



**Energize the CEE Region
Focusing Reliable Energy Security**

Workshop

16-17 November 2023, Visegrád

Society of Petroleum Engineers

Drilling Solutions for Geothermal applications

Focusing on enhanced performance, directional drilling and real-time logging while drilling solutions in HPHT environment



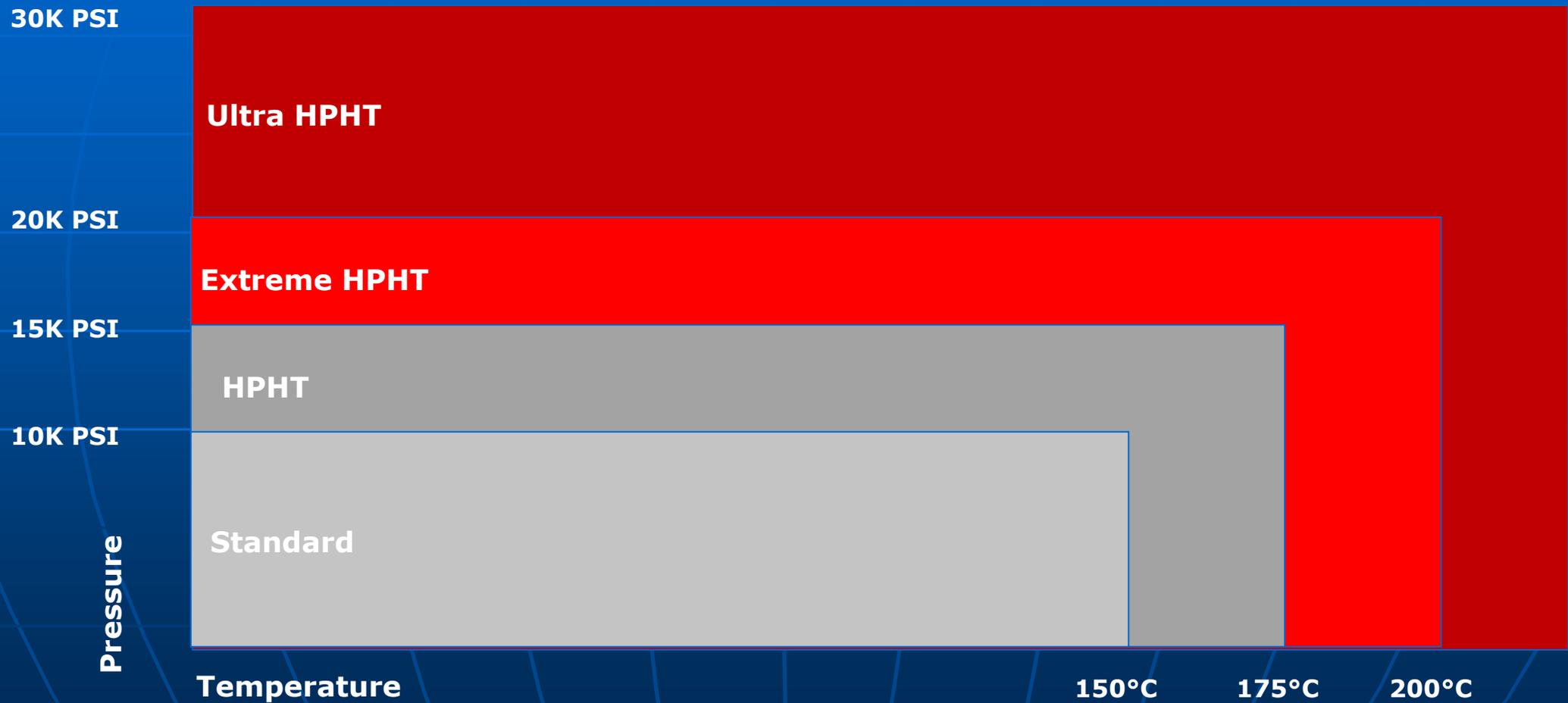
16 November 2023
István Árvai

Geothermal Drilling challenges

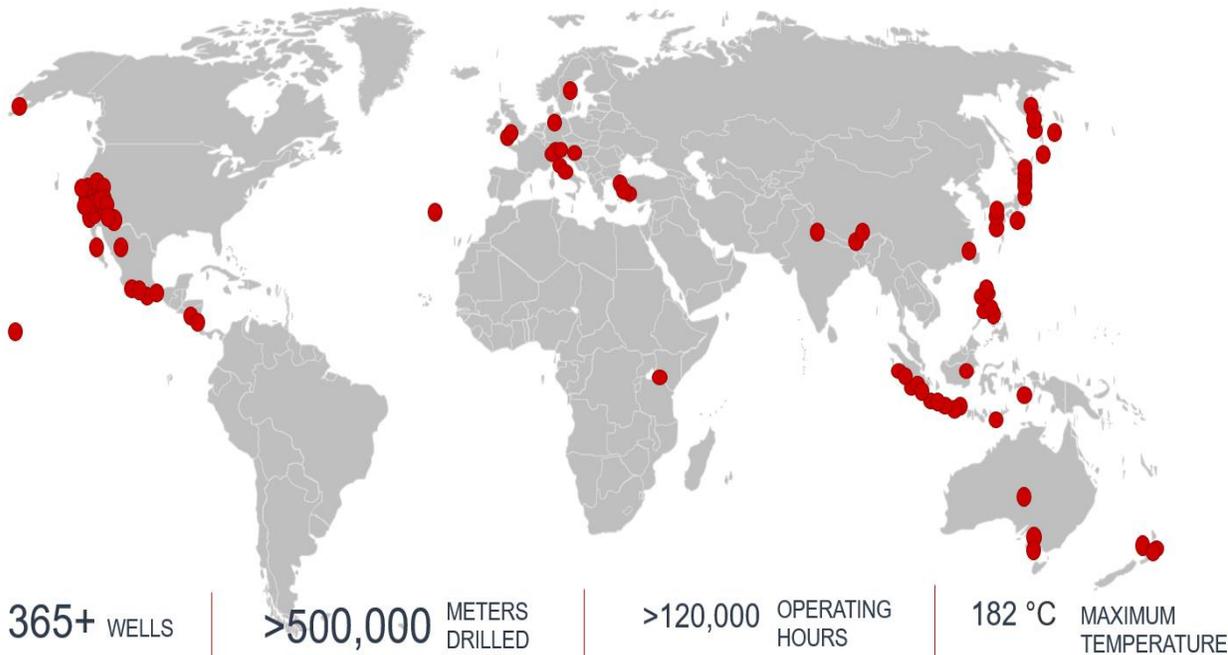
- Temperature! Drilling deeper and deeper into hotter and hotter rock.
- Low rate of penetration (ROP)! Harsh drilling environment, hardness of igneous and metamorphic rocks
- Reservoir characterization, fracture system and associated issues such as lost circulation and severe wellbore stability
- Higher cost than conventional Oil & Gas drilling



Feeling the heat



Global Geothermal Footprint



70

Years of geothermal service experience

392°F

Rating for Quasar L/MWD

+840°F

Geothermal well successfully cemented

350°F

Rating for continuous flowmeter

HPHT Solutions – Directional Drilling

Mud Motors

Positive Displacement Motors



- Motors Center of Excellence (MCE) offering customized Motor design for specific basin challenges
- High temperature elastomers (160°C to 188°C)
 - 175°C - 200°C (Field trials)
- Metal to metal (rotor to stator) power sections

iCruise/Geo-Pilot

Rotary Steerable Systems



- Legacy Solar 175°C Geo-Pilot RSS
- iCruise intelligent RSS 160°C (Field trials)
- iCruise intelligent RSS 175°C (2026)

Steerable Turbines

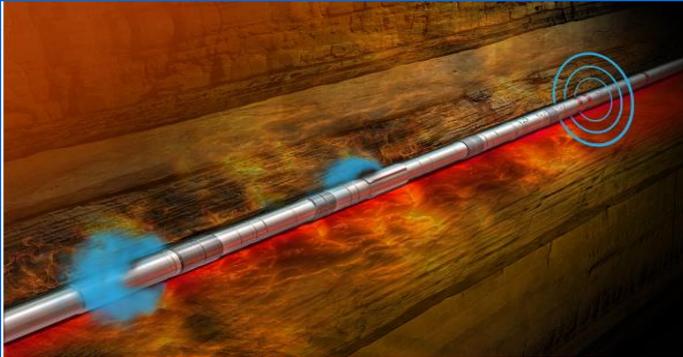


- Non-elastomeric configurations rated to 572°F (300°C) with high reliability
- Significant available pressure 1500–2000 psi (10-14 MPa)
 - High dogleg trajectories
- Drag friction limits progress into laterals for oriented drilling (like PDMs)

HPHT Solutions – Measurement & Logging While Drilling

QUASAR 200°C

Ultra High Temperature



- Quasar Pulse Service – M/LWD Directional and Formation Evaluation Measurements, Gamma Ray, Pressure-While-Drilling (PWD), and Telemetry
- Quasar Trio - Triple Combo Service (Resistivity, Neutron & Density)
- Up to 200°C/392°F and 172MPa/ 25,000 psi
- Available in 8 1/2" and 6" hole sizes

SOLAR 175°C

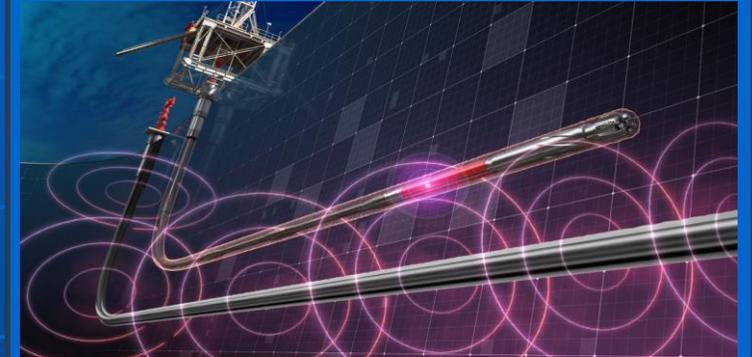
Legacy High Temperature



- Covers the majority of M/LWD measurements
- Since 1992

Magnetic Ranging

Aurora™, RMRS™, etc.



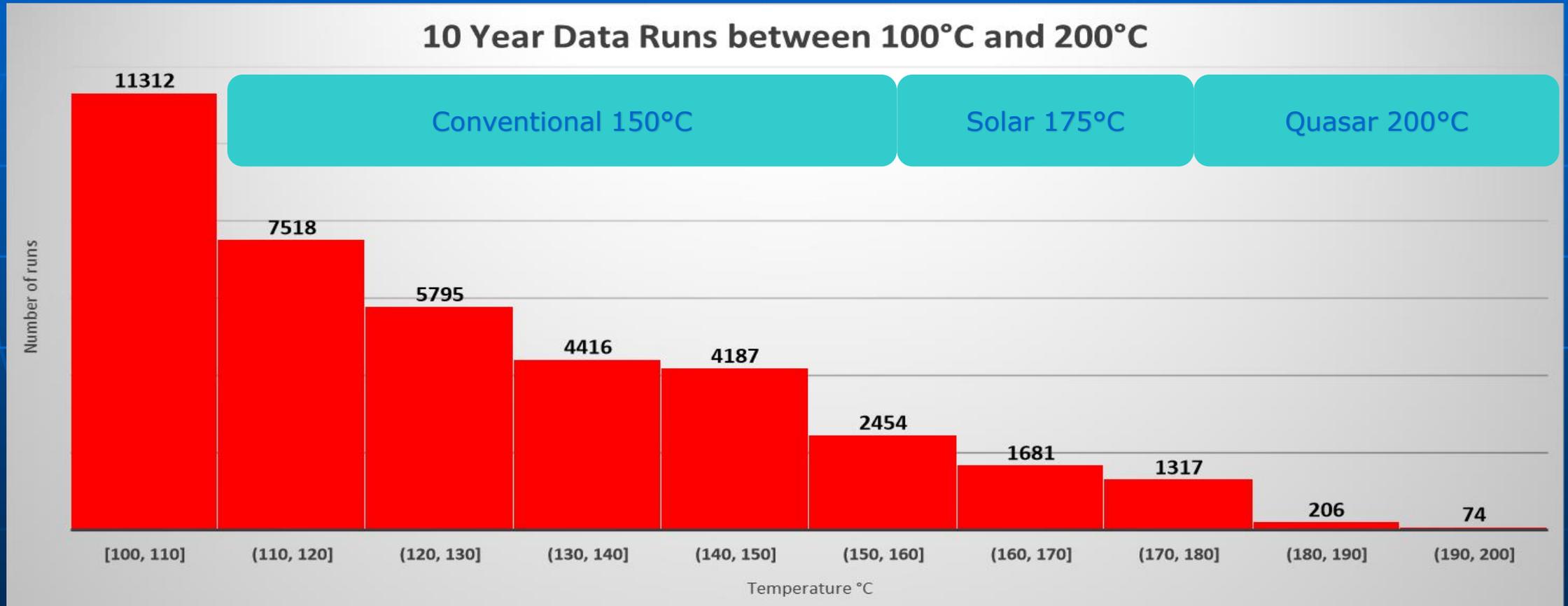
- Applicable in closed-loop EGS and AGS system
- Relative placement between parallel legs
 - Facilitate accurate and efficient intersections
- Current technologies are available to execute scope of work

Reliable Reach and Accurate Measurements

Tool/Sensors	Maximum Operation Pressure (psi) & Temperature (°C)							
	9½"		8"		6¾"		4¾"	
Rotary Steerable	30,000	175	30,000	175	30,000	175	30,000	175
Directional	30,000	175	30,000	175	30,000	200	30,000	200
PWD	30,000	175	30,000	175	30,000	200	30,000	200
Gamma	30,000	175	30,000	175	30,000	200	30,000	200
Resistivity	30,000	175	30,000	175	30,000	175	25,000	200
Density	25,000 ¹	150	30,000	175	30,000	175	25,000	200
Neutron	25,000 ¹	150	30,000	175	30,000	175	25,000	200
Sonic	25,000	175	30,000	175	30,000	175	30,000	175
Formation Tester	30,000	175	30,000	175	30,000	175	25,000	150
DrillDOC® Collar	25,000	175	30,000	175	30,000	175	25,000	175

Drilling high temperature & deviated wells

- 38'694 Global Positive Displacement Motor Runs 100°C – 200°C
- Solution: Tier technology into different temperature ratings

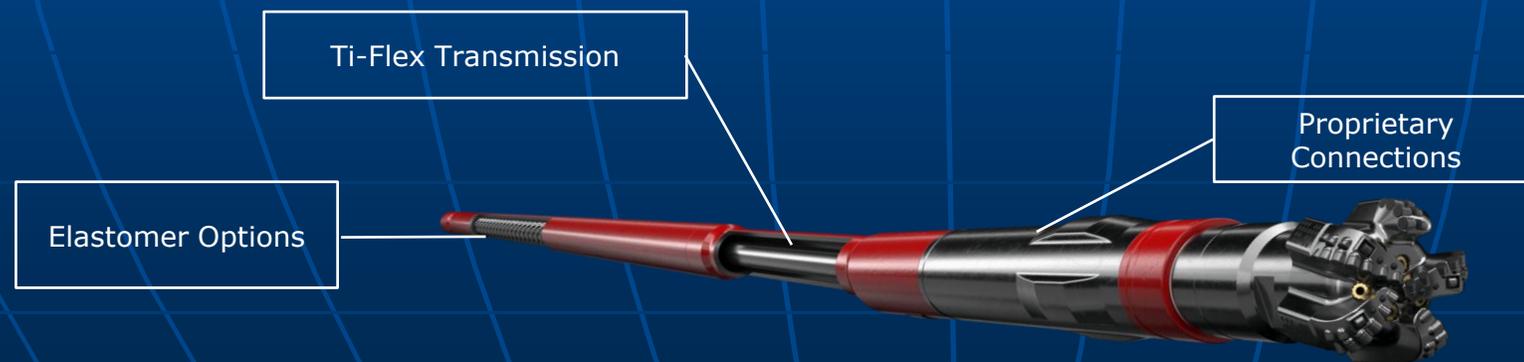


Positive Displacement Mud Motors (PDM)

- High temperature elastomers (320°F to 370°F [160°C to 188°C])
- Applicable for high dogleg trajectories in oriented mode
- Motors Centers of Excellence (MCE) deliver customized motor designs for specific basin challenges

Advancing Technology

- Metal to metal power sections
 - Non-elastomeric
 - Rotor to stator
 - Successful trial with NitroForce® High-Torque, High-Flow Motor transmission
 - Removes temperature de-rating of elastomers on constant velocity joint (CV) boot



Rotary Steerable Systems

- iCruise X[®] RSS rated to 302°F (150°C)
- SOLAR[®] Geo-Pilot[®] RSS rated to 347°F (175°C) with over 20 years experience
- High dogleg applications and lateral drilling

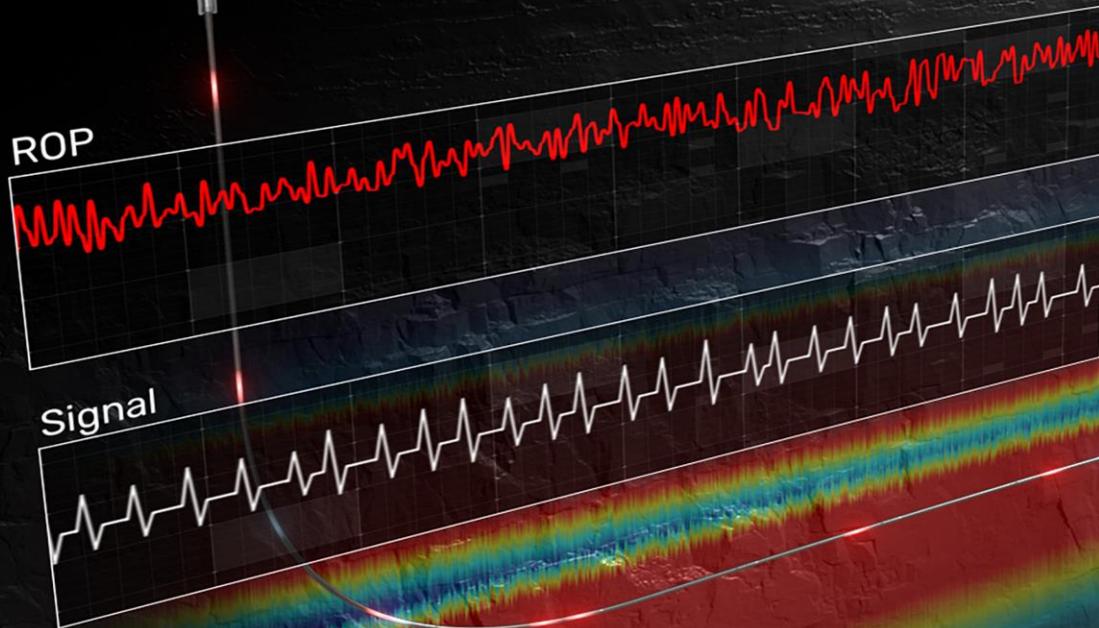
Advancing Technology

- High temperature dynamic metal seals and elastomers
- 572°F (300°C) electronics: power electronics, sensors for direction and inclination
- Oils maintain viscosity throughout the temperature range
- Field Trials:
 - High-temperature iCruise RSS with 320°F (160°C) capability
- Planned Development:
 - iCruise RSS 347°F (175°C) variants targeted 2024 - 2026



Telemetry & Directional Solutions

- Survey/directional telemetry essential for well trajectory
- Mud pulse telemetry due to extreme depths and pressures
- Similar technology requirements as RSS
- Rated to 200°C

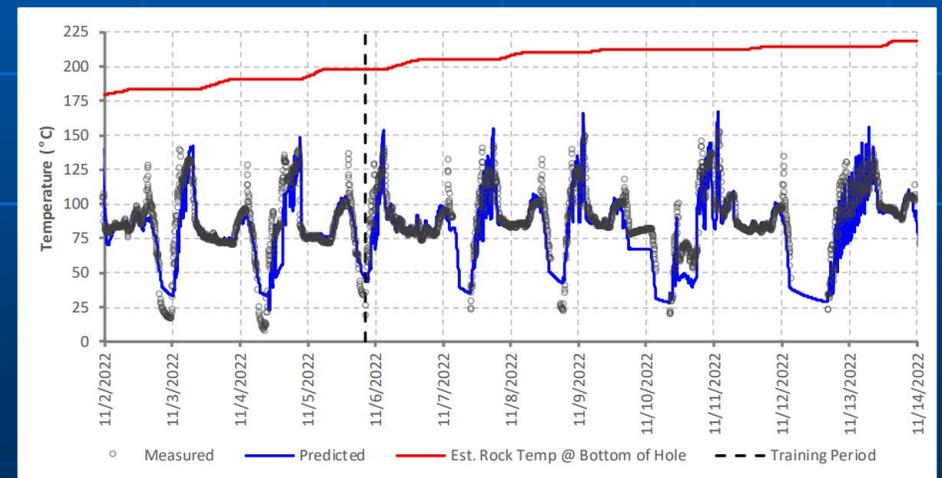
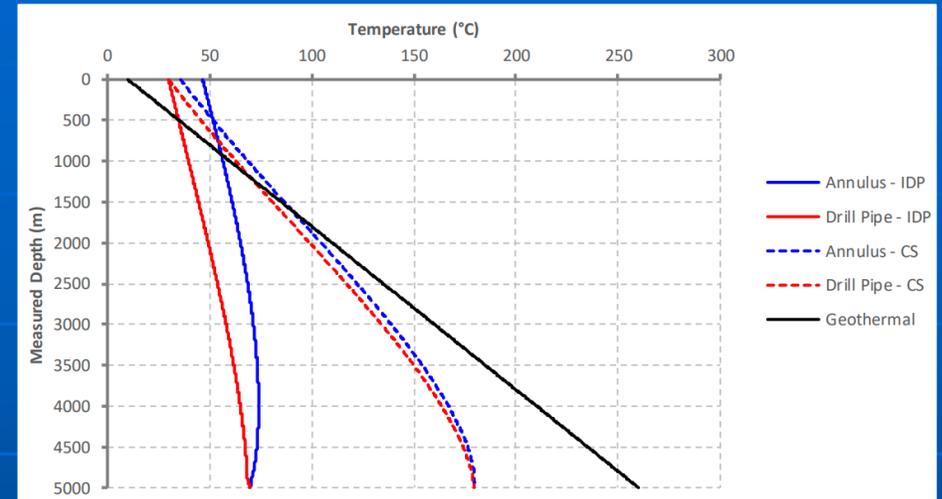


Advancing Technology

- 572°F (300°C) magnetometers/fluxgates need to be developed
- Lab calibration challenges and extreme temperatures
- 572°F (300°C) Electromagnetic Multi Shots (EMS)/Single Shots recorded surveys currently commercially available in retrievable flasked form, but not as real-time transmission

Insulated Drill Pipe

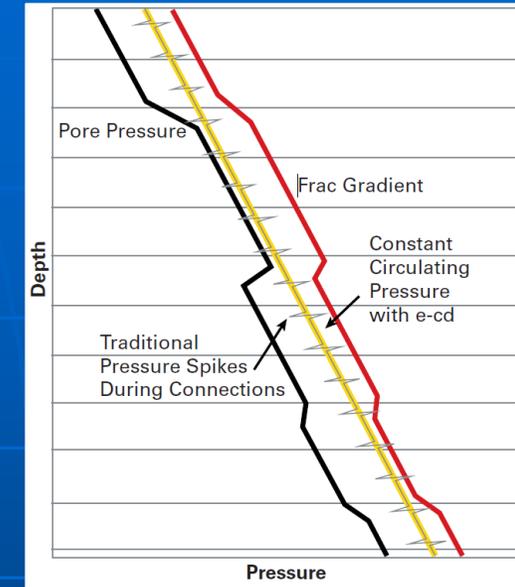
- Insulated drill pipe has the potential to increase temperature resistance vs. conventional drill pipe
- Can allow conventional 302°F (150°C)/347°F (175°C) equipment to be deployed
- Note the transient heat effects at connections where temperature increases – this is an observed fact from our own HPHT memory data over connections and on trips in hole
- Transient heat gain can be managed with Halliburton e-cd™
- See <https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2023/Holmes.pdf>



Figures from “Enablement of High-Temperature Well Drilling for Multilateral Closed-Loop Geothermal Systems (stanford.edu)”

Halliburton e-cd™

- Halliburton e-cd™ is an ENI patented continuous circulation system
- Modified float valve with a side entry manifold – made up to drill pipe and racked back
- Allows up to 1200 gpm to be continuously circulated while making connections
- Originally designed to solve the annular pressure fluctuations associated with pumps on/pumps off
- Manages transient temperature fluctuations in exactly the same way to flatten temperature increase over connections



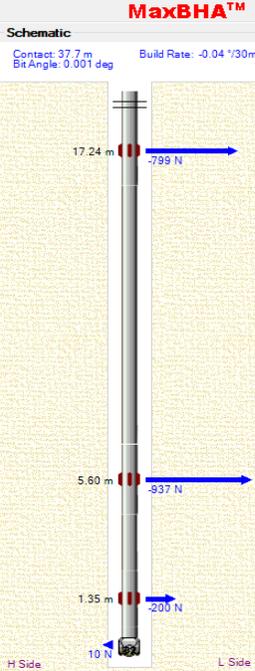
Drilling above 200°C: So how can we drill a given trajectory without motors or RSS?

- **KEEP IT SIMPLE!** Technologies to assist include:
 - Force Modelling
 - Sperry Drilling TurboPower Turbines (300°C)
 - EMS at run TD to survey the wellbore (315°C)
 - Wear resistant Stabilization
- Future state: *Customer collaboration* to develop appropriate technology, like the QUASAR project



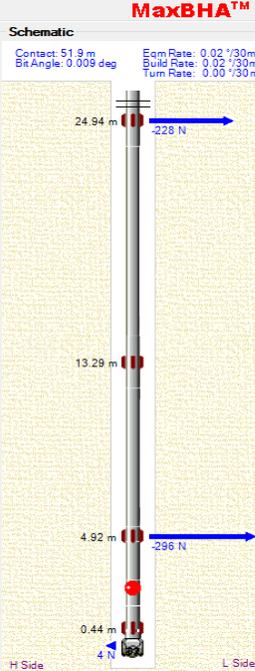
Force Balanced Packed Rotary BHA

COMPONENT DATA		
OD (mm)	Length (m)	Description
171.5	0.35	PDC (Gauge: 215.9 mm)
171.5	2.00	Non-Mag Integral Blade c/w totco ring
165.1	2.00	Pony Collar
171.5	2.50	Non-Mag Integral Blade
165.1	9.14	NMDC
171.5	2.50	Non- Mag Integral Blade
165.1	3.05	Pony Collar
127	266.00	5" X 3" SWDP #53.6 - NC50(IF)
174.5	9.50	6-3/4" Jar
127	57.00	5" X 3" SWDP #53.6 - NC50(IF)
165.1	9.00	Accelerator
168.4	2.00	DICV
127	28.50	5" X 3" SWDP #53.6 - NC50(IF)
127	91.44	5" X 4.276" - 19.5# 6-5/8" X 2-3/4" NC 50 (XH)



Force Balanced Packed Turbine BHA

COMPONENT DATA		
OD (mm)	Length (m)	Description
203.2	0.30	Diamond Bit (Gauge: 215.9 mm)
172	11.74	6-3/4" Turbodrill T1 LF ASD Bottom Stabilizer (Gauge: 212.7 mm, Pos*: 0.14 m) Top Stabilizer (Gauge: 214.3 mm, Pos*: 4.62 m)
171.5	2.50	Non-Mag Integral Blade c/w totco ring
165.1	9.14	NMDC
171.5	2.50	Non- Mag Integral Blade
165.1	3.05	Pony Collar
127	266.00	5" X 3" SWDP #53.6 - NC50(IF)
174.5	9.50	6-3/4" Jar
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Thank you!

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Location

Continental Europe



We **collaborate** to deliver engineered drilling solutions and reservoir insight to **maximize asset value**.

For more on Geothermal please visit <https://www.halliburton.com/en/products/geothermal>