Well Integrity Casing and Cement Inspection

Layth Jumaah - North America Well Integrity Advisor

May 2023

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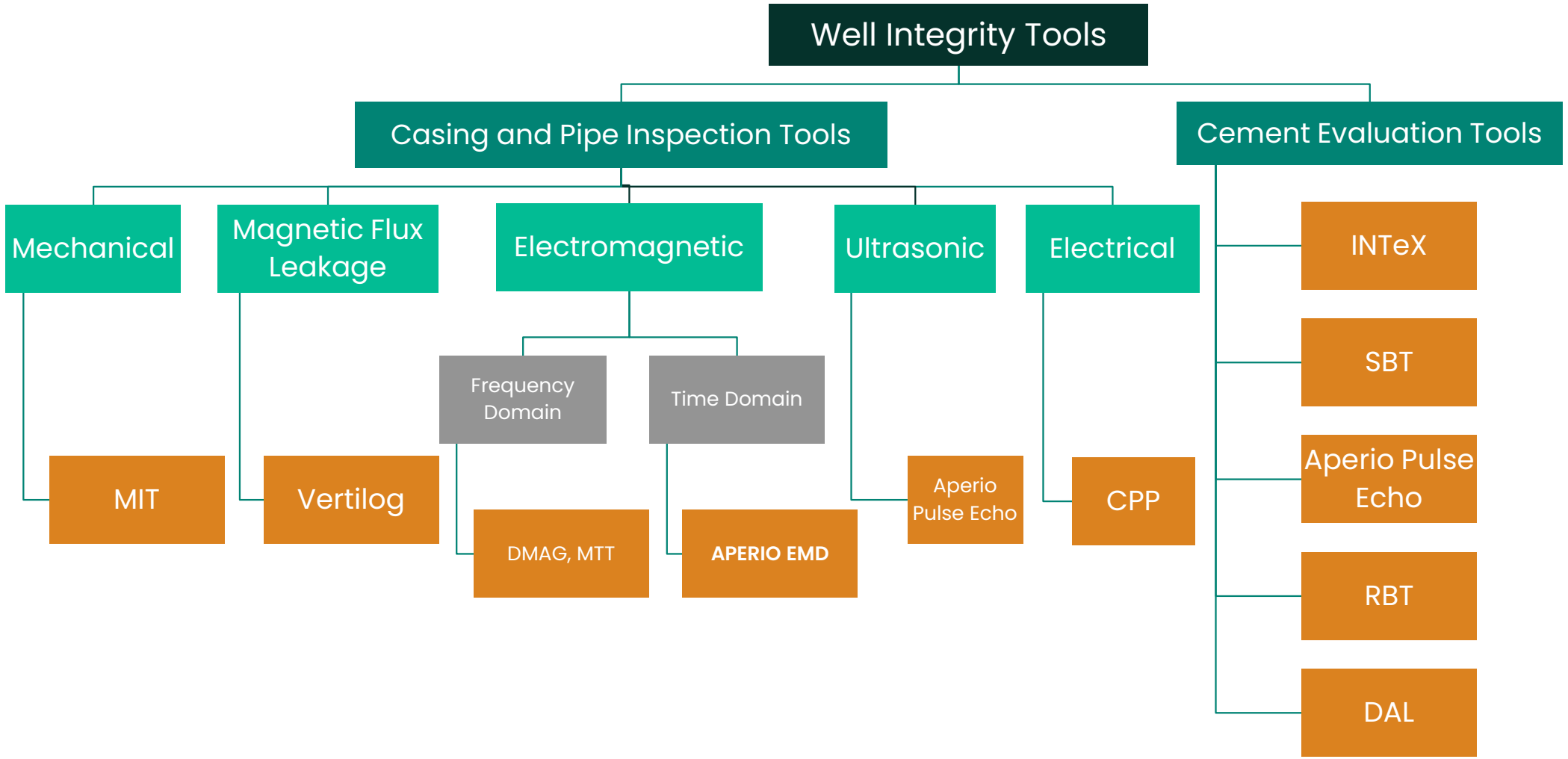
Baker Hughes Well Integrity Portfolio



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High-Resolution Vertilog - HRVRT

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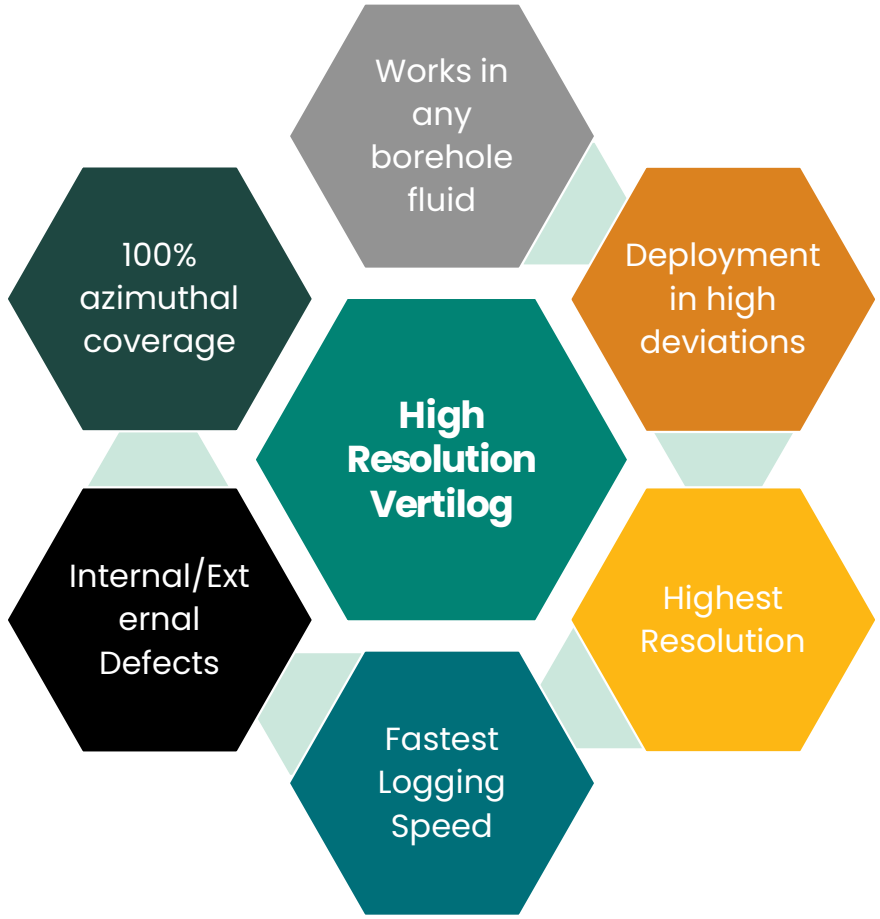
High-Resolution Vertilog

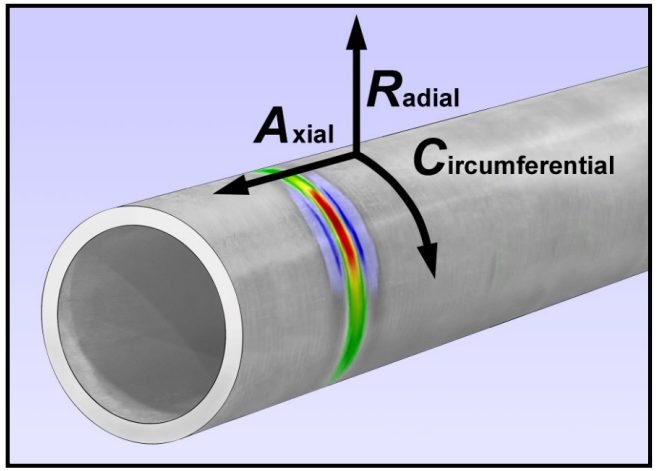
HRVRT is leading casing inspection tool compared to other tools

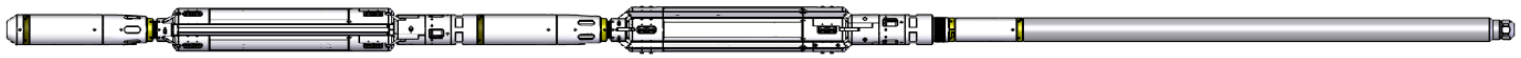
2500+ Operational jobs per year worldwide

Service covering range from 3 ½" to 9 5/8"

Global approval by more than 70 NOC/IOC







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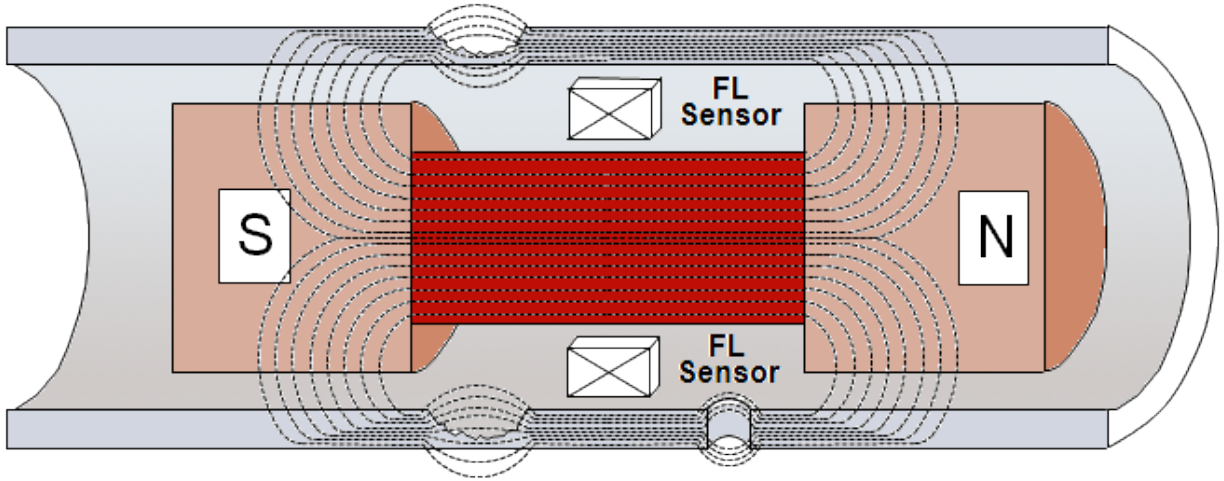
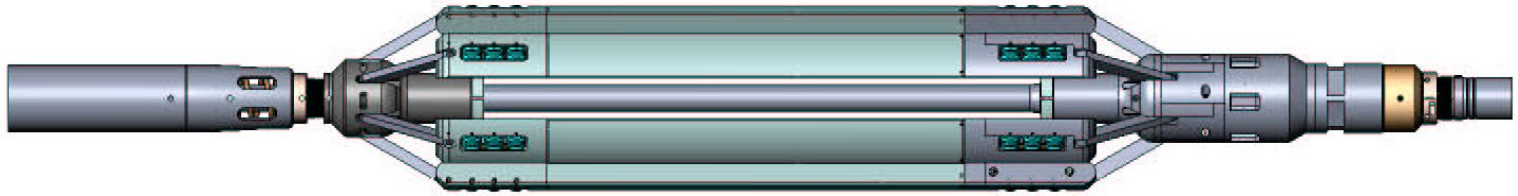
Measurement Theory – FL

- A permanent magnet circuit is completed through the tubular, producing a very high magnetic flux density within the tubular body wall.





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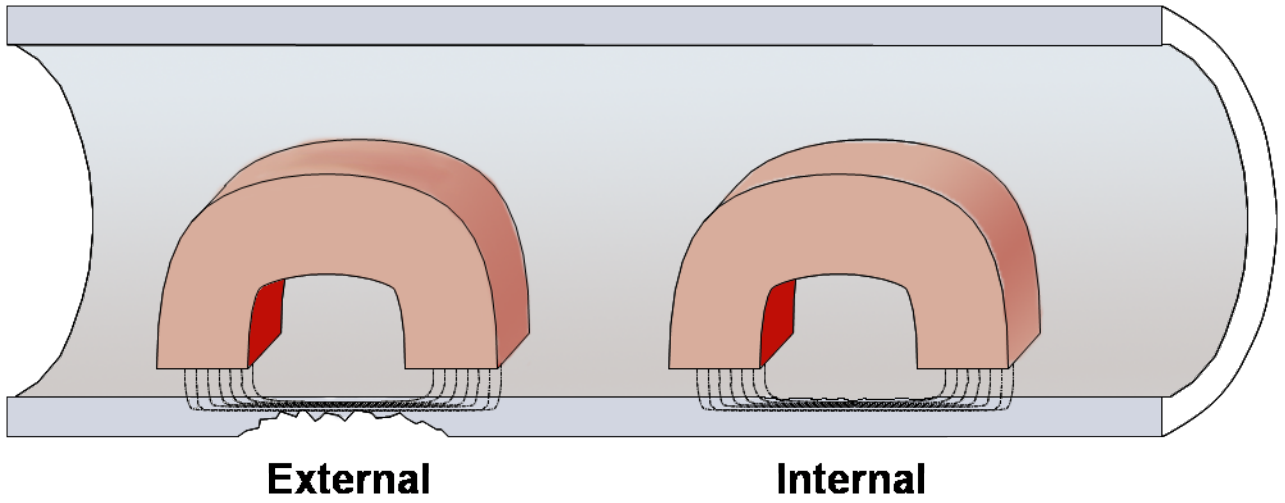
Measurement Theory - DIS

- FL sensors alone cannot differentiate internal from external defects. To perform this function, Discriminator (DIS) sensors are deployed within a weak magnetic field that is completed through the tubing's inner surface.



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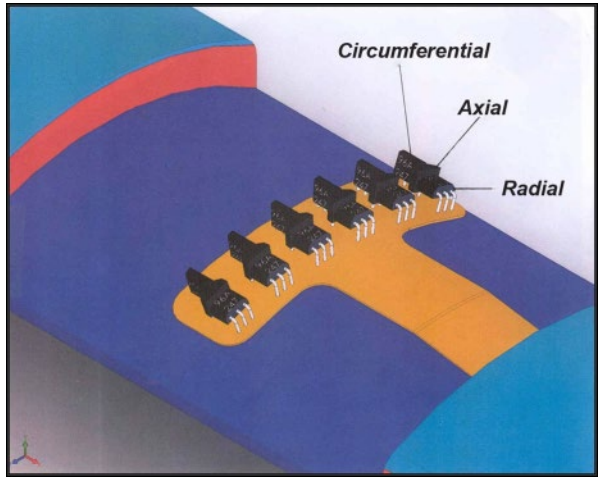
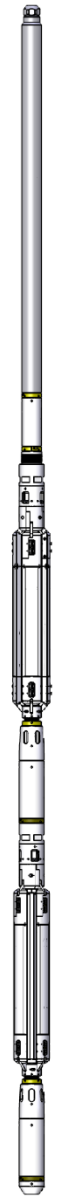
How do we get such high resolution

- Increased circumferential and axial resolution
  - Highest number of sensors
    - 144 FL , 48 DIS in 4 ½" tool
    - 144 FL , 48 DIS in 5" – 5 ½" tool
    - 288 FL , 96 DIS in 7" – 9 ⅝" tool
  - Smaller sensors (1 ¼'' coil to .25" Hall Sensors)

- Multi-axial Sensors
  - Results in better defect description

- Quantifiable defect description
  - Increased accuracy for length, width and depth of penetration determination
  - Results in better input into burst pressure calculations
  - Data base output for long term data storage and integration into other data systems





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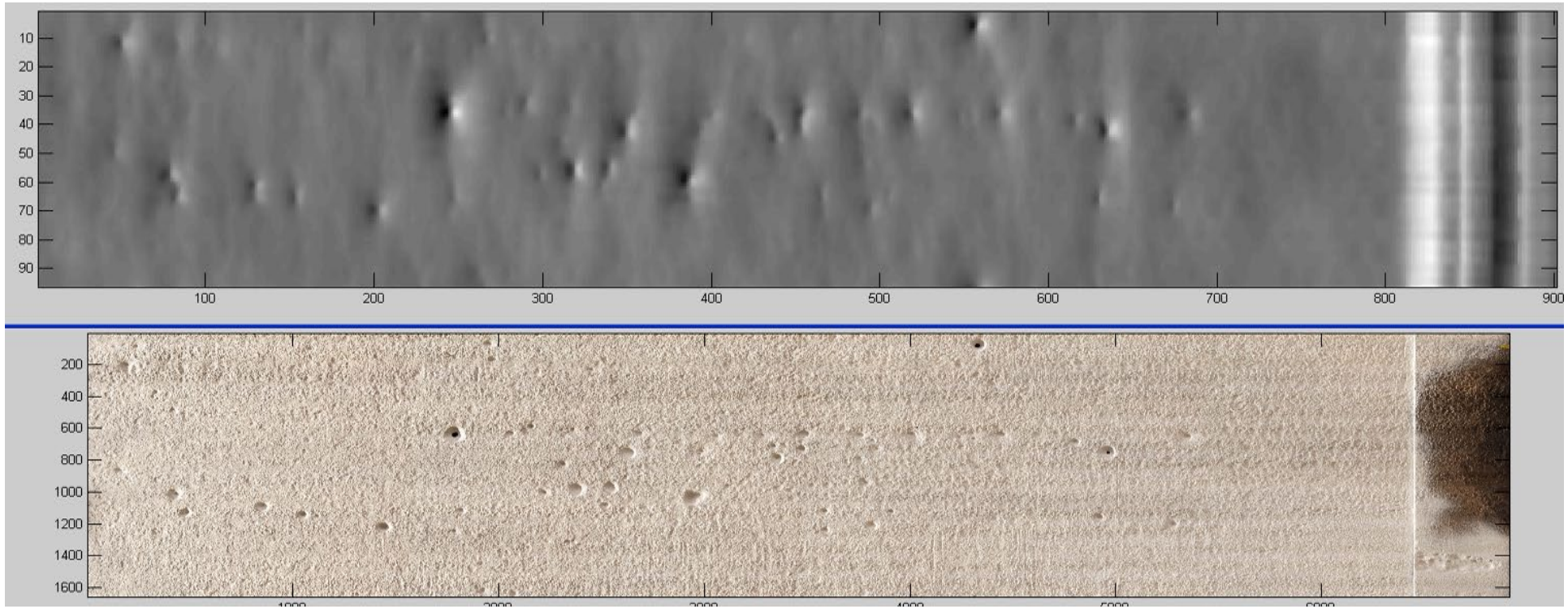
HR Vertilog

Casing Image from HRVRT



Casing Photograph

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HRVRT Characterization Improvements

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Outline

- Filled the gaps in existing database for missing pipes
- Larger spectrum of defects sizes (L × W × D) used for each pipe (82 defects)
- Characterized the effect of external casings

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Process of Characterization

- Identify and acquire casing sizes and grades missing in old database
- Machine 82 defects per casing compared to 32 defects in old characterization models
- Vertically string casings of each size and log together 25 to 30 times
  - Casing by itself (in a 30” well)
  - Casing with one or two external barriers, e.g., 5.5” inside 7 5/8” inside 9 5/8”
- Use modelling to fill the remaining gaps for grades and casing conditions that were not logged
- Train the algorithm using all runs in each configuration

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Database Upgrade with New Pipes

Tool	Casing Size, in.	Weight, ppf	Grade
4993	3.5	9.2	13Cr95, 13Cr110
4994	4 1/2	9.5	K55
		11.6	H40, J55
		13.5	J55
		15.1	P110
	5	15	P110
		18	P110
	5 1/2	14	K55
		15.5	J55
		17	J55
4995	5	15	P110
		18	P110
	5 1/2	14	K55
		15.5	J55
		17	J55
		23	P110
		29.7	L80
4997	7	17	K55
		23	J55, L80
		32	P110
		41	P110
	8 5/8	24	K55
		32	K55
		40	L80
		44	L80
	9 5/8	36	K55
		43.5	L80
		53.5	P110
		60	L80
	7 5/8	26.7	L80
		33.7	L80
		42.8	P110
		55.3	P110
	6 5/8	24	L80
		28	L80

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Conclusion

- Gaps were filled in the pipe database
- Database was expanded to include more defect sizes
- External casing effect was included in the database

  ⇒ **More accurate and stable algorithm today**

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HRVRT Advanced Analysis Advanced Reporting

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Log Format (Advanced Analysis)

Axial FL BKG →

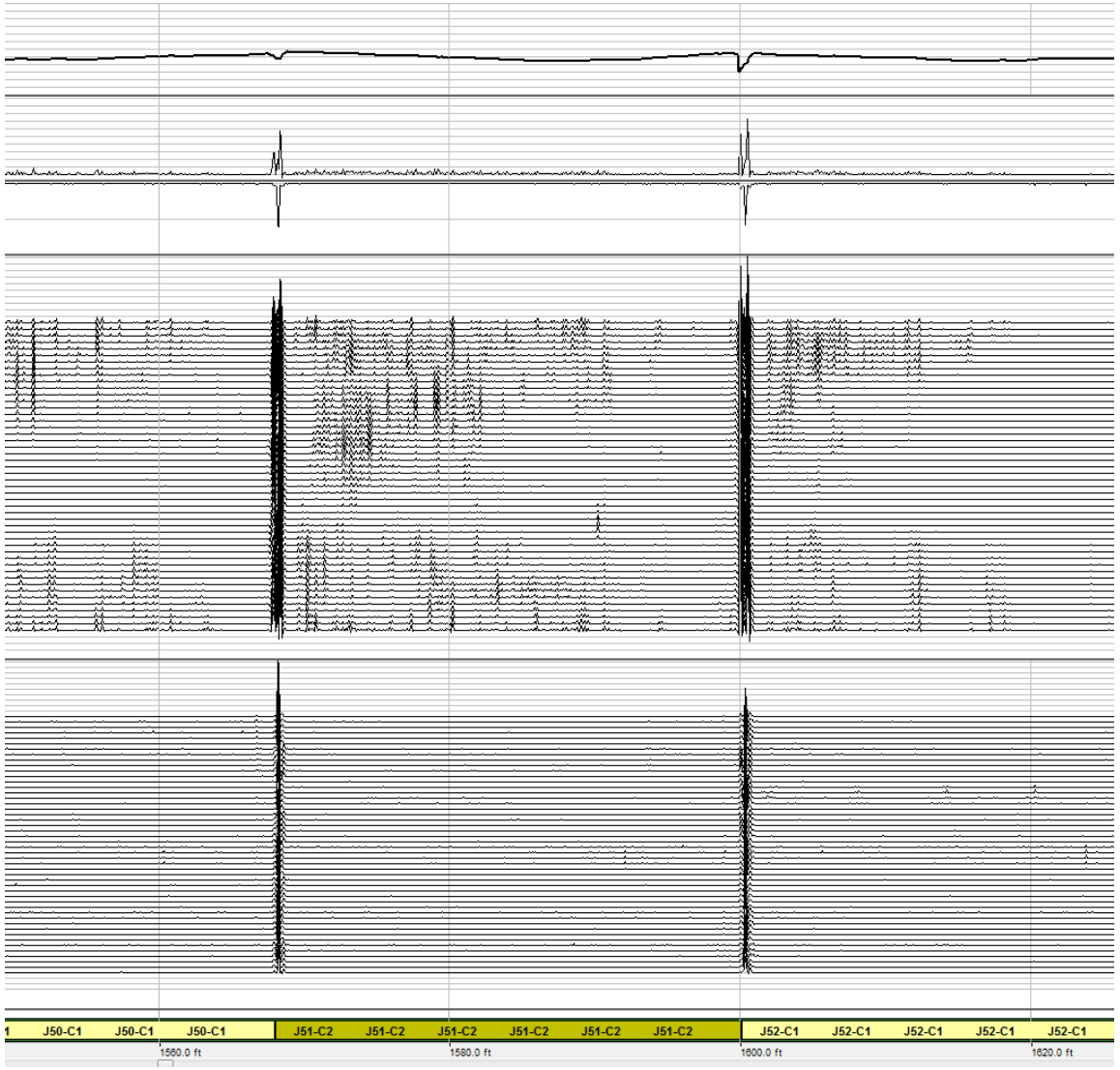
MAX FL →

MAX DIS →

FL Channels →

DIS Channels →

Joint Classification & Numbering →



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Reporting – Feature List Example

Log Depth	Dist UHC	Joint Length	Identifier	Class	Description	Surface Indication	Length	Width	Depth	Dim Class	P Safe Barlow	ERF Barlow	P Safe B31G	ERF B31G	P Safe Mod B31G	ERF Mod B31G	P Safe Effective Area	ERF Effective Area	NWT	Comment
ft	ft	ft					in	in	%		psi		psi		psi		psi		in	
1934.73	31.21	30.10	C-62	Collar															0.272	
1964.83	30.10	31.05	C-63	Collar															0.272	
1992.92	28.09	31.05	MLCB-63-1	Metal Loss Call Box		Internal	0.6	0.9	20	PITT	3416	0.381	4645	0.280	4987	0.261			0.272	
1995.88	31.05	33.27	C-64	Collar															0.272	
2029.15	33.27	26.79	C-65	Collar															0.272	
2055.94	26.79	32.65	C-66	Collar															0.272	
2088.59	32.65	30.71	C-67	Collar															0.272	
2091.09	2.50	30.71	MLCB-67-1	Metal Loss Call Box		Internal	0.8	0.6	23	PITT	3275	0.397	4614	0.282	4950	0.263			0.272	
2119.31	30.71	32.72	C-68	Collar															0.272	
2152.03	32.72	31.83	C-69	Collar															0.272	
2183.86	31.83	26.99	C-70	Collar															0.272	
2210.85	26.99	31.39	C-71	Collar															0.272	
2242.24	31.39	33.77	C-72	Collar															0.272	
2276.00	33.77	30.52	C-73	Collar															0.272	
2306.53	30.52	33.15	C-74	Collar															0.272	
2339.68	33.15	33.22	C-75	Collar															0.272	
2372.89	33.22	32.75	C-76	Collar															0.272	
2405.64	32.75	31.99	C-77	Collar															0.272	
2421.40	15.75	31.99	MLCB-77-1	Metal Loss Call Box		Internal	1.0	2.9	29	CIGR	3035	0.428	4534	0.287	4850	0.268			0.272	
2421.50	15.86	31.99	MLC-77-1	Metal Loss Cluster		Internal	3.4	4.5	37	GENE	2693	0.483	3940	0.330	4046	0.321	4374	0.297	0.272	
2421.59	15.95	31.99	MLCB-77-2	Metal Loss Call Box		Internal	1.3	1.1	37	PITT	2693	0.483	4365	0.298	4631	0.281			0.272	
2421.67	16.03	31.99	MLCB-77-3	Metal Loss Call Box		Internal	1.3	1.7	31	GENE	2949	0.441	4442	0.293	4732	0.275			0.272	
2421.77	16.13	31.99	MLC-77-2	Metal Loss Cluster		Internal	3.6	2.8	31	GENE	2949	0.441	4058	0.320	4208	0.309	4585	0.284	0.272	
2421.89	16.25	31.99	MLCB-77-4	Metal Loss Call Box		Internal	0.8	1.1	21	PITT	3377	0.385	4617	0.282	4953	0.262			0.272	
2422.09	16.44	31.99	MLCB-77-5	Metal Loss Call Box		Internal	1.4	1.5	26	GENE	3163	0.411	4457	0.292	4753	0.274			0.272	
2422.09	16.45	31.99	MLCB-77-6	Metal Loss Call Box		Internal	1.0	1.0	21	PITT	3377	0.385	4586	0.283	4916	0.264			0.272	
2422.17	16.53	31.99	MLC-77-3	Metal Loss Cluster		Internal	3.0	1.9	22	GENE	3331	0.390	4300	0.302	4536	0.287	4689	0.277	0.272	
2422.26	16.62	31.99	MLCB-77-7	Metal Loss Call Box		Internal	0.9	0.9	22	PITT	3331	0.390	4591	0.283	4922	0.264			0.272	
2422.61	16.96	31.99	MLCB-77-8	Metal Loss Call Box		Internal	1.1	0.7	20	PITT	3419	0.380	4574	0.284	4900	0.265			0.272	
2423.29	17.65	31.99	MLCB-77-9	Metal Loss Call Box		Internal	0.8	0.7	23	PITT	3304	0.394	4617	0.282	4953	0.262			0.272	
2423.82	18.17	31.99	MLCB-77-10	Metal Loss Call Box		Internal	1.2	1.7	22	PITT	3334	0.390	4539	0.286	4857	0.268			0.272	
2423.96	18.31	31.99	MLCB-77-11	Metal Loss Call Box		Internal	0.8	0.7	24	PITT	3239	0.401	4602	0.282	4935	0.263			0.272	
2425.22	19.57	31.99	MLCB-77-12	Metal Loss Call Box		Internal	1.6	1.0	24	PITT	3238	0.402	4435	0.293	4723	0.275			0.272	
2425.99	20.35	31.99	MLCB-77-13	Metal Loss Call Box		Internal	1.0	1.4	28	PITT	3077	0.422	4527	0.287	4842	0.268			0.272	
2426.23	20.59	31.99	MLCB-77-14	Metal Loss Call Box		Internal	0.9	0.9	31	PITT	2949	0.441	4550	0.286	4869	0.267			0.272	
2426.28	20.63	31.99	MLCB-77-15	Metal Loss Call Box		Internal	1.2	0.9	22	PITT	3334	0.390	4539	0.286	4857	0.268			0.272	
2426.60	20.95	31.99	MLCB-77-16	Metal Loss Call Box		Internal	1.5	1.3	33	GENE	2864	0.454	4358	0.298	4622	0.281			0.272	
2426.75	21.10	31.99	MLC-77-4	Metal Loss Cluster		Internal	5.0	5.3	33	GENE	2864	0.454	3920	0.332	4015	0.324	4360	0.298	0.272	
2426.81	21.16	31.99	MLCB-77-17	Metal Loss Call Box		Internal	0.9	1.8	23	PITT	3291	0.395	4586	0.283	4915	0.265			0.272	
2426.90	21.26	31.99	MLCB-77-18	Metal Loss Call Box		Internal	1.3	3.0	21	GENE	3377	0.385	4528	0.287	4843	0.268			0.272	
2427.21	21.57	31.99	MLCB-77-19	Metal Loss Call Box		Internal	1.1	1.8	23	PITT	3291	0.395	4552	0.286	4873	0.267			0.272	

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Summary

- Advanced analysis from three axes of magnetic flux leakage data
  - Depth Based Analysis – Length, Width, Depth
  - Pressures Based Analysis
    - Based on Client Selected Parameters
    - Five (5) formulae to determine Burst Pressure
      - Barlow, Canadian Z341, B31G, Modified B31G, Effective Area
    - Application of Safety Factors
    - Criteria for Feature Interaction
- Feature based reporting
  - Detailed information on each feature in the well

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Integrity Explorer – INTeX

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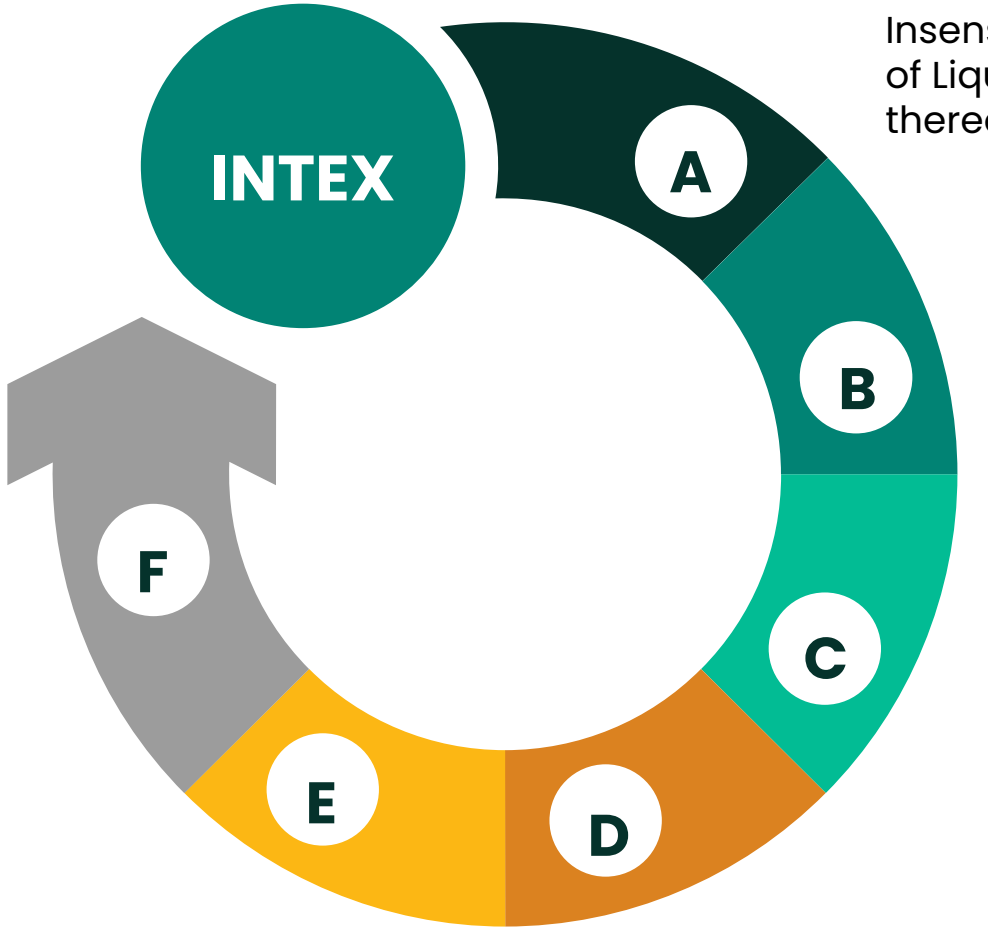
Wellbore Conditions Impacting Evaluation

- Green Cement: Most companies estimate 72 hours until cement is cured enough for evaluation
- Microannulus: From thermal contraction, thick mill varnish or hydrostatic differential from cementing to logging
- Thin Cement Sheath: At least 0.75” to attenuate signal fully otherwise good cement could look quite pessimistic
- Poor bonding to Formation: Thick wall cake, soft or unconsolidated formations
- Pipe in Pipe Conditions: Highly reflective surface of outer pipe can give unusual responses
- Lightweight Cement / Exotics / Contaminated cement

Integrity eXplorer Ultra HD



Wellbore

Insensitivity to type of or density of Liquid in the borehole, or lack thereof (air) including live wells

Casing Type

Ability to acquire data in casings up 10 1.2" thick Coated Pipe or 28% Cr pipe

Deliverables

Real-time answer product is available, not requiring timely post-processing

Resolution

Tool measurement physics allow for a significant improvement in resolution including CW & CCW.

Cement

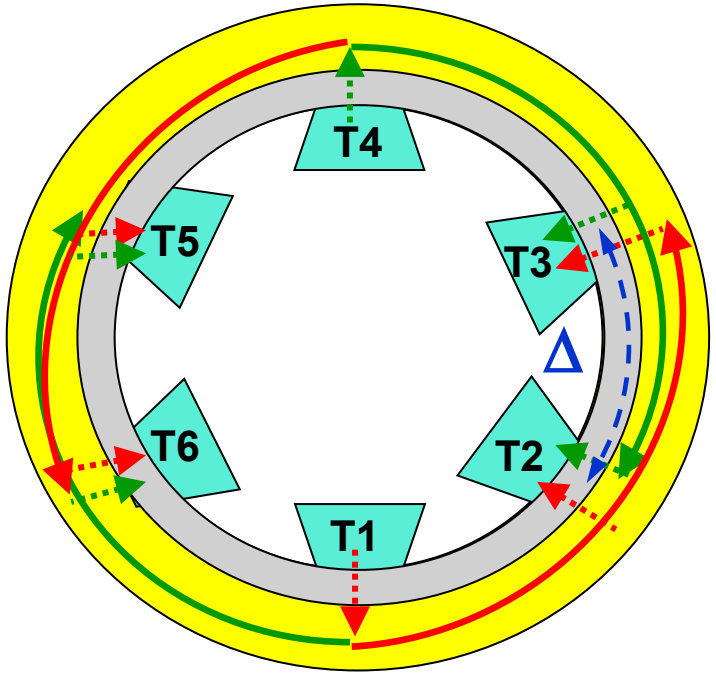
All types of cement density including foam.

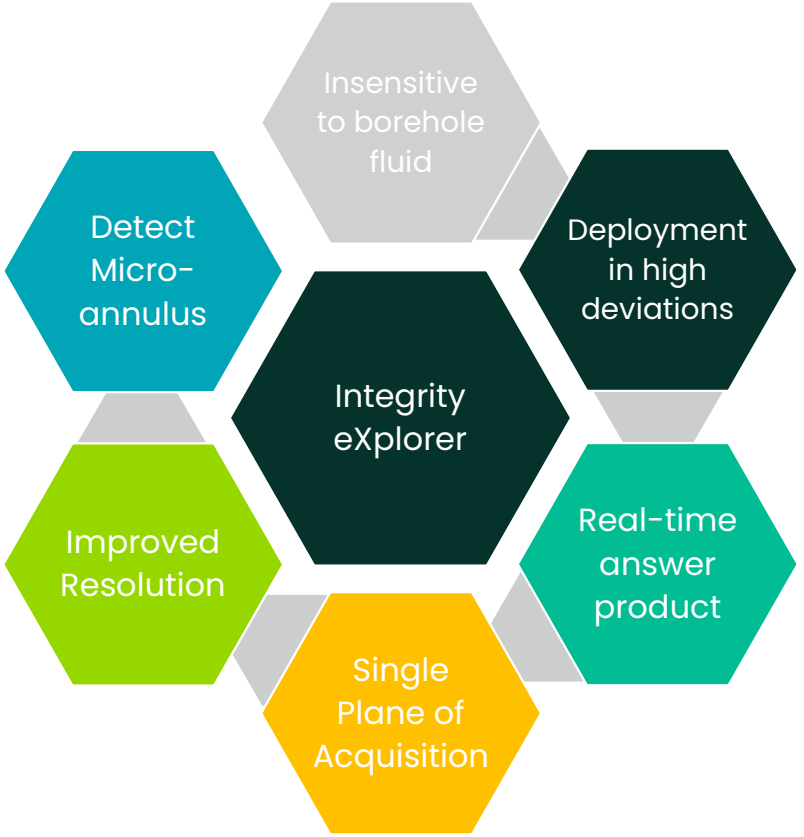
Micro-annulus & TIE

Overly of Flex & Shear allows for MA detection removing pressure pass. Allows for Flex & Shear TIE acquisition

Integrity Explorer

Temp. Rating (Deg. F)	Pressure Rating (PSI)	Casing thickness	Tool O.D. (in.)	Fluid Weight Restrictions	Min/Max Casing Sizes	Makeup length	Makeup weight
350 / 8 hrs.	20,000	**0.2 – 1"**	3.625"	None	**4.5/16"**	**20'**	**300 lbs.**





Sectored independently articulated 6 pads design

Multiples azimuthal measurements (12 CW and 12 CCW)

Fully compensated measurements

Centralized

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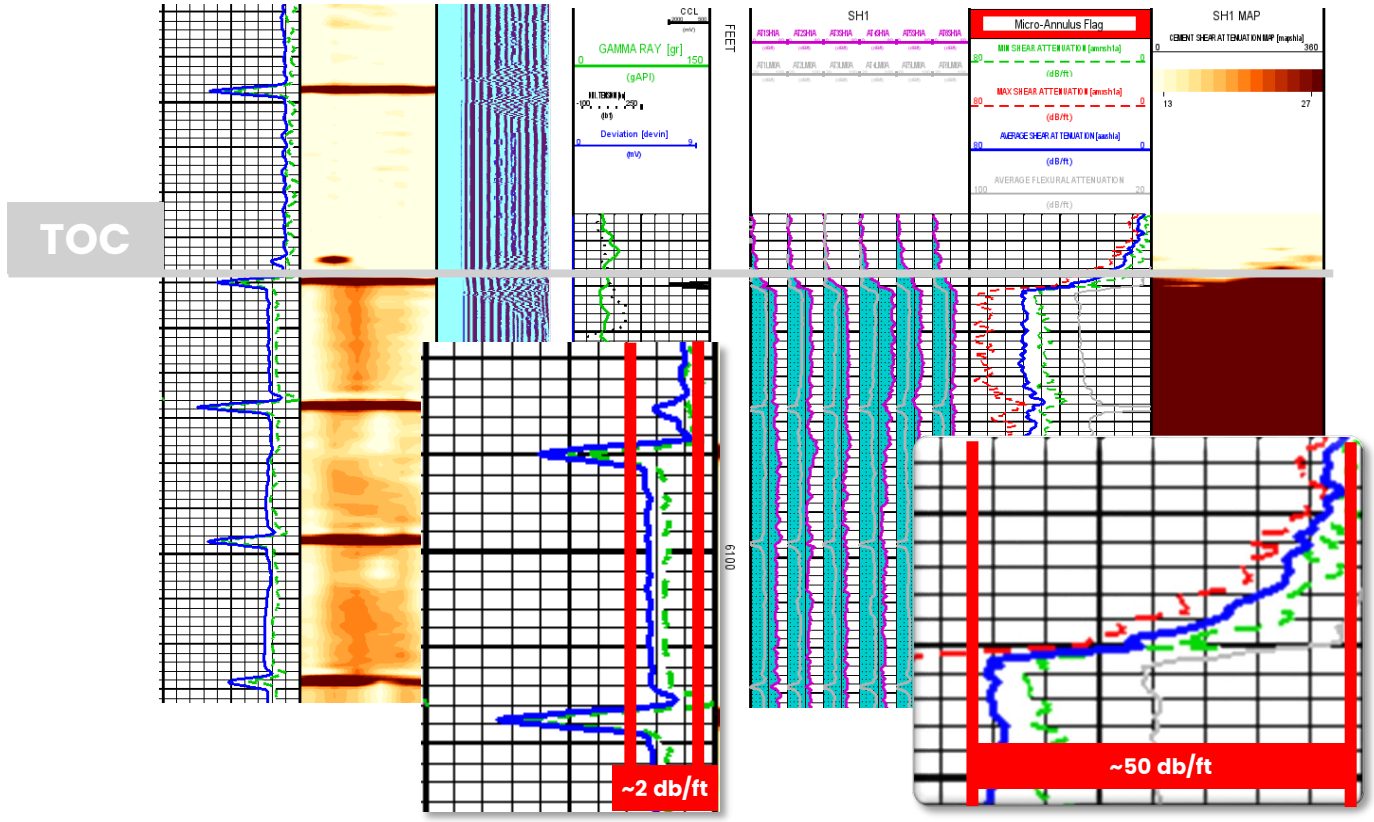
Lightweight Cement Evaluation

- Traditional cement evaluation techniques cannot accurately measure lightweight cement bond.
- Compressional measurement in example shows only ~ 2db/ft attenuation.
- High dynamic range shear measurement from INTeX shows ~50 db/ft attenuation.



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Cement Evaluation Logging in Gas-filled Borehole

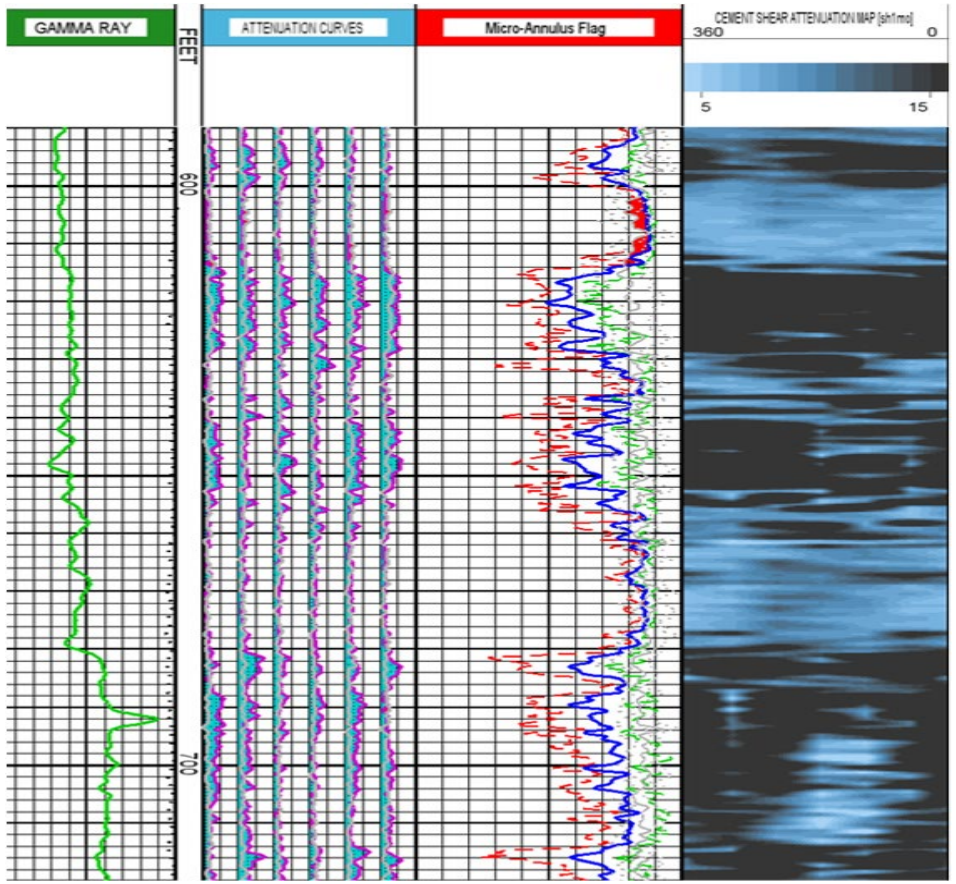
Location: Northern US

Customer Challenge:

- Evaluate cement in the absence of borehole fluids to determine zonal isolation

Results:

- Evaluated cement in gas-filled wellbore
- Removed the need for filling up the well with liquid
- Eliminated the need for additional operational and remedial services related to cement evaluation
- Determined long-term zonal isolation
- Saved valuable rig time and probable remediation costs



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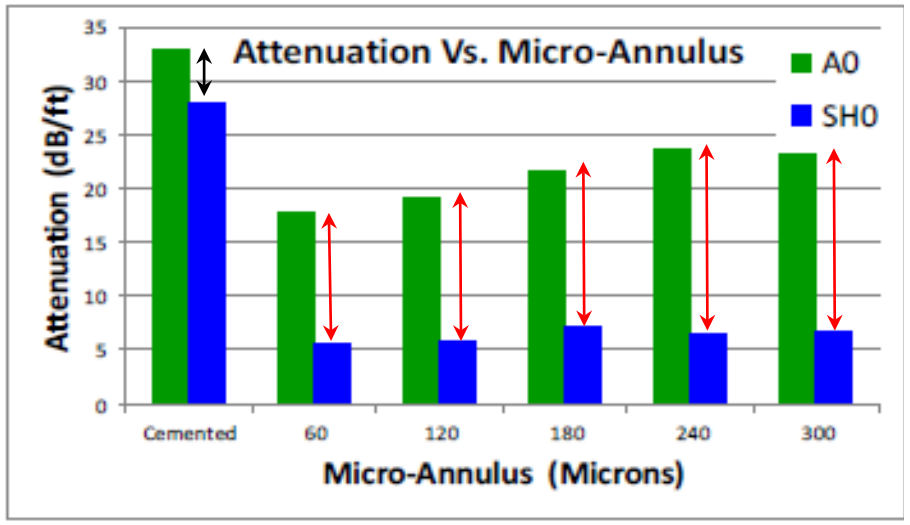
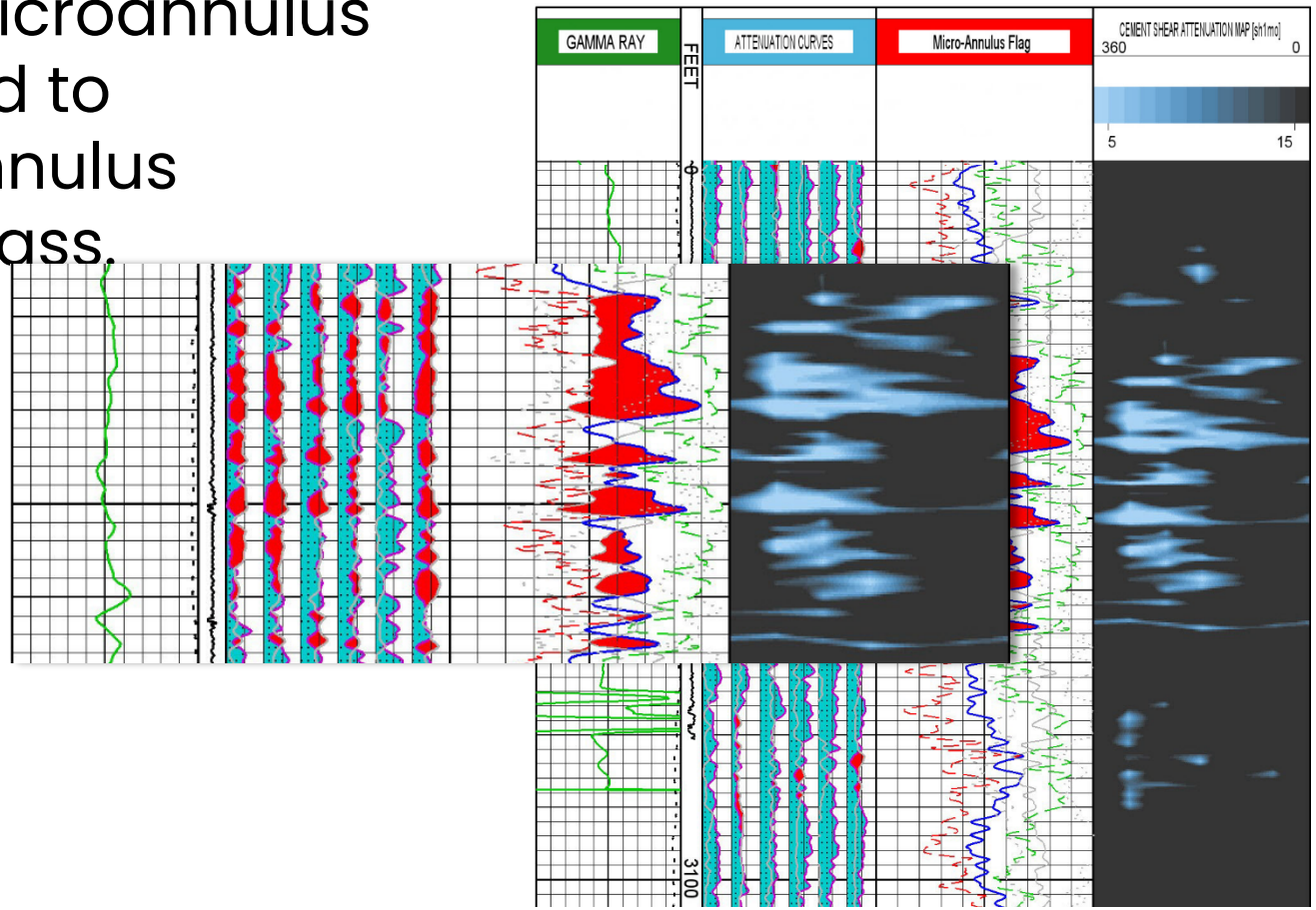
Microannulus Detection

The difference in response of microannulus to Shear and Lamb wave is used to determine presence of microannulus without a pressurized logging pass.





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Aperio Pulse Echo Applications and Functionality

Casing Inspection

- Resonance Frequency
- Transit time
- Internal & External Corrosion
- Casing ID & OD
- Casing Thickness
- Azimuthal measurements

Cement Evaluation

- Resonance Decay
- Acoustic Impedance
- Top of Cement
- Top of Solids
- Casing Cut Depth
- Azimuthal Cement Placement

Simultaneous Evaluation

- Pulse Echo method
- Casing Inspection
- Cement Evaluation

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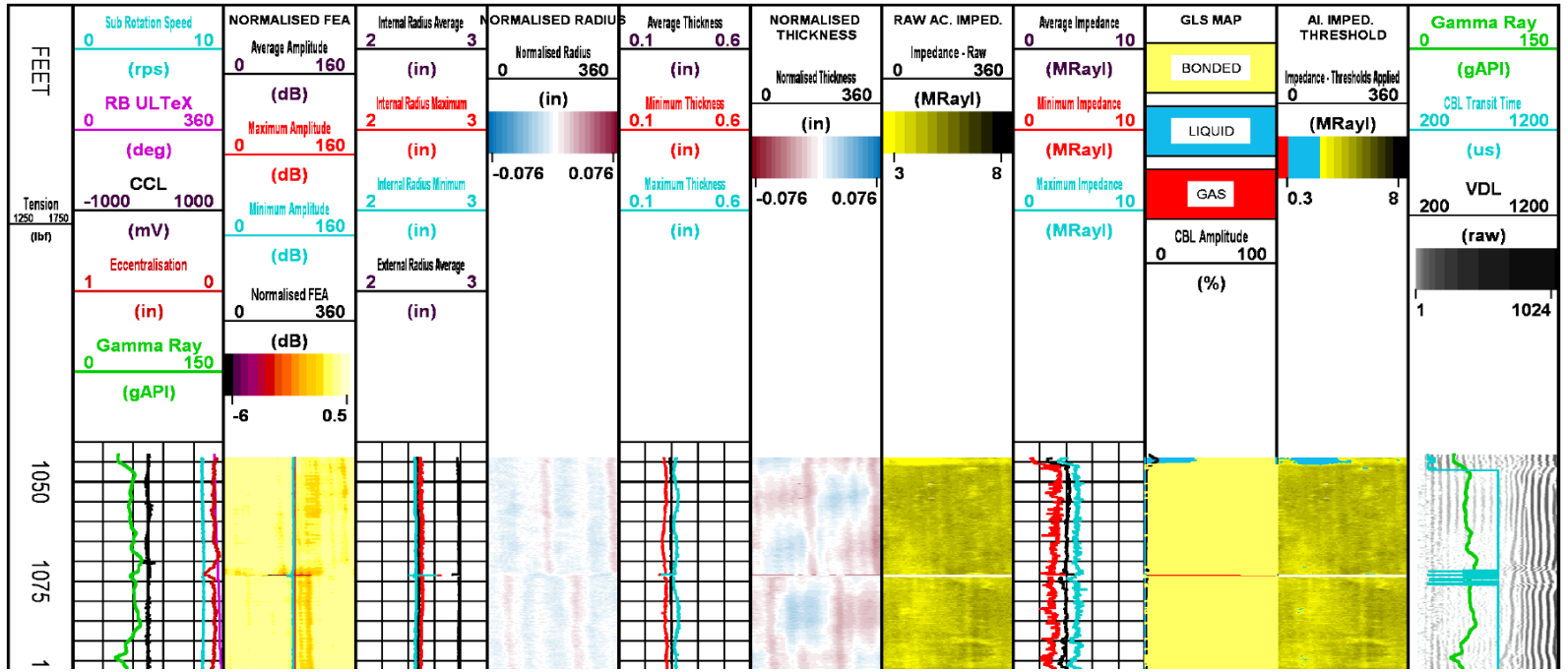
Aperio Pulse Echo



Challenge	Solution
Simultaneous Cement & Casing Evaluation	Yes
Casing Sizes	5 in to 20 in
Borehole OBM weights	Up to 1.6 g/cc
Maximum operating temperature	350 DegF
Maximum operating pressure	20,000 PSI
Maximum tool diameter	3-5/8 in
Azimuthal resolution	6 degrees
Vertical Resolution	1.5 in
Casing Thickness Range	0.2 in – 1* in
Logging Speed (recommended)	10-40 ft./min

***Provisional specifications, subject to change.**

Currently there are active engineering tests ongoing to qualify the service to be ran in higher mud weights and different casing types, casing thickness ranges and cement types and cement weights.

Combinable with DAL or INTEX

- ULTeX & DAL – Gas Micro annulus when combined with Aperio PE
- ULTeX & DAL – Liquid Micro annulus when combined with Aperio PE
- ULTeX & DAL – Top Cement and Top of Solids identification and acquire VDL data
- ULTeX & INTeX – used to differentiate solids (Barite) from cement bond, higher confidence in results combining two independent methods and combined casing and well integrity analysis

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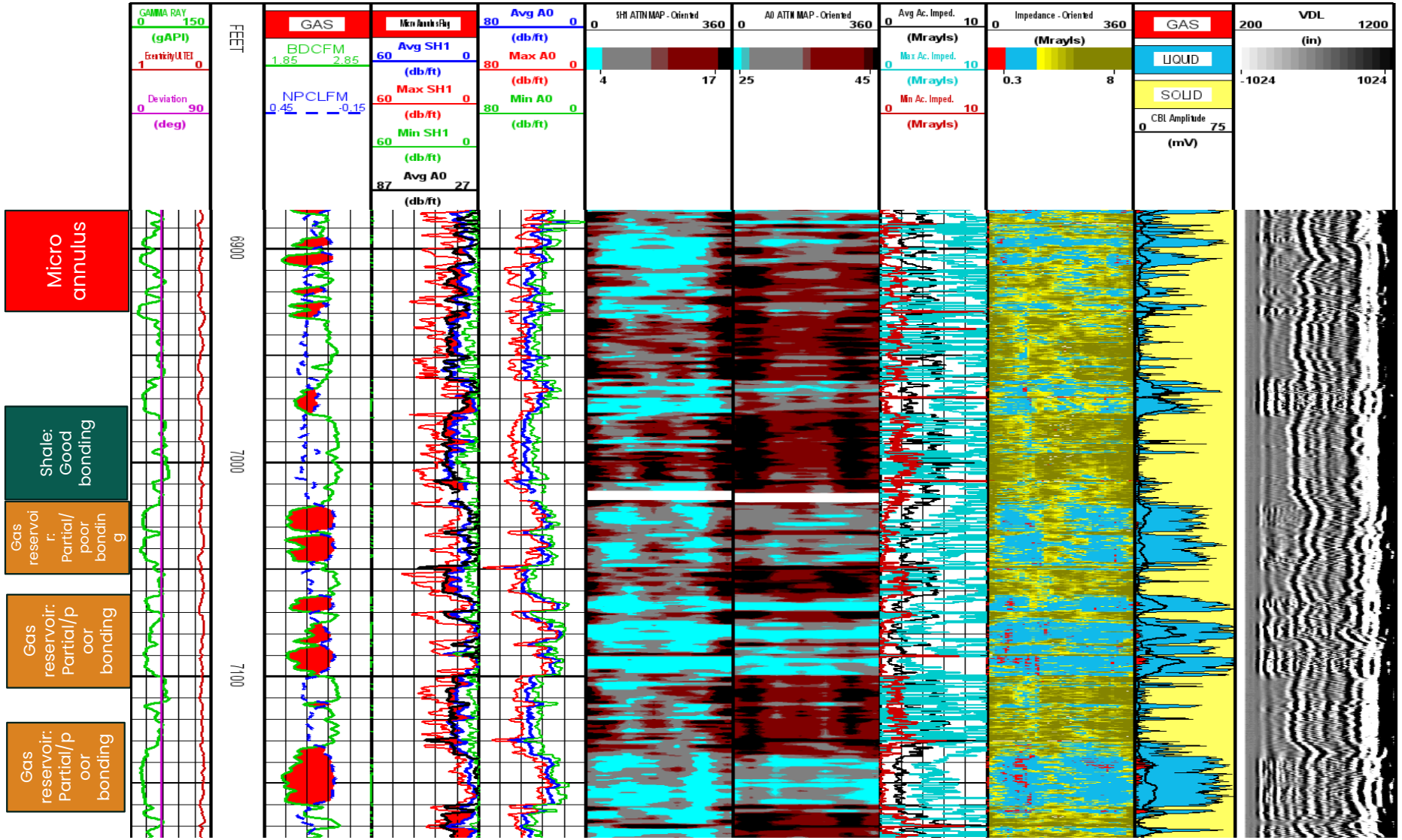
Aperio Pulse Echo - INTeX Combination



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Questions?

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