*SPWLA France Chapter*
*Section française de la SPWLA "Society of Petrophysicists and Well Log Analysts"*

# TECHNICAL SESSION:

# *GEOTHERMICS* / GEOTHERMIE

## Tuesday, November 27th 2018, 14:00-17:45

***Salle Van Straelen, SGF***
***77, rue Claude Bernard – 75005 Paris***

***Préambule / Forewords***

Suite à la signature de la charte SPWLA, la S.A.I.D., Société pour l'Avancement de l'Interprétation des Diagraphies, se dénomme désormais « SPWLA France Chapter ».
Cette session technique s'est déroulée en lien avec le workshop conjoint EAGE/IGA/DGMK sur la géothermie profonde tenue les 8 et 9 novembre 2018 à Strasbourg. Notre session a repris certains des papiers EAGE et proposé un éclairage de la technique géothermique sous l'angle du forage, des diagraphies et de l'évaluation de formation.

*After having signed the SPWLA charter, S.A.I.D. Société pour l'Avancement de l'Interprétation des Diagraphies, is now called "SPWLA France Chapter".*
*This technical session took place in close link with the joint EAGE/IGA/DGMK workshop on deep geothermal energy held in Strasbourg on November 8th-9th. Our session re-used some of the EAGE papers and proposed a different view focused on the drilling, logging and formation evaluation aspects.*



**Information sur / *more information on:*** https://la-said.org

# TECHNICAL SESSION:
# *GEOTHERMICS /* GEOTHERMIE

*SGF, Maison de la Géologie – 77, rue Cl. Bernard 75005 PARIS*
*Tuesday, November 27th 2018*

## Programme / *Program*

| | | |
|---|---|---|
| **14:00 - 14:05** | ***Welcome, Safety and preliminary remarks*** | E. Caroli |
| **Introduction** | | |
| **14:05 - 14:25** | **Que savons-nous sur le régime thermique des bassins sédimentaires ?** ***What do we know about the thermal regime of sedimentary basins?*** | Jean-Luc Rudkiewicz IFP-EN |
| **Study case #1: Bassin parisien / *Paris basin*** | | |
| | ***Towards a new standard in well architecture and wireline logging in the Paris basin: the Cachan pilot site approach*** | |
| **14:25 - 14:45** | ■ ***Well architecture, drilling/geosteering*** | Mélanie Davaux GPC-IP, Pierre Ungemach, Geofluid |
| **14:45 - 15:10** | ■ ***Logging and formation evaluation*** | Chiara Cavalleri, Erik Wielemaker, SLB |
| **Study cases #2: Fossé rhénan / *Rhine graben*** | | |
| **15:10 - 15:40** | ***Wellbore logs in Rittershoffen, Alsace: Acquisition, analysis and integration for fractured reservoir characterization*** | Giovanni Sosio, SLB Régis Hehn, ES Géothermie |
| **15:40 - 16:10** | **Pause /** ***Break*** | |
| **Technologies / *Technologies*:** | | |
| **16:10 - 16:40** | ***DRIMP and Pseudo Impedance as a proxy of rock properties*** | Alfazazi Dourfaye, Dhaker Ezzedine, VAREL Intl |
| **16:40 - 17:10** | ***Using the Bit to Measure How Rock Reacts to Force: An* In Situ *Rock Mechanical Measurement*** | Josh Ulla FRACTURE-ID |
| **Generalités et conclusion / *Generalities and conclusion*** | | |
| **17:10 - 17:25** | ***The Geothermal Industry*** | Roger Henneberger, GeothermEx-SLB |
| **17:25 - 17:40** | ***Geothermal Well Logging and Analysis: Opportunities and Challenges*** | |
| **17:40 - 17:45** | **Clôture de la session** ***/ Session closure*** | E. Caroli |

# TECHNICAL SESSION:
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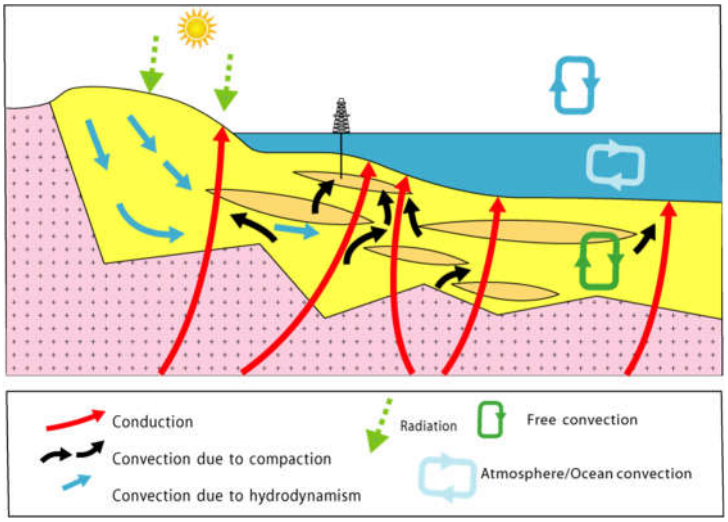
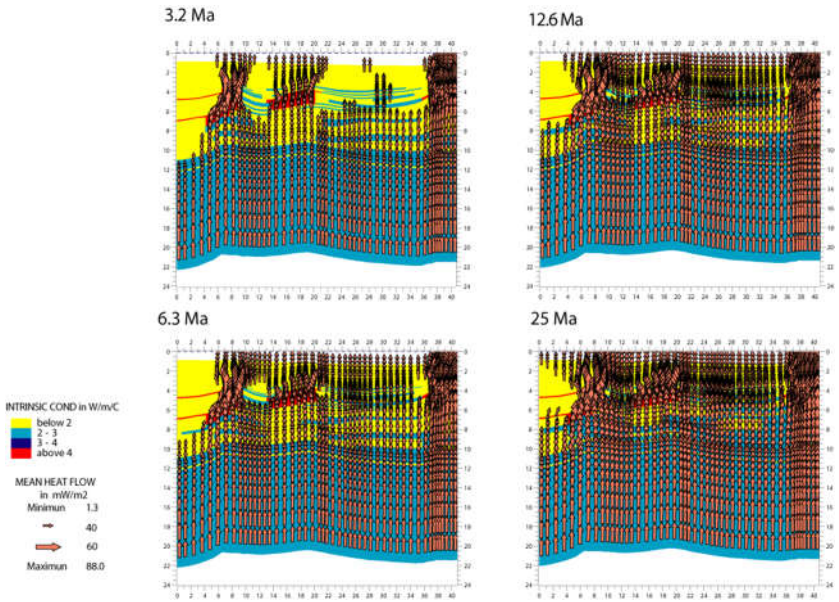
## Résumé des présentations / *Abstracts*

**Que savons-nous sur le régime thermique des bassins sédimentaires ? / *What do we know about the thermal regime of sedimentary basins ?,*** Jean-Luc Rudkiewicz*, IFP-EN

IFPEN has worked on the thermal regime of sedimentary basins and its modelling since it was recognized that temperature through geologic time impacts hydrocarbon generation.
Modelling present day temperature at basin scale sometimes requests to take the geological evolution into account. My presentation will recall the main physical aspects of heat transfer, show how to take those into account.




The definition of the area to model, and the need for dynamic of heat transfer, as illustrated below, will also be shown.




Examples cover the Paris Basin, the Arabian-Iranian collision belt and the Gulf of Mexico.

**Towards a new standard in well architecture and wireline logging in the Paris basin: the Cachan pilot site approach**

***Well architecture*** **, drilling/geosteering** by Mélanie Davaux*, Pierre Ungemach* and Miklos Antics, GPC-IP

The subhorizontal well (SHW) concept has long been advocated as a means for reclaiming heat from low permeability geothermal reservoirs. It was finally validated in 2018 on a Geothermal District Heating site located at Cachan, in a low to medium permeability, multi-layered reservoir. A single doublet succeeded in replacing two existing doublets, aged 34 years, thus pioneering a world premiere in geothermal well design.
The well path chosen was a compromise between single horizontal and multilateral well profiles, since the planned SHW trajectory intersects the whole multilayered reservoir sequence, thus cumulating its individual layer flow contributions. Given a thin layered reservoir setting and a long-legged drain, the latter would, in most instances, trend near horizontal and drain accordingly significantly larger flow amounts compared to a standard deviated well design.
Geosteering on the first well (GCAH1) is illustrated in Figure 1. In particular, XRD/XRF geochemical monitoring used alkaline and mineral proxies as porosity and diagenetic markers respectively, and metal oxide marine littoral (carbonate barrier) lithofacies indicators. The data set and experience gained on well GCAH1 were integrated into the geosteering of (injector) well GCAH2, which addressed a more complex reservoir and structural setting characterised by a poorly porous/pervious reservoir and fast varying upward dipping context.
The Cachan (DBH3) SHW project achieved technical and economic viability of the subhorizontal well concept in a multilayered reservoir sedimentology setting and densely populated urban and drilling environments.

***Wireline logging and formation evaluation*** by Chiara Cavalleri*, Erik Wielemaker* and Giovanni Sosio, Schlumberger

For geothermal projects to be economic requires a combination of high temperature and sufficient flow rates. Log data can help making this assement at the early stage and allow for optimal decision making. In the case of the Cachan project, a unique log combination was run to assess lateral homogeneity and flow potential in the target Oolithic limestone layers.
For the first time Nuclear Magnetic Resonance and advanced dipole sonic technology are applied to the geothermal project and in a lateral well to help define the reservoir quality and isolate layers with higher flow potential. In particular, standard NMR measurements typically applied to oil and gas industry have proven to be fully applicable to geothermal when describing the pores system, particle size and sorting, assessing the fluid movability through the thin layers.
The log results complement and integrate the porosity data derived from sonic and density logs adding important details. Deeper and non-standard azimuthal data of the sonic were also explored to complement the overall understanding of the different measurements and better define the structural model.
The logging tools were pushed to the desired depths using open hole tractor; thus, demonstrating that wireline conveyed logging in high angle well is a viable and effective approach.

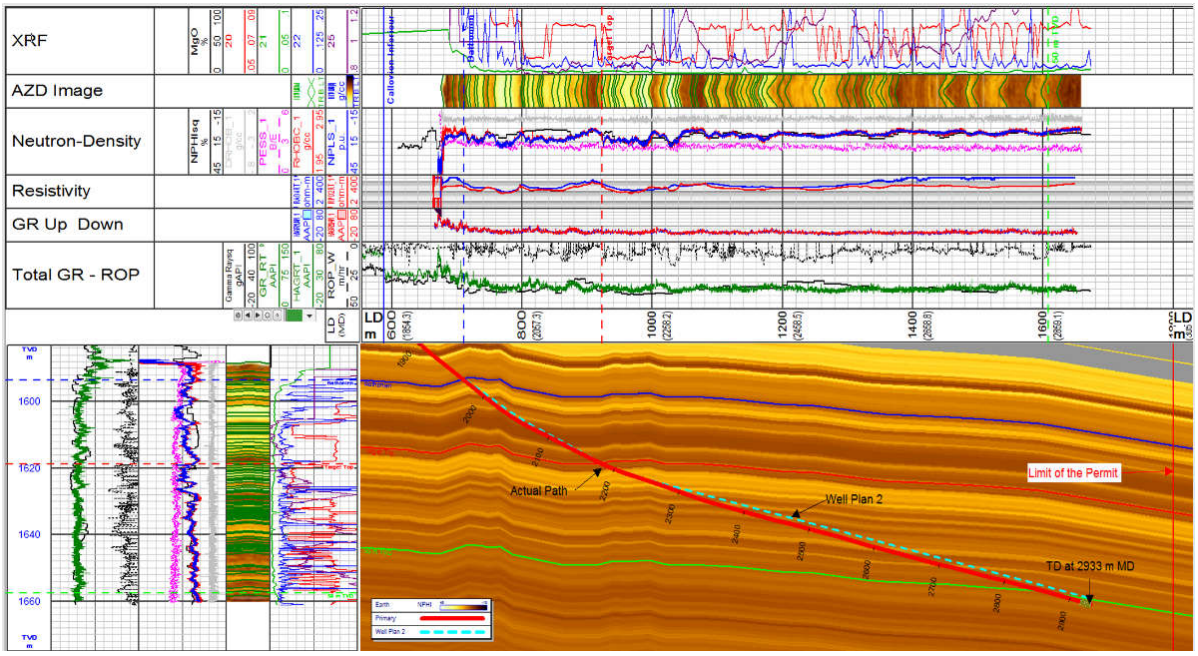



***Figure 1*** *Geosteering window: top, real-time parameters from mud logging (geochemical), LWD and drilling parameters; bottom left, logs from vertical offset wells; bottom right, curtain section with the planned and actual well trajectory plotted against a layered reservoir model*

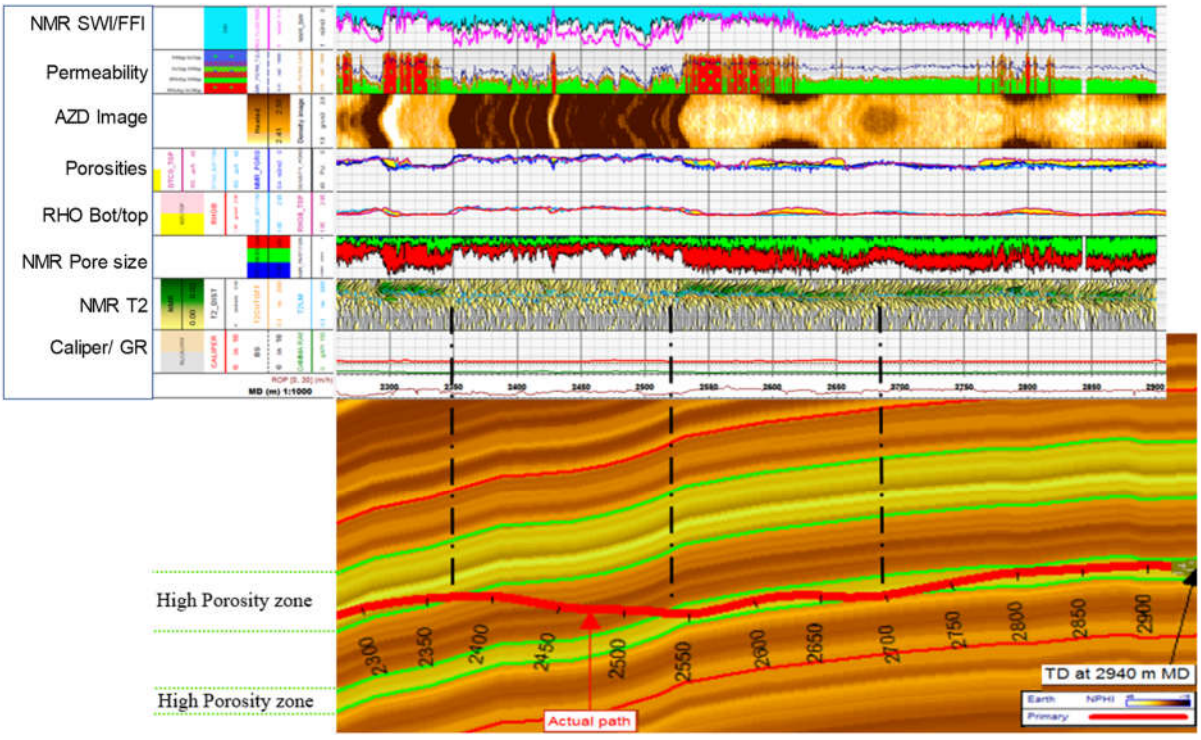



***Figure 2*** *The analysis of NMR logs together with sonic and density images allows for a quick evaluation of reservoirs quality and rock permeability distribution to highlight intervals with higher flow rate potential.*

**Wellbore logs in Rittershoffen, Alsace: acquisition, analysis and integration for fractured reservoir characterization**

Giovanni Sosio*, Andreia Mandiuc and Annalisa Campana, Schlumberger
Jeanne Vidal and Régis Hehn, ÉS Géothermie

The ECOGI project consists in a geothermal doublet in Rittershoffen (Alsace), producing heat for an industrial plant. The two wells, GRT-1 and GRT-2, targeted local natural fracture zones in the vicinity of a large normal fault across the Buntsandstein sediments and the granitic basement at a depth below 2000 m below surface.

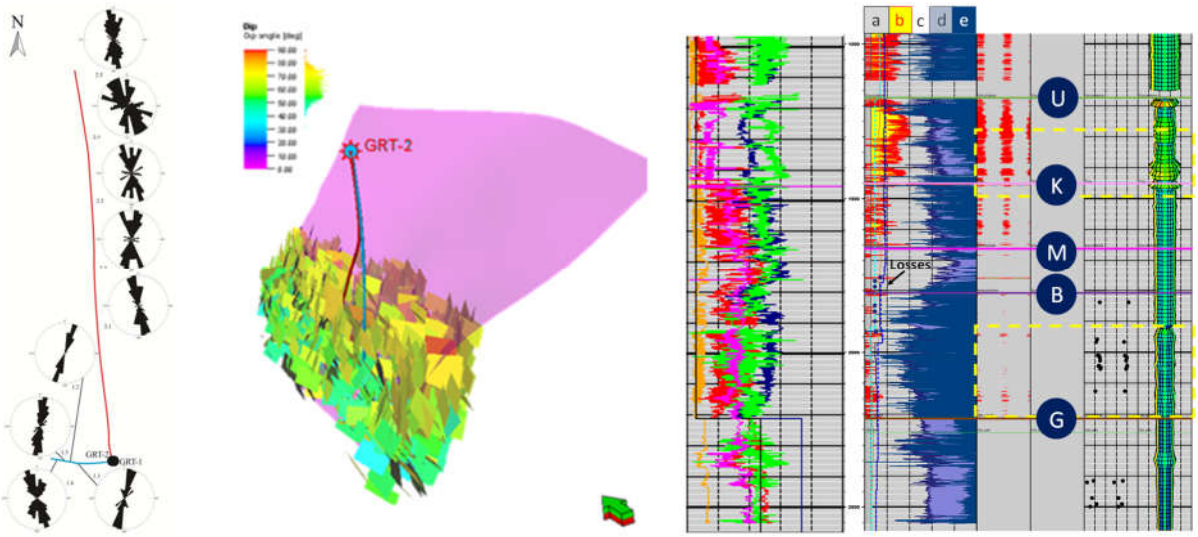
An extensive measurement campaign was carried out in both wells by means of wireline logging. Pressure and temperature logs, nuclear logs (density and porosity), resistivity logs, dipole sonic logs, and wellbore image logs were acquired in the open hole over the target fractured aquifer and partially across the overburden.

These logs were processed and interpreted to build an integrated model of the site, describing its geological properties, notably the fracture network, its dynamic behaviour in terms of fluid and heat flow, and its geomechanical properties.

Wellbore imaging results from acoustics imagers were interpreted to understand the geometry of the natural fracture network, which acts as the main fluid pathway in the Rittershoffen geothermal system. The results were integrated with temperature logging to understand which fractures were open and therefore cooling down when invaded by the drilling mud.

Density and sonic logs were used to derive the mechanical properties of the near-wellbore rock and the stress magnitudes; the interpretation of drilling-induced features in the wellbore images allowed determining the orientation of the local stress acting on the wellbore. The geomechanical model obtained was used to predict the occurrence of mechanical or hydraulic instability along the well and compare the prediction with the events actually observed in the well, providing a validation of the geomechanical model.

The results of well-centric fracture and geomechanical analysis were integrated in a 3D reservoir model and used to understand the performance and the risks associated with geothermal operations at the site.




*Left: rose diagrams representing natural fracture strikes along the GRT-1 and GRT-2 trajectories and reconstructed natural fracture network model.*
*Right: wellbore stability analysis of well GRT-1 (left to right: mechanical property profiles from wellbore logs; critical mud weights; predicted breakout image; formation markers; observed breakouts; observed borehole shape.*

**DRIMP and Pseudo Impedance as a proxy of rock properties**, Alfazazi Dourfaye* and Dhaker Ezzedine, VAREL Intl

Determining rock properties with a higher resolution is key to the optimization of the recovery of mineral and geothermal resources. Conventional logging tools such as sonic and resistivity tools have a vertical resolution of 2 feet and depths of investigation of 12 in. Drill bits have depth of cut varying between 0.1 mm to few millimetres and rock properties changes are immediately reflected by the rate of penetration changes. Thus, the drill bit can be an excellent logging tool when drilling performance changes are carefully monitored and translated into rock properties variations versus drilling depth.
For that purpose, a downhole data recorder was developed by Varel to record bit dynamics and applied drilling parameters as close as possible to rock and the cutting elements. The latest memory recorder tool named DataTrack* developed by VAREL can handle temperature up to 165°c and is capable to record tri-axial bit accelerations, downhole bit rotation speed D-RPM, weight on the bit D-WOB, torque at the bit DTOB, temperature, and several other parameters. The sample frequency is adjustable between few hertz to 250 Hz.
Data collected while drilling are processing to generate two new logs named: Drilling Impedance (DRIMP) and Pseudo Impedance (PI) in reference to the compensated SNAPLOG introduced by IFPEN in 2000

$$\mathbf{DRIMP = WOB^{a} / DOC^{b}}$$

Where a and b are drill bit dependent,
DOC is the depth of cut expressed in mm/rev. **DOC= ROP/RPM**

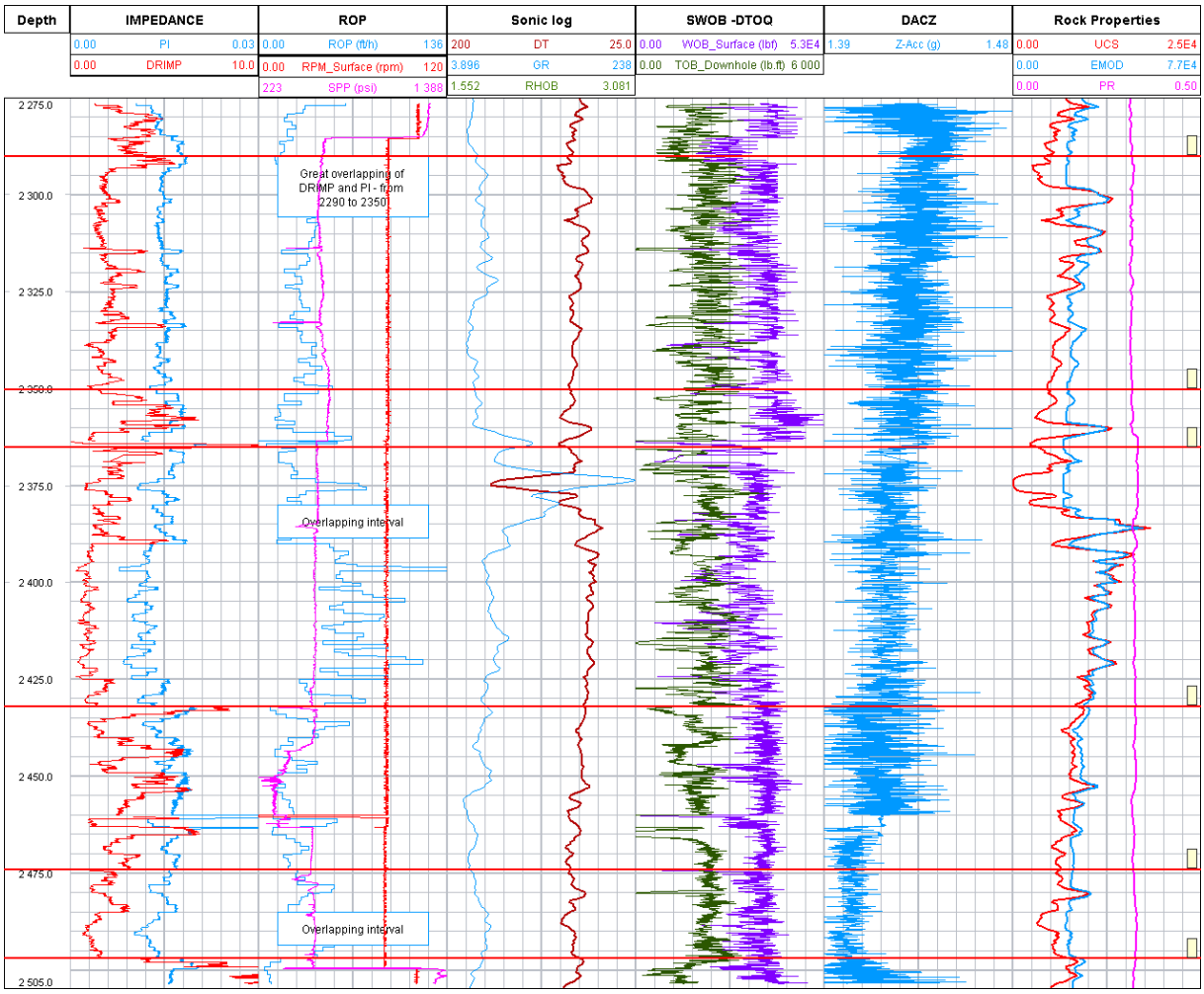
$$\mathbf{PI = A / (RPM*ROP)}$$

Where A is the root mean square axial (Z) acceleration over a short constant time interval

Both logs are compared to each other, to sonic log, to UCS, to Young Modulus and to Poisson ratio processed from conventional wireline logs (UCS = unconfined compressive strength, or uniaxial compressive strength, in the well axis).

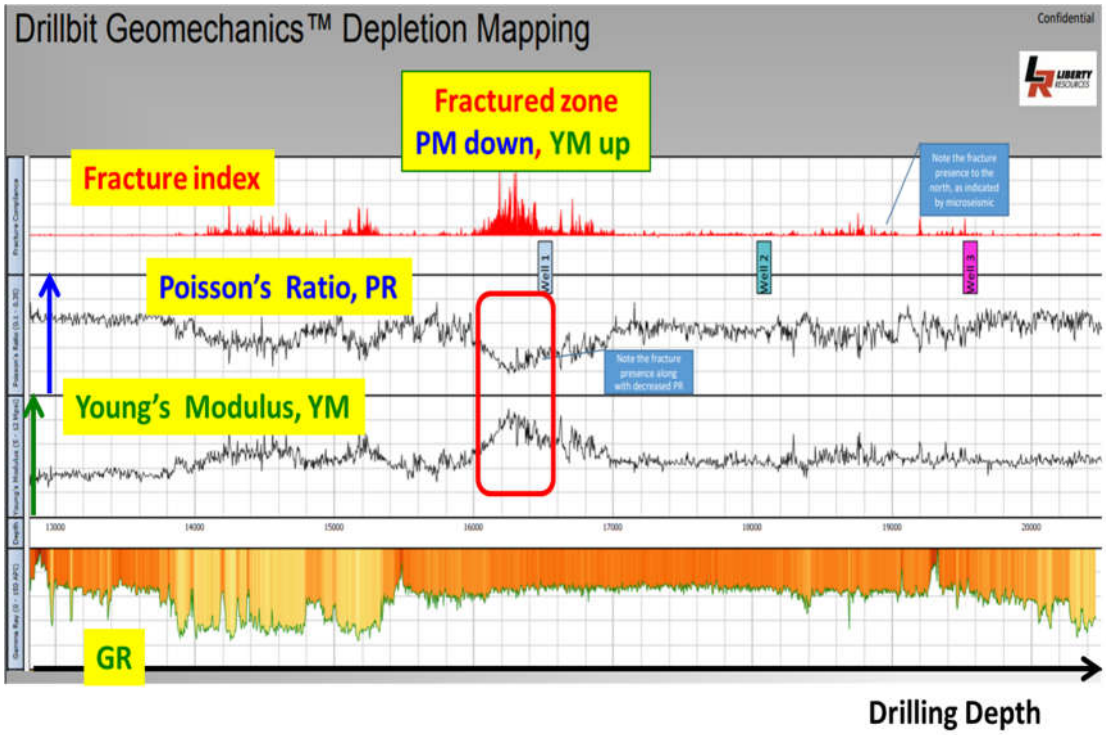
First there is a good match between DRIMP and PI in the case study and more cases will be needed to confirm the trend. On another hand the comparison of the new logs (DRIMP and PI) with raw data such as sonic log and rock mechanical properties revealed a good match as shown on the graphs below, locally at depth 2375 unit?, but not everywhere. Therefore, if the trend is confirmed with more cases, expensive wireline logs can be complemented by a low-cost solution using DRIMP and PI as a proxy of rock mechanical properties, including for fractured zone detection.

*VAREL Trademark


Depth
IMPEDANCE
0.00 PI 0.03
0.00 DRIMP 10.0
ROP
0.00 ROP (ft/h) 136
0.00 RPM_Surface (rpm) 120
223 SPP (psi) 1 388
Sonic log
200 DT 25.0
3.896 GR 238
1.552 RHOB 3.081
SWOB -DTOQ
0.00 WOB_Surface (lbf) 5.3E4
0.00 TOB_Downhole (lb.ft) 6 000
DACZ
1.39 Z-Acc (g) 1.48
Rock Properties
0.00 UCS 2.5E4
0.00 EMOD 7.7E4
0.00 PR 0.50
2 275.0
2 300.0
2 325.0
2 350.0
2 375.0
2 400.0
2 425.0
2 450.0
2 475.0
2 505.0
Great overlapping of DRIMP and PI - from 2290 to 2350
Overlapping interval
Overlapping interval

**Using the Bit to measure How Rock Reacts to Force: An In Situ Rock Mechanical Measurement,** by Josh ULLA*, FRACTURE-ID

PDC bits crush the rock as they drill, going through elastic, plastic then full failure of the geology at the cutter interface. Fracture ID can measure how the bit moves during the crushing mechanism to determine mechanical characteristics of the rock such as Young's modulus and Poisson's ratio. These measurements prove to be quite useful in determining formation quality and depletion. This talk will walk through the technology applied and a few key examples. More information can be found at www.fractureid.com.




**The Geothermal Industry,** Roger Henneberger*, GeothermEx (a Schlumberger company)

An overview of geothermal systems and their exploitation: where they are found, which countries have significant developments, how large a resource base is available, how the industry has grown, who the developers/operators are, typical exploitation schemes, pros and cons, and the outlook for the future.

**Geothermal Well Logging and Analysis: Opportunities and Challenges,** Roger Henneberger*, GeothermEx (a Schlumberger company)

A review of the geothermal environment and how it affects and responds to logs that are used routinely in the oil & gas industry. The focus will be on the volcanic environments that commonly host high-temperature geothermal systems, and the constraints on logging and challenges to interpretation that they present.

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## Biographie des présentateurs / *About the Speakers*

**Que savons-nous sur le régime thermique des bassins sédimentaires ? /**
***What do we know about the thermal regime of sedimentary basins ?***

**Jean-Luc Rudkiewicz*** is in IFPEN's Geosciences R&D Direction. He has a long experience in petroleum system modeling software development and use in real cases. Cases are located both in extensional and compressional complex structural settings. His current field of interest is 3D structural kinematic modeling, its links to paleo fracturation through strain and stress reconstruction. Jean-Luc studied at Ecole des Mines and holds a PhD on the structural and thermal evolution of the Tethyan margin in the French Alps.

**Towards a new standard in well architecture and wireline logging in the Paris basin: the Cachan pilot site approach**

**Melanie Davaux*** is a geologist with structural analysis background and seismic interpretation work experience. Her task focuses on geological analysis, geothermal reservoir simulation (simultaneous heat, mass and solute transport) and well tests analysis. She is involved in feasibility studies addressing the review of well design and exploration/production permitting documents in the deep sedimentary geothermal aquifers in the Paris Basin. She holds two master's degrees in petroleum geology from IFP School and University Paris VI.

**Miklos Antics,** presently Managing Director of GPC IP and GEOFLUID France, is a graduate and post graduate reservoir engineer of the Ploiesti (Romania) School of Petrol. Holds a PhD in well testing, multiphase flow and reservoir simulation. Miklos Antics has gained a wide experience in resevoir engineering, simulation, well testing/logging and drilling/production in teaching, field practice and operation management areas. He is currently President of EGEC (European Geothermal Energy Council). Former member of the IGA BoD and past Chairman of the IGA European Branch. He authored/co-authored over 50 technical papers and four textbooks.

**Pierre Ungemach*** is the Chairman of Geofluid. He has a geophysical engineering degree (IPGP, Strasbourg) and MSc in applied mathematical and physical science degrees. He has 40 years of experience in geophysics, hydrogeology, engineering, reservoir simulation, log analysis, geothermal production and maintenance, thermochemical scaling and corrosion processes, geothermal project feasibility, project management and R&D programs. He has been for groundwater, hydrocarbons and geothermal resources. He has been vice-president of EGEC and he has authored more than 50 scientific and technical publications.

**Chiara Cavalleri*** is a Principal Petrophysics Domain Champion with Schlumberger, based in Aberdeen, UK. She provide technical support to logging activities and technology application for formation evaluation across Europe, working primarily in the field of wireline logging and related data services, from planning of the evaluation program to data interpretation. She joined Schlumberger in 2005 as a Wireline field engineer in Congo, then worked as petrophysicist and Wireline petrophysics Domain in different locations in West Africa, before moving to UK. She received a B.S. in engineering from the Technical University of Pavia, Italy.

**Erik Wielemaker*** is a Principal Acoustic Domain Champion for the Eastern Hemisphere with Wireline Schlumberger. Based in The Hague, his role is to support the logging, processing and interpretation of Schlumberger acoustic tools, including for geomechanics and rock physics. After a MSc in Geophysics from the university of Utrecht, he started his career in seismic processing and joined Geco-Prakla in 1997, where he led operations in 4 continents. He moved to Schlumberger Wireline in 2001, first to evaluate sonic tools in the SKK technology center in Japan, then as a petrophysicist in Mexico and finally in the Netherlands since 2005.

**Wellbore logs in Rittershoffen, Alsace: acquisition, analysis and integration for fractured reservoir characterization**

**Giovanni Sosio*** is a technical team leader with Schlumberger in Paris. After graduating in Environmental engineering and Applied geophysics in Milan, he joined Schlumberger as a wireline field engineer in the North Sea in 2005. He has held a variety of positions since then: providing software support in Italy, managing a CO2 storage site modeling project in Spain, developing the geomechanical software business in Europe, coordinating consulting projects in France where he is based since 2009.

**Andreia Mandiuc** is a senior geoscientist working for Schlumberger in Paris. Her domain of expertise spans structural and reservoir geology, geomodelling and geomechanics. She has joined Schlumberger in 2007 and worked on support, training and consulting in the geoscience domain; more recently she is in charge of

geomechanical consulting for customers across Europe. She graduated in Geological engineering from the university of Bucharest.

**Annalisa Campana** is a senior geologist in the business development team for Europe in Schlumberger. She holds a master's degree in Geology from the Sapienza university in Rome. With a strong expertise in all the geoscientifical domains, she has held positions as reservoir engineer and geologist in three countries since joining Schlumberger in 2009.

**Jeanne Vidal** is a geologist and earned a PhD in Geology at the University of Strasbourg in 2017. Her research focuses on natural fracture systems and she has notably applied it extensively to geothermal contexts. She is currently working as a geologist for ES Géothermie.

**Régis Hehn** is a reservoir engineer at ES Géothermie, based in Strasbourg. He holds an engineering diploma from the École des Mines de Nancy and a MSc in hydrogeology and geothermal energy from the University of Neuchâtel. He has worked on stress and flow characterization from wellbore logs in geothermal wells and is in charge of thermo-hydro-mechanical modeling and simulation and testing operations for the geothermal projects at ES Géothermie.

## DRIMP and Pseudo Impedance as a proxy of rock properties

**Alfazazi Dourfaye*** is Director of optimization services at Varel International. He holds an engineering diploma from École des Mines d'Alès and earned a PhD in Techniques et Economie de l'Exploitation du Sous-sol at École des Mines de Paris. He has 23 years experience in drill bit industry focused primarily on PDC bit design methodology, product management, software development and business development.

**Dhaker Ezzeddine** is engineer at Varel International. He holds an engineering diploma from Tunisia Polytechnic School and earned a PhD in Techniques et Economie de l'Exploitation du Sous-sol at École des Mines de Paris. He has 6 years' experience in drill bit industry focused primarily on drilling data mining and analysis, drilling data acquisition, and new product and software development.

## Using the Bit to measure How Rock Reacts to Force: An In Situ Rock Mechanical Measurement

**Josh Ulla*** has a proven track record of applying innovative and outside-the-box solutions to geoscience problems. Originally from Canada, Josh spent his last 6 years before joining Fracture ID working with ExxonMobil in Houston, Texas in the Geophysical Operations and Formation Evaluations Groups. At ExxonMobil, Josh served as the Global Borehole Seismic Expert, and was relied upon to model, design, acquire, process, and interpret seismic and petrophysical data. Prior to this, he completed his masters in potential field magnetic interpretation, bridging his Mathematics degree nicely into geophysical data analytics. Josh has both research & development, as well as hands on field experience.

## The Geothermal Industry and Geothermal Well Logging and Analysis: Opportunities and Challenges

**Roger Henneberger*** has 35 years of experience in the investigation and development of geothermal resources. Since 1984 he has been an employee of GeothermEx (now a Schlumberger Company), where he is the Earth Science Manager. His work has included exploration of new fields, participation in the drilling, logging, testing and sampling of deep geothermal wells, conceptual modeling and resource assessment, management of national and regional studies, economic analysis, and assessment of project risks. In all, he has reviewed or assessed more than 100 geothermal resources and has worked in more than 20 countries. He holds degrees from Stanford University in the United States and the University of Auckland in New Zealand.