment contains sensitive electronic instrumentation and must be handled with care at all times.

Limitations of Liability

Vista Clara Inc. expressly disclaims any liability whether in negligence, strict liability, or warranty for damage or injuries resulting from using, operating, servicing, maintaining, or failure of the equipment caused by not following Vista Clara's safety warnings, manuals, and training or because of the sole negligence of purchaser.

Limited License

The purchaser is granted a limited use license to use Vista Clara's technologies, including its proprietary processing and other software, for its own use only in order to operate the Javelin Wireline equipment and to process data collected by the Javelin Wireline equipment. Vista Clara retains ownership of the technologies. The purchaser is not authorized to make or provide copies of the software or sublicense the technologies to anyone else or to use the software for any other purpose.

Certification

See following pages.

DECLARATION OF CONFORMITY

Primary Directives
2006/42/EC Machinery
2014/35/EU Low Voltage
2014/30/EU EMC
2014/68/EU Pressure Equipment
2014/34/EU ATEX
2011/65/EU RoHS

Additional Directives
1993/68/EEC 1993 CE Marking
1993/58/EEC 1993 Safety Signs
1986/188/EEC 1986 Noise
1989/656/EEC 1989 Personal Protective Equipment
2011/65/EU 2011 RoHS Directive

Reference Standards
EN 292-1, -2 1991 Safety of Machines
ISO14121 2012 Safety of Machinery – Risk Assessment (supersedes EN1050-1997)
EN 12100 2009 Safety of Machinery – Basic Concepts and General Principles
EN 60204-1 2016 Safety of Machines, Electrical, 2016
IEC 61010-1 2012 Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use. UL 61010-1 third edition, March 11, 2012

Ancillary Standards
I-Codes 2018 International Code Council (ICC) I-Codes
NFPA 70 2017 National Electrical Code (NEC)
NFPA 79 2018 Electrical Standard for Industrial Machinery
UL 508A 2010 Industrial Control Panels
ANSI Z535.4 2011 Product Safety Signs and Labels
ISBN 0471978159
2008 Guidelines for Hazard Evaluation Procedures by the Center for Chemical Process Safety, American Institute for Chemical Engineers

EMC Test Standards
EN 61326-1:2013
FCC 18.305:2018
FCC 18.307:2018
ICES-001:2006 updated 2014
AS/NZS CISPR 11:2011
CISPR 11:2015 +A1:2016

DECLARATION OF CONFORMITY

Name of Manufacturer

Vista Clara, Inc.

Full postal address, including country of origin

12201 Cyrus Way, Suite 104
Mukilteo, WA 98275
United States of America

Description of Product

Instrument for the characterization of underground water.

Name, type, model, and serial number

Type: Geophysical Instrument

Make: Vista Clara

Model: Javelin Wireline

Location: Mukilteo, Washington, USA

Supply: 220V/50Hz or 110V/60Hz (user-configurable)

Reference: CD2019-10

Country of Origin: USA

European Normalized Standards Applied

EN 292-2:1991	Basic concepts, general principles for design – Technical principles and specifications
EN 60204-1:2016	Basic concepts, general principles for design – Technical principles and specifications
UL 61010-1:2008	Standard for Safety, Electrical Equipment for Measurement, Control, and Laboratory Use
ISO 14121	Safety of Machinery – Risk Assessment (formerly EN1050:1997)
ISO 3864	Safety colours and safety signs
NFPA 70-2008	National Electric Code
NFPA 79-2007	Electrical Standard for Industrial Machinery

DECLARATION OF CONFORMITY

<u>Manufacturer</u>

Place of issue	USA	Date of issue: November 14, 2019
Title of signatory	Name	Signature
President	David Walsh	______________________________

Declaration

I declare that as the authorized representative, the above information in relation to the supply and manufacture of this product, is in conformity with the stated standards and other related documents following the provisions of the above Directives and their amendments.

Copies of the Technical File are kept by the authorized representative for inspection by enforcement authorities.

2 Warnings and Alerts

The following document contains important information regarding the safe and effective operation of your new Javelin Wireline system. Improper use of this system can result in physical damage to the instrument, personal injury, or even death.

It is essential that you read carefully through the entire Manual and Documentation (especially the Safety Information) before attempting to operate the system.

The symbols used in this Manual and Documentation have the following meanings.

DANGER	**DANGER:** Indicates a potentially hazardous situation which, if not avoided, will result in death or serious injury
WARNING	**WARNING:** Indicates a potentially hazardous situation or an unintended use which, if not avoided, could result in death or serious injury
CAUTION	**CAUTION:** Indicates a potentially hazardous situation or an unintended use which, if not avoided, may result in minor or moderate injury and/or appreciable material, financial and environmental damage
	**MAGNETIC FIELD HAZARD:** Indicates a hazard associated with strong magnetic fields surrounding downhole probes.
	**ELECTRICAL HAZARD:** Indicates an electrical hazard associated with high-voltage power
	**LIFTING HAZARD:** Indicates a lifting hazard associated with the moving of heavy components
NOTICE	**NOTICE:** Highlights important notes or instructions which must be closely followed for proper operation of equipment or software

4 System Components

The Javelin Wireline is a magnetic resonance (MR) logging system designed for deployment with 4-conductor wireline logging cable. The tool can be used in open or PVC-cased boreholes to estimate formation properties, including porosity and permeability.

The specifications, electrical requirements, and important safety features of each component of the Javelin logging system are outlined in this section.

4.1 Summary of Components

Primary Units

- Javelin Wireline Surface Station
- Javelin Wireline downhole logging tool, consisting of two or three sections
    - *Two-section systems:*
        1. Analog MR Probe
        2. Digital and Power Module
    - *Three-section systems:*
        1. Analog MR Probe
        2. Digital Module
        3. Power Module

Additional Components

- Connection Cables

Software

- *For systems without integrated downhole PC:*
    - Javelin Digital acquisition software (installed on laptop computer)
- *For systems with integrated downhole PC:*
    - Javelin Wireline Remote Terminal Software (installed on laptop computer)
    - Javelin NMR Logger Acquisition Software (installed on downhole PC)
- *For all systems:*
    - Javelin ProPlus, for monitoring, processing, and interpreting Javelin magnetic resonance data (installed on field laptop)

Documentation

- Javelin Wireline Manual and Documentation (this document)

User-Supplied Components

The following components are required for logging, but are typically not supplied by Vista Clara:

- Generator Power Source
    - *Preferred rating is 5 kW or higher.*
    - *Preferred configuration is without inverter.*
- Winch with 4-conductor wireline logging cable
- Tripod, Mast, or Crane
- Sheave Wheel
- Laptop Computer (running Windows 64-bit)
- Wireless Networking Hub

4.2 General system specifications

- Operating Frequency: 240-450 kHz

4.3 Downhole Logging Tool

4.3.1 Versions

The Javelin downhole magnetic resonance logging tool has multiple possible configurations. At present these are:

1. **Javelin Slim**
    - 2.38-inch Digital and Power Module
    - Supports interchangeable 2.38-inch and 3.5-inch Analog Probes
    - Comprised of two sections (Analog Probe + Digital Electronics/Power)
    - Sections connect via Field Joints (coupled mechanical/electrical)
2. **Javelin Max** (Two-Section)
    - 3.5-inch Digital and Power Module
    - Supports interchangeable 3.5-inch and 5.25-inch Analog Probes
    - Comprised of two sections (Analog Probe + Digital Electronics/Power)
    - Sections connect via Field Joints (coupled mechanical/electrical)
3. **Javelin Max** (Three-Section)
    - 3.5-inch Digital and Power Modules
    - Supports interchangeable 3.5-inch and 5.25-inch Analog Probes
    - Comprised of three sections (Analog Probe + Digital Electronics + Power)
    - Sections connect via Double Joints (separate mechanical and electrical)

A Javelin Slim system is depicted in Figure 1 and a Javelin Max system (Three-Section version) in the field is depicted in Figure 2.

Figure 1: Example of a Javelin Slim downhole logging system, shown with 2.38-inch Analog MR Probe.

Figure 2: Example of Javelin Max downhole logging system (three-section), shown with 5.25-inch Analog MR Probe.

4.3.2 Connections

The sections of the downhole logging probe connect to one another via Field Joints or "Double Joints" (Figure 3).

Field Joints have integrated mechanical and electrical connections in a single coupling.

Double Joints have separate mechanical and electrical connections. Electrical connections must be made by connecting individual wiring harnesses, followed by the mechanical connection joining the two probe shells.

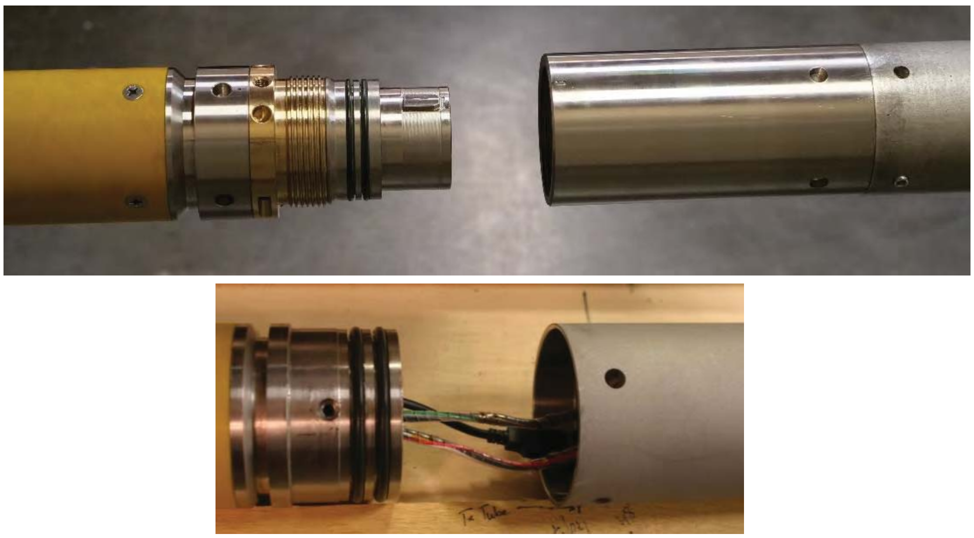


Figure 3: Examples of a Field Joint, with integrated electrical and mechanical coupling (top) a Double Joint, with separate electrical and mechanical connections (bottom).

4.3.3 Specifications

Table 1: Typical specifications for 3-section Javelin Max downhole logging system (contact Vista Clara for most up-to-date specifications).

Specifications:	***Electrical Requirements:***
Analog MR Probes JP350F: 3.50” Dia. x 73” L; Weight 55 lbs. JP525F: 5.25” Dia. x 62”L; Weight 93 lbs.	Power supplied by Digital Electronics and Power Modules via one 8-pin Molex mini-fit junior and one 2-pin high current snap locks.
Power Module 3.50” Dia. x 49” L; Weight 27 lbs.	Power supplied by Digital Module via Molex connectors.
Digital Module 3.50” Dia. x 51” L; Weight 34 lbs.	Power and telemetry supplied by Javelin Wireline Surface Station through Century 4-pin logging head and 4-conductor steel armored logging cable with maximum length of 1000m.
Downhole Tool with JP350F 3.50” Dia. x Total Length 14ft; Total Weight 116 lbs. **Downhole Tool with JP525F** 5.25” Dia. x Total Length 13ft; Total Weight 154 lbs.	**Maximum depth: 1000m** **Maximum depth: 600m**

Table 2: Typical specifications for Javelin Slim downhole logging system (contact Vista Clara for most up-to-date specifications).

Specifications:	***Electrical Requirements:***
Analog MR Probes JPY238: 2.38in. Dia. x 187cm L; Weight 25 lbs. Shipped length: 198cm JPY350: 3.50in. Dia. x 183cm L; Weight 56 lbs. Shipped length: 194cm	Power supplied by Digital Electronics and Power Module via Field Joint.
Digital Electronics and Power Module 3.50" Dia. x 263cm L; Weight 53 lbs. Shipped length: 269cm	Power and telemetry supplied by Javelin Wireline Surface Station through Century 4-pin logging head and 4-conductor steel armored logging cable with maximum length of 1200m.
Assembled Downhole Tool with JPY238 2.38in. Dia.; Total Length 450cm; Total Weight 78 lbs. **Assembled Downhole Tool with JPY350** 3.50in. Dia.; Total Length 446cm; Total Weight 109 lbs.	
JP350 Adapter (for running JPY350 on standard Javelin) 51cm L; Weight 13 lbs. Shipped length: 58cm	

4.3.4 Analog MR Probe

The Analog MR Probe contains a magnet and coil array, and analog and digital electronics for coil tuning, transmit/receive switching, and detection of magnetic resonance signals. The Analog MR Probe is housed in a fiberglass enclosure with outer diameter of 2.38 inches, 3.5 inches, or 5.25 inches (depending on your system configuration).

⚠WARNING

Magnets in the downhole probes create very STRONG MAGNETIC FIELDS THAT ARE ALWAYS PRESENT, even when no power is connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not secured.

Persons wearing any type of electronic medical device such as a pacemaker must not operate the system and should remain at least 5 meters (15 feet) away from all instrument components due to strong magnetic fields.

⚠WARNING

The logging system produces high-voltage power in excess of 2000V AC when transmitting. The Analog MR Probe should never be powered on or used in any way unless it is fully connected and properly mated and sealed to the Power Module and the Digital Module.

Figure 4: Examples of Analog MR probes:
Top - JPY238 Probe (with Field Joint)
Middle - JPX350F Probe (with Double Joint)
Bottom - JPX525F Probe (with Double Joint)

4.3.5 Digital Electronics and Power Module (2-section systems only)

The Digital Electronics and Power Module contains high speed analog to digital and digital to analog converters, power supplies, telemetry modem, signal conditioning and control circuitry high voltage, energy storage capacitors, and an RF amplifier to produce high power RF magnetic resonance excitation pulses.

The lower end of the Digital Electronics and Power Module connects to the Analog MR Probe using a Field Joint.

The upper end of the Digital Electronics and Power Module connects to the wireline cable via a Century 4-conductor logging head.

Figure 5: Digital Electronics and Power Module of Javelin Slim system.

4.3.6 Power Module (3-section systems only)

The Power Module includes high voltage energy storage capacitors and an RF amplifier to produce high power RF magnetic resonance excitation pulses. The lower end of the Power Module connects to the Analog MR Probe using a Field Joint, or via Molex through a Double Joint, and the upper end of the Power Module connects to the Digital Module using a Field Joint, or via Molex and USB connectors through a Double Joint.

Figure 6: Power Module of Javelin Max (3-Section).

WARNING The Power Module stores and produces high-voltage power in excess of 600V AC when transmitting, and in excess of 100V DC when powered on. The Power Module should never be powered on or used in any way unless it is fully connected and properly mated and sealed to the Analog MR Probe and the Digital Module.

4.3.7 Digital Module (3-Section systems only)

The Digital Module includes a downhole computer, high speed analog to digital and digital analog converters, various power supplies, a telemetry modem, and various signal conditioning and control circuitry. The lower end of the Digital Module connects to the Power Module using a Field Joint or via feed-through connectors, and the upper end of the Digital Module connects to the wireline cable via a Century 4-conductor logging head.

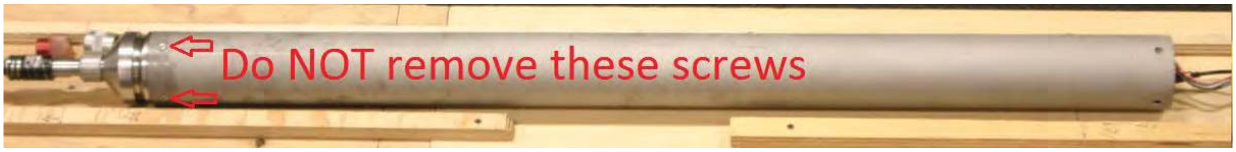


Figure 7: Digital Module of Javelin Max (3-section).

The Digital Module stores and produces high-voltage power in excess of 300V DC when powered on and stores high voltage in excess of 10V for a significant period of time after being powered down. The Power Module should never be powered on or used in any way unless it is fully connected and properly mated and sealed to the Analog MR Probe and the Digital Module.

For systems with downhole PCs, rapid data downloading can be achieved by adding the External Battery Lead (see *Spare Cables for downhole computer* section in this document) to the Digital Module (12V battery is not provided with the system).

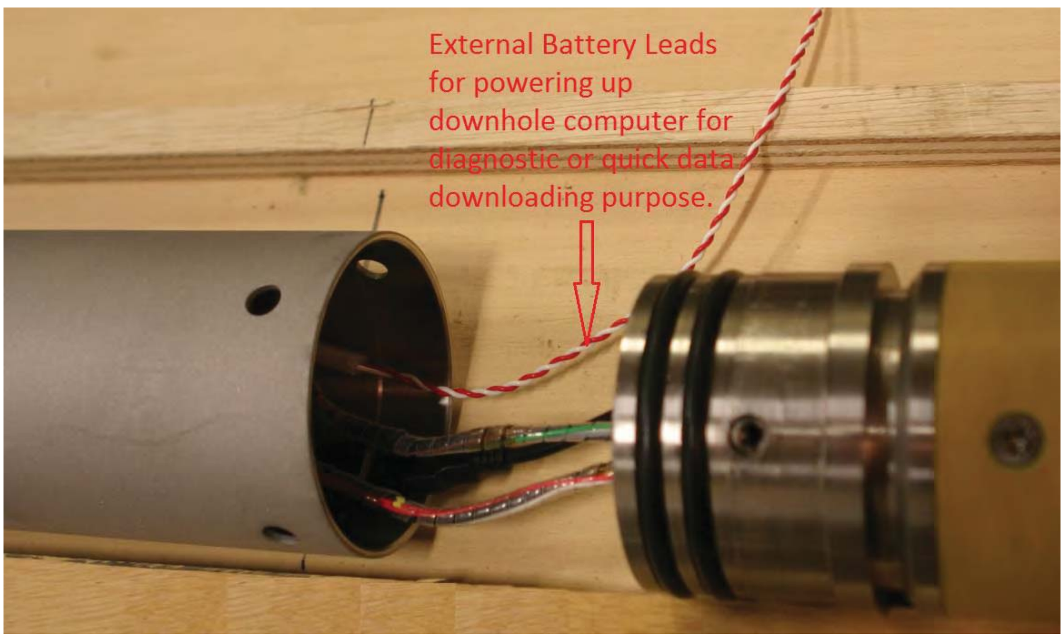


Figure 8: External Battery Leads for powering up downhole computer for diagnostic or quick data downloading purpose. Do not connect this cable during normal logging.

4.4 Cable Winch with 4-conductor Wireline Logging Cable

Always refer to the winch manufacturer operating manual for instructions and warnings.

The electrical slip ring installed on the winch should have a minimum of 4 isolated contacts, with each slip ring contact rated for a voltage of at least 400 volts DC and current of at least 1.0 amps DC.

The winch should be loaded with an appropriate 4-conductor wireline logging cable. The cable should have a minimum wire gauge of #24 AWG for each conductor and a voltage rating of at least 315 VDC for each conductor.

The wireline logging cable should have a length between 500 m and 1200 m. A cable with length longer than 1200 m will reduce the power available to the downhole tool, requiring lower duty cycle measurements. A cable shorter than 500 m will provide insufficient resistance to limit the short-term line current to 2.0A or less, as required by the Javelin system.

WARNING The Cable Winch and cable carry high-voltage power. Do not allow water or rain to reach the winch. Never allow water to reach the contacts between the slip ring and cable conductors.

4.5 SURFACE STATION

The Javelin Wireline Surface Station (WJSS) controls and powers the downhole logging system. The Surface Station connects to the field computer using a single USB data cable.

Internally, the Surface Station contains:

- AC/DC converter to supply high voltage DC power to the downhole logging tool.
- Modem-based telemetry to enable remote control and monitoring of downhole logging.
- Depth counter.
- Overvoltage and over-temperature protection circuitry.

The Surface Station is supplied with a separate, required power supply.

The Surface Station and power supply are configured for rack-mount. The Surface Station (3U) and power supply (1U) can be mounted in any standard electronics rack or are available in a single shock-mounted enclosure, as shown in Figure 9.

Figure 9: Javelin Wireline Surface Station packaged with power supply in a shock-mounted enclosure.

⚠WARNING The Surface Station produces high-voltage power. Never touch, connect, or disconnect the High-Voltage Winch Cable when the system is powered on, or if the analog voltmeter on the front panel indicates 10V or higher on the DC power.

Table 3: Specifications for Surface Station.

Specifications:	***Electrical Requirements:***
Weight: 55 lb. (in shock-mount enclosure) Dimensions: 31in L X 23in W X 12in H (in shock-mount enclosure) Typical power consumption: 400 W Peak power consumption: 1000 W	AC Line Requirements: 110VAC/60Hz **or** 220V/50Hz (user-selectable) Generator Requirements: - 3KVA for Javelin Wireline System only - Additional 2KVA for Winch (follow specifications for your winch)

4.5.1 Voltage Requirements

The surface station receives AC power from a portable generator during logging operations.

The Surface Station and power supply each require their own power cord. Both cords use C13 connectors (Figure 10).

The input voltage to the power supply can be either 110V or 220V; **no configuration is necessary to use either voltage.**

The input voltage to the Surface Station can be either 110V/60Hz or 220V/50Hz; **user configuration is required to select between voltage inputs.** A rotating switch to the left of the power input can be used to select between 110V and 220V (Figure 11).

Figure 10: Rear view of the Surface Station (upper unit) and power supply (lower unit), showing C13-style power inputs (circled). The Surface Station power input (red circle) ***requires user configuration to select between 110V and 220V.*** *The power supply power input (blue circle) can accept 110V/60Hz and 220V/50Hz without user configuration.*

Figure 11: Power input to Surface Station configured for 110V/60Hz (left) and 220V/50Hz (right).

CAUTION **Ensure that the Surface Station voltage input selection switch is correctly matched to the power source.**

4.6 Cables

4.6.1 NMR Winch Connector Cable

The 6-conductor Winch Connector Cable connects the Surface Station to the Cable Winch and carries high voltage power and low-voltage telemetry signals to the Downhole Cable and Tool.

WARNING The Winch Connector Cable carries high voltage DC power in excess of 300 V DC to the probe. This cable is directly connected to significant high voltage energy stored on significant capacitance on both the surface station and the downhole tool. The Winch Connector Cable should never be disconnected or connected to either the winch or the surface station while the surface station analog voltmeter reads more than 5 V DC.

4.6.2 Depth Encoder Cable

The 7-conductor Depth Encoder Cable connects the depth encoder (which is typically mounted on either on either the winch or sheave wheel) to the Surface Station. The Surface Station includes a depth counter that converts pulses from the depth encoder into digital depth data, which is read and stored by the NMR acquisition software and which is also displayed on the Depth Encoder display on the front panel of the Surface Station.

Vista Clara can provide panel mount mating connectors for winch cable and depth encoder cable. They will be mounted onto customer's winch according to the wiring diagrams show in *Appendix* section at the end of this document.

4.6.3 Tension Monitor Cable

A Tension Monitor Cable (Figure 12) may be provided with one end unterminated. Please install an appropriate connector for the tension meter in your logging system. Refer to the appropriate Wiring Diagram in the Appendix for wiring notes.

Figure 12: Tension Monitor Cable (terminated one end only).

4.6.4 AC Power and USB Cable

AC Power Cable and USB Cable are shown in the picture below.

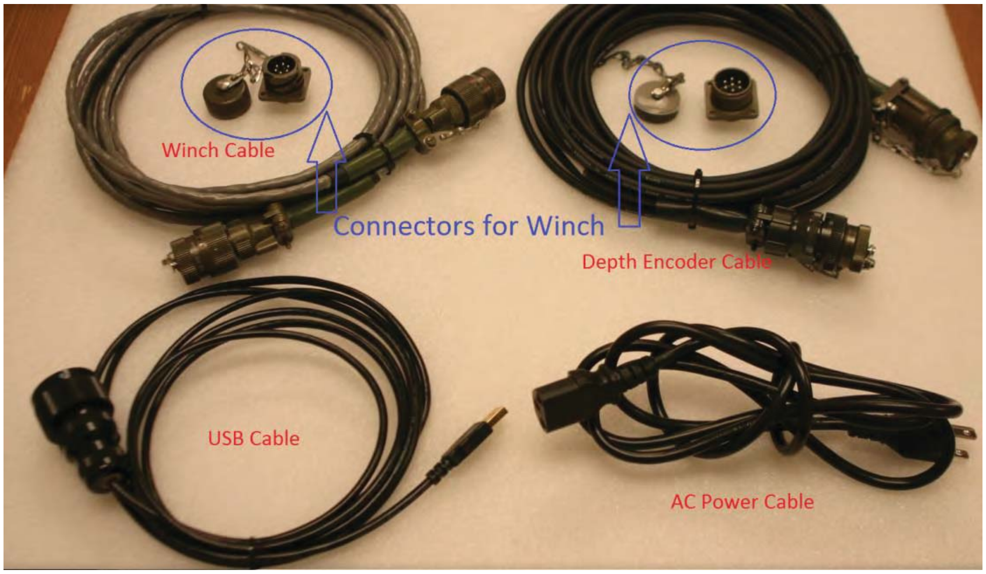


Figure 13: Miscellaneous cables - Winch Connection Cable, Depth Encoder Cable, USB Cable, AC Power Cable.

4.7 Laptop Computer

A laptop computer is required to run the system. The minimum requirements of the laptop computer are:

- Microsoft Windows, 64-bit

A USB drive containing installation software for data acquisition, processing and interpretation is provided.

4.7.1 Laptop accessories (for systems with Downhole Computer)

Additional accessories may be necessary for operating systems with integrated Downhole Computers. These include:

- A WiFi router, for connecting to the Downhole Computer.
- Network connectivity between laptop and router, either via WiFi or RJ45 Ethernet cable.

Spare Cables for Downhole Computer

Three spare cables are provided with the system for diagnostics purpose when working with downhole computer only without using the surface station.

- Monitor cable for downhole computer
- Ethernet Cable
- External Battery Cable (battery not provided)

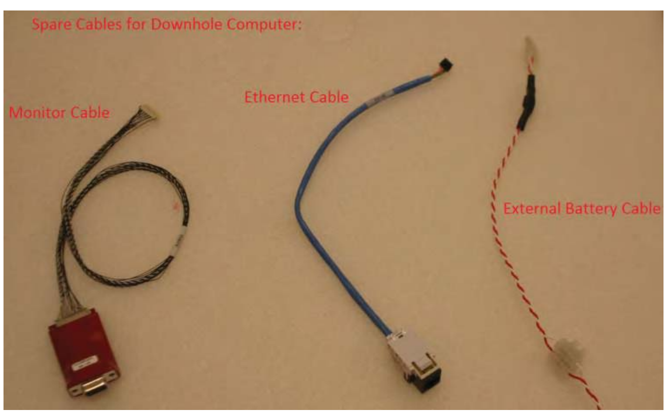


Figure 14: Monitor cable, Ethernet cable, and external battery cable for downhole computer.

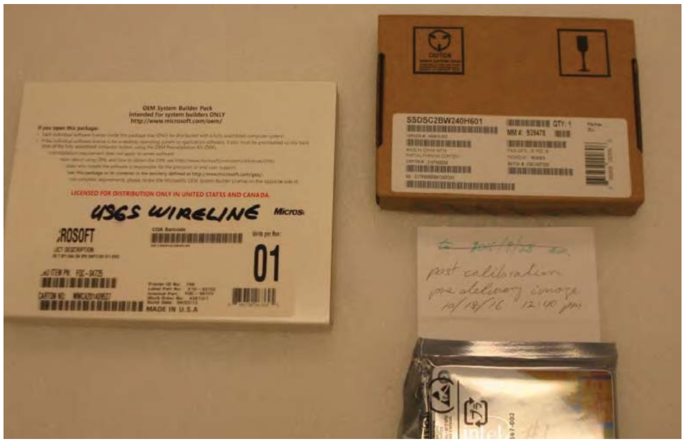


Figure 15: Windows 7 license and spare hard drive image for downhole computer.

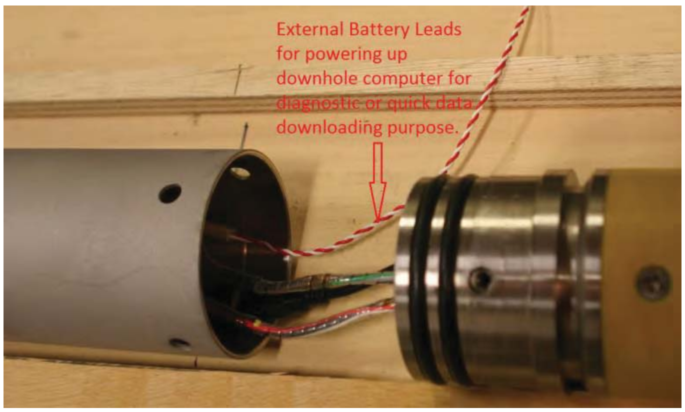


Figure 16: External Battery Leads for powering up downhole computer for diagnostic or quick data downloading purpose. Do not connect during normal logging.

4.8 Software and Software Installation Guide

Javelin software is provided on a USB thumb drive. All software should be installed before attempting to operate the Javelin instrument.

4.8.1 Data Acquisition and Control Software

4.8.1.1 For systems without a Downhole Computer

General Software

- **"Javelin Digital,"** for data acquisition, data logging, and control of the downhole logging system.

4.8.1.2 For systems with a Downhole Computer

- **"Javelin Wireline Acquisition,"** the magnetic resonance logging software installed on the downhole computer. This program is typically installed on the Windows desktop. A shortcut to this program must be included in the global startup list so that it automatically starts whenever the downhole tool is powered on.

- **"Javelin Wireline Remote Terminal,"** the control and monitoring program installed on the surface laptop computer.

A separate serial driver is required to enable communication with the depth encoder and must be installed separately.

4.8.2 Processing Software

- **"Javelin ProPlus,"** for post-processing and hydrological interpretation of raw Javelin logging data.

Javelin ProPlus is provided with a stand-alone User Guide, detailing system requirements and installation instructions.

5 SYSTEM ASSEMBLY

5.1 UNPACKING THE SYSTEM

Magnets in the downhole probes create very strong magnetic fields that are always present, even when power is not connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not properly secured. Sharp ferrous metal objects such as knives, scissors blades should be kept a minimum distance of 2 meters away from the probes at all times. Magnetic fields can cause damage to electronics and devices with magnetic encoding (e.g. hard drives and credit cards); keep all such objects away from probes.

The Javelin system is delivered in wooden or plastic shipping crates to prevent damage during shipment. If shipped in wood crates, the materials used are heat-treated, and have not been treated with hazardous chemicals. The foam is 100% recyclable polyethylene foam. Although the shipping materials can be safely disposed or recycled, it is recommended that the purchaser retain the shipping crates and packaging to be used for future shipment or to protect the system during transport.

The Analog MR Probe sections are shrouded in steel shielding tubes to suppress the magnetic field. Before unpacking the Analog MR Probe, ensure that there are no unsecured magnetic objects or electronics nearby in the unpacking area. To unpack the probes, first remove wooden supports or removable foam lining and lift the steel shielding tubes from the crate. Next, remove the caps from the steel tubes (if present) and carefully slide the probe from the shielding tube.

The Digital Module and Power Modules, if separate units, are typically shipped together in the same plastic shipping case. The Javelin Wireline Surface Station normally ships in a separate shipping crate along with the connection cables.

After unpacking the system, the user should check all system components for signs of damage during shipping. If any dents, scrapes, or rattling noises are observed, the user should not use the system and should immediately contact Vista Clara to discuss repairs.

5.2 Downhole Tool Assembly

5.2.1 Systems with Field Joints

All systems with Field Joints include Spanner Wrenches for tightening and loosening Field Joints (Figure 17).

Figure 17: Adjustable spanner wrenches for tightening and loosening Field Joints. One pin may be slightly smaller to fit smaller tightening divots on Field Joint.

1. Begin assembly by placing the two sections of the tool on a flat, level, clean working surface. Remove the protective caps from the field joints and store them safely.
2. Inspect all threads and O-rings for damage or foreign debris.
3. Align the two halves of the Field Joint (Figure 18).

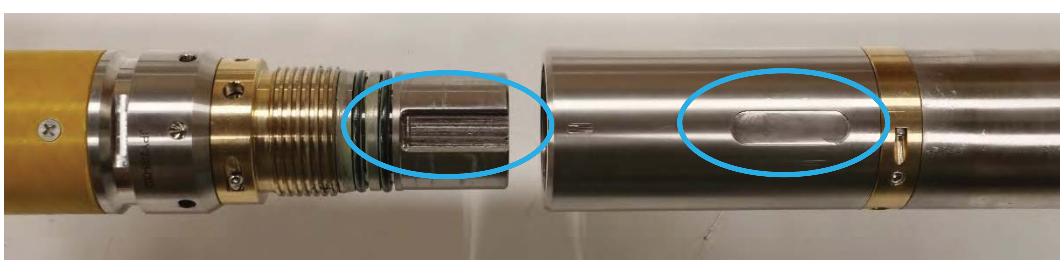


Figure 18: Proper alignment of the Field Joints of the Javelin Slim – the dimpled markings on the two sides of the joint (circled) should be aligned with one another.

4. Gently insert the two halves of the Field Joint until the brass threads on the lower (downhole) joint are flush with the edge of the upper (uphole) joint (Figure 19).

Figure 19: Insert the two sections of the tool together until reaching this point—O-rings are completely inside the field joint, and the brass threads are just touching the uphole side of the Field Joint.

5. Ensure that the set screws in the threaded brass section are loose (see Figure 20), then begin twisting the brass threaded section by hand until the threads begin to engage (Figure 21). **Twist only the brass threaded section – it should spin smoothly and independently from the rest of the tool joint. The upper and lower probe sections should not rotate.**

NOTICE **Never loosen, tighten, or remove the Field Joint housed in the Digital Module.**

Figure 20: Three types of screws and holes on the threaded brass section of the Javelin Slim. (A) Spanner Wrench Divot – use to tighten and loosen the two sides of the Field Joint together. (B) Set Screws (2x) – tighten these to secure brass threaded section and prevent it from rotating. (C) Assembly Screws (2x) – do not remove these except to ***disassemble*** *the brass threaded section (e.g., for cleaning or repair).*

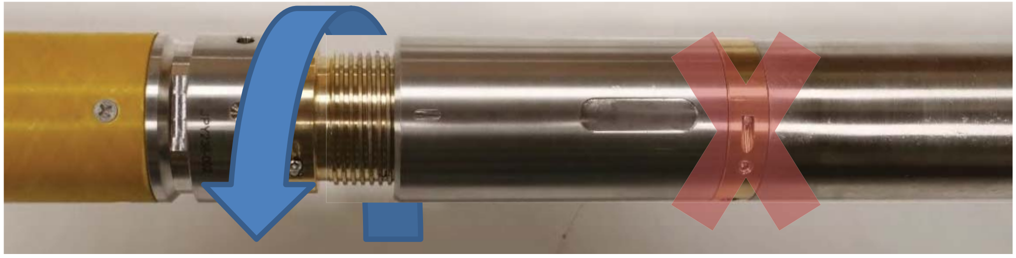


Figure 21: Direction of rotation of the threaded brass section to engage the connection of the Javelin Slim Field Joint. ***Never twist or disconnect the brass ring on the Electronics Section.***

6. When you can tighten the threads no further by hand, use the Spanner Wrenches to tighten the joint (Figure 22). One wrench should engage the brass threaded section of the Field Joint, and the other wrench should engage the *downhole* side of the same side of the Field Joint (i.e., both Spanner Wrenches should be on the probe side of the Field Joint.

NOTICE **Note that the pins on the spanner wrenches may be of two different sizes—be sure to use the smaller pin on the smaller set of holes.**

7. After the Field Joint has been tightened, <u>tighten both set screws</u> (Figure 20) to prevent the Field Joint from loosening during logging.

NOTICE **Always tighten the set screws in the Field Joint prior to logging (and loosen them prior to disassembly of Field Joint).**

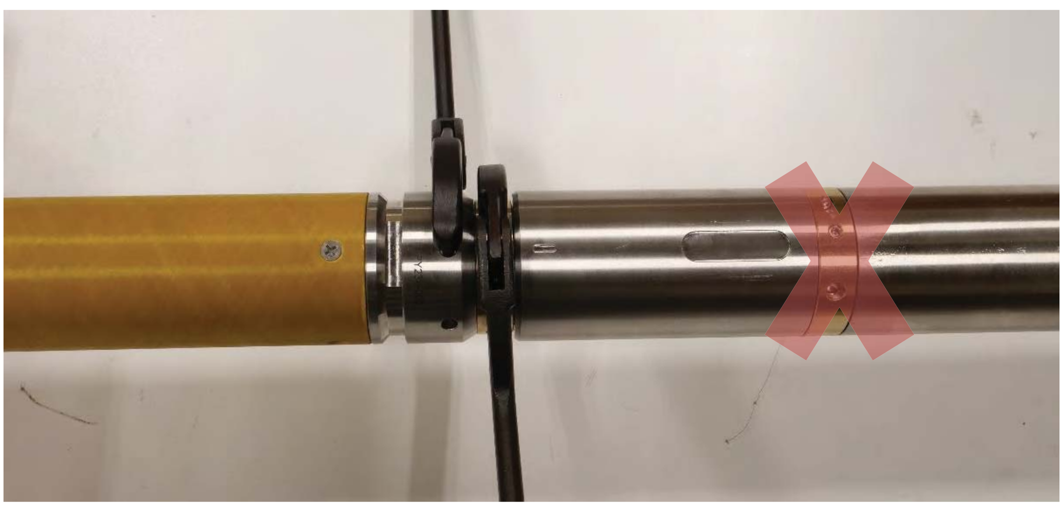


Figure 22: Proper positioning of Spanner Wrenches to tighten the Javelin Slim Field Joint. ***Only twist the lower (downhole) brass threaded section. Never tighten or loosen the upper (uphole) brass ring (red 'X').***

Figure 23: Field Joint connection of Javelin Slim completely made. Always tighten set screws prior to logging (green arrow; second set screw not pictured). ***Never adjust the upper (uphole) brass section.***

5.2.2 Systems with Double Joints

Before assembling the downhole logging tool, ensure O-ring seals on all joints are completely clean, and free of foreign matter and/or moisture. Apply generous layers of new vacuum grease over and between O-rings. Ensure inner lining of tube is completely clean and free of moisture, dirt and scratches.

Line up sections to be connected, taking extra care that all electrical connections are made and enclosed, and push the tool joints together until they are completely mated, and the 4 screw holes are properly aligned. Insert and tighten the four screws to secure the joint connection.

5.2.2.1 Analog MR Probe to the Power Module

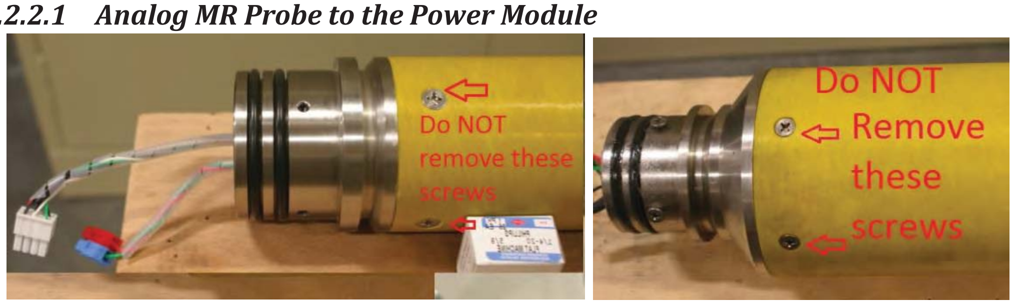


Figure 24: Double Joint on the uphole side of the JPX350F (left) and JPX525F (right). Each of these joints connects to the Power Module.

Figure 25: Connection between Power Module and Analog MR Probes.

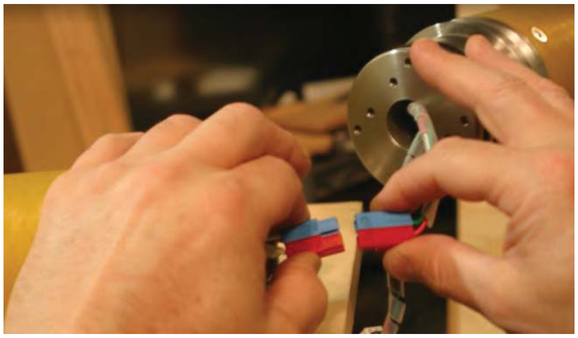


Figure 26: Connecting/disconnecting transmitter coil connectors.

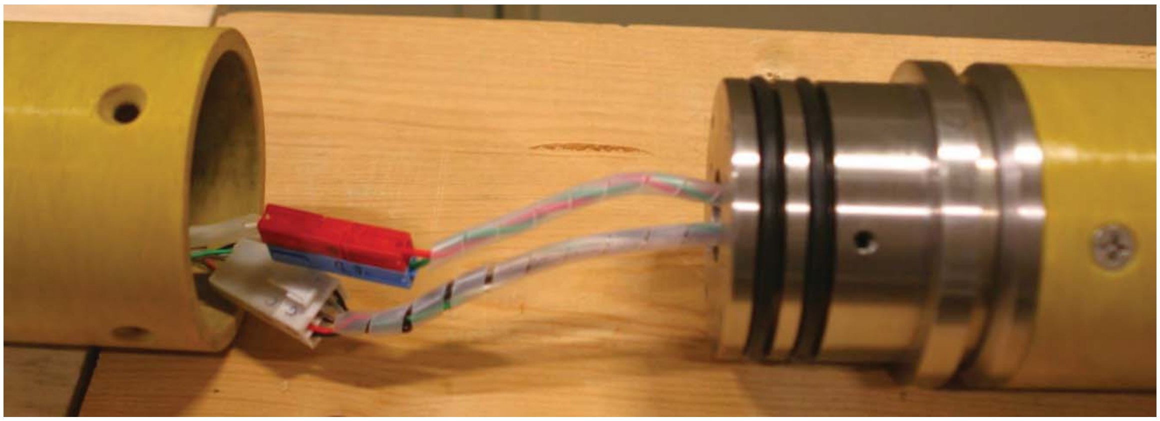


Figure 27: Electrical connections made prior to mechanical connection of Double Joint.

Figure 28: Completely assembled Double Joint. Use Phillips Machine Screws, #1/4-20 x 5/8". For disassembly, do not remove the screws on the "downhole" side of this or any of the Double Joints.

5.2.2.2 Power Module to Digital Module

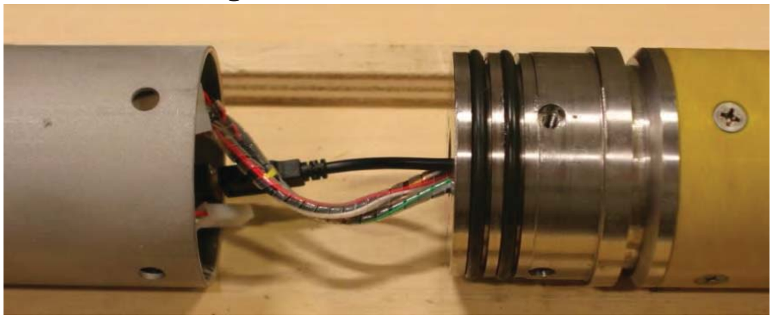


Figure 29: Electrical Connections made between Digital Module and Power Module.

Figure 30: Connection between Digital Module and Power Module (3-section systems with Double Joints).

Figure 31: Completely assembled Double Joint between Digital Module and Power Module. Connect Socket Head Cap Screws (1/4-20 x 1/2") for securing Joint to Digital Module. Never remove the screws on the "downhole" side of the Double Joint.

5.2.2.3 Completely assembled system

Once the modules have been joined, the logging system can be connected to the logging cable (Figure 32).

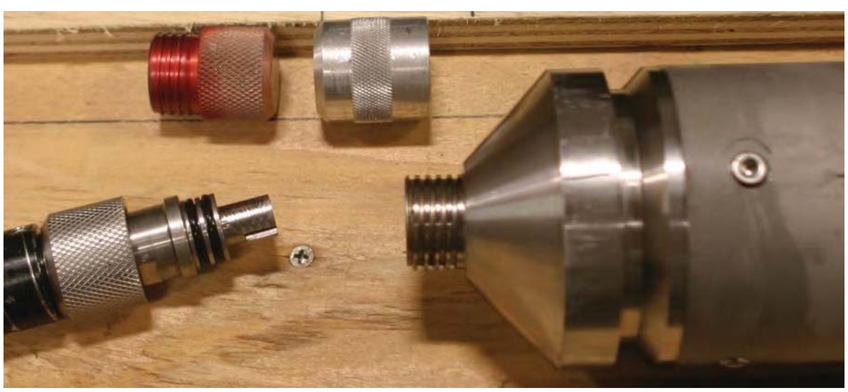


Figure 32: Connector between logging cable and Digital Module.

Figure 33: Assembled three-section Javelin Wireline Tool with JPX350F Analog MR Probe.

Figure 34: Assembled three-section Javelin Wireline Tool with JPX525F Analog MR Probe.

6 Field Operation

6.1 Site Setup

WARNING Do not power on the system until instructed to do. Powering on the system before properly connecting all components may cause permanent damage to the Javelin system.

1. ***Determine Site Layout***

Prior to setting up a logging survey, determine a working layout for the survey equipment. Components and cable should be arranged in a manner that minimizes hazards. Ensure that the logging cable will not be disturbed by persons or vehicles. Place appropriate safety markers in areas where potential hazards are identified.

2. ***Set up the tripod or crane with sheave wheel***

Center the tripod or crane and sheave wheel over the logging hole. Stabilize the tripod or crane so that it will not shift or tilt during logging.

3. ***Assemble and connect all components.***

Assemble the toolstring following the instruction is Section 5.2 “Downhole Tool Assembly.”

Connect all components following the instructions in Section 6.2 “Connection Guide.”

NOTICE Inspect all O-rings during connection. Replace, clean, and lubricate any O-rings if dirty, damaged, or missing. Never attempt to operate probe with missing O-rings.

6.2 Connection Guide

The following instructions describe how to properly and safely connect all the components of the Javelin system.

NOTICE Never attempt to connect or disconnect any cable in the Javelin Wireline system when the system is powered on, or when more than 10V DC is indicated on the analog voltmeter on the front panel of the Surface Station. Permanent damage to the Javelin Wireline System may occur if the system is powered on prior to completing connections or if any connections are adjusted while the system is powered.

NOTICE DO NOT power on the Javelin system until all connections are completed. Powered operation is described in the "Operation" section.

1. ***Connect the Logging Cable to the Downhole Probe***

First ensure that the Surface Station is powered off and the analog voltmeter on the front panel of the Surface Station reads 10V or less.

Next unwind the winch to provide enough slack in the logging cable to enable the cable connector to be easily attached to the connector on the top of the logging tool string.

Check O-rings in Logging head and Protection Cap. O-rings should be present, well lubricated with silicone (non-conductive) grease, and free of any dirt. If the O-ring is dirty or not well lubricated follow the instructions for cleaning and lubricating the O-ring in "System Care." Store the cap in a secure and dust-free location to avoid loss or damage.

Carefully insert the cable connector into the tool connector, using the connector key as visual guide. Ensure the connection keys are aligned before tightening the screw cap. Manually tighten the screw cap. Hand tightening is sufficient. Do not use tools to tighten.

2. ***Connect the Surface Station to the Winch and Depth Encoder***

The surface station has connections to the winch and depth encoder on the back panel. The 6-pin cable connects from the connector labeled "To NMR Logging Tool" on the surface station and connects to a similar 6-pin connector on the logging winch. Two of the conductors carry HVDC (~300V DC) and power return to the logging tool. Two additional conductors carry the telemetry signals, and two more conductors constitute a safety interlock circuit that disables power to the surface station if the panel connector and/or 6-pin cable are completely plugged into the winch connector. The 7-pin connector labeled "To Depth Encoder" connects to the depth encoder output on the winch or sheave wheel, via the 7-pin cable.

3. ***Connect the Surface Station to the laptop computer:***

The laptop connects to the surface station via the single USB connector on the front panel of the surface station. To ensure adequate data transfer performance the length of the USB cable should be 10 feet or less.

4. Connect power cables to the Surface Station and Cable Winch

Connect the AC power cable to the Javelin Wireline Surface Station but do not yet supply power to the cable. Refer to Section 4.5.1 “Voltage Requirements” (page 22) for details on correct voltage.

WARNING An appropriate power source must be used to power the surface station. Use of an incorrect power supply will cause permanent damage to the Javelin system and may result in serious injury to operators or bystanders. Surface station power requirements may vary by model.

NOTICE The surface station and winch may have different voltage requirements. Always confirm requirements before applying power.

5. Prepare all generator connections

If using a generator, adjust the generator power to the appropriate settings for the surface station. If AC line voltage is too low, do NOT use bucking transformer for the Surface Station.

Ground the generator according to local requirements.

Plug the power cables for surface station and winch into the generator power outputs but do not yet power the generator. Note that the winch may require a different voltage from the surface station.

6.3 System Check

After system has been fully assembled and connected, and while the probe is still at the surface, before placing the logging probe in the well, a system check should be performed.

1. ***Double-check all connections***

Confirm that all connections have been made properly, that no connections are loose, and that all cables are arranged such that they do not present a tripping hazard.

2. ***Power on generator***

This supplies power to the Surface Station, the Cable Winch, and the laptop.

3. ***Test Data Acquisition***

Refer to Section 7.1 "Program Setup and Pre-Logging Check" (page 47) to complete setup of the Data Acquisition software and verify that the logging system and software are functioning properly.

NOTICE **Always confirm that the system is operational before placing the logging system in the well and lowering the probe to depth. This includes (a) the software on the uphole computer, (b) the downhole logging system, and (c) telemetry between the two.**

6.4 Starting a Logging Run

Once the system has been established to be working properly (see Section 6.3), the tool can be placed in the well and lowered to the desired starting logging depth to begin logging. The system power should remain on after system setup, and should remain on until the logging is complete and the tool has been retrieved to the surface.

1. ***Position the logging tool string in the well***

Using a C-plate

If you are using a crane that is not tall enough to place the probe in the well directly, you must use a C-plate.

Attach and secure the landing plate (or C-plate) to the slot located on the stainless tool joint (Figure 35).

Be sure you have a correctly sized landing plate for the tool diameter. Some landing plates can be configured for use on multiple tool diameters (Figure 36 & Figure 37).

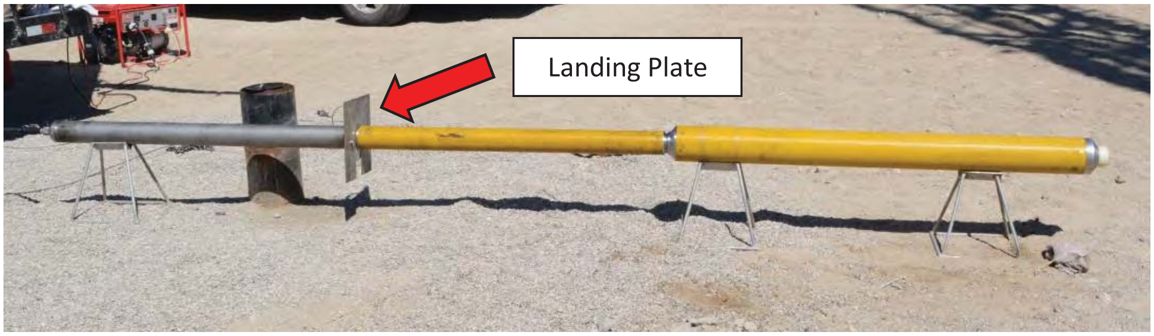


Figure 35: Landing plate (or C-plate) in position on a 3-section system.

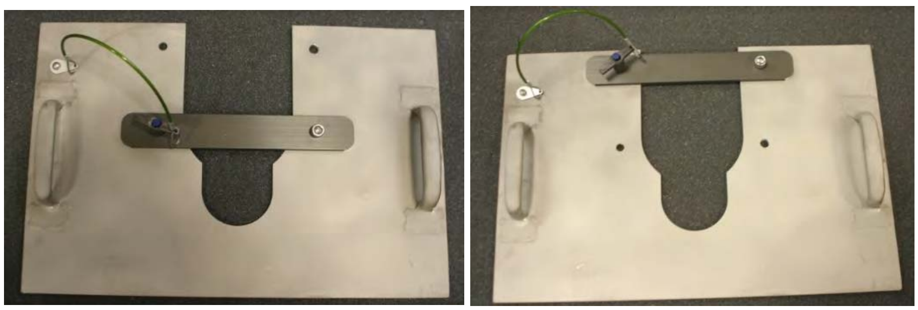


Figure 36: Re-configurable C-plate/landing plate for Javelin Max system, shown configured for Analog MR Probes JPX350 (left) and JPX525 (right).

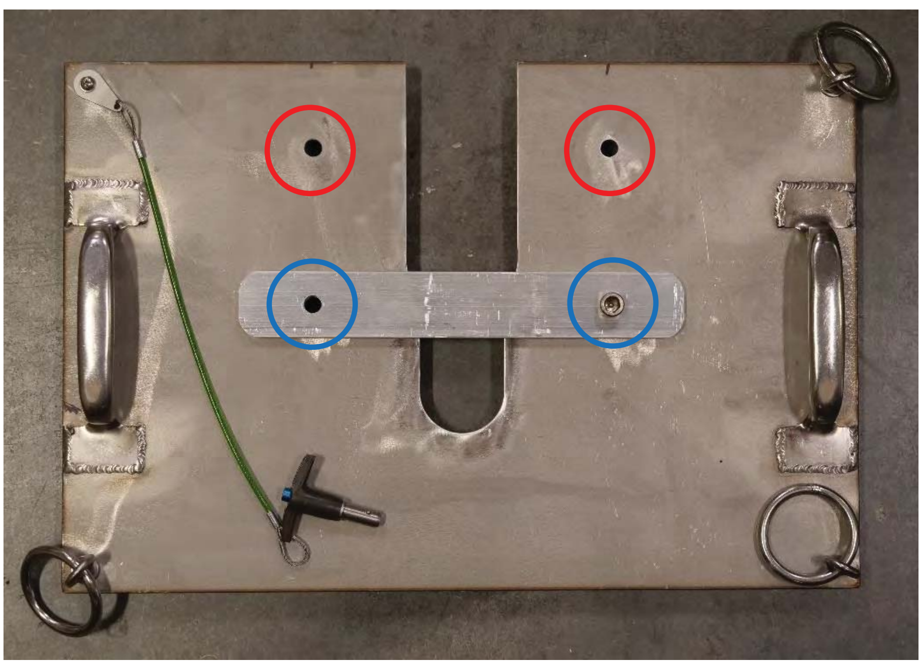


Figure 37: Re-configurable C-plate/landing plate for Javelin Slim system, with holes for Analog MR Probes JPY238 (blue circles, as configured) and JPY350 (red circles).

Next, secure the landing plate to an appropriately rated crane using a suitable chain or cable. Use the crane to lift the tool string to a vertical position, raise it off the ground, position it above the well head, and carefully lower the tool into the well until the landing plate is resting securely on the wellhead (or ground surface if the wellhead is below ground surface). Ensure full tool weight supported by the landing plate. Disconnect the supporting chain from the landing plate and the crane. Install the sheave wheel on the crane and thread the wireline logging head through the sheave wheel. Center the sheave wheel over the over the logging hole. Ensure the logging cable is securely connected to the Downhole Tool (refer to "Connection Guide" on page 38). Transition the weight of the tool string to the logging cable. Use the Cable Winch to slightly lift the tool string and unweight the C-plate, then remove the C-plate. See Figure 38.

Figure 38: Lowering the tool string into a well using a landing plate/C-plate and crane (left). Transitioning the weight of the tool string to the logging cable (right).

Without a C-plate

If you have a sufficiently tall crane, you can place the probe in the well directly, without use of a C-plate.

⚠WARNING Always use appropriate personnel protective equipment when standing or working in the vicinity of any crane, the logging tool string, or other potentially hazardous machinery or equipment.

⚠WARNING Magnets in the downhole probes create very STRONG MAGNETIC FIELDS. Use extreme caution when handling and transporting the probes.

2. Remove the landing plate and zero the depth counter

Use the cable winch to raise the probe slightly and lift the landing plate off the well head, then remove the landing plate. Be careful to ensure that the logging head and strain relief stay below the sheave wheel.

Use the winch controls to slowly and carefully lower the probe until the bottom of the cable head is even with the top of the well casing. Hold the probe steady at this point, while setting the depth counter on the front panel of the Javelin Surface Station to 0.00 meters[1].

NOTICE **Note: Do not press the "RST" button on the Depth Counter during logging, or the current depth will be lost.**

If the winch controller has an independent depth counter, also zero this depth counter at this time.

Using this depth referencing convention, all depths reported on the depth counter during logging will be the depth from the top of the casing to the tip of the logging cable. The vertical offset between the tip of the logging cable and the center of the measurement coil of the probe will be automatically added during processing, so that depths in the final log represent the depth of the Magnetic Resonance measurement below the top of the casing.

3. Lower the logging tool to the desired starting depth

Use the winch controls and refer to the depth counter to lower the loggin tool to the desired starting depth for the logging run.

4. Start Data Acquisition

Refer to Section 7.2 "Logging" (page 59) for complete instructions on using the Data Acquisition software to collect a Magnetic Resonance log.

---

[1] The Depth Counter can usually be set to 0.00 by pressing the "RST" button. If this sets the Depth Counter to a value other than 0.00, or if you want to set the depth counter to a different value, refer to Appendix Section **Error! Reference source not found.**.

6.5 Stopping a Logging Run

The following instructions describe how to properly and safely shut down and disconnect all components of the Javelin system.

EMERGENCY SHUTOFF PROCEDURE

If any electrical hazard arises, or in case of any emergency, shut off power to the Javelin Wireline Surface Station by removing power to the system (such as by turning off the generator) or by turning off the main power switch (if the Surface Station is powered on).

WARNING Never touch, connect, nor disconnect any cable when the system is powered on. Always power the system off before touching any connections. Disconnecting or reconnecting the downhole probe while the Surface Station is powered will cause permanent damage to the Javelin system.

1. Halt Data Acquisition

Refer to Section 7.2 “Logging” (page 59) for instructions on halting data acquisition in the logging software.

2. Turn off the Surface Station

Turn off the surface station by toggling the main power switch. Wait until the bright yellow warning LED dims and turns off before disconnecting any cables.

3. Power down and store the Field Computer

While waiting for the Surface Station to bleed its remaining power, you can power down the Field computer and store it in a safe place.

4. Remove and Disconnect the Downhole Probe

WARNING **Magnets in the downhole Analog MR probes create very STRONG MAGNETIC FIELDS. Use extreme caution when handling and transporting the probes.**

a) Ensure that the field computer is powered down and stored at a safe distance before removing the Downhole Probe from the logging hole. Strong magnets on the downhole probe could damage the field computer if a safe distance is not maintained.

b) Remove the Downhole Probe from the logging hole and place probe on the ground or on appropriate tool stands. If necessary, use a landing plate and reverse the process of placing the probe in the well.

c) Disconnet the Downhole Cable from the Probe logging head by unscrewing the screw cap connection at the base of the cable.

d) Replace dust caps on logging and cable heads.

e) Store the Analog MR probes in the steel isolation tubes and cases for safe transport.

f) Reel in remaining slack in the logging cable, removing the logging cable from the sheave wheel.

NOTICE Check that all O-rings are in place following disconnection. Two O-ring should be located on the Cable Logging Head.

5. Power down the generator

Turn off the generator and disconnect all power cables.

6. Disconnect remaining cables and pack components

Disconnect all remaining cables and store them in the cable case. Replace caps on all connection ports.

7 DATA ACQUISITION

7.1 PROGRAM SETUP AND PRE-LOGGING CHECK

7.1.1 Systems without Downhole Computer

1. ***Open the control software***

Open the data acquisition program "Javelin Digital" on the field laptop.

2. ***Select Calibration folder***

Immediately upon opening the software, you will be prompted to select a calibration folder. Navigate to and select the correct calibration folder[2]. (Note that the files in this folder will be hidden.)

NOTICE Be sure to select the correct calibration folder for your current system. Using incorrect or out-of-date calibration files can result in **inaccurate results** or **system damage**.

3. ***Establish Telemetry with Downhole Logging System***

In some systems, you may need to manually enter COM port numbers for the Data Acquisition and Depth Counter interfaces. In some systems, this may be done automatically.

When the COM interface has not been established, or is configured incorrectly, the software will display "NO COM" (Figure 39).

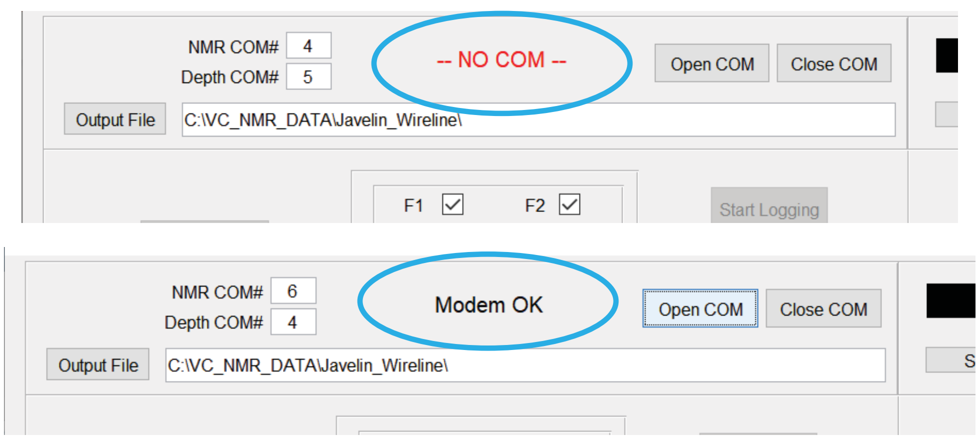


Figure 39: Data Acquisition software with telemetry not established, or misconfigured (top). Data Acquisition software with telemetry established (bottom).

[2] For more information on Calibration Files, refer to Section 12.4 in the Appendix (page 69).

If you are required to determine and enter COM port numbers manually, click "Open COM" to establish connection with these ports. When telemetry has been established, the software will display "Modem OK" (**Error! Reference source not found.**).

4. Set acquisition sequence

Confirm the acquisition sequence timing (Tr, number of echoes, number of averages, and frequency selection). Modify any of these parameters if required[3].

You must send these acquisition parameters to the downhole system by clicking the "Program Tool" button. The software will indicate that these parameters are being sent, and that they have been received (Figure 40).

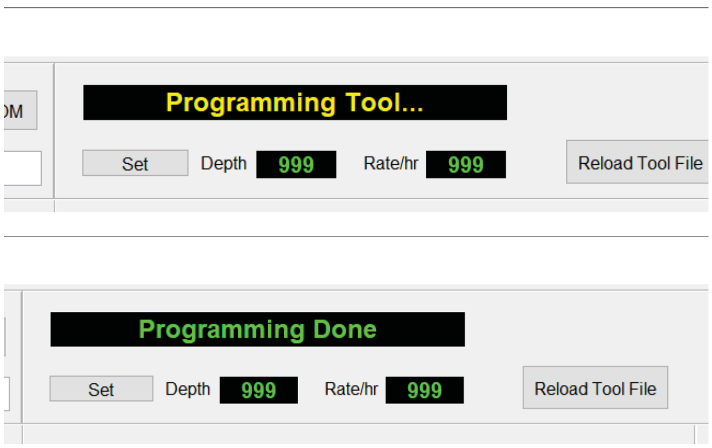


Figure 40: Sending acquisition sequence parameters to the downhole logging system (top). Acquisition sequence parameters successfully received by the downhole logging system (bottom).

5. Perform Ping Test (Optional)

Note: A Ping Test is not required prior to logging. However, it is strongly recommended, as it helps ensure that the system is functioning properly before placing it in the borehole.

Click the "Ping Test" button to perform a simple system diagnostic. Ensure that no metal is in the vicinity of the measurement zone of the probe, which encompasses the lower third of the Analog Probe Section (e.g., metal tool stands).

Confirm that the system is returning a successful ping (e.g., Figure 41) before putting the logging probe in the borehole or attempting to start a log.

[3] These values are loaded into the software from the 'seq' calibration file. You may edit this 'seq' file to establish different default sequence parameters. Any changes to the 'seq' file will take effect when you next open the software.

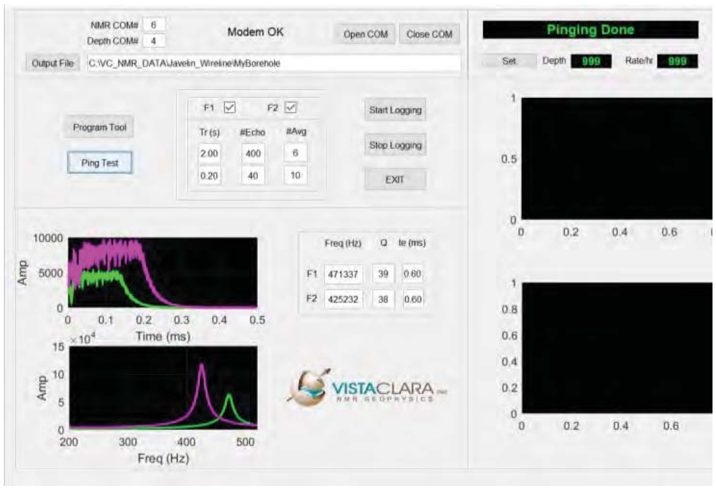


Figure 41: Results of a successful Ping Test.

6. Set Depth Counter (Optional)

You can use the Data Acquisition software to set a value on the Depth Counter. Click the "Set" button and enter a desired value, in meters (Figure 42).

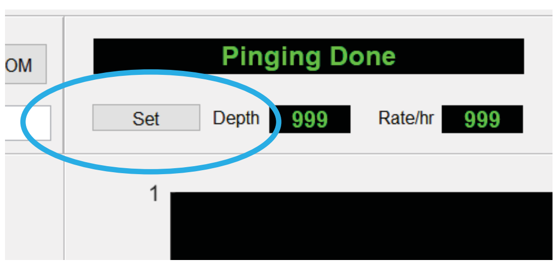


Figure 42: Use the "Set" button to push an arbitrary value to the Depth Counter.

7.1.2 Systems with Downhole Computer

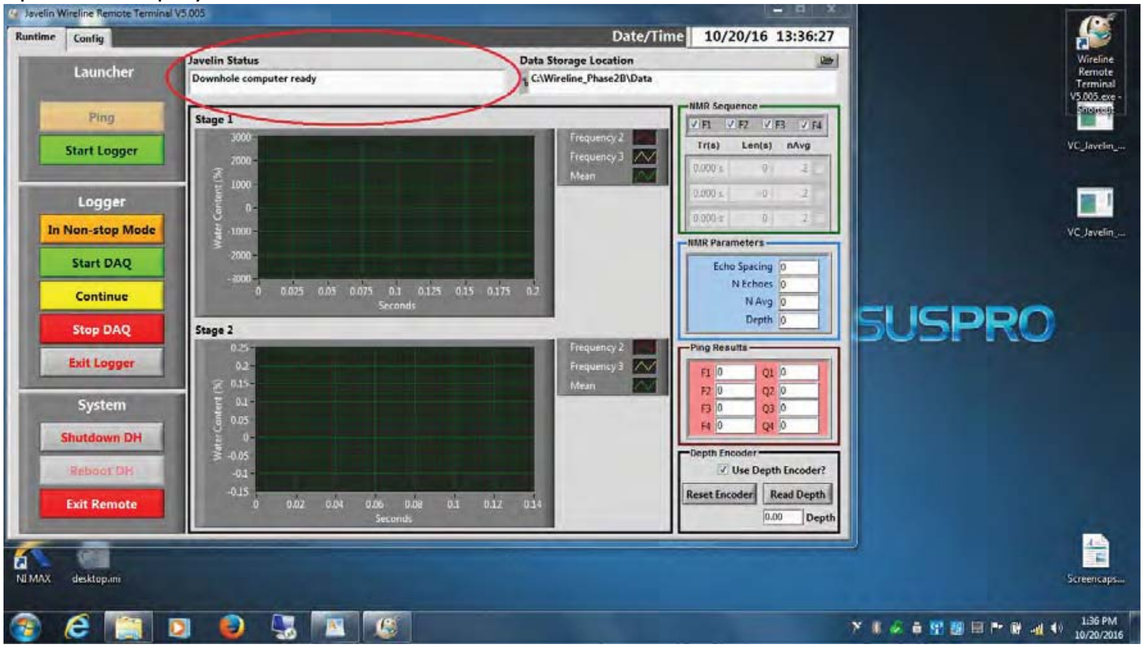
1. Set up uphole computer and wireless data hub

Position the wireless ethernet router in a location where it will enable good communications to both the surface laptop and the downhole computer inside the logging tool. Turn on the wireless hub before powering up either the surface laptop or the downhole probe. The wireless newtork router should have a minimum data transfer speed up to 450Mbps.

2. Start Wireline Remote NMR Monitor software

- Plug in all cables for surface station (WJSS), Wireless Ethernet Router, and downhole tool. Plug in AC cable but with AC power switch OFF on WJSS. Please note that the depth counter on WJSS will always be ON once AC cable is plugged in).
- Open "Wireline Remote Terminal" software, the graphical user interface should

open and display as shown below.



3. Power on the Surface Station

Make sure the Javelin Wireline Surface Station is connected to a 110V 60Hz AC power supply, and all other connections between the laptop computer, surface station, winch and depth encoder have been properly made and secured.

Turn on the on/off switch on the front panel of the surface station. The red lamp on the rocker switch should illuminate immediately, and the analog DC voltmeter on the front panel should rise to an intermediate level between 150V and 300V, and the analog DC current monitor should also increase from zero amps to a level between 0.25 amps and 1.5 amps. The DC current will vary during the startup period for up to 1 minute as various components in the downhole tool turn on and reach their steady state operating power consumption modes.

After the initial startup period (wait for about 1 to 2 minutes), the analog DC voltage monitor should indicate the DC voltage rising and leveling off at a steady state voltage of about 300VDC, the Amp meter will go up to about 1A and gradually drop back to 150mA.

Look for “Downhole Computer Ready” message in “Javelin Status” message box in Wireline Remote Terminal. This confirms that the downhole computer has successfully booted, and telemetry has been established between uphole and downhole computers.

If the DC voltage exceeds 340V, internal circuitry will turn off the system power to the surface station and the OVP/OTP light will turn on. This indicates that the input voltage is too high (more than 123.5VAC, outside the operating range for the Javelin surface station). If this is the case, the AC power supply voltage must be adjusted to bring it within the acceptable operating range for the Javelin Surface Station. Some generators exhibit significant variability in their AC output voltage, and some generators have throttle settings that can be adjusted to lower the output voltage.

Similarly, if the AC input voltage from the AC power suppply is too low, the DC voltage output of the Javelin Surface Station will be less than 290V. In this case the system may not provide sufficient power to the downhole tool to sustain the pre-programmed and calibrated pulse sequences.

In general, the Javelin system should not be used for logging when the DC supply output is less than 290V or greater than 340V. It is strongly suggested that users find and test adequate generators or other power supplies prior to mobilizing to well logging sites, to ensure that their AC generator will provide AC power within the acceptable range of the Javelin system.

NOTICE

Note: In case of generator shutting down by accident or running out of gas, downhole the computer will most likely crash, since there is no backup battery in downhole tool.

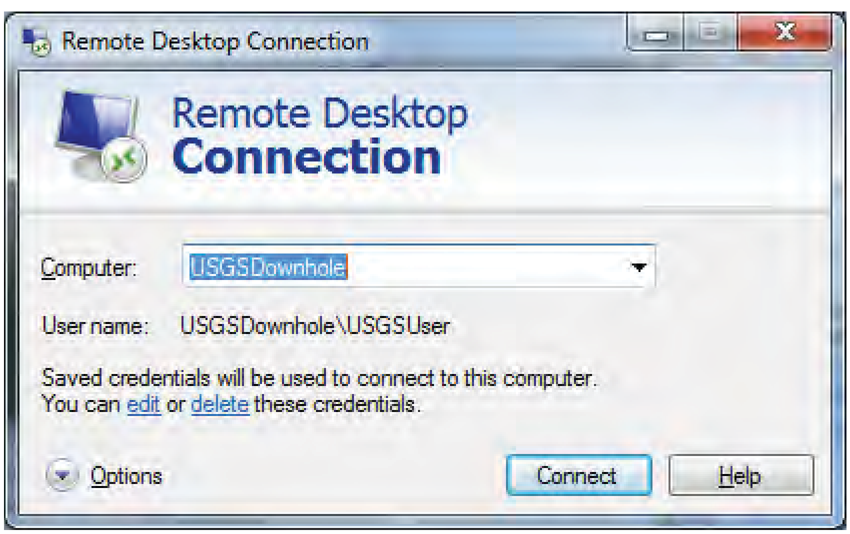
WARNING

Ensure there is gas in generator at all times. Damage to system can result if the generator runs out of gas while the system is operating.

The Surface Station will warn of an over temperature state if the internal electronic temperature exceeds 60°C. If the Surface Station is over temperature, move the Surface Station into a cooler area and allow the system to cool for at least 10 minutes after the OTP/OVP light delluminates.

4. ***Open wireless connection and establish virtual terminal to downhole computer***

- Open the Windows Program "Remote Desktop Connection." Click on "Connect" button, wait for up to 1 minute until certificate warning window comes up, and click on "Yes" button.



- Wait for “VC NMR Combo Launcher” comes up on remote desktop window for downhole computer.

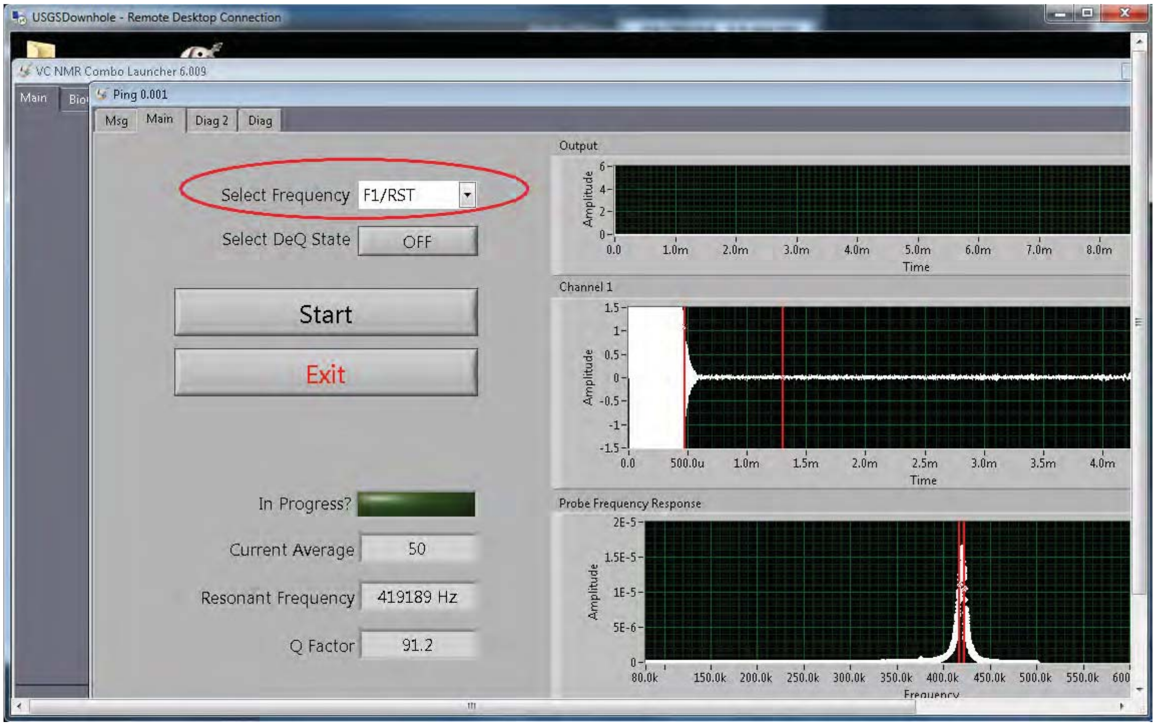
5. Run the Ping program to estiablish that the downhole tool is working properly.

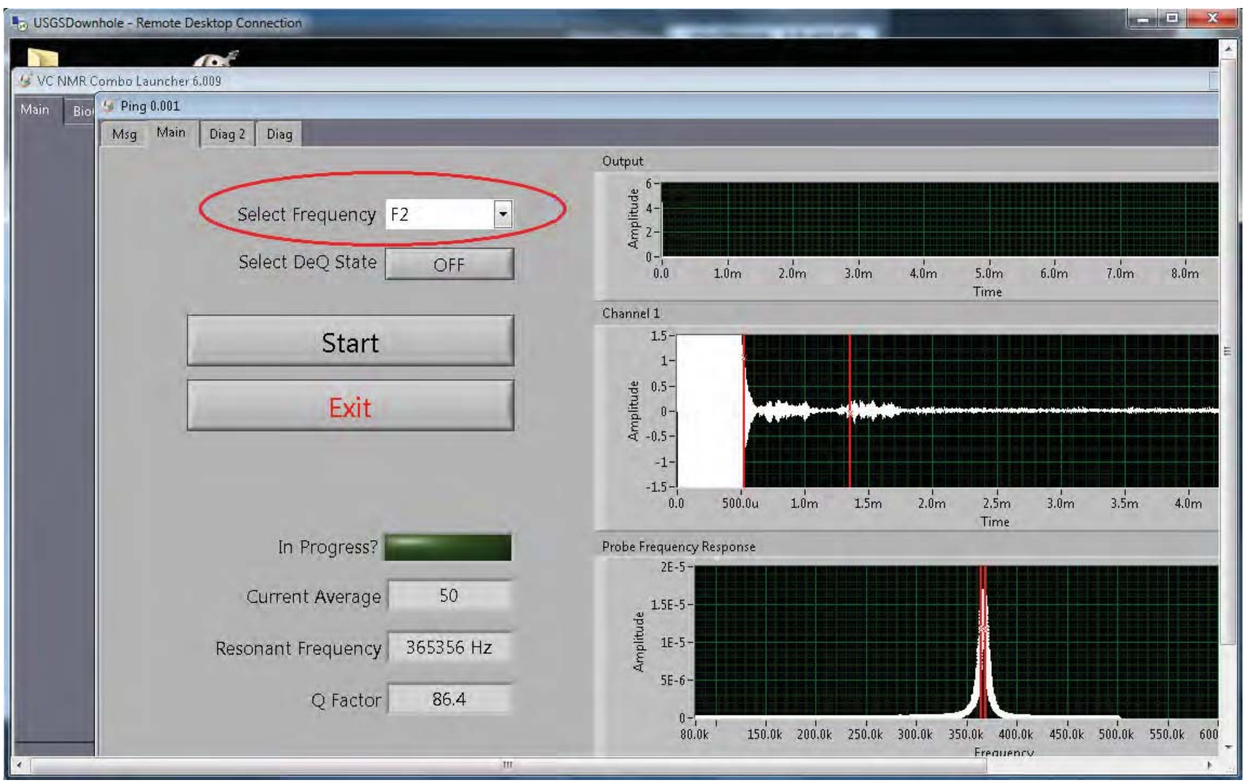
Following are steps to following to make sure the downhole tool is functioning normally.

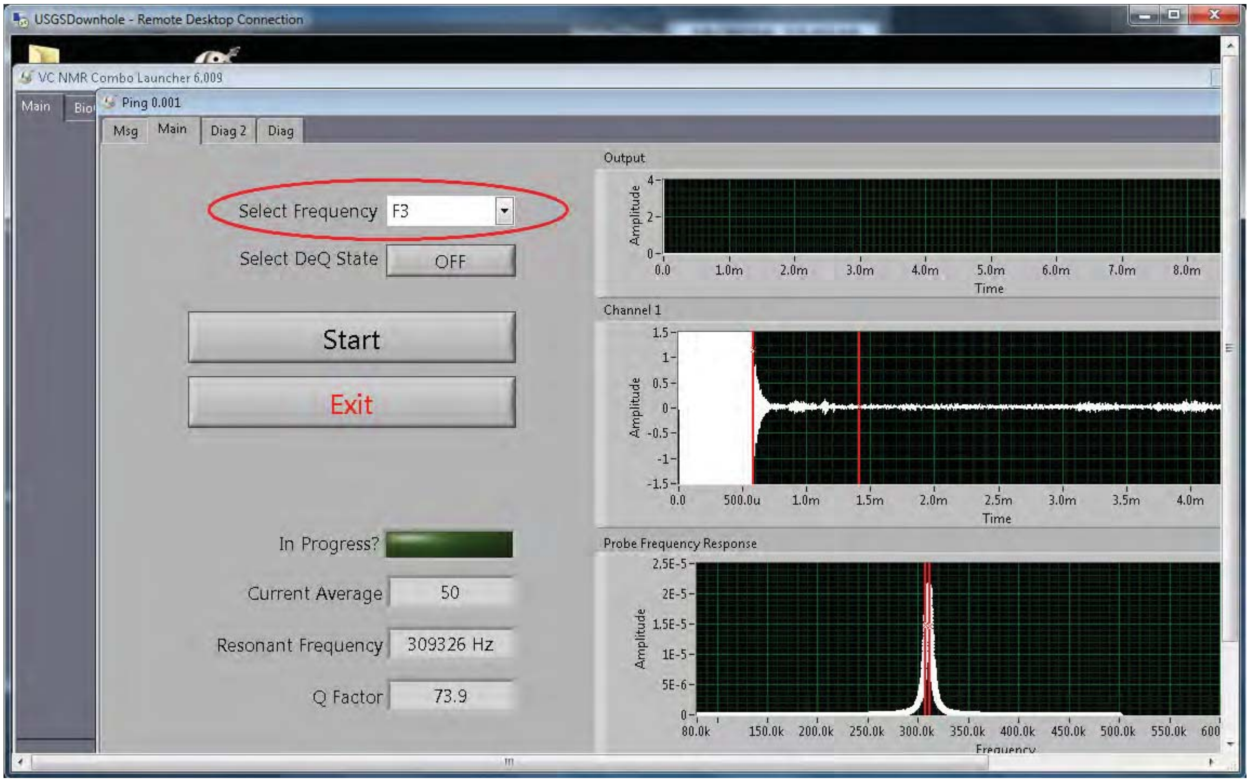
NOTICE

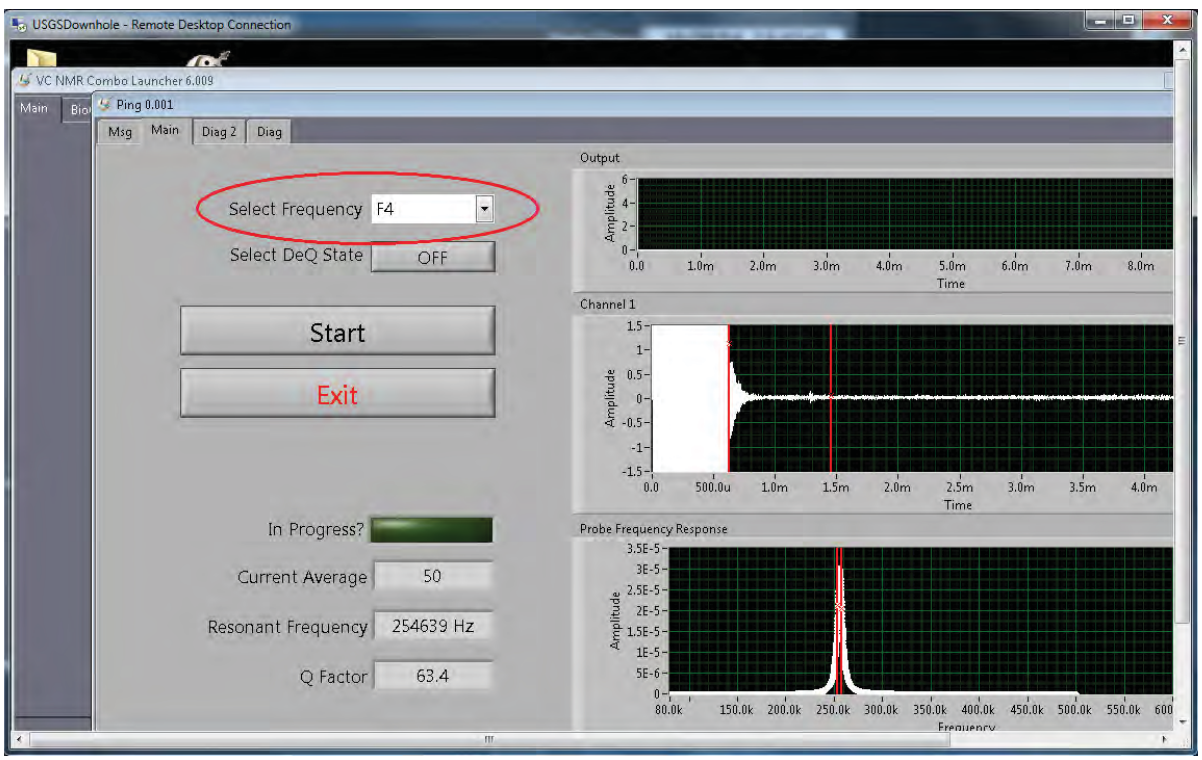
NOTE: Do NOT close the logger program after this step.

- Click “Ping” button. In Ping window shown below, select frequency and click “Start” button. Repeat for all four frequencies.


USGSDownhole - Remote Desktop Connection
VC NMR Combo Launcher 6.009
Main
Ping 0.001
Msg
Main
Diag 2
Diag
Select Frequency
F1/RST
Select DeQ State
OFF
Start
Exit
In Progress?
Current Average
50
Resonant Frequency
419189 Hz
Q Factor
91.2
Output
Amplitude
Time
Channel 1
Probe Frequency Response
Frequency


USGSDownhole - Remote Desktop Connection
VC NMR Combo Launcher 6.009
Main
Ping 0.001
Msg
Main
Diag 2
Diag
Select Frequency
F2
Select DeQ State
OFF
Start
Exit
In Progress?
Current Average
50
Resonant Frequency
365356 Hz
Q Factor
86.4
Output
Amplitude
Time
Channel 1
Probe Frequency Response
Frequency

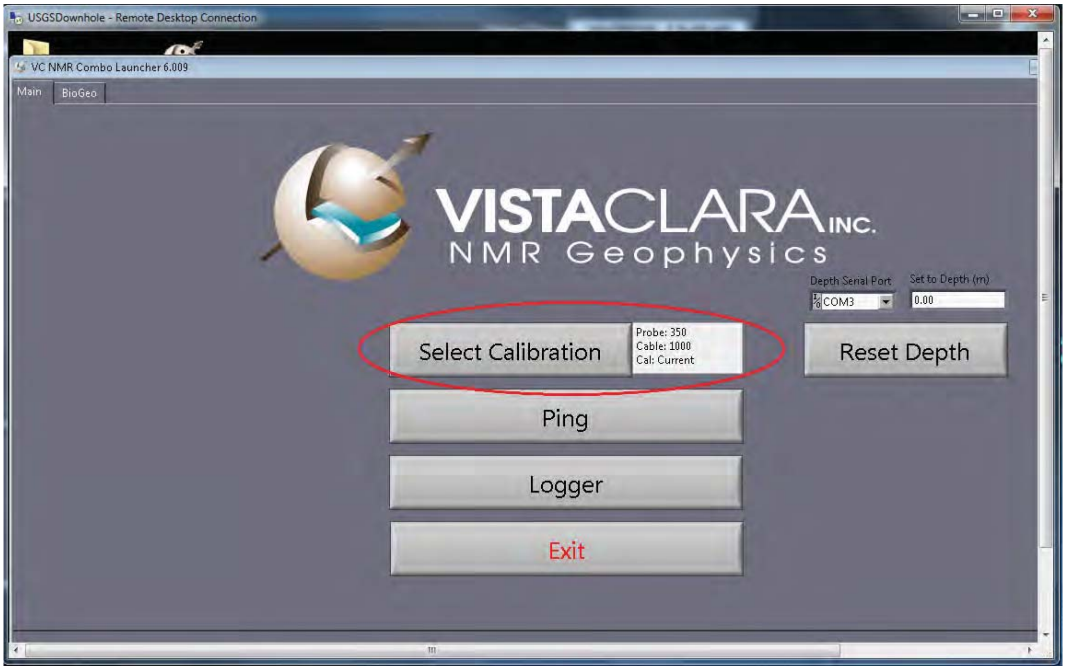




- If all works fine, click on "Exit" button to go back to VC NMR Combo Launcher.

(Note: noise on the above ping signals are due to the fact that the downhole tool was setup outside of the shield room in an office laboratory.)

- Click on “Select Calibration” button to select the appropriate calibration file from remote desktop window for downhole computer.



- Click on the “Logger” button to bring up “VC NMR Combo Logger” window. Un-check “Use Sequencing File?” checkbox to reveal data acquisition parameters in all sequences and made sure the correct calibration file is loaded. **Click “Use Sequencing File?” checkbox again to go back to use sequencing file before launch data acquisition.** Click “Exit” button to go back to VC NMR Combo Launcher.


USGSDownhole - Remote Desktop Connection
VC NMR Combo Launcher 6.009
VC NMR Combo Logger 6.0.2
C:\VC_NMR_Data\Wireline\161020_134623
Start Index
Time Estimate
1.0 minutes per level
Depth Count
Calibration Info
Probe: 350
Cable: 1000
Cal: Current
Well Height (m)
Start Depth (m)
Stop Depth (m)
Increment (m)
Number of Averages
4
Use Sequencing File?
Depth Serial Port
COM5
Use Depth Counter?
Start
Continue
Stop DAQ
Exit
Ping Response
Timing Detail
Advanced
Power Info
Status
Graphs
Operations
Debug
NMR
Average
REF
Amplitude
Time


USGSDownhole - Remote Desktop Connection
VC NMR Combo Launcher 6.009
VC NMR Combo Logger 6.0.2
C:\VC_NMR_Data\Wireline\161020_134623
F1 F2 F3 F4
Tr (s) Len (s) nAvg
9.000 s 200m 4
1.000 s 20m 24
0.150 s 15m 80
Use Sequencing File?
Start
Continue
Stop DAQ
Exit
NMR
Average
REF
Amplitude
Time

NOTICE **<u>Note:</u>** Do NOT close the above logger program.

6. Exit the Remote Desktop session

Prior to logging, exit from the remote desktop session on the uphole computer and (optionally) exit from the WiFi network interface.

7.2 LOGGING

7.2.1 Systems without Downhole Computer

The following instructions assume that (a) the Data Acquisition software has been opened, (b) telemetry has been established with the logging system, (c) acquisition sequence parameters have been sent to the downhole logging probe, and (d) a Ping Test has been performed. **If this is not the case**, refer to Section 7.1 "Program Setup and Pre-Logging Check" on page 47 and complete those instructions before proceeding further in this section.

1. ***Set file name***

Create an Output File name for this log (typically site or well name).

2. ***Perform a Ping Test (Optional)***

Vista Clara recommends performing an additional ping test immediately before commencing data collection.

3. ***Start Data Acquisition***

Click the "Start Logging" button to start data acquisition.

At this time, begin running the winch at an appropriate speed[4,5].

During normal data acquisition, the Status in the Data Acquisition software will cycle between:

- **Pinging**
- **Acquiring Data**
- **Retrieving Data**
- **Data Retrieved**

---

[4] Typically, a speed projected to generate one full sequence of MR measurements over a distance corresponding to the height of the measurement coil of the probe. See Appendix Section 12.2.2 for more information.

[5] The software will periodically report the approximate observed logging speed, but you should confirm that the logging speed is optimal by processing the data in the "Javelin ProPlus" processing software and observing the Window Size, found in the QC panel. The Window Size should correspond to the height of the measurement coil of the probe; e.g., if the measurement coil is 25cm, you should have a Window Size of 25cm (when data is being processed *without* vertical averaging).

These statuses indicate normal operation of the tool. See Figure 43.

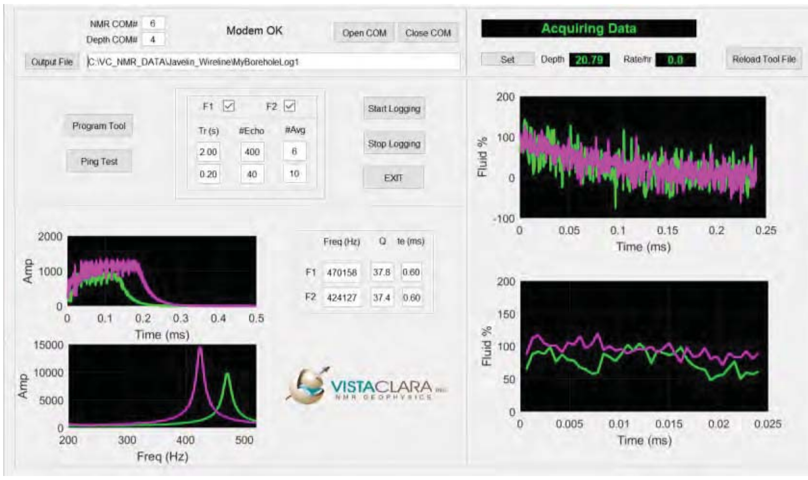


Figure 43: Normal operation of the Data Acquisition software during logging. The upper right plot shows a spin echo decay for the long-Tr measurement; the lower right plot shows a spin echo decay for the short-Tr measurement. The colors correspond to the two different frequencies (measurement shells).

4. Stop Data Acquisition

In case of emergency, turn off power to the Surface Station immediately, without regard to the state of the software or data acquisition.

To halt data collection, click the "Stop Logging" button. The button will display "Finishing…" (Figure 44); during this time, the program will continue its current measurement sequence (which could take up to several minutes), and then data collection will halt. In this scenario, the data record that was in progress when "Stop Logging" was clicked **will** be completed and written.

If you wish to stop data collection *immediately*, click the "Abort" button, and data collection will cease immediately. The data record that was in progress when "Abort" was clicked will **not** be completed or written.

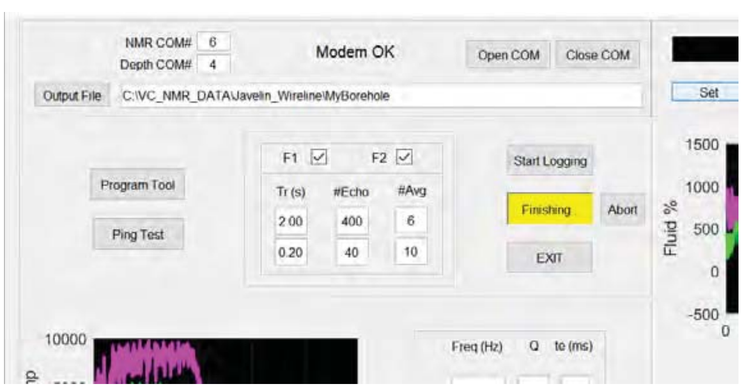


Figure 44: Stopping data collection.

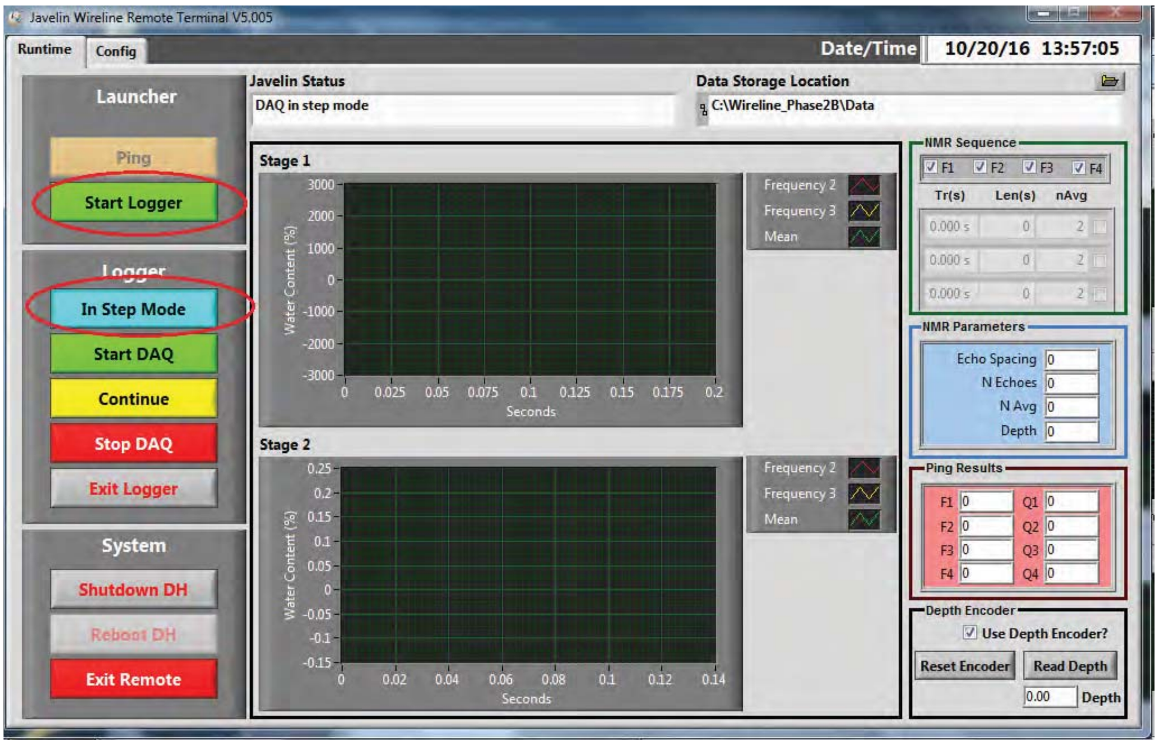
To conclude logging operations, refer to Section 6.5 "Stopping a Logging Run" (page 45).

7.2.2 Systems <u>with</u> Downhole Computer

1. Starting and monitoring the logging run

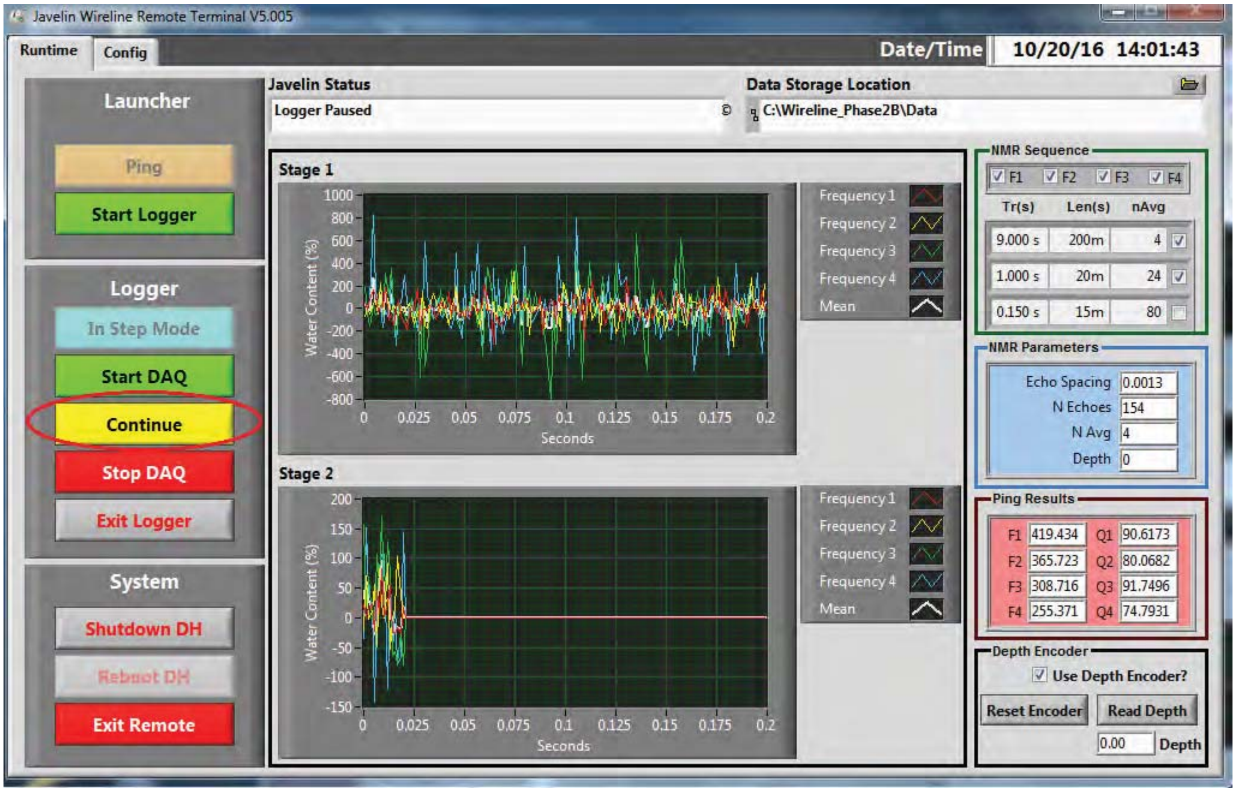
On the remote terminal software GUI, press the "Start Logger Button". The message box should report a text message from the downhole computer as "Logger Started", as shown below.

- Go to "Remote Terminal" window on laptop computer. Click "Start Logger" button and wait for "VC NMR Combo Logger" showing up in remote desktop for downhole computer. Click on "Select Logger Mode to "Step Mode" or "In Non-stop Mode".



- Click "Start DAQ" button. During data acquisition the Volt meter on WJSS front panel may drop down to 220VDC and the Amp meter will fluctuate between 150mA and 1.5A.

- If it is set to "In Step Mode" for stepped logging, Javelin Status message box will displace "Logger Paused" after current scan is finished. Click "Continue" button to start next scan.



For continuous logging, press the “Continuous/Stepped Mode” button one or more times, until you see a message confirming that the downhole software is in “continuous mode”

Next start the winch and adjust the winch speed to match the desired logging rate for the programmed NMR acquisition sequence.

Next Press the “Start DAQ” Button on the Remote Terminal GUI. This will start the magnetic resonance data acquisition. The message box should report a text message from the downhole computer indicating that the downhole logging program has successfully retrieved the current probe depth from the depth counter at the surface, and is starting the first magnetic resonance measurement.

Each complete magnetic resonance measurement takes a certain fixed period of time, typically between 30s and 90s, and is determined by the data acquisition sequence that is programmed or selected by the user. During this time, magnetic resonance measurements are being performed at between 1 and 4 different frequencies, and at either one or two different wait times with differing numbers of signal averages. The downhole probe is moving at a nominally constant speed during the measurement, so it is best practice to set and maintain a logging speed such that the time required for one complete measurement (scan) is approximately the same time that it takes the tool to move one half meter (one half meter is the approximatel vertical resolution of the magnetic resonance sensor.

Following each scan, the downhole acquisition program will transmit a reduced version of the acquired data to the surface computer via the modem-based wireline telemetry. This data will be displayed on the GUI of the front panel as shown below. The downhole program will then automatically acquire the current depth reading and start a new magnetic resonance scan. This process will continue until the user presses the stop button. Thus during normal magnetic resonance logging, the user should not press any buttons on the GUI or take any other action other than to monitor and adjust the logging speed of the winch.

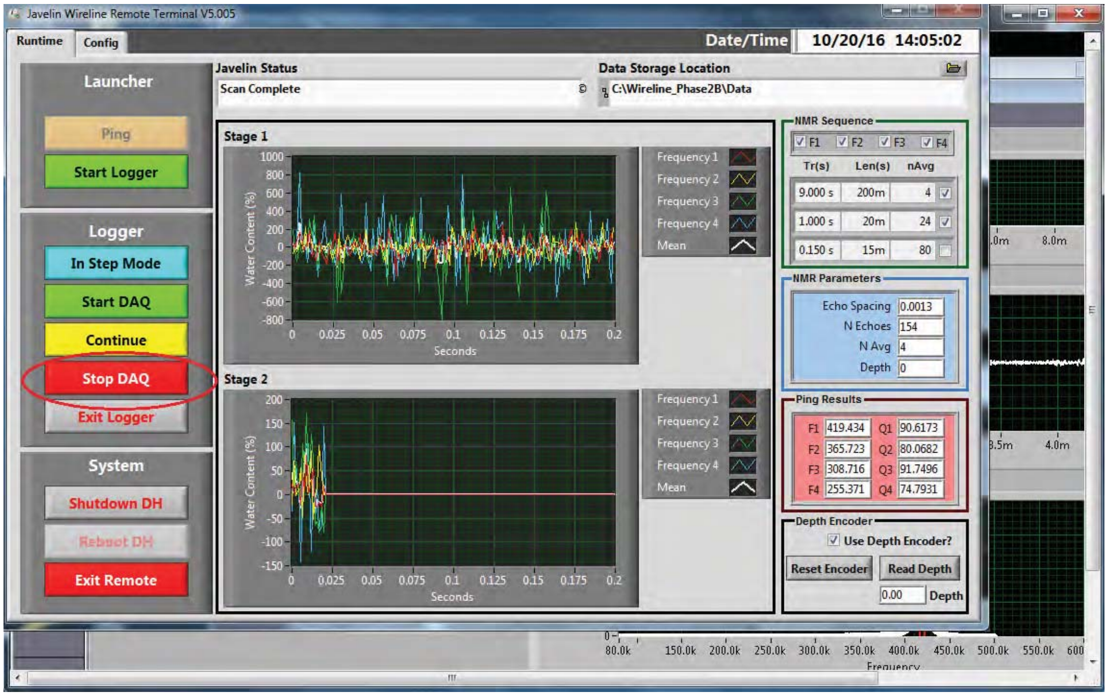
The filenames are automatically generated using the date/time stamp at the start of the logging measurement as the base filename. Individual data files are generated and saved for each for each frequency shell acquired, for each wait time, and for each depth interval. So for example, a log that was started on September 12, 2016 at 8:06:14 am, would have the base filename “160912_080614_”. If the user selected sequence file specified to perform measurements in frequency shells 2 and 3, and with two different wait times of 1.0s and 5.0s, the following set of 4 data files would be generated and saved for the first depth level:

```
160912_080614_freq2_Tr1000_1.lvm
160912_080614_freq3_Tr1000_1.lvm
160912_080614_freq2_Tr5000_1.lvm
160912_080614_freq3_Tr5000_1.lvm
```

Successive data files would be saved for each additional depth level using the same base filenames but with the final number in the filename indicating the depth increment i.e. 1…2…3, etc…

2. Stopping the logging run

- Click the “Stop DAQ” button to abort the data acquisition and wait until “Scan Complete” shows up in Javelin Status message box.



3. Starting another logging run

To start a new logging run, simply set the winch to the desired starting depth and logging speed, and press the "Start DAQ" button and follow the procedures outlined above. A new set of files will be generated and stored on the downhole computer using the same naming convention ans specifically identified via the date/time prefix at the start of the filenames.

4. Transferring data from the tool to the surface computer

The normal method for transferring data from the downhole computer to the surfac e laptop is to use the wireless network and the Windows 'Remote Desktop' application.

This aplication allows simple copy and paste functions so that data files stored on the downhole computer can be copied to the surface station laptop for processing and archiving.

For a good wireless connection have the surface station laptop, the wireless hub and the tool all within about 30' of each other.

Establish a remote desktop connection as described in Section **Error! Reference source not found.** "**Error! Reference source not found.**."

5. Open wireless connection and establish virtual terminal to downhole computer

The downhole computer in the logging tool stores data in the folder:

“C:/VC_NMR_Data/Wireline/data”

Folder names and file names are in the format ‘date_time’. These names are generated at the start of each acquisition from the time on the downhole computer bios clock. Note that without a regular connection to the internet the downhole computer clock may drift over time and should be checked and adjusted through the downhole computer control panel before acquisition if high accuracy is required.

To transfer data select the desired folders from the downhole computer and select ‘copy’. Then on the chosen folder on the surface station laptop computer select ‘paste’

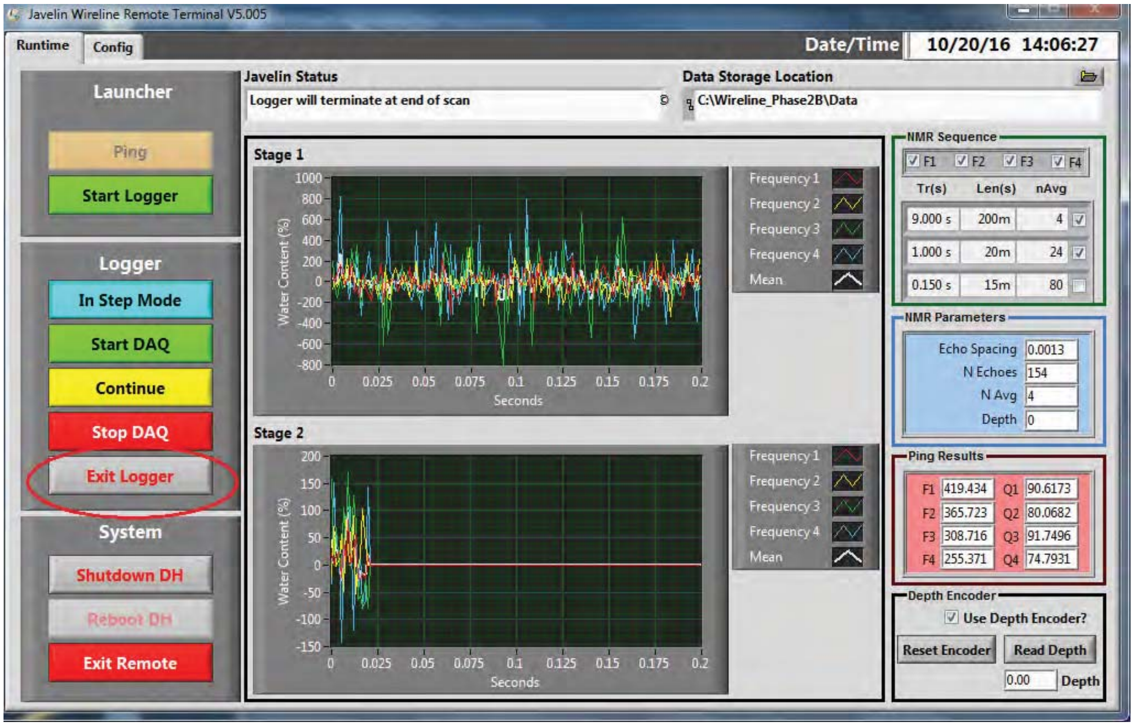
6. *Shutting off power to the tool*

NOTICE

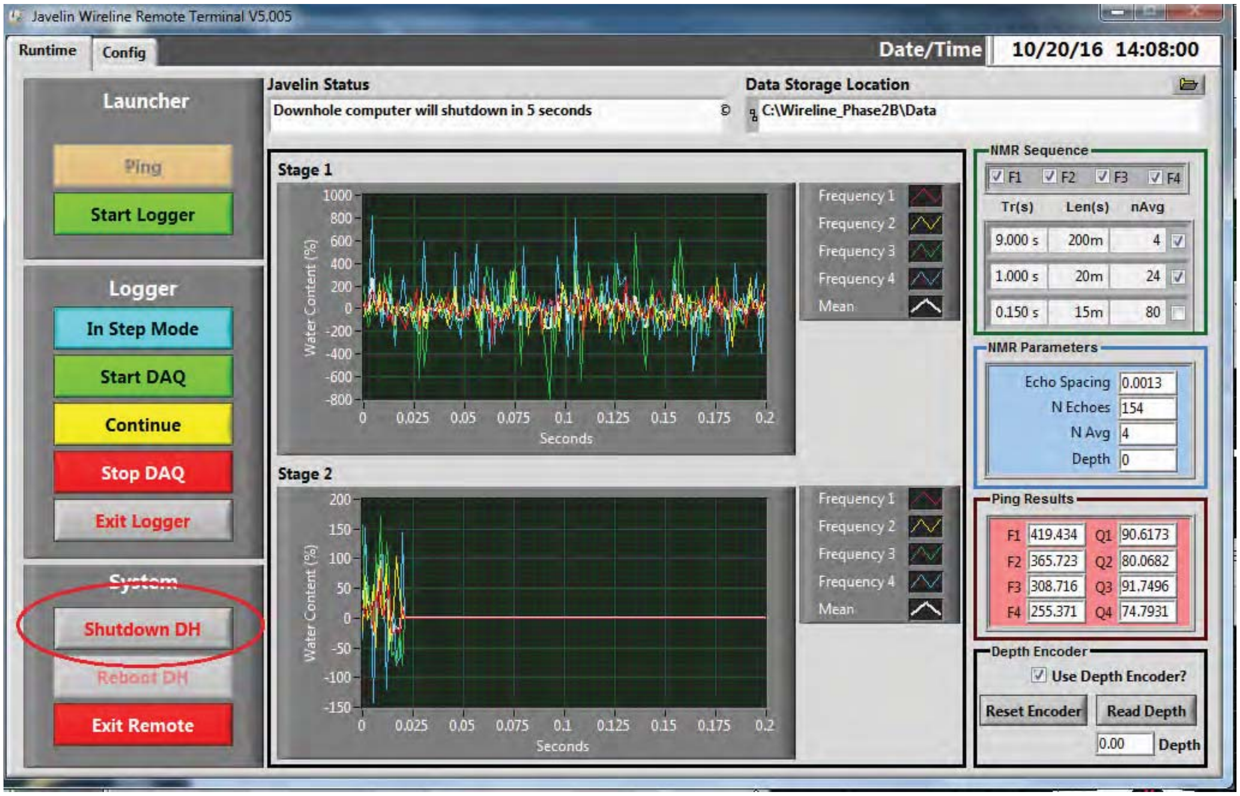
Note: It is very important to shut down the downhole computer using the Remote Monitoring Software before shutting off power to the downhole tool. If the power to the downhole tool is shut off before the computer is allowed to shut down normally, the embedded computer’s operating system and/or hard drive may become corrupted. In the event of a corrupted computer operating system or hard drive, the Digital Module may need to be returned to the manufacturer for repair, and all magnetic resonance logging data stored on the downhole drive may be irretrevably lost.

To use the remote monitoring software to power down the downhole computer, follow the steps below:

- Click the “Exit Logger” button, and “Logger will terminate at end of scan” will show up in Javelin Status message box. Wait until logger terminates.



- Click the “Shutdown DH” button and wait for about 20 seconds until the remote desktop window for the downhole computer is closed. Watch the Amp meter on WJSS’s front panel. The current reading will drop from 130mA to 100mA when downhole computer is turned off. After that, the Amp meter reading will go up and down quickly at about 1minute intervals due to bleeding of energy storage capacitors inside the downhole tool.



7. Alternate shutdown method

If for some reason the modem link is unresponsive but the ‘remote desktop’ connection is available the downhole comuter can be shut down remotely by going to the ‘start menu’ on the downhole computer and selecting the ‘security’ tab. Then, on the far lower right of the downhole computer desktop there will be a shut down option. Use this option to shut down the downhole computer. Then, after a 15 second delay turn off the surface station power and allow the DC supply to discharge.

⚠WARNING

NEVER reboot the downhole computer using this method if the tool is powered from the surface station. If high voltage is present before the downhole computer boots takes control of the logging tool, amplifier failure will occur.

- Turn off the AC power switch on WJSS front panel, wait until the Analog Volt and Amp meters read zero and the bright yellow LED distinguishes before disconnecting any cables.

⚠CAUTION

Caution: Never “Reboot” or “Restart” the downhole computer using the Operating System on the downhole computer. Only use the “Shut down” function in the uphole software to turn off the downhole computer. Using the “Restart” or “Reboot” options in Windows can cause the transmitter to inadvertently turn on during the “Restart” sequence, and damage the RF amplifier.

NOTICE

Note: In the event that power to the surface station is interrupted by accident during a logging run, or otherwise while the downhole computer is turned on, the computer may still be shut down manually by using the “shut down downhole computer” button on the remote terminal software. In this event the operator must act immediately to shut down the computer before it loses power.

8 DATA PROCESSING

Data processing and interpretation is done using the “Javelin ProPlus” software program. Refer to a separate User Manual for details on the operation of this program.

9 MAINTENANCE

WARNING

The Javelin Wireline instrument generates and stores very large amounts of electrical energy. Attempting to service the Javelin internal electronics can cause severe electrical shocks, burns, or even death.

Any of the following actions by the user are **expressly forbidden** and will render all warranties void, unless the user has received prior written authorization from Vista Clara.

-Removal of any Javelin Wireline Surface Station instrument panel.

-Servicing any internal components of the Javelin Wireline Surface Station

-Opening the Downhole Probe houssing

-Servicing or accessing components inside the Downhole Probe

-Servicing or modifying the Custom Downhole Cable

-Servicing or modifying any primary connection cables

JAVELIN HARDWARE CONTAINS TAMPER EVIDENT SYSTEMS THAT WILL INDICATE ANY OCCURANCE OF UNAPPROVED INTERNAL ACCESS.

Under ordinary circumstances, the customer should not expect to receive authorization for any of the above acions.

Under extraordinary circumstances, Vista Clara will consider such requests subject to the ability of the customer to provide competent electronic technicians trained in the servicing of high voltage power electronics geophysical equipment.

UNAUTHORIZED SERVICING OR ACCESSING OF COMPONENTS INTERNAL TO THE PRIMARY SYSTEM COMPONENTS OR PRIMARY CONNECTION CABLES IMMEDIATELY VOIDS THE MANUFACTURER'S WARANTY AND RENDERS THE SYSTEM UNSAFE FOR USE.

9.1 SYSTEM CARE

It is important to provide regular care, maintenance, and inspection of all cases, external surfaces, and connections on the Javelin equipment to enhance the operational lifetime of the system and limit the need for repairs.

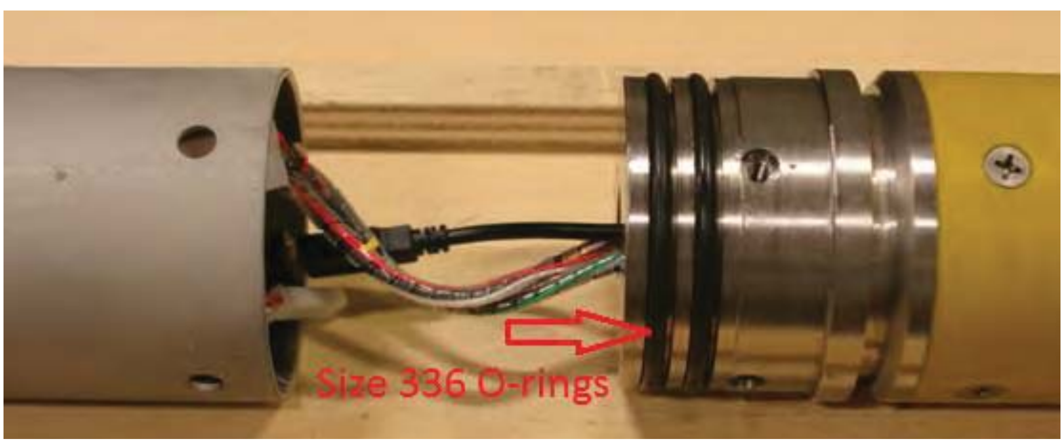
9.2 O-RINGS

The connection between the Downhole Probe sections and logging head should always remain clean and well lubricated.

Whenever connecting and disconnecting a Downhole Probe, check to ensure that the O-rings are clean and well lubricated. If the conncetions become dirty, clean them with a soft cloth which may be dampened with isopropyl alcohol. Periodically apply non-conductive vacuum grease (DOW CORNING high vacuum grease) to the surfaces of the downhole cable connection. In particular, ensure that the O-ring is clean and lubricated.

O-rings for Logging head (Century Part Number 765-2115):

Size 336 O-rings for 3.5” Digital Module (for Stainless Steel Housing only):



Size 334 O-rings for 3.5” Power Module and NMR Sensors:

9.3 Grease the cablehead

Every time the tool is pulled out of a borehole, fill the grease chamber with fresh grease through grease fittings on the logging head.

For details, please refer to a separate document "Cablehead Assembly" by Century Geophysical Corp.

9.4 Storage

After using the instrument, all surfaces and connections on the primary units should be wiped clean of any dirt and moisture, and inspected for damage. Never attempt to clean the system using sprayed water. External surfaces of the instrument (not any of the connection ports) can be cleaned with a damp cloth. If necessary, a mild general purpose detergent without any ammonia may be used (not on any of the connection ports). Flamable residues from any source must never be left on any part of the system to avoid potential fire hazards.

The Javelin Wireline system should be kept in a clean, dry area when not in use. The Javelin Wireline system should never be left deployed in the field overnight or unattended. The system should be stored upright and all connections should be dried and then capped. During storage or transport of the system, the individual units should never be tilted beyond 45 degrees from the normal vertical upright position.

Connection Cables should be regularly inspected for any cuts or abrasion to the insulation and/or protective jacket. **If damage is present: the cables are not safe to use.** Contact Vista Clara for instructions on repair or replacement of damaged cables or cable connectors.

Cable connectors must be kept clear of debris, soil, sand, oils, conductive fluids and corrosive agents. If exposed to water, be sure that all connectors are completely dry before replacing caps. Fluid should not be used to clean any the connection ports, however, it is acceptable to use pressurized air to blow out any moisture or particulate matter from the connections. It is recommended that the user apply a non-conductive, non-reactive silicone lubricant to the exterior threads or bayonet-style slides of the connection ports to reduce connection friction and wear. Do not use a spray applicator as this may discharge lubricant onto the electrical contacts.

If cuts or significant abrasions to the insulation are observed at any time, the connector cable is unsafe to use. Do not attempt to repair the wire by splicing or by attaching electrical tape. Immediately contact Vista Clara, Inc. to discuss repair or replacement options.

If any component of the Javelin system ceases to function properly, immediately discontinue use and contact Vista Clara, Inc. for further instructions.

9.5 System Servicing

WARNING

WITH THE EXCEPTION OF THE O-RING CONNECTION ON THE DOWNHOLE CABLE AND THE AIR FILTER, THE JAVELIN CONTAINS NO USER-SERVICEABLE PARTS. UNAUTHORIZED SERVICING OR ACCESSING OF COMPONENTS INTERNAL SURFACE STATION OR DOWNHOLE PROBES WILL RENDER THE MANUFACTURER'S WARANTY IMMEDIATELY AND ENTIRELY VOID, AND THE SYSTEM UNSAFE FOR USE. JAVELIN HARDWARE CONTAINS TAMPER EVIDENT SYSTEMS THAT WILL INDICATE UNAPPROVED ACCESSING OF INTERNAL COMPONENTS.

Contact Vista Clara for all servicing requirements.

10TROUBLESHOOTING GUIDE

This section describes basic troubleshooting procedures if the user encounters common problems with the system:

Problem: Javelin Wireline NMR Logger program appears non-responsive.

Reason #1: The computer is not communicating with the Data Acquisiton Unit inside WJSS because the Javelin Surface Station is not powered on.

Reason #2: Wireline Javein Surface Station is not connectored to downhole logging tool. Check continuety of the logging cable using the wiring diagram shown in the *Appendix* section. In case any problems identified, re-assembly Cablehead following instructions in a separate document “Cablehead Assmly” by Century Geophysical Corp.

Reason #3: The Javelin Wireline Downhole Tool is not powered upproperly. Contact Vista Clara engineers for support.

Problem: No NMR signal is detected

Reason #1: No groundwater is present in the investigated zone. Some formations (granite) have very little groundwater. Also very little water is likely to be present above the water table.

Reason #2: Extremely short decay times prevent signal detetion. Water in very fine grained materials (such as certain clays) will exhibit very short decay times (sometimes less than 0.5 ms). As a rule of thumb, the Javelin system will only decect water having T_2 decay times greater than ½ the echo time.

11 SAFETY

11.1 SAFETY INFORMATION

The Javelin Wireline system is designed for the sole purpose of conducting magnetic resonance logging investigations. The system is only approved for use as specifically outlined in this Manual. Unsanctioned or improper use of the system can result in physical damage to the instrument, personal injury, or even death. It is the responsibility of the owner to ensure that any person using the instrument is qualified and capable of safely operating the system.

In order to ensure safe operation of the system, a qualified operator should have read the complete contents of the Manual and Documentation, and also must have been provided extensive on-site training by an experienced user (Vista Clara recommends a minimum of 3 days). The owner of the system should develop a formal training course to properly train additional operators of the Javelin instrument. The system should never be operated by minors or any person under the influence of drugs or alcohol.

The Javelin system should be operated only by geoscientists or engineers who have previous experience operating geophysical instruments in the field.

11.2 SAFETY CHECKLIST

The following safety checklist should be reviewed by all users and field assistants prior to handling or operating the Javelin system:

- Always be aware of the strong magnetic fields surrounding the downhole probes.
- Do not allow magnetic objects (such as steel) near the probes.
- Do no allow persons with implanted medical device, such as defibrillators or pacemakers within 5 meters of any instrument components.
- Always secure probes inside steel shielding tubes and secure other steel objects during transport.
- Do not connect or disconnect the High Voltage NMR Winch Cable, Downhole Cable, or Downhole probe when the system is powered on.
- Ensure that all connection ports are capped when not connected to cables.
- The Javelin system should never be left deployed in the field overnight or unattended.
- Do not attempt to operate the system if there is damage to the Downhole Cable, High Voltage NMR Winch Cable, or damage to any other parts.
- System components are heavy. At least four people should work together to lift and move the main component units.
- Always check the O-rings on the downhole cable connection to ensure they are clean and free of any dirt or debris. Apply vacuum grease if they O-rings require lubrication.

- Always check the system for damage before use. Do not attempt to use the system if any case, seal, meter, connector, or cable is visibly damaged.
- Do not stand or sit or place any heavy objects on any of the cases, even when closed. Do not stack cases on eachother.
- Do not use the system if there is a chance of electrical storms with lightning. The user must respond responsibly to changing weather conditions and discontinue use before a danger becomes present. If lightning is nearby, abandon the sytem without regard to its currrent state and seek shelter immediately!

11.3 Weather

WARNING

The Javelin Surface Station and Cable Winch are not approved for use in the rain! In case of rain, the Surface Station and Cable Winch must be kept covered and dry at all times.

Under no circumstances should the instrument be used if there is a chance of lightning.

The user is responsible for monitoring changing weather conditions and responding appropriately before a danger becomes present. If weather changes and a storm becomes likely, seek shelter. The following preventative steps for protecting the Javlin system should be carried out only if conditions safely permit with the following priority:

(i) Turn off the system.

(ii) Disconnect cables and replace unit covers.

The user's first reponsibility is for the safety of all field operators.

If lightning is nearby, abandon the sytem without regard to its currrent state and seek shelter immediately.

11.4 Hazardous Materials

All components included the Javelin system are RoHS compliant. Batteries are not included with the system, but likely contain hazardous chemicals. Batteries should be handled and disposed of in a safe manner as prescribed by the battery manufacturer.

11.5 Storage, Transport, and Handling

The following guidelines for storage, transport, and handling must be followed to maximize the lifetime of your Javelin system and to prevent unnecessary hazards from arising.

Magnets in the downhole probes create very strong magnetic field that are always present, even when now power is connected. Use extreme caution when transporting the probes. Do not allow magnetic objects (such as steel) near the probes; magnetic objects and probes will be attracted and may become projectiles if not properly secured. Magnetic fields can cause damage to electronics and devices with magnetic encoding (e.g. hard drives and credit cards); keep all such objects away from probes.

During storage, all panels on the instrument should be covered and all ports should be capped. The Javelin system should only be stored indoors; no component of the system should ever be left outdoors or unattended. The storage environment must be dry and maintain a temperature between -20°C and 50°C with a relative humidity of less than 95% non-condensing. The storage space should be free of rodents or other pests that are known to bite or otherwise damage the insulation material on electrical cables. Components should never be stacked, nor have heavy items placed upon them. Any structures or shelving used to support instrument components must be appropriately rated for the load to be carried.

During transport, the Javelin system should be treated and handles as sensitive electronic equipment. When placed in any vehicle for transport, the system should be well-secured to prevent sliding. Additionally, padding should be placed under and between instrument components to prevent them from banging against one another or against other objects; connectors and external ports can be easily damaged as a result of such impacts. When traveling on rough roads, transport the system in vehicles with adequate suspension and drive slowly to avoid unnecessary bouncing or vibration. If extensive transport in rough conditions is required, ensure that the instrument components are adequately packaged, with soft padding and a rigid outer casing, to protect from shock and hard impact.

12 APPENDICES

12.1 OVERVIEW OF MAGNETIC RESONANCE

The Javelin Wireline System directly detects the presence of groundwater utilizing a phenomenon known as proton nuclear magnetic resonance (NMR). Proton magnetic resonance is observed when protons spins associated with hydrogen atoms in groundwater are subjected to a perturbation in the background magnetic field. In a static magnetic field, B_0, the proton spins will preferentially align in the same direction as the field and so form a small magnetic moment. In the case of the Javelin system, the background field is created by magnets in the probe.

The spin magnetic moments associated with groundwater can be excited from their equlibrium state by transmitting an radio-frequency RF pulse at a specifically tuned frequency. This pulse is generated by the probe and causes a portion of the spin magnetization to rotate perpendicular to the background field, into the so-called “transverse plane.” In this excited state, the magnetization will then precess about the background field and generate an RF signal which has the same frequency as the transmitted pulse. This frequency is called the Larmor frequency, f_0, and it is proportional to the magnitude of the background magnetic field. For hydrogen in water, the Larmor frequency can be calculated as:

$$f_0 = 4258(Hz/Gauss) * B_0(Gauss)$$

A series of EM pulses are used to measure the transverse magnetization signal which decay as the spins return to their equilbrium state.

In the basic CPMG experiment, a series of RF pulses are transmitting in short-sucession. Between each pulse, a NMR spin echo is measured generating a so called “echo train”. The time spacing between each pulse (also the duration between each echo signal is known as the “echo-time”. The center frequency of the spin echo signal is the Larmor frequency. The intial amplitude of spin echo train is directly proportional number of proton spins being measured (i.e. the amount of water). The echo train exhibits a decay over time characterized by the decay time T_2 (typically between 1ms and 1s). The T_2 decay time provides information about the pore-scale environment of the spins and can be used to derive estimates of pore size and permeability.

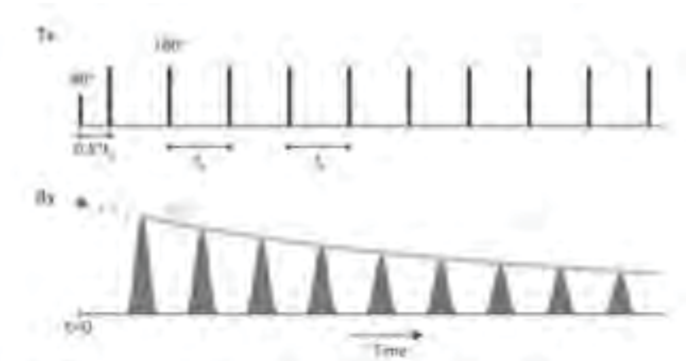


Figure 1. Schematic illustration of the CPMG pulse sequence showing timing of transmitted B_1 pulses in the top panel, and received NMR echo signals (dark gray) in the bottom panel. The lighter gray line represents the spin echo decay curve $S(t)$ with an initial amplitude proportional to water content and an exponential decay time T_2.

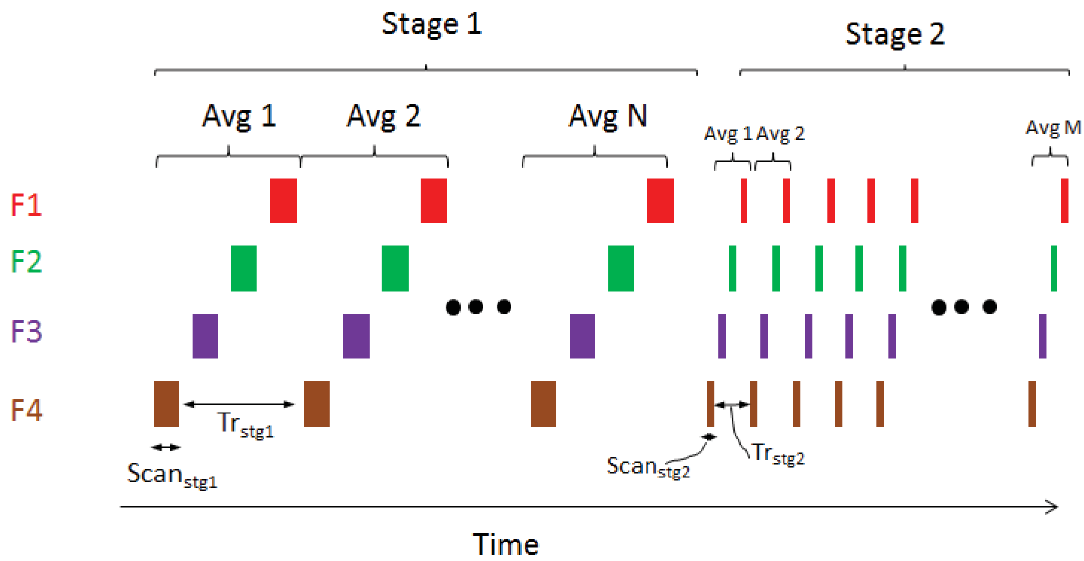
As the Javelin probe is lowered into the formation, multiple CPMG measurements are collected (or “stacked”) at each depth interval. After a series of measurements are collected at one depth interval, the probe is lowered and another series of measurements is collected to generate a magnetic resonance depth log used for interpretation.

12.2 Acquisition Sequence Parameters

12.2.1 Details

An example logging measurement sequence is shown below. At a given depth level, one or more stages of measurement are performed. The stages are comprised of scans at different frequencies (“F1”, “F2”…), and each scan is repeated to form multiple measurement averages. What differs between each stage is the time between each repeated measurement average (“Tr”) and the length of each measurement scan

("Scan"); also each stage may include a different number of averages. The practical importance of these sequence parameters is described briefly below.



An example sequencing setting showing the use of multiple measurment frequencies and multiple averaging stages.

-Frequency: The Javelin Wireline probes can operate at up to four different frequencies. Lower frequency measurements provide sensitivity at a maximum radial depth of investigation. The higher frequency measurements provide a radial depth of investigation closer to the probe (by approximately 0.5 inch per frequency step).

_-Tr_: The recovery time controls the amount of time between sucessive CPMG measurement scans at a given measurement frequency. The value of Tr will determine how much time is allowed for water in the formation to recover between measurements. If Tr is set to a long value, all the water in the formation will recover between measurements and all water will be detected. If Tr is set to a short value, only the water with short relaxation times (fast recovery time) will be measured accurately and water with long relaxation times (slow recovery) will be muted. A Tr value of 10 will allow complete recovery for any type of water regardless of formation, but will yield a slower logging speed (long time between measurements). A Tr of 0.5 second will allow much faster logging and will allow complete recovery/detection of water in silty formations, but may result in underestimation of water in unexpected coarse layers. To balance the advantages of long and short Tr values, data are often acquired in a multi-Tr mode as shown above: A few averages are acquried with a long Tr to accurately detect water in large pores with long T_2 and many more averages are acquired with short Tr to accurately detect and resolve water in small pores with short T_2 .

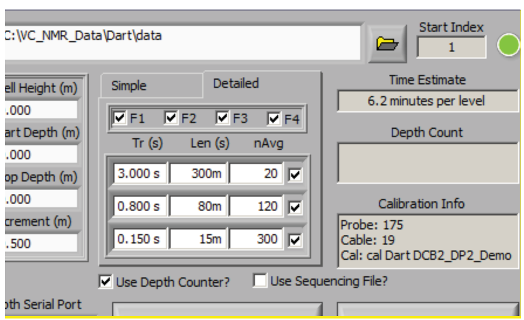
-Scan Length: The scan length is the length of each CPMG. As the value of Tr is decreased, the scan length must also be decreased so that the total measurement duty cycle does not exceed a recommended value. In general, the following equation should be satisfied to avoid errors:

(#frequencies)*(scan_length) */ Tr <= 0.2*

- #Averages: The number of averages is the number of complete CPMG scans collected at each depth interval using the user specified Tr. Increasing this number will increase the signal to noise of the log but will also increase the total acquisition time. It is recommended that a larger number of averages be used for formations with low water content or for very shallow surveys which may be affected by cultural noise. A suggested value for #Averages is 6. Doubling the #Averages will double the survey time but will also increase the signal to noise ratio by a factor of approximately sqrt(2).

-Echo Spacing: The echo spacing is the time delay between transmitted refocusing pulses and is also the spacing between receive magnetic resonance spin echo signals. Using the shortest "default" echo spacing will provide higher signal to noise and will decrease the influence on diffusion on measured relaxation times. Only expert users should change the echo spacing from the default value. Refer to table Table 1 in the Appendix for a list of default echo spacings for a each probe.

Adjusting Sequence Parameters : The sequence parameters can be adjusted either by changing the sequence file in the calibration folder. It is suggested that if a new sequence will be used repeatedly (e.g., for a survey with many holes in a particular geology), the sequence file should be updated.



User access to multiple scan stages by deselecting "Use Sequence File?"

Here, the frequencies used in the measurment can be selected or delected on the top row. Fields for up to three stages are provided. For each stage (each row) the user can select the value of Tr, the scan length, and the number of averages. Each stage is enabled by checking the box at the right of the matrix. These values can also be set in the sequencing file as described later. Note that the controls shown above are only accessible when the probe is within wifi communication distance of the uphole computer. Practically this means only when it is above ground level.

12.2.2 Relationship to logging rate

For continuous logging, it is typically desirable to complete one full sequence of MR measurements during the time it takes the probe to traverse a distance corresponding to the height of the measurement coil.

For example, a logging sequence consisting of 20 averages with a Tr of 3.0 sec will take *approximately*[6] 60 seconds to complete all 20 averages. If the measurement coil of the probe being used is 25cm, then the logging speed should be 25cm per 60 seconds (1m per 4min, or 15m/hr).

12.3 Javelin Data Formats

12.3.1 JRD and LVM files compared

As of 2019, all Javelin Wireline systems generate *.jrd files, but not all systems generate *.lvm files. If your Javelin Wireline system contains a downhole computer (3.5" Digital Modules only), *.lvm files will be created and stored on the downhole computer.

JRD files contain stacks of the spin echo data. LVM files contain unstacked data. One JRD file is produced per depth step, whereas multiple LVM files are produced per depth step (one for each permutation of frequency and Tr being collected). LVM files are built up during data collection, whereas JRD files are created only after data collection at a depth step has been completed.

Both JRD and LVM files can be used to generate final logs. The reasons to prefer one format over the other are summarized as follows:

- LVM files must be used if you wish to apply spike noise removal. Spike noise removal is not possible with JRD data.
- JRD files are significantly smaller. If you wish to share raw data electronically, JRD data is preferable. A full log of JRD files may be several MB, whereas a full log of LVM files may be several GB.
- JRD files can be monitored in near real-time using the Javelin ProPlus software. Refer to the separate Javelin ProPlus User Manual for more details.

Both LVM and JRD files should be retained and archived.

12.3.2 Javelin Reduced Data (*.jrd)

JRD files are tab-delimited ASCII text files. The format of this file is a series of repeating triplet rows, one triplet for each combination of frequency and Tr that was collected. Each triplet consists of:

- A header row, containing metadata.
- A data row, containing spin echoes (real part).
- A data row, containing spin echoes (imaginary part).

The header rows contain the following data:

---

[6] There are numerous factors which influence the actual duration of a sequence of MR measurements. These include (a) the duration of the ping test at the start of each stack, (b) the scan length, and (c) the interleaving of short-Tr bursts. Additionally, different configurations of Javelin systems handle acquisition timing differently. Please contact Vista Clara if you would like assistance calculating sequence durations for your system.

Index	Name	Units
1	Tex	s
2	Echo spacing	r
3	# echoes	
4	Transmit freq	Hz
5	# avgs	
6	Decimation freq	Hz
7	Q	
8	Preamp gain	
9	Depth	m
10	SW version	
11	Probe ID	
12	Cable ID	
13	Tune setting	
14	Tr	s
15	Well height	m
16	Start depth	m
17	Stop depth	m
18	Depth increment	m
19	Sensor offset	m
20	245 H2O	
21	245 Echo time shift	
22	245 Echo phase shift	
23	245 Echo freq shift	
24	245 Calibration Q	
25	E1 Scale	
26	LV H2O	
27	LV Phase	
28	NC	
29	NC	
30	245 Tex	us
31	245 DeQ length	us
32	245 DeQ delay	us
33	NC	
34	NC	
35	NC	
36	MF width	us
37	Shell depth	in
38	Hanning window	
39	NC	
40	NC	
41	NC	
42	NC	

43 NC
44 NC
45 NC
46 NC
47 # AI chan
48 Datatype
49 Battery Monitor
50 DAQ device

12.3.3 Javelin Data Format (*.lvm)

*Note: Your system may or may not create *.lvm files. See Section 12.3.1 "*JRD and LVM files compared*" (page 80) for more information.*

The raw Javelin data for each logged depth interval (with ".lvm" extension) are saved as binary files. Each file contains four data channels written with big-endian format and 64-bit double precision.

Channel#	Data Acquisition Variable
1	Detection coil in phase data
2	Detection coil quadrature data
3	Reference coil in phase data
4	Reference coil quadrature data

The first 50 entries of each binary raw data file contain header information and are the same for all four columns. The header information is specified below:

Entry#	Data Acquisition Variable	Range/Units
1	Excitation pulse length	Seconds
2	Echo Time	Seconds
3	Number of Echoes	Integer
4	Measurement Frequency	Hz
5	Number of Averages	Integer
6	Preprocessed Sampling Frequency	Hz
7	Quality Factor	Float
8	Preamplifier Gain	Float

9	Measurement Depth	Meters
10	Acquisition Version	#.#
11	Probe ID	e.g. 175.2001 is 175B-001
12	Cable ID	Meters
13	Operation Mode	Integer (0,1,2)
14	Tr	Seconds
15	Wellhead height above ground	Meters
16	Start Depth	Meters
17	Stop Depth	Meters
18	Depth Increment	Meters
19	Sensor Offset from Logging Head	Meters
20	100% H_2O Calibration Scaling	Float
21	Echo Time Shift	Microseconds
22	Echo Phase Shift	Degrees
23	Echo Frequency Shift	Hz
24	Quality Factor During Calibration	Float
25-50	00000 -- For Future Use	---

12.4 Calibration Files

12.4.1 Systems with Downhole Computers

The calibration files should be located in the following folder on the downhole computer:

```
C:/VC_NMR_Data/Calibrations/Wireline calibrations/Current
```

When the magnetic resonance acquisition software on the downhole computer loads, it will look in this folder *and only this folder* for calibration files.

There should be three calibration files in this calibration folder:

1) *seq*.ini -- This file may be edited by any user. It contains the sequencing information that is read in by default to the Logger software. If “Use Seq File?” is selected in the Logger, the parameters of the sequence file will be used.
2) *cal*.ini – **This file should not be edited.** This file contains calibration information for the specific probe/cable combination being used. The only field in this file that should be changed by the user is the echo spacing. Changing other fields may lead to invalid results and may cause system damage.
3) *surf*.ini – **This file should never be edited by any user.** This file specifies interfacing protocols of the surface station and probe.

These files contain required acquisition and processing parameters specific to the Javelin magnetic resonance logging probe, downhole logging cable length, and desired magnetic resonance logging measurements.

These files should be carefully managed and protected to prevent changes to the file data or loss of the files. Use of an incorrect or corrupted calibration file will lead to improper acquisition and will render data collected unusable. Carefully maintain clear file and directory naming conventions for your calibration files.

Details

1. The tool calibration file. The tool calibration file contains the operational settings and calibration data specific to each Analog MR probe, including:
    a. The transmit pulse length for each frequency
    b. the echo spacing
    c. the active Q-damping timing settings
    d. the standard echo integration settings
    e. the scalar factor for converting integrated echo values to water content.

   The values in the tool calibration file are determined at the factory prior to shipping and under normal circumstances should not be changed by the user without consulting Vista Clara first. Incorrect settings may damage the tool. The calibration filename is always named as “cal_*.ini”

2. The sequence file. The sequence file contains information on the magnetic resonance pulse sequence to be performed, including:

a. which of the four available frequency shells to use,
b. whether to perform a long wait time scan, a short wait time scan, or both,
c. the wait time, scan length and number of averages for each of the scans.

The sequence filename is always named as "seq_*.ini". An example of the sequence file content is as follows:

```
; Javelin v5+ Sequencing file
[freqs]
f1 = 1
f2 = 1
f3 = 1
f4 = 1
n_avg = 10

[stage1]
enable = 1
tr_s = 16
len_s = 0.2
n_mult = 1

[stage2]
enable = 0
tr_s = 1
len_s = 0.022
n_mult = 4

[stage3]
enable = 0
tr_s = 0.150
len_s = 0.015
n_mult = 20
```

3. The surface station file. This designates the type of surface station. For the Javelin Wireline system, this should always indicate Javelin Wireline and should not be changed. An example surface station file is as follows:

```
;; Javelin v5+ Surface Station file

[sw]
permit = user

[surface]
;; 0 - ni-pxi 2x
;; 1 - ni-usb
daq_type = 1
num_tools = 1
```

```
    tool_sel = 1

    [tool1]
    ;; 0 Fixed Tuning
    ;; 1 Javelin Classic
    ;; 2 Javelin Serial
    ;; 3 Discus
    ;; 4 Dart
    ;; 5 Wireline
    tune_style = 5
    num_freq = 4

    [tool2]
    [tool3]
[tool4]
```

12.5 Calibration for Depth Counter (Rate Scaling)

The depth counter converts encoder revolution rate to logging rate based on the "r1nP1" register value in the depth counter unit. The r1nP1 scale factor should be determined by the following equation:

$$r1nP1 = \frac{(pulses\ per\ revolution)}{(depth\ per\ revolution)}$$

The software <u>is not capable of adjusting the rate scaling factor – this parameter must be set manually.</u>

To manually adjust the rate scaling factor :
Press **"PAR" once**: Display toggles between "Pro" and "no"

1. Press **"F1" four times**: Display toggles between "4 – rte" and "Pro"
2. Press **"PAR" six times**: Display toggles between "rdSP 1 " and "001000"
3. Press **"F1""F2"** multiple times to set to "**3600**" for units in **per hour**
   (Press "RST" to toggle between blinking digits)
4. Press **"PAR" once:** Display toggles between "r 1nP 1" and "####.#"
5. Press **"F1""F2"** multiple times to set value to r1nP1 as calculate by above equation.
   (Press "RST" to toggle between blinking digits)
6. Press **"PAR" once**: Display toggles between "round and "1"
7. Press **"DSP" once**: Display shows "End" shortly and goes back to current depth value

12.6 Calibration for Depth Counter (Depth Scaling)

The depth counter converts encoder revolutions to depth based on the 'ASCFAC' register value in the depth counter unit. The ASCFAC scale factor should be determined by the following equation:

$$\frac{50\ \times (depth\ per\ revolution)}{(pulses\ per\ revolution)}$$

For systems with a winch.ini file, the software automatically resets the ASCFAC value every time the software is opened based on the pulses per revolution and depth per revolution listed in the winch calibration file.

<u>The ASCFAC parameter can be set directly on the counter unit, but this value will be reset every time the software is reopened.</u>

To manually adjust the depth scaling factor:
Press **"PAR" once**: Display toggles between "Pro" and "no"

8. Press **"F1" once**: Display toggles between "1 – 1 np" and "no"
9. Press **"PAR" four times**: Display toggles between "ASCFAC" and "#.#####"

The displayed # value is the current calibration value. Multiply this value by the correction factor N to determine the new calibration value.

10. Press **“F1” “F2”** multiple times to set “#.#####” to the new calibration value.
11. Press **“PAR” once**: Display toggles between “ASCALr” and “1”
12. Press **“DSP” once**: Display shows “End” shortly and goes back to current depth value

12.7 Manual Depth Entry for Depth Counter

To reset the depth to an arbitrary value (in meters):

1. Press **“PAR” once**: Display toggles between “Pro” and “no”
2. Press **“F1” once**: Display toggles between “1 – 1 np” and “no”
3. Press **“PAR” six times**: Display toggles between “ACnLd” and “yyyy.yy”
4. Press **“F1” “F2”** multiple times to set the previous RST value “yyyy.yy” to “2016.11” Press **“RST”** to toggle between digits.
5. Press **“PAR” once**: Display toggles between “A P – up” and “no”
6. Press **“DSP” once**: Display shows “End” shortly and goes back to “xxxx.xx”
7. Press **“RST” once**: Display should show the new depth value.

Note:

- In case of getting lost during programming, press “DSP” button and start all over again from the first step of the above instructions.
- Please DO NOT change any parameter settings of the counter other than the “ACnLd” value of the counter.

12.8 Wiring Diagrams

Wiring Diagrams may differ between systems. Verify that you are following the correct Wiring Diagram for your system.

12.8.1 Javelin Max

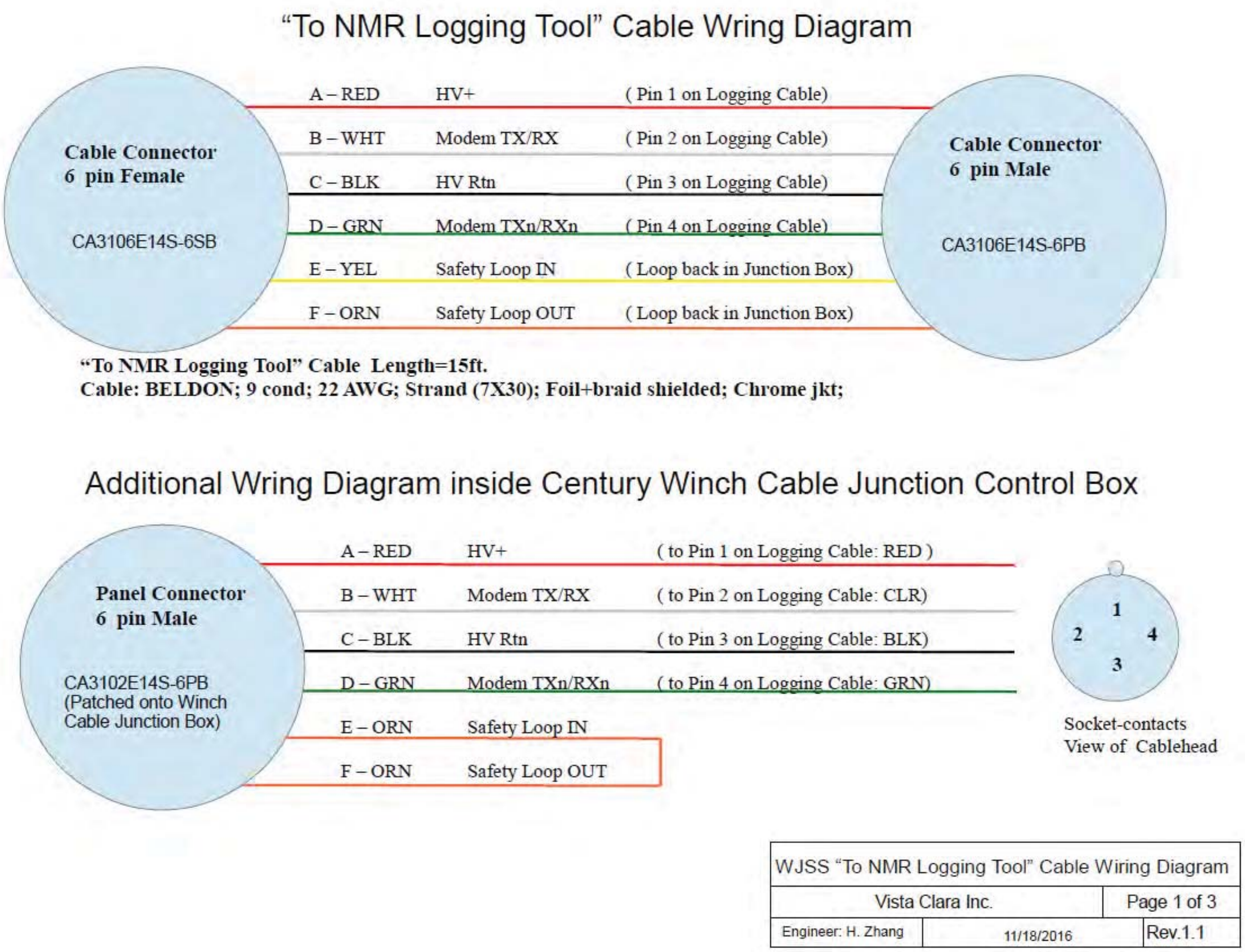


Figure 45: Wiring Diagram for Javelin Max system.

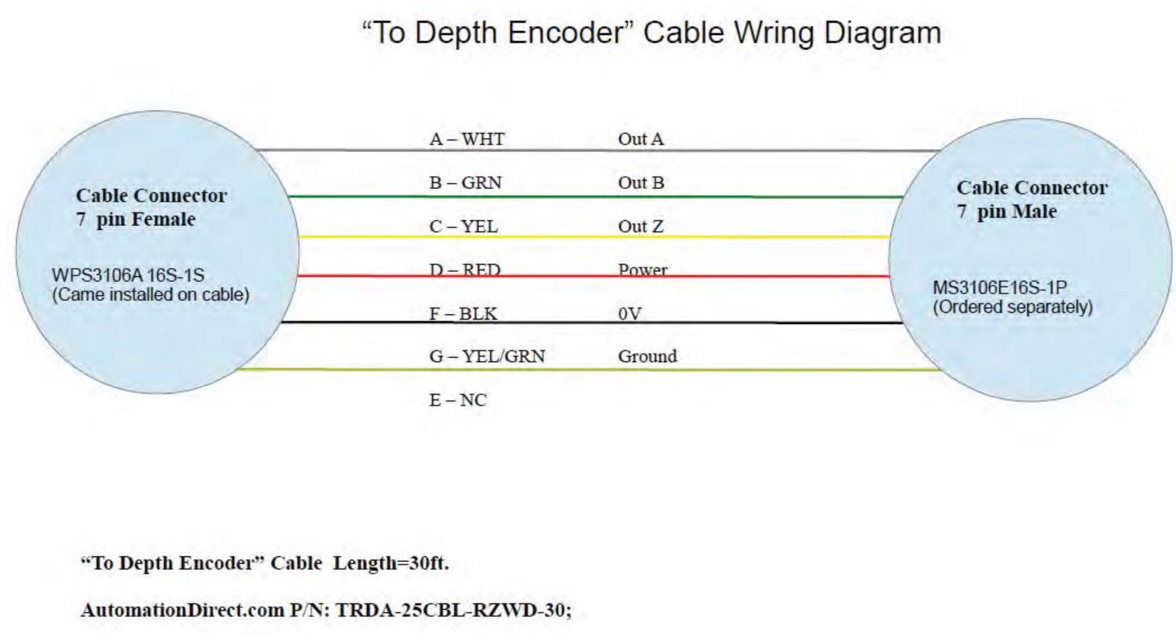


Figure 46: Wiring Diagram for Javelin Max system Depth Encoder.

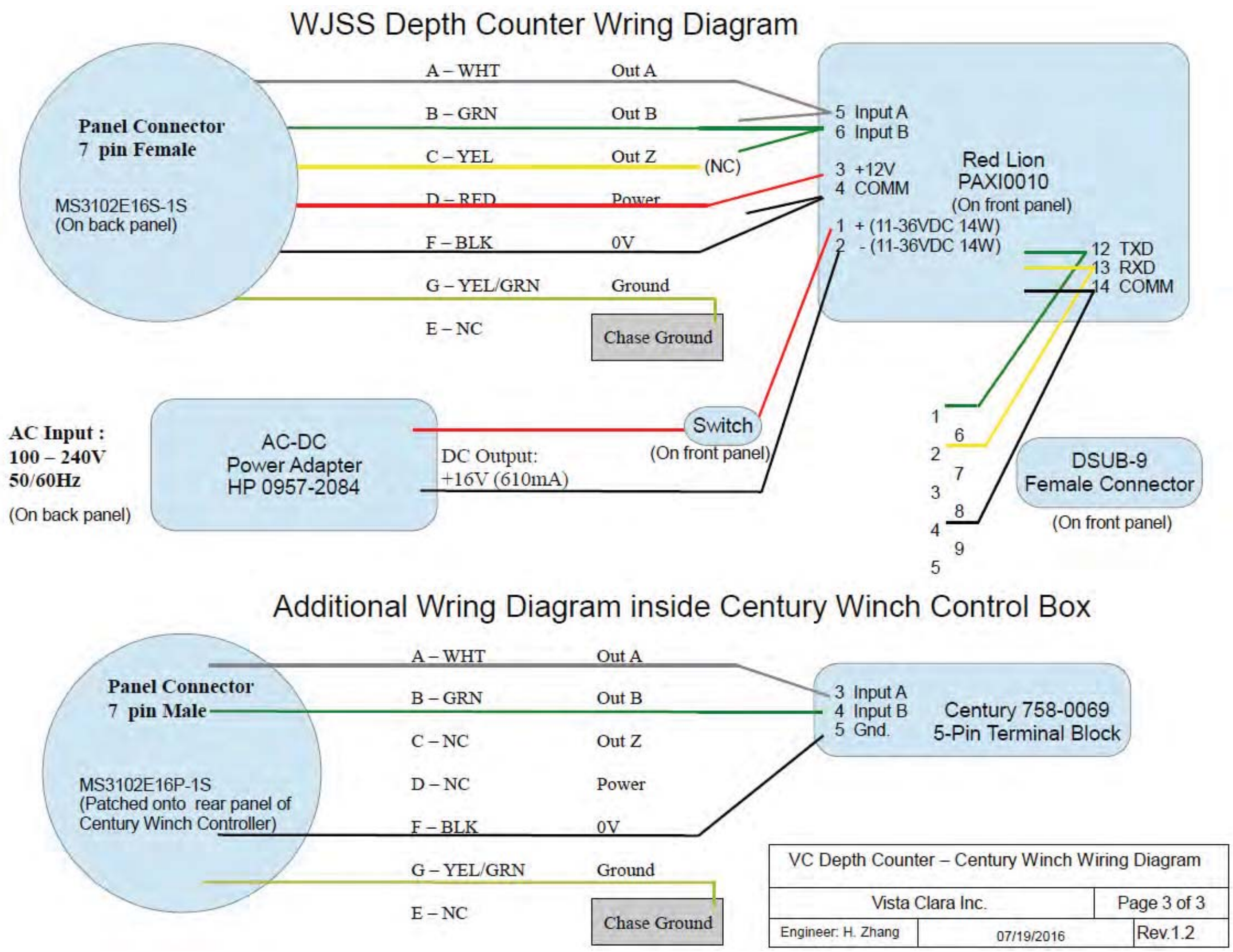


Figure 47: Wiring Diagram for Javelin Max.

12.8.2 Javelin Slim

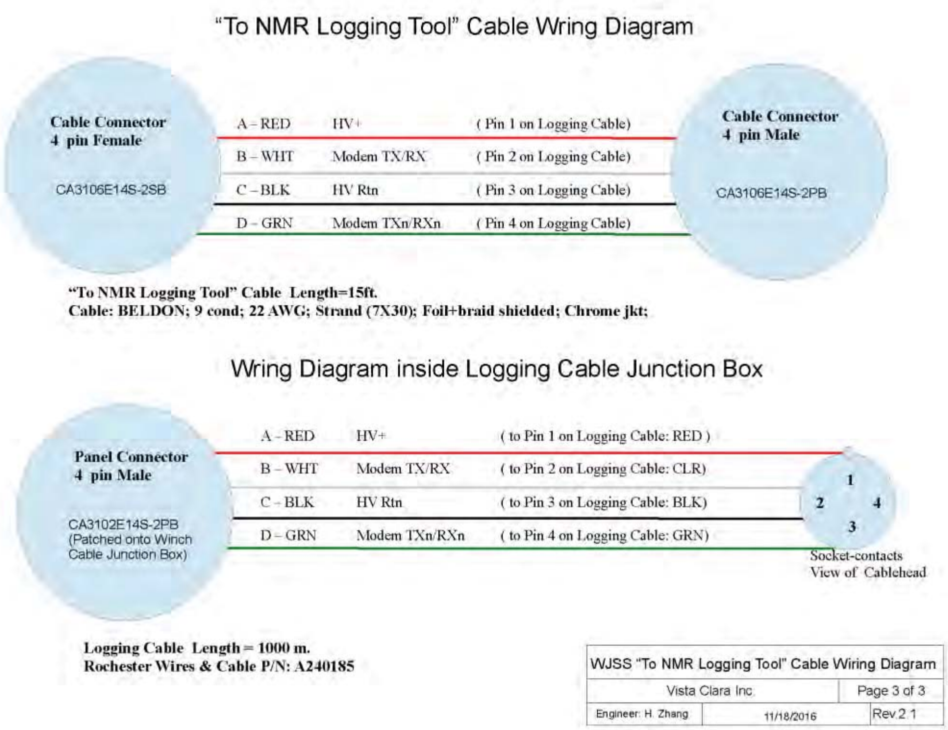


Figure 48: Wiring Diagram for Javelin Slim system.

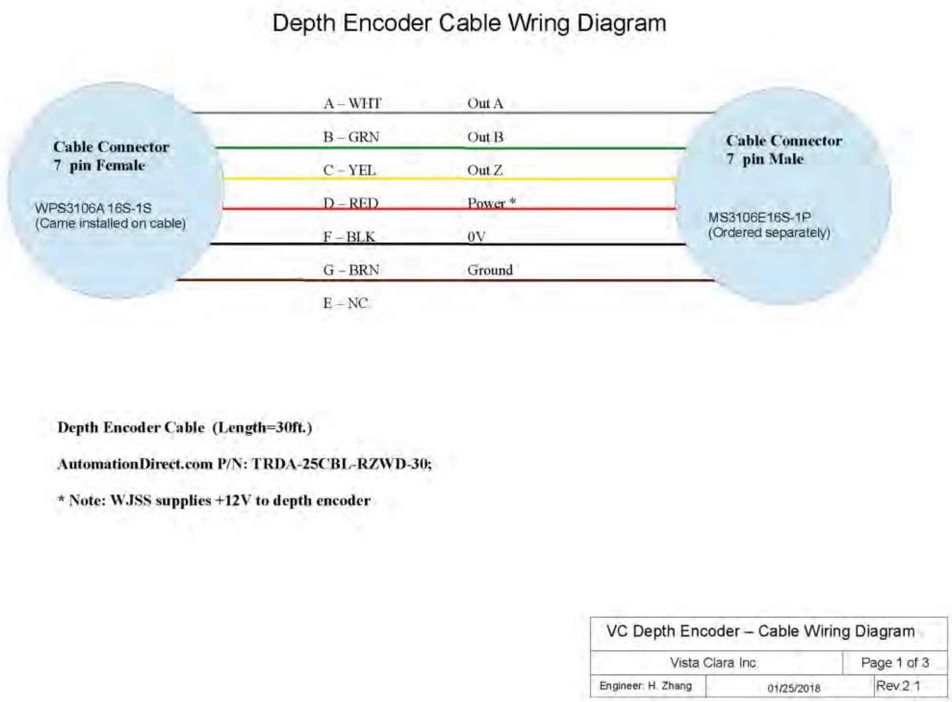


Figure 49: Wiring Diagram for Javelin Slim system Depth Encoder.

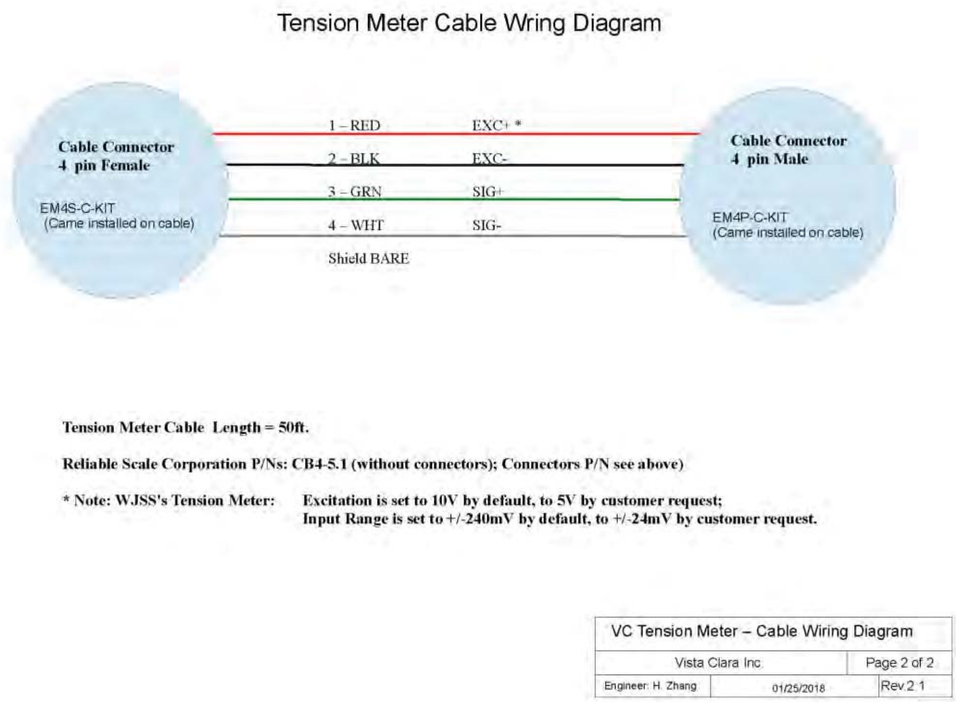


Figure 50: Wiring Diagram for Javelin Slim system Tension Meter cable.

12.9 PRODUCT IDENTIFICATION

12.9.1 Serial Number Conventions

Surface Station	Serial No.: ***WJSS-xxx***
Downhole Digital Module	Serial No.: ***JPX-xxx***
Downhole Power Module	Serial No.: ***JPXRFA-xxx***
Downhole Digital Electronics and Power Module (3.5in)	Serial No.: ***JPX-xxx***
Downhole Digital Electronics and Power Module (2.38in)	Serial No.: ***JPY-xxx***
Downhole Analog MR Probe (3.5in for Javelin Max)	Serial No.: ***JPX350F-xxx***
Downhole Analog MR Probe (5.35in for Javelin Max)	Serial No.: ***JPX525F-xxx***
Downhole Analog MR Probe (2.38in for Javelin Slim)	Serial No.: ***JPY238F-xxx***
Downhole Analog MR Probe (3.5in for Javelin Slim)	Serial No.: ***JPY350F-xxx***
	(XXX = 001, 002, 003, …)

12.9.2 System-specific specifications

Table 4: Dimensions, weights, and serial numbers for Javelin Slim system delivered to LIAG (Nov. 2019).

		Metric					Imperial					
Item	Serial Number	Length (cm)	Width (cm)	Height (cm)	Diameter (cm)	Weight (kg)	Length (in)	Length (ft)	Width (in)	Height (in)	Diameter (in)	Weight (lb)
Javelin Digital and Power Module	JPY-002	263			60	24	103.5	8.6			2.375	53
Javelin Analog Probe (2.38")	JPY238-001	187			60	11	73.6	6.1			2.375	25
Javelin Analog Probe (3.5")	JP350-001	183			89	25	72.0	6.0			3.5	56
Javelin 350 Adapter		51			89	6	20.1	1.7			3.5	13
Surface Station	WJSS-005	79	58	30		24	31	2.6	23	12		55

13 Contact Information

Vista Clara, Inc.

12201 Cyrus Way, Suite 104

Mukilteo, WA 98275 USA

For contact with Vista Clara Inc. regarding any issues or concerns, please phone, fax, or e-mail. Check our website for changes of address and other contact information: www.vista-clara.com.

Phone: +1 (425) 493-8122

Fax: +1 (425) 493-8223

Email:

info@vista-clara.com

Appendix B

Borehole Geophysical Logging Data Plots (WellCAD)

- Lithology Suite
- Structural Suite
- Hydrogeology Suite
- Engineering Suite

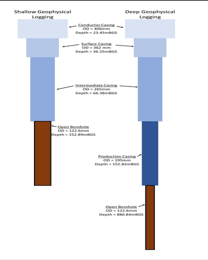
SB_BH01 - RECORD OF BOREHOLE GEOPHYSICAL LOGS

Project : South Bruce Initial Drilling and Testing
Project Number: 20-211-1
Client: NWMO

Site Location: Teeswater, Ontario
Coordinates: UTM Zone 17 - 404127.4 E, 4733259.2 N
Reference Surface Elevation: 291.494 masl, 29 May 2021
Depth: MBGS Along Borehole

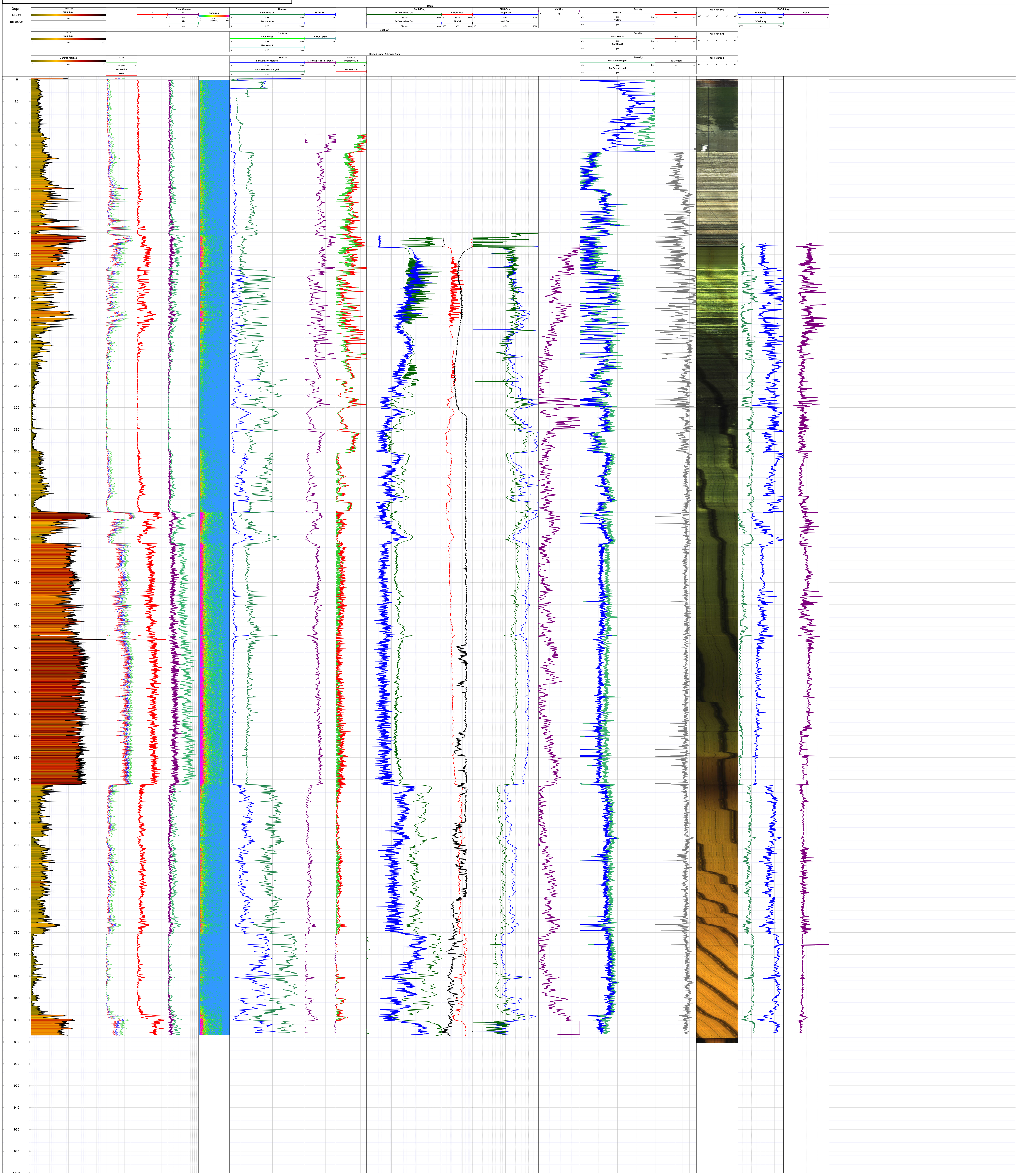
Borehole Specs.: PQ3 Diamond Drilling - 83 mm core, nominal 123mm borehole
Drilled: 29 Apr 2021 to 18 Sep 2021

Project Manager: Sean Sterling
Drilling Contractor: Vital Drilling Inc.
Data Collection: Colog, Lakewood, CO, US
Processing & Interpretation: P. Pehme *Waterloo Geophysics Inc*



Geophysical Logs - Lithology

Notes:
1- Merged tracks include upper and lower open hole data where available
2- Shale volume estimate: 0%=avg[303.46:309.32 mbgs] ; 100%=avg[398.43:401.67mbgs] {3 models used}
3- Shale corrected Neutron porosity based on extremes of of shale volume estimates
4- OTV resampled to nominal 0.005m



SB BH01 - RECORD OF BOREHOLE GEOPHYSICAL LOGS

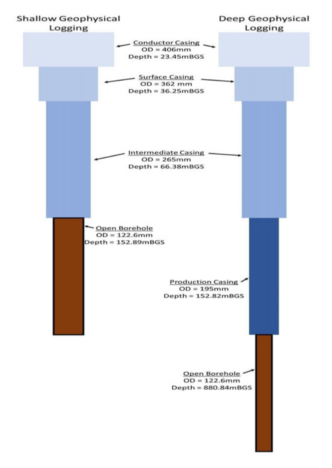
GEOFIRMA ENGINEERING

Project : South Bruce Initial Drilling and Testing
Project Number: 20-211-1
Client: NWMO

Site Location: Teeswater, Ontario
Coordinates: UTM Zone 17 - 404127.4 E, 4733259.2 N
Reference Surface Elevation: 291.494 masl, 29 May 2021
Depth: MBGS Along Borehole

Borehole Specs.: PQ3 Diamond Drilling - 83 mm core, nominal 123mm borehole
Drilled: 29 Apr 2021 to 18 Sep 2021

Project Manager: Sean Sterling, Geofirma Engineering Ltd.
Drilling Contractor: Vital Drilling Inc.
Data Collection: Colog, Lakewood, CO, US
Processing & Interpretation: P. Pehme *Waterloo Geophysics Inc*



Geophysical Logs - Structures

Notes:
1- Shallow and Deep images optimiszed (scaled) individually due due to different borehole conditions
2- Magnetic declination 9.33deg W (22-09,2021)

Discontinuities *(Interpreted from Image Logs)*

- Breccia / Broken Zone -Undifferentiated
- Karst - Void Large
- Joint - Major Open
- Joint - Major Open - Stained
- Joint - Minor Open
- Joint - Continuous
- Joint - Incomplete
- Aligned Voids/porosity

Lithology *(Major Contacts & Select Secondary)*

- Lithologic Contact - Sharp
- Lithologic Contact - Gradational Boundary
- Bedding / Lithology

SB BH01 - RECORD OF BOREHOLE GEOPHYSICAL LOGS

GEOFIRMA ENGINEERING

Project : South Bruce Initial Drilling and Testing
Project Number: 20-211-1
Client: NWMO

Site Location: Teeswater, Ontario
Coordinates: UTM Zone 17 - 404127.4 E, 4733259.2 N
Reference Surface Elevation: 291.494 masl, 29 May 2021
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Project Manager: Sean Sterling, Geofirma Engineering Ltd.
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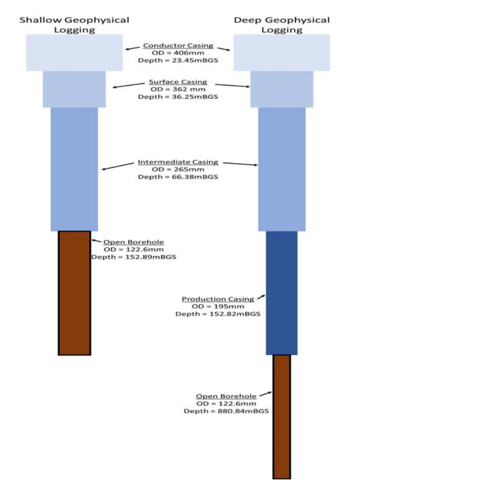


Geophysical Logs - Hydrogeology

Notes:

1- Virtual Caliper from deep borehole, in casing above 153mbgs
2- Virtual Caliper Max (April) limited data collected after blockage removal is the final assessment of the borehole
3- NMR porosity distribution based on Limestone T2 cut-offs (Clay-3ms, Capillary-90ms).
4- NMR data collected in 2 mobilizations (Oct. & June 2022) pre and post removal of blockage at 618mbgs
5- EM flowmeter data collected in 2 mobilizations (Oct. & April 2022) pre and post removal of blockage at 618mbgs
6- Temperature, Fluid Conductivity and Impeller data collected in Oct 2022, soon after drilling and developement
7- Deep borehole was drilled with brine, flushed with fresh water after drilling, followed by addition of 2cm slug of brine from surface

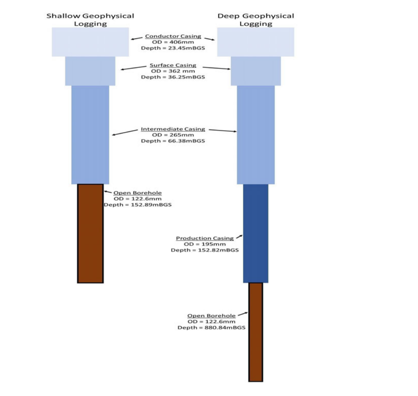
SB BH01 - RECORD OF BOREHOLE GEOPHYSICAL LOGS

Project : South Bruce Initial Drilling and Testing
Project Number: 20-211-1
Client: NWMO

Site Location: Teeswater, Ontario
Coordinates: UTM Zone 17 - 404127.4 E, 4733259.2 N
Reference Surface Elevation: 291.494 masl, 29 May 2021
Depth: MBGS Along Borehole

Borehole Specs.: PQ3 Diamond Drilling - 83 mm core, nominal 123mm borehole
Drilled: 29 Apr 2021 to 18 Sep 2021

Project Manager: Sean Sterling
Drilling Contractor: Vital Drilling Inc.
Data Collection: Colog, Lakewood, CO, US
Processing & Interpretation: P. Pehme *Waterloo Geophysics Inc*



Geophysical Logs - Engineering

Notes:

1- FWS only in lower hole.
2- Mechanical caliper above 153mbgs in cased hole

Lithology Suite

The geophysical data included in the WellCAD file for the Lithology Suite of logs (Figure B.1) are summarized in Table B.1.

Table B.1 Data included in Lithology Suite of Log (WellCAD)

Data & units	Range	Date Collected	Track
Natural Gamma Shallow API	0-200	24-06-2021	1
Natural Gamma Deep API	0-200	02-10-2021	1
Natural Gamma Merged API	0-200	n/a	1
Shale Vol (Linear)	0-1	n/a	2
Shale Vol (Lanrionov-Old)	0-1	n/a	2
Shale Vol (Steiber)	0-1	n/a	2
Potassium %	0-5	02-10-2021	3
Thorium ppm	0-15	02-10-2021	4
Uranium ppm	0-15	02-10-2021	4
Gamma Spectrum (0-150 ch of 255) CLR-cps	0-5	02-10-2021	5
Neutron (Near,Far) Shallow	0-3500	09-07-2021	6,6
Neutron (Near,Far) Deep	0-3500	07-10-2021	6,6
Neutron (Near,Far) Merged	0-3500	n/a	6,6
Neutron Porosity Deep %	0-30	see above	7
Neutron Porosity Deep %	0-30	see above	7
Neutron Porosity Merged %	0-30	n/a	7
Shale Corrected (Linear) Neutron Porosity %	0-25	n/a	8
Shale Corrected (Steiber) Neutron Porosity %	0-25	n/a	8
Elog (16",64") Ohm-m	1-1000 log	03-10-2021	9,9
Elog (Sing Pt) Ohm-m	1-1000 log	03-10-2021	10
Elog (SP) mV	100-600	03-10-2021	10
Form. Conductivity (Deep,Med) mS/m	10-1000 log	04-10-2021	11,11
Mag Suceptability cgs	0-15	06-10-2021	12
Density (near,far) Shallow g/cm^3	0-3.5	09-07-2021	13,13
Density (near,far) Deep g/cm^3	0-3.5	06-10-2021	13,13
Density (near,far) Merged g/cm^3	0-3.5	n/a	13,13
PE (shallow, deep, merged) b/e	2.5-3.5	06-10-2021	14,14,14
Optical Image Shallow RGB,Dir MN	0-360	26-06-2021	15
Optical Image Deep RGB, Dir MN	0-360	30-09-2021	15
Full Waveform Sonic Pwave Interp. m/s	1500-6500	see below	16
Full Waveform Sonic Swave Interp. m/s	1500-6500	see below	16
VelP/VelS Ratio	1-3	see below	17

Structure Suite

The geophysical data included in the WellCAD file for the Structure Suite of logs (Figure B.2) are summarized in Table B.2.

Table B.2 Data included in Structure Suite of Log (WellCAD)

Data & units	Range	Date Collected	Track
OTV Image Shallow MN RGB,Dir	0-360	26-06-2021	1
OTV Image Deep MN RGB, Dir	0-360	30-09-2021	1,2
ATV Amplitude Shallow Amp NM	0-15000	24-06-2021	3
ATV Amplitude Deep Amp NM	0-12000	01-10-2021	3
ATV Travel Time Shallow µs	70-90	24-06-2021	4
ATV Travel Time Deep µs	60-100	01-10-2021	4
Caliper 3-Arm mm	0-300	04-10-2021	5
Caliper Merged (Max, Average) mm	90-190	n/a	6,6
Structural Image Interpretation MN Dip degrees	0-90	n/a	7
Lithological Image Interpretation MN Dip degrees	0-90	n/a	8
Structural Image Interpretation TN Dip degrees	0-90	n/a	9
Lithological Image Interpretation TN Dip degrees	0-90	n/a	10
Orientation Az Gyro ATV MN Merged degrees	0-360	n/a	11
Orientation Tilt Gyro ATV Merged degrees	0-2	n/a	11
Orientation Easting Gyro ATV MN Merged m	-4-1	n/a	12
Orientation Northing Gyro ATV MN Merged m	0-15	n/a	12
Orientation Az Gyro ATV TN Merged degrees	0-360	n/a	13
Orientation Easting Gyro ATV TN Merged m	-4-1	n/a	14
Orientation Northing Gyro ATV TN Merged m	0-15	n/a	14
Orientation TVD ATV MN Merged m	0-1000	n/a	15

Hydrogeology Suite

The geophysical data included in the WellCAD file for the Hydrogeology Suite of logs (Figure B.3) are summarized in Table B.3.

Table B.3 Data included in Hydrogeology Suite of Log (WellCAD)

Data & units	Range	Date Collected	Track
Caliper 3-Arm mm	0-300	04-10-2021	1
Vert Caliper (Max, Average) Merged mm	80-190	n/a	2,2
NMR T2 Dist Merged m^3/m^3	-0.001-0.006	n/a	3
NMR Porosity %	0-0.4	n/a	4
Water Volume (Total, Mobile) %	0-0.4	n/a	5,5
Fluid Temp °C (Linear)	5-17	02-10-2021	6
Fluid Cond µS/cm (Log)	0-200,000	02-10-2021	6
Fluid Temp Grad	-0.5-0.5	n/a	7
Fluid Cond Grad	-500-500	n/a	8
Fluid Cond Grad V2	-10,000-10,000	n/a	9
Impeller Flowmeter Spinner Dn @D4 cps	400-1000	07-10-2021	10
Impeller Flowmeter Spinner Dn @D8 cps	1000-1600	08-10-2021	10
Impeller Flowmeter Spinner (Up @D4, Up @D8) cps	0-20	07-10-2021	10,10
Impeller Flowmeter Spinner Up @U4 cps	400-1000	08-10-2021	11
Impeller Flowmeter Spinner Up @U8 cps	800-1400	08-10-2021	11
Impeller Flowmeter Spinner (Dn @U4, Dn @U8) cps	0-20	08-10-2021	11,11
Impeller Flowmeter Flow (U4, U8, D4, D8) l/min	-25-40	n/a	12,12,12,12
EM Flow Stat (2021 Oct x4, 2022 Apr x2) Average l/m	-3-3	n/a	13,13,13,13 13,13
EM Flow Stat (2021 Oct x4, 2022 Apr x2) St Dev l/m	0-20	n/a	14,14,14,14,14,1 4

Engineering Suite

The geophysical data included in the WellCAD file for the Engineering Suite of logs (Figure B.4) are summarized in Table B.4.

Table B.4 Data included in Engineering Suite of Log (WellCAD)

Data & units	Range	Date Collected	Track
Comp Density g/cm^3	2-4	n/a	1
M Caliper mm	0-300	04-10-2021	2
FWS RX2-1A Wide Band µs	-2000-2000	05-10-2021	3
FWS Interp Velocity (P,S) m/s	1500-7000	n/a	4,4
FWS Interp P Velocity/S Velocity	1-3	n/a	5
FWS Interp slowness (P,S) µs/m	0-700	n/a	6,6
FWS Velocity Analysis µs/m	0.2-1.05	n/a	6
Poisson’s Ratio	0-0.5	n/a	7
Shear Modulus MPa	0-40,000	n/a	8
Young’s Modulus MPa	0-100,000	n/a	9
Bulk Modulus MPa	0-100,000	n/a	10
Bulk Comp 1/MPa	0-0.001	n/a	11
Acoustic Imp.mg/scc	0-50,000	n/a	12

Appendix C

Summary of Statistics for Borehole Geophysical Logging Data in SB_BH01

Table C.1 Summary of Statistics for Borehole Geophysical Logging Data in SB_BH01

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Natural Gamma	API	Lithology	Min:	0		0	0	37
			Max:	389		384	209	155
			Avg:	40		121	28	85
			Median:	29		119	24	85
			SDev:	39		40	23	16
Potassium, K	%	Lithology	Min:	n/a	0.00	0.01	0.00	0.21
			Max:	n/a	5.62	5.90	5.60	6.66
			Avg:	n/a	0.65	2.52	0.60	3.03
			Median:	n/a	0.27	2.52	0.48	3.07
			SDev:	n/a	0.84	0.76	0.55	0.96
Uranium, U	ppm	Lithology	Min:	n/a	0.0	0.0	0.0	0.0
			Max:	n/a	10.7	11.6	11.0	9.3
			Avg:	n/a	1.0	3.1	0.9	1.5
			Median:	n/a	0.6	2.8	0.6	0.6
			SDev:	n/a	1.1	2.0	0.9	2.0
Thorium, Th	ppm	Lithology	Min:	n/a	0.0	0.0	0.0	0.0
			Max:	n/a	29.2	28.3	16.1	23.0
			Avg:	n/a	2.2	8.6	2.2	3.9
			Median:	n/a	1.2	8.3	1.5	2.1
			SDev:	n/a	2.9	4.8	2.2	4.6

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Neutron-Far	cps	Lithology	Min:	0		77	154	831
			Max:	1,439		950	2,008	2,258
			Avg:	312		167	905	1,563
			Median:	239		153	788	1,550
			SDev:	230		62	414	301
Neutron-Near	cps	Lithology	Min:	283		541	885	1,600
			Max:	2,726		2,265	3,284	3,180
			Avg:	1,192		897	2,164	2,669
			Median:	1,081		856	2,090	2,689
			SDev:	481		157	486	235
Density Far	g/cm^3	Lithology	Min:	1.25		1.83	2.25	2.5
			Max:	3.21		2.96	3.3	3.15
			Avg:	2.75		2.77	2.86	2.78
			Median:	2.78		2.77	2.86	2.77
			SDev:	0.14		0.06	0.08	0.1
Density Near	g/cm^3	Lithology	Min:	1.1		1.49	2.05	2.54
			Max:	3.21		3.11	4.11	3.13
			Avg:	2.79		2.85	2.9	2.85
			Median:	2.83		2.86	2.91	2.84
			SDev:	0.17		0.08	0.07	0.08
Photoelectric	b/e	Lithology	Min:	0.75		0.83	1.42	2.2
			Max:	3.73		3.65	6.83	4.15
			Avg:	3.03		3.10	3.13	3.13
			Median:	3.08		3.12	3.13	3.12
			SDev:	0.28		0.15	0.16	0.24

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Magnetic Susceptibility (normalized)	cgs	Lithology	Min:	n/a	-33.8	-30.3	-30.6	3.8
			Max:	n/a	62.1	36.1	38.7	149.2
			Avg:	n/a	4.8	3.1	3.1	55.4
			Median:	n/a	4.4	0.6	1.4	45.22
			SDev:	n/a	8.1	6.5	5.7	36
Resistivity Elog 64"	ohm-m	Lithology	Min:	n/a	1.3	1.3	1.3	5.1
			Max:	n/a	959.3	22.1	376.8	389.5
			Avg:	n/a	30.6	5.3	35.1	142.7
			Median:	n/a	15.8	5	19.9	138.8
			SDev:	n/a	48.3	2.4	41.8	79.6
Resistivity Elog 16"	ohm-m	Lithology	Min:	n/a	4.4	10.3	6.8	113.5
			Max:	n/a	1832	68.4	1421	1336.6
			Avg:	n/a	50.2	18.4	237.8	775.3
			Median:	n/a	35.2	17.2	130.5	820.7
			SDev:	n/a	83.1	5.2	239.4	266.4
Single Point Resistance	ohm-m	Lithology	Min:	n/a	2	4	10	48
			Max:	n/a	514	22	338	268
			Avg:	n/a	10	10	87	189
			Median:	n/a	8	10	65	206
			SDev:	n/a	18	4	59	52
Spontaneous Potential	mV	Lithology	Min:	n/a	236	280	158	62
			Max:	n/a	528	528	534	290
			Avg:	n/a	421	474	356	201
			Median:	n/a	426	490	328	210
			SDev:	n/a	69	46	101	46

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Apparent Conductivity Deep Corrected	mS/m	Lithology	Min:	n/a	-317	194	48	-50
			Max:	n/a	1519	561	827	213
			Avg:	n/a	347	448	147	83
			Median:	n/a	246	461	133	86
			SDev:	n/a	271	57	87	43
Apparent Conductivity Med Corrected	mS/m	Lithology	Min:	n/a	-124	90	25	-45
			Max:	n/a	891	278	394	191
			Avg:	n/a	204	207	78	70
			Median:	n/a	166	211	71	71
			SDev:	n/a	117	26	37	36
Velocity: P Wave	m/s	Lithology, Engineering	Min:	n/a	2,696	3,073	3,601	4,464
			Max:	n/a	7,353	5,946	6,707	6,203
			Avg:	n/a	5,093	3,849	5,309	5,679
			Median:	n/a	5,127	3,742	5,319	5,682
			SDev:	n/a	769	380	461	253
Velocity: S-Wave	m/s	Lithology, Engineering	Min:	n/a	1,502	1,557	1,732	2632
			Max:	n/a	3,731	3,107	3,471	3,425
			Avg:	n/a	2,670	1,914	2,859	3,243
			Median:	n/a	2,809	1,866	2,874	3,289
			SDev:	n/a	479	205	273	127
VP/VS		Lithology, Engineering	Min:	n/a	1.22	1.59	1.55	1.53
			Max:	n/a	3.11	2.94	3.11	1.90
			Avg:	n/a	1.93	2.02	1.86	1.75
			Median:	n/a	1.87	2.05	1.85	1.75
			SDev:	n/a	0.22	0.15	0.09	0.04

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Porosity Neutron	%	Lithology	Min:	0		2	-1	-2
			Max:	52		24	18	3
			Avg:	12		13	3	0
			Median:	12		13	3	-1
			SDev:	6		2	2	1
Shale Content Gamma Linear	0-1	Lithology	Min:	0		0	0	0.21
			Max:	1		1	1	0.97
			Avg:	0.23		0.73	0.16	0.52
			Median:	0.16		0.74	0.13	0.52
			SDev:	0.24		0.21	0.14	0.1
Shale Content Gamma Steiber	0-1	Lithology	Min:	0		0	0	0.08
			Max:	1		1	1	0.91
			Avg:	0.12		0.54	0.07	0.27
			Median:	0.06		0.48	0.05	0.26
			SDev:	0.18		0.28	0.08	0.09
Porosity Shale Correction Linear	%	Lithology	Min:	-13		-11	-13	-14
			Max:	52		19	12	-4
			Avg:	8		1	1	-9
			Median:	8		1	0	-9
			SDev:	6		4	2	2
Porosity Shale Correction Steiber	%	Lithology	Min:	-12		-11	-12	-11
			Max:	52		22	14	-1
			Avg:	10		4	2	-5
			Median:	10		5	2	-5
			SDev:	6		5	2	1

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Mechanical Caliper	mm	Structure, Engineering, Hydrogeology	Min:	n/a	118	127	121	88
			Max:	n/a	211	211	173	124
			Avg:	n/a	132	135	132	123
			Median:	n/a	131	135	133	124
			SDev:	n/a	7	8	6	3
Compensated Density	g/cm^3	Engineering	Min:	1.30		1.82	2.01	2.34
			Max:	3.57		2.98	3.43	3.24
			Avg:	2.79		2.74	2.84	2.75
			Median:	2.80		2.74	2.84	2.75
			SDev:	0.16		0.07	0.09	0.1
Acoustic Impedance	g/(cm^2·s)	Engineering	Min:	n/a	5,610	6,015	9,308	11665
			Max:	n/a	21,724	16,937	21,208	18,859
			Avg:	n/a	14,061	10,560	15,110	15,657
			Median:	n/a	14,162	10,270	15,105	15,624
			SDev:	n/a	2,508	1,147	1,545	1051
Poisson's Ratio		Engineering	Min:	n/a	-0.54	0.17	0.14	0.13
			Max:	n/a	0.44	0.43	0.44	0.3
			Avg:	n/a	0.3	0.33	0.29	0.26
			Median:	n/a	0.3	0.34	0.29	0.26
			SDev:	n/a	0.05	0.04	0.02	0.02
Bulk Modulus	MPa	Engineering	Min:	n/a	1,873	13,458	18,855	23436
			Max:	n/a	124,703	81,621	118,170	67,677
			Avg:	n/a	46,216	27,486	49,554	50,262
			Median:	n/a	43,748	26,364	49,529	50,454
			SDev:	n/a	15,893	6,856	9,428	6139

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Young's Modulus	MPa	Engineering	Min:	n/a	11,706	12,654	22,982	46250
			Max:	n/a	108,468	72,161	94,960	89,635
			Avg:	n/a	52,937	27,027	60,804	73,169
			Median:	n/a	55,252	25,636	60,668	7,3732
			SDev:	n/a	18,290	5,956	11,809	6,620
Bulk Compressibility	10^5/MPa	Engineering	Min:	n/a	0.8	1.23	0.85	1.48
			Max:	n/a	53.38	7.43	5.3	4.27
			Avg:	n/a	2.46	3.84	2.10	2.02
			Median:	n/a	2.29	3.8	2.02	2
			SDev:	n/a	1.12	0.88	0.44	0.30
ATV Virtual Caliper Avg	mm	Structure, Engineering, Hydrogeology	Min:	93		104	106	104
			Max:	158		142	141	106
			Avg:	114		115	112	105
			Median:	110		115	113	105
			SDev:	10.5		6.5	5.3	0.4
ATV Virtual Caliper Max	mm	Structure, Engineering, Hydrogeology	Min:	99		107	106	104
			Max:	201		150	152	116
			Avg:	116		116	113	105
			Median:	112		115	113	105
			SDev:	11.5		7.2	6	0.7
MNR Porosity Total	0-1	Hydrogeology	Min:	n/a	0.01	0	0	0
			Max:	n/a	0.46	1.32	0.95	0.56
			Avg:	n/a	0.1	0.06	0.13	0.17
			Median:	n/a	0.08	0.04	0.12	0.15
			SDev:	n/a	0.06	0.08	0.09	0.1

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
MNR Porosity Clay Bound Water	0-1	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	0.15	0.15	0.24	0.13
			Avg:	n/a	0.02	0.02	0.01	0.01
			Median:	n/a	0	0	0	0
			SDev:	n/a	0.03	0.02	0.03	0.03
MNR Porosity Capillary Water	0-1	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	0.22	0.33	0.71	0.36
			Avg:	n/a	0.04	0.02	0.06	0.08
			Median:	n/a	0.03	0.01	0.03	0.03
			SDev:	n/a	0.03	0.03	0.07	0.10
MNR Porosity Mobile Water	0-1	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	0.31	1.27	0.99	0.50
			Avg:	n/a	0.05	0.02	0.06	0.07
			Median:	n/a	0.02	0.01	0.00	0.01
			SDev:	n/a	0.06	0.07	0.09	0.11
Fluid Temperature	°C	Hydrogeology	Min:	n/a	5.85	7.99	12.93	15.96
			Max:	n/a	7.99	12.89	16.17	16.47
			Avg:	n/a	6.69	10.24	14.59	16.24
			Median:	n/a	6.37	10.12	14.66	16.25
			SDev:	n/a	0.61	1.42	0.92	0.11
Fluid Temperature Gradient	°C/5cm	Hydrogeology	Min:	n/a	-0.84	-1.3	-2.4	-2.78
			Max:	n/a	1.66	1.39	1.29	1.40
			Avg:	n/a	0.01	0.02	0.01	0.08
			Median:	n/a	0	0.01	0	0.08
			SDev:	n/a	0.08	0.17	0.17	0.58

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Fluid Conductivity	µS/cm	Hydrogeology	Min:	n/a	29717	2,610	1,109	2,616
			Max:	n/a	182,280	49,086	2,781	2,790
			Avg:	n/a	96935	15,922	1,553	2,694
			Median:	n/a	86493	12,109	1,523	2,684
			SDev:	n/a	47,480	11934	340	54
Fluid Conductivity Gradient	µS/5cm²	Hydrogeology	Min:	n/a	-20760	-18,741	-1,103	-347
			Max:	n/a	475695	6,667	2,247	209
			Avg:	n/a	-460	-212	1	-12
			Median:	n/a	-444	-121	3	-11
			SDev:	n/a	7229	978	66	66
Impeller Rotations Down (down 8m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	1,231
			Max:	n/a	1,836	2,719	3,426	1,664
			Avg:	n/a	1,330	1,347	1,260	1,441
			Median:	n/a	1,338	1,357	1,376	1,436
			SDev:	n/a	147	142	434	61
Impeller Rotations Up (down 8m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	93	566	1255	0
			Avg:	n/a	0	0	0	0
			Median:	n/a	0	0	0	0
			SDev:	n/a	1	4	10	0
Impeller Rotations Down (down 4m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	407
			Max:	n/a	2,064	1,450	1,531	676
			Avg:	n/a	582	594	566	520
			Median:	n/a	590	597	595	515
			SDev:	n/a	89	67	125	43

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Impeller Rotations Up (down 4m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	372	477	716	0
			Avg:	n/a	0	0	0	0
			Median:	n/a	0	0	0	0
			SDev:	n/a	3	3	7	0
Impeller Rotations Up (down 4m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	372	477	716	0
			Avg:	n/a	0	0	0	0
			Median:	n/a	0	0	0	0
			SDev:	n/a	3	3	7	0
Impeller Rotations Down (up 8m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	339	407	397	123
			Avg:	n/a	0	0	0	0
			Median:	n/a	0	0	0	0
			SDev:	n/a	2	2	4	3
Impeller Rotations Up (up 8m/min)	cps	Hydrogeology	Min:	n/a	243	0	0	0
			Max:	n/a	2,218	2,521	1,947	2,868
			Avg:	n/a	1,132	1,125	1,131	1,100
			Median:	n/a	1,126	1,126	1,147	1,069
			SDev:	n/a	134	107	159	215
Impeller Rotations Down (up 4m/min)	cps	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	169	220	294	77
			Avg:	n/a	0	0	0	0
			Median:	n/a	0	0	0	0
			SDev:	n/a	1	1	2	2

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
Impeller Rotations Up (up 4m/min)	cps	Hydrogeology	Min:	n/a	25	0	0	0
			Max:	n/a	1302	827	796	1133
			Avg:	n/a	514	516	507	494
			Median:	n/a	512	518	507	493
			SDev:	n/a	57	65	43	72
Impeller Flow (down 8m/min)	l/min	Hydrogeology	Min:	n/a	-36.6	-35	-64	-29
			Max:	n/a	8	112	118	-20
			Avg:	n/a	-19	-21	-11	-24
			Median:	n/a	-20	-22	-22	-24
			SDev:	n/a	7	11	37	2
Impeller Flow (down 4m/min)	l/min	Hydrogeology	Min:	n/a	-12	-8	-19	1
			Max:	n/a	66	28	55	8
			Avg:	n/a	3	0	3	6
			Median:	n/a	0	-1	-1	7
			SDev:	n/a	10	4	10	2
Impeller Flow (up 8m/min)	l/min	Hydrogeology	Min:	n/a	-19	-19	-87	-7
			Max:	n/a	22	10	10	81
			Avg:	n/a	-1	-1	0	0
			Median:	n/a	0	0	1	-4
			SDev:	n/a	4	5	10	8
Impeller Flow (up 4m/min)	l/min	Hydrogeology	Min:	n/a	-18	-15	-7	-22
			Max:	n/a	13	7	7	29
			Avg:	n/a	0	-1	-1	-1
			Median:	n/a	0	0	-1	-1
			SDev:	n/a	3	3	2	2

Data Parameter	Units	WellCAD Suite	Interval Depth	Above Ordovician Shale (Queenston)		Ordovician Shale	Ordovician Limestone	Precambrian
			Top	66.7[b]	150[c]	424.37[a,d]	644.77[a,e]	860.33[a]
			Bottom	424.37[a]	424.37[a]	644.77[a]	860.33[a]	875.8
EM Flow October 2021	l/min	Hydrogeology	Min:	n/a	-2.91	-0.76	n/a	n/a
			Max:	n/a	3.67	0.23	n/a	n/a
			Avg:	n/a	-0.11	-0.02	n/a	n/a
			Median:	n/a	-0.11	0.04	n/a	n/a
			SDev:	n/a	1	0.2	n/a	n/a
EM Flow SDev. October 2021	l/min	Hydrogeology	Min:	n/a	0	0	n/a	n/a
			Max:	n/a	15.29	0.26	n/a	n/a
			Avg:	n/a	2.19	0.02	n/a	n/a
			Median:	n/a	0.04	0	n/a	n/a
			SDev:	n/a	4.67	0.05	n/a	n/a
EM Flow April 2022	l/min	Hydrogeology	Min:	n/a	-0.61	-0.19	-0.45	-0.23
			Max:	n/a	0.15	-0.15	0.15	-0.19
			Avg:	n/a	-0.18	-0.17	-0.2	-0.21
			Median:	n/a	-0.15	-0.19	-0.19	-0.21
			SDev:	n/a	0.25	0.02	0.11	0.02
EM Flow SDev. April 2022	l/min	Hydrogeology	Min:	n/a	0	0	0	0
			Max:	n/a	0.04	0.08	0.83	0.04
			Avg:	n/a	0.02	0.02	0.12	0.02
			Median:	n/a	0.04	0	0.04	0.02
			SDev:	n/a	0.02	0.03	0.23	0.02

Notes:

a) All interval statistics have a 1 m gap (0.5 m above & below specified boundary except at the top and bottom of the log)
b) Bottom of intermediate casing at 66.38 mBGS.
c) Bottom of production casing at 152.82 mBGS
d) Top of Queenston Formation shale at 424.37 mBGS
e) Top of Cobourg Formation (Collingwood Member) at 644.77 mBGS