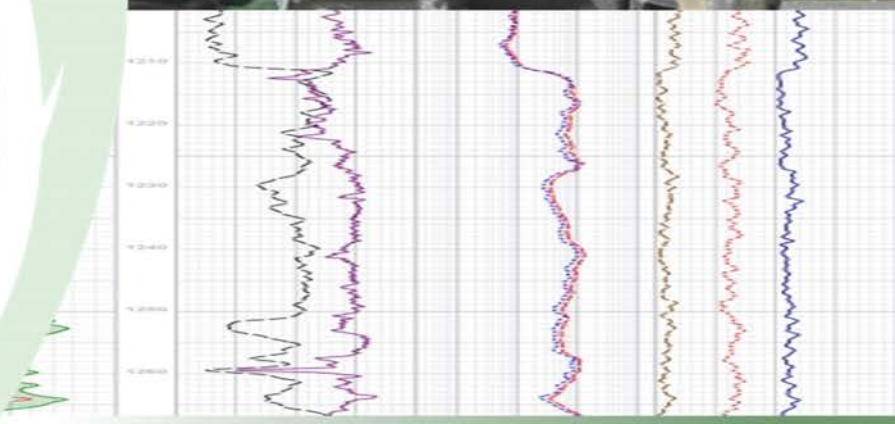
CORDAX™

LWT™ - Logging While Tripping™

Affordable, efficient openhole logging data acquired during pipe trip in vertical, deviated, horizontal and tough logging condition wells.



Cordax Evaluation Technologies

www.cordax.com

Logging While Tripping™

Cordax Evaluation Technologies provides formation evaluation solutions using the Logging While Tripping (LWT) platform. LWT is a patented logging technique in which memory based openhole logs are acquired in a method that is more cost effective, uses less rig time, and has fewer inherent risks than wireline, shuttle (thru-the-bit), or logging-while-drilling (LWD) methods. LWT allows openhole logs to be acquired in vertical, deviated, horizontal and tough logging condition wells where logging was previously considered too risky or uneconomic.

The true cost of openhole logging is the incremental rig time used in conveyance and acquisition. LWT acquires wireline quality data while essentially eliminating this considerable expense and mitigating operational risk.

With more than 600 jobs acquired worldwide in onshore and offshore applications, LWT tools have achieved greater than 98.5% uptime with no tools ever being lost in hole. LWT operations are simple and reliable:

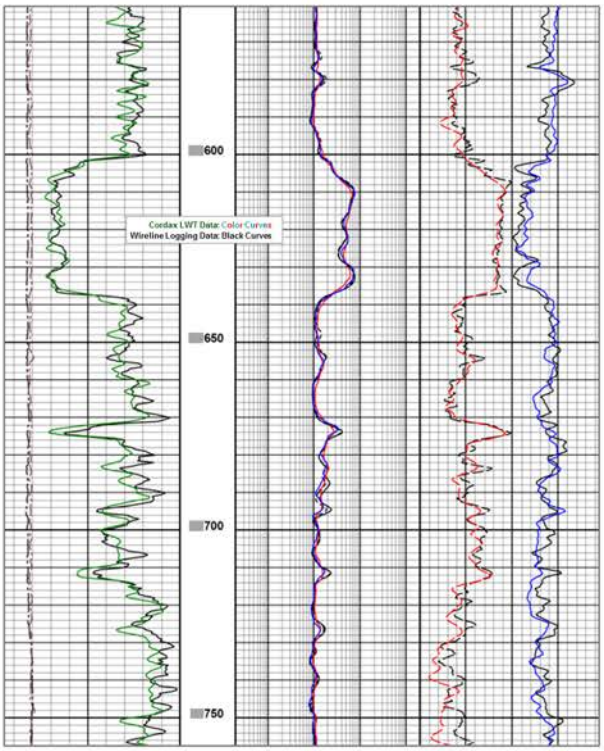
- LWT drilling collars are positioned in the BHA during the last bit run.
- The slim LWT tools are pumped down through the drill pipe and latched into LWT collars.
- Vertical, deviated, horizontal and tough logging condition wells can be safely logged while tripping out.
- At all times during LWT operations full well control is maintained allowing pipe rotation, reciprocation and circulation.
- There are no wireline, tractors, shuttle systems or specialized bit designs required.
- Ample 72 hour battery life as well as tools rated to 300°F (150°C) and 14 kpsi (100MPa) ensure a wide range of applications.
- Tools and sources may be retrieved by slickline or wireline at any time during operations.
- With full retrievability, lost-in-hole charges are virtually eliminated.
- LWT's total cost (service + rig time) is significantly less than any alternate openhole logging service.

LWT is a commercially proven, proprietary formation evaluation technique. Immediately after drilling has been completed, the LWT tools are deployed and wireline quality openhole logs are acquired in memory from within LWT collars positioned in the drill string during the trip to surface. The LWT suite of logging tools includes:

- Gamma Ray (GR)
- Spectral Gamma Ray (SGR)
- Compensated Neutron (CN)
- Density (DEN)
- Dual Induction (DUIN)

LWT Logging devices are API calibrated and meet all requirements for porosity and resistivity measurements.

The LWT collars, inserted into the drill string on the last bit trip, or on the planned reamer run, do not require any change in drilling plans or extra rig time to change to a specialized BHA. LWT tools are deployed (pumped down) when TD is reached and



LWT data has been validated in multiple "log-offs" against all major formation evaluation providers. The above overlay shows a comparison of LWT and conventional wireline.

log untethered in memory during the normal pipe trip out of the hole. Data is downloaded from tools at surface and logs delivered to client. Virtually no additional rig time is required for logging.

Throughout LWT operations, the fully retrievable logging tools and nuclear sources are safely housed inside the LWT steel and/or composite drill collars. As tools are never exposed to well conditions, the risk of damage or loss is practically eliminated. Full well control including pipe rotation, reciprocation and mud circulation are maintained at all times during logging. Unlike LWD, the LWT tools are not a permanent part of the bottom hole assembly, but instead are deployed and retrieved from the drill string only when log data is required.

The LWT collars can be positioned at several points in the drill string depending on logging application and BHA configuration. The Cordax technical team reviews LWT collar placement prior to the job to ensure successful drilling, tool pump-down and logging operations.

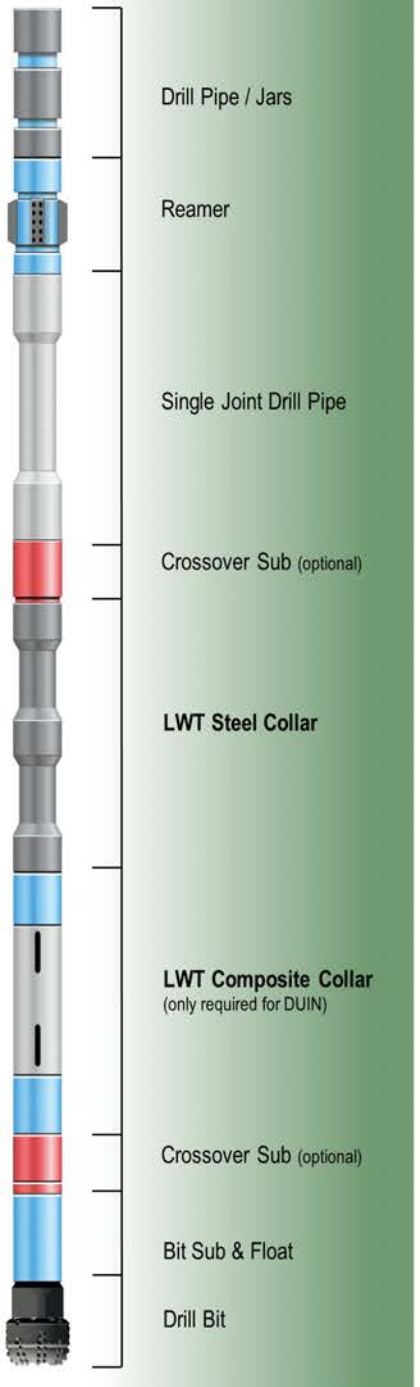
LWT logging operations are virtually invisible to the drilling process and enable operators to make informed decisions at any point in the well construction cycle.

In addition to conventional openhole formation evaluation applications, LWT combined with the Cordax Zone Grader™ interpretation solution is utilized to optimize complex well construction, and improve producibility by enhancing well completion strategies.

	LWT	Thru-Bit or Shuttle	Wireline	Pipe-Conveyed Wireline	LWD
Horizontal Well Capability					
Well Control					
Tool /Source Retrievability					
Log Quality					
LIH Risk					
LIH Cost					
Rig Time					
Log Delivery	Memory	Memory	Real Time	Real Time	Memory / Real Time
Total Logging Cost (Logging + RigTime)					

Comparison of logging conveyance options and costs demonstrating LWT operational and cost advantages.

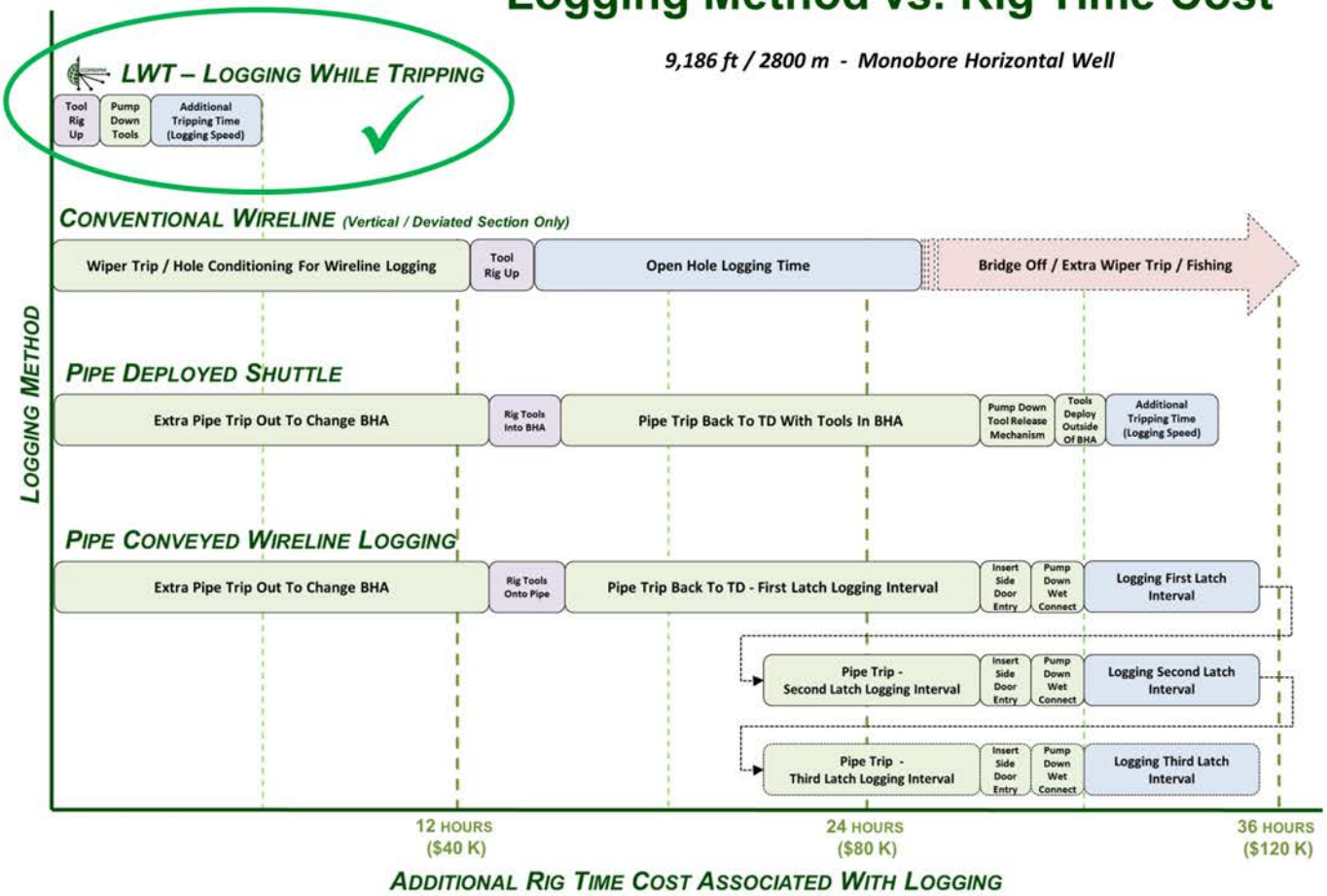
Typical BHA configuration for LWT Triple Combo Reamer Run



LOGGING METHOD RIG TIME COMPARISON

Logging Method vs. Rig Time Cost

9,186 ft / 2800 m - Monobore Horizontal Well



LWT Full Combo

- **SGR / GR / CN / DEN / DUIN**
- requires composite collar

Other Available Tool Combinations:

LWT Triple Combo

- GR / CN / DEN / DUIN
- requires composite collar

LWT Double Combo

- GR / CN / DEN
- steel collar only

LWT Double Combo w/SGR

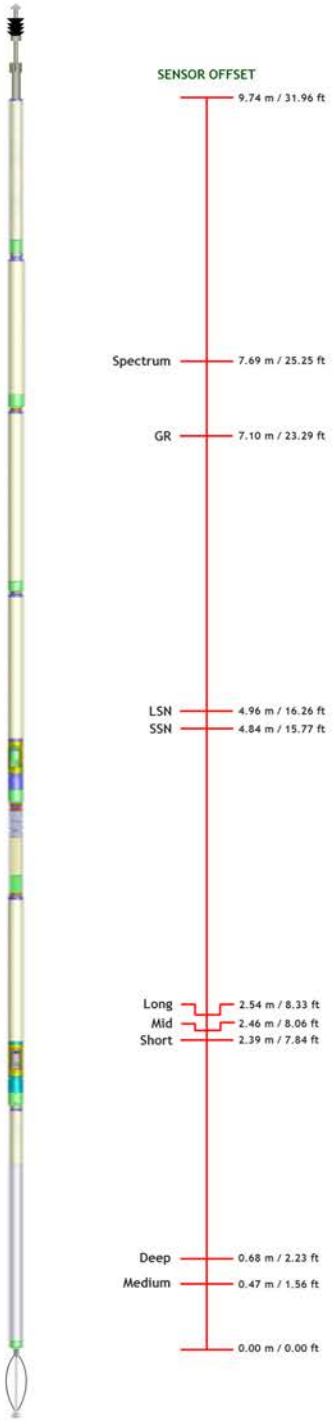
- SGR / GR / CN / DEN
- steel collar only

LWT Neutron

- GR / CN
- steel collar only or cased hole

LWT Neutron w/SGR

- SGR / GR / CN
- steel collar only or cased hole



DUAL INDUCTION (DUIN)

The Dual Induction tool operates from inside the electrically invisible LWT composite drill collar. Tuned transmitter coils induce an electromagnetic field in the borehole and adjacent formations. The magnitude of the magnetic field's ground loop current induces voltages in the receiver coils proportional to variations in the total localized conductivity, which is then converted to resistivity. Corrections including geometric factor, borehole, skin effect, coil temperature and salinity are applied through software during acquisition.

1185 DUIN	
Receiver Coils	2
Transmitter Coils	Deep: 1 emitting, 3 focusing Medium: 1 emitting, 1 focusing
Operating Frequencies (at 10 mS/m)	Deep: 50 kHz Medium: 100 kHz
Recorded Curves	Deep Conductivity (mmho): Cdeep Medium Conductivity (mmho): Cmedium Sonde Temperature (deg C): temp
Calculated Curves	Deep Resistivity (ohm-m): Rdeep Medium Resistivity (ohm-m) Rmedium

TRIPLE DETECTOR DENSITY (DEN)

The Triple Detector Density contains a gamma ray source and three high sensitivity scintillation detectors. Gamma radiation from the source is back scattered by the formation and is measured by three detectors equipped with proprietary shielding designed to optimize gamma ray collimation. Borehole effects are removed through computed stand-off and mud density measurement derived from differential relative readings of the multiple spaced detectors with reference to calibrated, modeled, and empirical responses. An apparent bulk density is then calculated from borehole compensated data as well as an average caliper and density correction.

1481 DEN	
Detector Type	NaI
Radioactive Source	Cs_{137}- 74 GBq (2 Ci)
Recorded Curves	Short Spaced (cps): SSRaw Medium Spaced (cps): MSRaw Long Spaced (cps): LSRaw
Calculated Curves	SS density, borehole corrected MS density, borehole corrected LS density, borehole corrected Apparent Bulk Densiy (g/cm^3 – kg/m^3) Omnidirectional Average Caliper Density Correction

COMPENSATED DUAL NEUTRON (CN) & Gamma Ray (GR)

The Dual-detector Neutron tool uses a chemical nuclear source and two thermal neutron detectors. The source emits neutrons that are slowed down and then captured primarily by hydrogen atoms in the formation fluids. The detectors count the neutrons deflected back to the tool. The ratio of the short-spaced over the long-spaced count rate is processed to calculate the porosity, which relates to the hydrogen content of the formation. Using a scintillation detector, the combined Gamma Ray tool measures the total natural radioactivity of the formation caused by the emission of gamma rays by unstable radioactive isotopes of elements in the formation.

1473 CN & GR	
Neutron Detector	He3
Radioactive Source	AmBe - 592 GBq (16 Ci)
GR Detector	NaI
Recorded Curves	Short Spaced (cps): SSRaw Long Spaced (cps): LSRaw
Calculated Curves	Count Rate Ratio (SS/LS) Matrix Neutron Porosity (PU) (sandstone, limestone, dolomite) GR (API)

SPECTRAL GAMMA RAY (SGR)

The Spectral Gamma Ray tool measures the entire gamma spectrum from 0 to 3,000 keV. All detected gamma rays that exceed a threshold-level energy are counted to produce the total gamma ray curve. A spectrum-fitting algorithm uses all the available counts to determine the quantitative content of the three main unstable isotopes—potassium, uranium and thorium—that contribute to natural radiation emissions. Environmental corrections for KCl mud, hole size and casing are applied through software.

1460 SGR	
Detector Type	CsI Crystal
Spectrum Range	0-4.2 MeV
Recorded Curves	Spectrum (256 Channels) Total Gamma Ray: GR raw (CPS)
Calculated Curves	Gamma Ray (gAPI): GR Thorium (ppm) (Bq/kg): U Gamma Ray (gAPI): GR Thorium (ppm) (Bq/kg): TH Uranium (ppm) (Bq/kg): U Potassium (%) (Bq/kg): K Potassium plus Thorium : KTh Ratio Uranium/Thorium: RUK Ratio Thorium/Potassium: RThK Ratio Thorium/Uranium: RThU Spectrum Fit Quality Indicator: ChiSqr

MEMORY LOGGER (MEMBAT)

The 3102 Memory Logger records data acquired by the connected logging tools. Sleep time, start time, logging duration and sample rate are programmed into the Memory Logger before tool deployment. The Memory Logger contains a lithium battery that provides power for both the logger and connected tools during recording. It also includes an accelerometer to record shock encountered during deployment/ recording.

LWT Collar Working Limitations						
LWT Collar	**3.5 in IF (4.75 in OD)**	**XT39 (5 in OD)**	**4 in FH (5 in OD)**	**4 in FH (5.25 in OD)**	**4.5 in XH (6.375 in OD)**	**4.5 in IF (6.75 in OD)**
Makeup Torque (ft-lbf)	9,100	10,800	10,800	10,800	17,000	18,000
Max Drilling / Reaming Torque (ft-lbf)	12,000	18,000	18,000	20,000	24,000	24,000
Max Tension (lbm)	200,000	290,000	290,000	330,000	400,000	400,000
Max Compression (lbm)	120,000	180,000	180,000	229,000	240,000	240,000
Max Pressure (psi)	4,000	5,000	5,000	5,000	5,000	5,000
Burst Pressure (psi/kPa)	5,600 / 38,610	7,000 / 48,263	7,000 / 48,263	7,700 / 53,089	7,000 / 48,263	7,000 / 48,263
Collar Only (no logging tools landed)						
Max Flow Rate (gal/min / m3/min)	396 / 1.5	396 / 1.5	396 / 1.5	396 1.5	528* / 660** 2.0* / 2.5**	700 / 2.65
Max Rotation (rpm)	80	80	80	80	80	100
Logging tools landed in collar						
Max Flow Rate (gal/min / m3/min)	198 / 0.75	198 / 0.75	198 / 0.75	198 / 0.75	264* / 396** 1.0* / 1.5**	450 / 1.7
Max Rotation (rpm)	40/25(w/DUIN)	40/25(w/DUIN)	40/25(w/DUIN)	40/25(w/DUIN)	40/25(w/DUIN)	40/25(w/DUIN)
Logging Speed (ft/min / m/min)						
w/o SGR Open Hole	36 / 11	36 / 11	36 / 11	36 / 11	36 / 11.6	36 / 11
w/SGR (>30 GAPI) Open Hole	23 / 7	23 / 7	23 / 7	23 / 7	23 / 7	23 / 7
w/SGR (<30 GAPI) Open Hole	10 / 3	10 / 3	10 / 3	10 / 3	10 / 3	10 / 3
Casing	36 / 11	36 / 11	36 / 11	36 / 11	36 / 11	36 / 11

LWT Collar Dimensions				
Collar type	**OD (in/mm)**	**ID (in/mm)**	**Length (ft/m)**	**Weight (lbm/kg)**
3.5 in IF Steel	4.75 / 120	2.50 / 63.5	15.5 / 4.72	500 / 227
3.5 in IF Composite	4.75 / 120	2.50 / 63.5	17.6 / 5.36	300 / 136
XT39 Steel	5.0 / 127	2.67 / 67.8	15.5 / 4.72	500 / 227
XT39 Composite	5.0 /127	2.67 / 67.8	17.6 / 5.36	345 / 156
4 in FH Steel	5.0 /127	2.67 / 67.8	15.5 / 4.72	535 / 243
4 in FH Composite	5.0 / 127	2.67 / 67.8	17.6 / 5.36	345 / 156
4 in FH Composite	5.25 / 133	2.69 / 68.3	17.6 / 5.36	370 / 168
4.5 in XH Steel	6.375 / 162	3.0 / 76.2	15.5 / 4.72	765 / 347
4.5 in XH Composite	6.375 / 162	3.0 / 76.2	17.6 / 5.36	535 / 243
4.5 in IF Steel	6.75 / 172	3.0 / 76.2	15.5 / 4.72	920 / 417
4.5 in IF Composite	6.75 / 172	3.0 / 76.2	17.6 / 5.36	640 / 290

*2.165 in (55 mm) ID restriction sub installed in box end of steel collar (4.75, 5.0, 5.25, 6.375 in OD steel collars)
**2.38 in (60.4mm) ID restriction sub installed in box end of steel collar (6.375, 6.75 in OD steel collar)

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Logging While Tripping™

LWT Tool Specifications					
LWT Tool	**Dual Induction (DUIN)**	**Triple Detector Density (DEN)**	**Compensated Neutron & Gamma Ray (CN & GR)**	**Spectral Gamma Ray (SGR)**	**Memory Logger (MEMBAT)**
Weight (lbm / kg)	17.6 / 8.0	38.4 / 17.4	58.4 / 26.5	22.7 / 10.3	14.6 / 6.6
Length (ft / m)	6.19 / 1.89	5.43 / 1.65	3.07 / 10.07	3.94 / 1.20	4.0 / 1.22
Outside Diameter (in / mm)	$1\ ^{11}/_{16}$ / 43	2.0 / 52.0	2.0 / 52.0	2.0 / 52.0	$1\ ^{11}/_{16}$ / 43
Max Temp (°F / ° C)	300 / 150	300 / 150	300 / 150	300 / 150	300 / 150
Max Pressure (psi / MPa)	14,000 / 100	14,000 / 100	14,000 / 100	14,000 / 100	14,000 / 100

LWT Logging Parameters				
LWT Tool	**Dual Induction (DUIN)**	**Triple Detector Density (DEN)**	**Compensated Neutron & Gamma Ray (CN & GR)**	**Spectral Gamma Ray (SGR)**
Max Logging Speed (ft/min / m/min)	36 / 11	36 / 11	36 / 11	23 / 7 (> 30 GAPI) 10 / 3 (< 30 GAPI)
Sample Rate	1 sample/sec	1 sample/sec	1 sample/sec	1 sample/sec
Depth of Investigation Rt/Rm=10 (in / mm)	Deep: 51 / 1,300 Medium: 25.6 / 650	3.9 / 100	CN: 10 / 260 at 20 PU	11.8 / 300
Vertical Resolution Rt/Rm=10 (in / mm)	Deep: 51 / 1,300 Medium: 25.6 / 650	17.6 / 448	22.4 / 570	5.9 / 150
Min Hole Size (in / mm)	4.9 / 125	4.9 / 125	4.9 / 125	4.9 / 125
Max Hole Size (in / mm)	9.8 / 250	9.8 / 250	9.8 / 250	9.8 / 250
Measurement Range	Resistivity 0.5-2,000 ohm-m	Bulk Density: 1-3 g/cm3	Porosity: 0-60% GR: 0-400 API	GR: 0-3000 API K: 0-100% U: 0-1,000 ppm Th: 0-1,000 ppm
Accuracy	Max Error: 5% (at 0.5 ohm-m)	Bulk Density: ± 0.05 g/cm3	Porosity: 0-10 PU: ± 0.5 PU 10-30 PU: ± 8% 30-60 PU: ± 10% GR: ± 2% measured values	GR, K: ± 2% measured values U, Th: ± 3% measured values

Operational Considerations

Drifting the pipe

- The minimum pipe ID for LWT for deployment is 2.21 in (56 mm)
- The entire BHA must be drifted prior to running LWT tools.
- There are two ways to drift:
  1) Upon reaching TD/ICP, the rig pumps down drift, trips out and retrieves drift once on surface.
  2) Drift every stand in the derrick while running in hole.

Strapping the pipe

- An exact pipe tally is required for depth control.
- The pipe tally is compared to the Electronic Drilling Recorder (EDR) for depth measurement corrections during tripping.

BHA configuration

- The LWT collars are rigged up as close to the bit as possible based on BHA components.
- All BHA configurations are reviewed prior to job.
- Cordax does not recommend the use of jars with LWT collars and tools.
- A float is required in the BHA during logging operations.

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