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Bridging the Gap Between Geothermal and Oil & Gas in Mexico: Three HPHT Case Studies Using PTS-CCL-GR Logging

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ABSTRACT

We here present the consolidation of a tailor-fitted geothermal workflow with niche-technology in the High Pressure - High Temperature realm for the Mexican geothermal and O&G industries, establishing cross-sector synergy by way of operational excellence. This paper presents three case studies performed under this geothermal workflow where data was acquired on memory mode using a single PTS-CCL-GR geothermal collar in producing wells. This operational approach reduced logging time and cost (>25% savings) compared to conventional multi-tool workflows. **Case 1:** A 7678psi, 148°C O&G well in southern México undergoing workover operations, where data acquired during a 24-hour coiled-tubing correlation pass, allowed the reduction of uncertainty to ±0.7m for packer-placement and puncher-run operations. **Case 2:** A 480psi, 250°C vertical geothermal producer in central México logged on slickline, resulting in measurements which proved congruent with expected values for the main production feed zone, the well-casing diagram, and the well-stratigraphic column. **Case 3:** A high-risk, workover operation on a 380psi, 230°C geothermal well in northern México, in which we quantified severe mechanical damage across a 46m casing interval. These results demonstrate that proven procedural expertise, coupled with technological edge can enhance field-wide management policies, like reservoir monitoring and workover operations in geothermal and O&G fields, globally.

1 INTRODUCTION

México possesses one of the world's most complex energy portfolios. For over a century, its oil and gas (O&G) industry has built solid expertise in subsurface exploration, deep drilling, and reservoir engineering (Martinez, 2012; Perez, et al. 2016; del Angel, 2024). Simultaneously, Mexico ranks among the top ten countries globally for geothermal power capacity: according to Gutiérrez-Negrín (2024), it has 1001.9 MW of installed capacity, almost entirely high-enthalpy, liquid-dominated hydrothermal systems managed by the Comisión Federal de Electricidad (CFE). México stands among the world's top geothermal producers. Yet generation of electricity has stagnated despite an estimated conventional potential of ~2500 MW and vast untapped prospects for Enhanced Geothermal Systems. The same can be said of declining hydrocarbon production in large but mature fields with minimal production from Enhanced Oil Recovery Systems. Unlocking this potential requires precise investigation under High Pressure-High Temperature (HPHT) conditions exceeding 150 °C, essential not only for reservoir engineering (Axelsson and Steingrímsson 2018), but also for workover operations (Marbun et al. 2019 and Bujakowski et al. 2020).

Therefore, these two mature, yet traditionally isolated industries now occupy a strategic crossroads: as México advances its energy transition, converging hydrocarbon and geothermal ecosystems represent a critical opportunity for innovation and efficiency, such as the persistence of technological gaps: O&G well diagnostics technology -like Wireline and Logging While Drilling (Hashem et al. 2024)- is typically rated to 150°C, with restricted availability in the 175-200°C range, limiting its operational True Vertical Depth in the Mexican geothermal context.

Conversely, geothermal technology routinely operates in the HPHT realm and can assess O&G wells that remain unlogged or insufficiently characterized. Bridging this divide yields substantial benefits by enabling cross-application of high-temperature well diagnostics. **Figures 1**-**2** and **Table 1** are the best evidence we have to support this claim because it illustrates the duality of our energy landscape, as it highlights the cross-sector pioneering volume of work Jarkol Technologies (JT) has undertaken in it.

Ours is a multidisciplinary team, composed of geoscientists, engineers, and PhDs, many of whom were trained within the world's leading O&G companies. This O&G background is fundamental, providing a deep institutional knowledge of best operational practices and rigorous Health, Safety, and Environment (HSE) standards that are directly transferable to geothermal operations. We are trained in the operation, maintenance, and calibration of

advanced HPHT logging systems. This background enables us to deploy solutions that are common in O&G, but innovative for the geothermal sector, specifically the use of the standard, single collar, PTS-CCL-GR (Pressure-Temperature-Spinner-Casing Collar Locator-Gamma Ray) logging suite.

The inclusion of CCL and GR measurements, which are fundamental for O&G applications, provides critical, high-fidelity data for exact depth correlation and lithological identification (Aicholzer et al. 2019), data consistently omitted in conventional geothermal logging runs. This paper's case studies are built upon this foundation of direct field experience, which includes a substantial track record of successfully logged hours and meters in challenging HPHT conditions (**Figures 1**-**2** and **Table 1**).



Figure 1. Geothermal workflow activity in México and Central América.

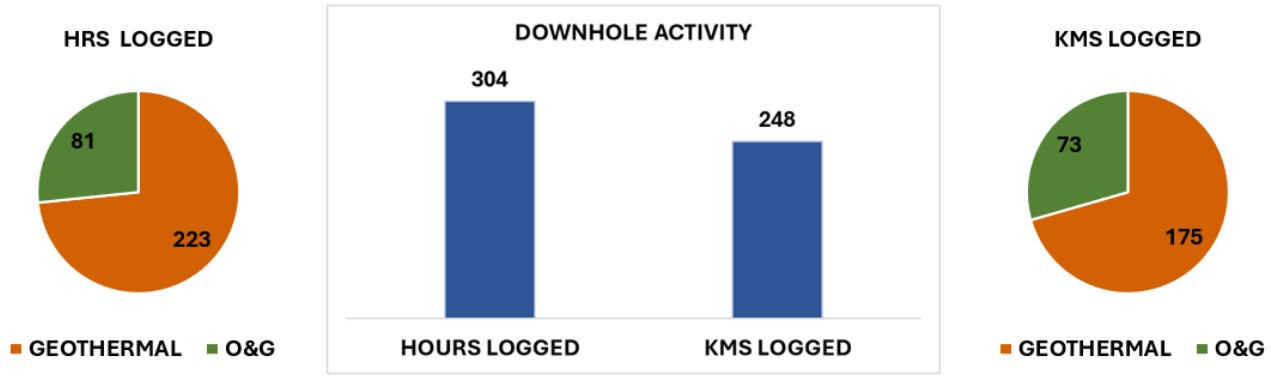


Figure 2. Geothermal workflow volume of downhole activity.

Table 1. Geothermal workflow downhole activity by the numbers.

Industry	Activity	Field	M Logged	Hrs Logged
Geothermal	2021	Acoculco	7986	33
	2021-2022	Los Azufres	2100	5
	2018	Los Cabos	200	1

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	2025	Berlín	3800	5
	2018	Celaya	2000	2
	2021	Cerritos Colorados	10432	7
	2021	Cerro Prieto	4754	4
	2019-2023	Domo de San Pedro	141,046	163
	2021-2023	Los Humeros	3320	3
O&G	2018	Tabasco	6500	8
	2020	Chiapas	11770	23
	2021	Veracruz	5220	12
	2022	Campeche	23174	18
	2025	Tabasco	26120	20

Therefore, bridging the gap between the O&G and geothermal sectors requires more than just access to edge technology; it demands a specialized, agile service partner capable of navigating the bureaucratic, operational and safety cultures of both industries. The successful migration of HPHT logging workflows, as presented in this paper, is contingent upon this specialized expertise. While large service companies traditionally serve the O&G market, their workflows and cost structures are not always optimized for the unique, cost-sensitive, and extremely high-temperature environments of geothermal fields.

2 CROSS-SECTOR BACKGROUND FUNDAMENTALS

Perez, et al. (2016), and del Angel, (2024) provide insight into O&G dynamic and static reservoir modeling. Both authors regard data acquisition as vital for reserves estimation. Regarding geothermal, well diagnostics technology for the applications here presented was introduced by Stevens (2000). Fundamentals on well-logging applications for geothermal fields like those of Steingrímsson (2013), are of invaluable support for any field or non-field personnel, especially those coming from O&G. He paints a comprehensive picture of what is expected of logging operations, the reasons behind them and the interpretation of PT results. Axelsson and Steingrímsson (2018), and references therein, delve into the intricacies of geothermal reservoir physics and engineering. The final two articles point to one important fact: it is vital to log the well as it is being drilled, because temperature controls casing design and casing depth. This point is further articulated by the works of Ngigi, (2015), and Wardana & Akhwan, (2023), both of which are guided by the New Zealand Standard, (2015).

Marbun et al. (2019), arguments to the fact that in Field Dieng, Indonesia, most wells are riddled with problems because they were designed according to O&G standards without considering a) extreme temperature, b) thermal effect on casing grade selection, and c) inclination and azimuth effect. In order to raise the financial viability of geothermal projects, Marbun, et al. (2019), and Bujakowski, et al. (2020), conclude that workover on old geothermal wells and repurposing O&G infrastructure for geothermal applications is much more profitable than drilling new wells. This point is within the scope of this paper, because we have witnessed first-hand, that strictly following O&G drilling and workover standards, without the above basic geothermal field considerations, leads to red money. This is another area of opportunity to bridge the gap as pertains to field-wide financial health and its cascading ramifications on the benefits of logging wells during drilling, for workover objectives, such as is the example of **Cases 1** and **3**, or for standard reservoir monitoring like **Case 2**.

3 CASE STUDIES

3.1 Case 1: southern México

According to Martinez (2012), this mature O&G naturally fractured carbonate field is controlled by saline tectonics making hydrocarbon compartmentalization (in structural and stratigraphic traps), vertically, but not horizontally communicated through cretaceous stratigraphic units. When excess salt becomes unmanageable, the field operator -through workover operations- isolates the older, deeper cretaceous strata and produces the overlaying, younger cretaceous reservoir. This, in and of itself, represents other technical challenges not

discussed here. What is important -at the time this log was acquired- is a current 18.7 bpd production, as opposed to a peak production of 18.7 mbpd in 2012. Gas production remains constant at 61.5 mmcfd. As per the operator's intervention program (see Well Sketch on **Figure 3**), the objective is two-fold: 1) isolate the 3 1/2″ slotted liner by way of packer / cement placement, and 2) perforate 20m of the overlaying 3 1/2″ blind liner.

Therefore, the objective for JT becomes a precision CCL-GR correlation log aimed towards defining 1) packer placement depth and 2) puncher placement depth. Logging program first order considerations are: mandatory wiper-trip immediately before logging-trip begins; S-type well with a >45° curve and vertical landing; production liner internal diameter (ID) variations; coiled-tubing conveyance method; depth tracking; tool structural integrity; tool logging rate; tool logging speed; tool memory capacity; tool battery life. The technical proposal, turned strategy, involved a trip speed of 10m/min with decrease to 5m/min at three discrete depths of production liner ID reduction for a total duration of 24 hrs.

Considering the tonnage needed to displace >5000m of coiled-tubing with a 1 3/4" logging instrument on its tip, tool structural damage is of very high probability, therefore the wiper trip ensures a clean path, and the slow speed minimizes the risk of the tool getting crushed, especially at liner ID reductions. Independent dual depth trackers are utilized to guarantee redundancy. With a logging rate of 0.1 samples / second, measurement data density is more than guaranteed at such trip speed. Tool memory capacity at 1,000,000 samples with the above logging rate is enough to record for almost 30 hours. Battery life consumption for this operation was fractional (<1Ahr) when considering a brand-new dual cell is 5Ahr/7.2V.

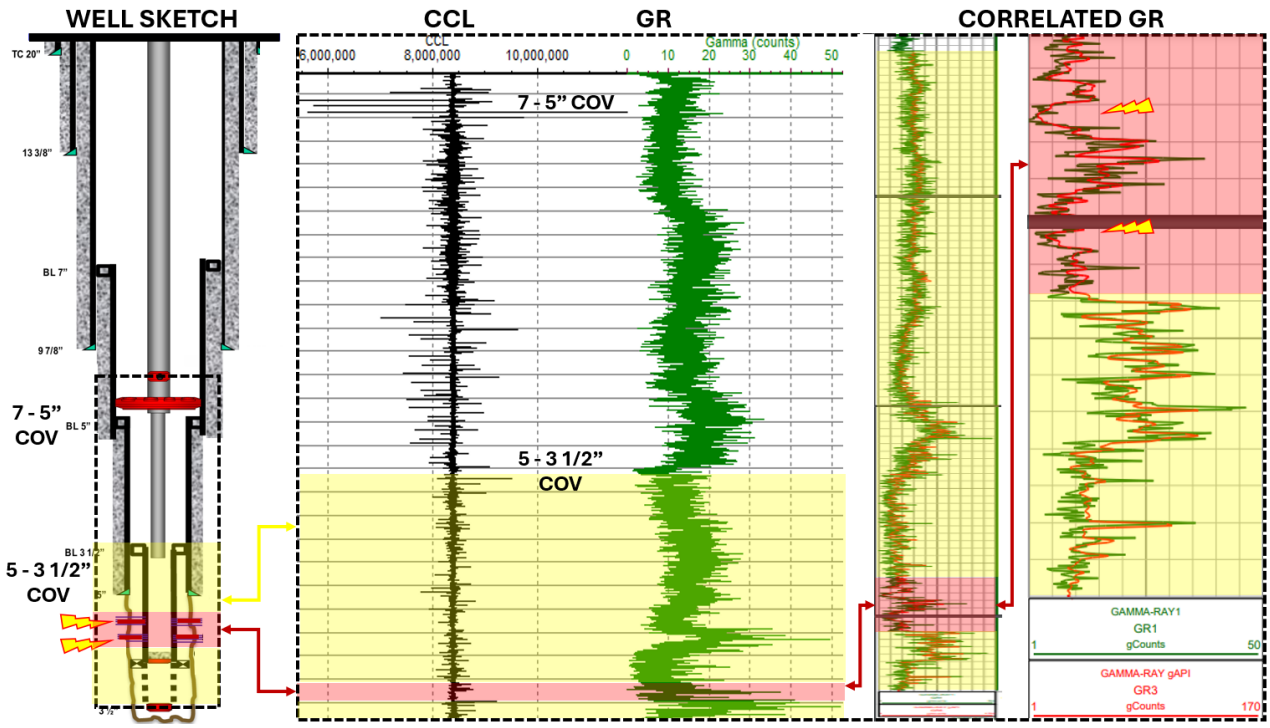


Figure 3. From left to right: Well Sketch according to completions design. Black dashed box indicating extent of data shown by CCL and GR track, beginning at the 7 - 5" casing overlap (COV), through the 5 - 3 1/2″ COV and ending in the 3 1/2″ slotted liner. Correlated GR is an internal deliverable image where the green profile is our raw data-counts, and the red curve is a previously acquired WL gAPI profile, which begins at the 5 - 3 1/2″ COV. Correlated interval shaded yellow, and puncher target interval shaded red.

Execution was flawless. Tool was safely recovered on surface. Bullnose received expected, but tolerable damage. Staging was performed for 45 minutes to allow the tool to cool down before breaking connections, thus avoiding damage upon threads. Once the flask connection was broken, another 45-minute period was given for trapped heat to escape the Inconel 718 housing chamber before removing the electronics module. Data download took 20 minutes and totaled >70% of available memory capacity. Field deliverables were distributed in under three hours after data download was finalized.

After log quality control was accepted and CCL correlated with the well casing diagram, the field operator provided a wireline GR API curve (red) to correlate against our GR raw-counts curve (green), the correlated results are displayed in **Figure 3**. The Field Operator adjusted our depth ±0.7 m and signed us off from the

wellsite. 24hr time savings stem from field operators' intervention program requesting two correlation runs. We did it all in one run. Postmortem analysis indicates proper isolation of the slotted liner production zone, as well as two successful puncher runs in the overlaying blind liner production zone.

The tool was put to the test with regards to heat exposure. Internal temperature readings reached 100°C for over 6hrs, with a 20-minute plateau of 110°C, while pulling out of the hole. Even though the tool can withstand temperatures exceeding 350°C for >4hrs with the flask on, internal electronic components are graded up to 177°C, and the Li-dual cell battery is graded to 165°C, which is why the tool must be extracted from the well at a timely fashion and allowed to cool down, in stages, once on surface. Temperature-minded staging procedures ensure personnel safety, tool integrity and data safeguard.

This illustrates the importance of synergistic meticulous planning, while integrating all external O&G procedures and workflows to satisfy four basic geothermal tool considerations: memory capacity, battery life, logging speed, HPHT limitations. This is how O&G takes advantage of the superior limitations of geothermal minded technology, while on the flipside, clear and efficient geothermal workflows (as seen in **Figure 4**) ratify operational success and proper procedural transfer of knowledge within the O&G environment.

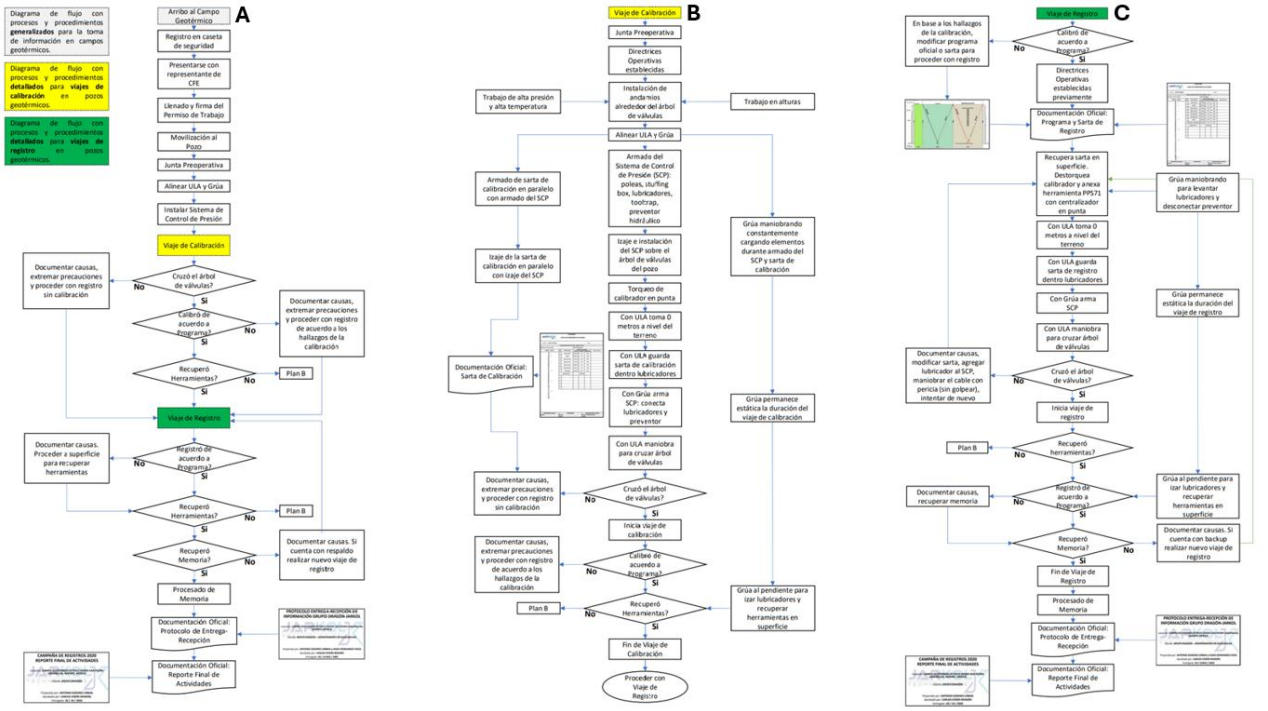


Figure 4. A) Master workflow detailing general processes and what procedures are to be carried out in the sequential order in which they are to be fulfilled, by assigning roles and responsibilities to all involved personnel. B) Secondary workflow detailing all the procedures needed to fulfill one single process: wiper trip. C) Secondary workflow for the log run.

3.2 Case 2: central México

This mature geothermal field is located in the NE portion of the Trans Mexican Volcanic Belt. It is a stunning caldera-complex housing a steam-dominated super-hot (320-380°C range) geothermal system, exploited since the 1990s. According to Cavazos-Alvarez, et al. (2020), highly deformed and fractured Mesozoic metamorphic assemblages and overlaying Miocene-Pleistocene pre-caldera andesites host the lower part of geothermal reservoir. Weydt, et al. (2021), present results on the petrophysical properties of plugs cored within the lower and upper reservoir andesites. The lower fractured reservoir rocks have relatively low matrix porosity 5-10% and permeability of < 0.1 milidarcy ($10^{-16}m^2$); in contrast, the upper reservoir andesites are not fractured, they have far greater matrix porosity (50%) and permeability 100 milidarcys ($10^{-13}m^2$), than the andesites below.

The lower reservoir rock may be tighter, yet fractures connect and increase, otherwise isolated matrix porosity. This opens migration pathways for lateral hydraulic communication across a discrete stratigraphic unit. From Cavazos-Alvarez, et al. (2020) and references therein, fracture networks are corroborated by a) direct structural outcrop measurements on fracture and stratigraphic relationships on the surface, which are valid analogs for

the subsurface; b) and most importantly, because the reservoir feed zone is located in the lower andesites, just as is demonstrated in **Figure 5**.

The highlight of this case study for JT, is the complete technology adoption cycle, from procurement and training to successful first deployment. This presented a golden opportunity for identification of areas of improvement, documentation of findings, remedial action proposals, and tailor-fitted procedural workflows which consider available infrastructure and field conditions, the most important being reciprocal knowledge transfer.

The conclusion of the adoption cycle came with the tool test-run in a live production well (255psi well-head pressure). Previously, during the training phase, local insight guided the best operative course of action, as workflows were adapted to the conditions on the ground. Health and safety, clear work orders, well-defined personnel responsibilities, all gravitating around simple procedures to successfully log a well (see **Figure 4**). Using slickline conveyance, the log itself was of short duration, just under two hours of trip time and one 5-minute station. From our internal deliverables report, **Figure 5** is the compound graphical result of this endeavor.

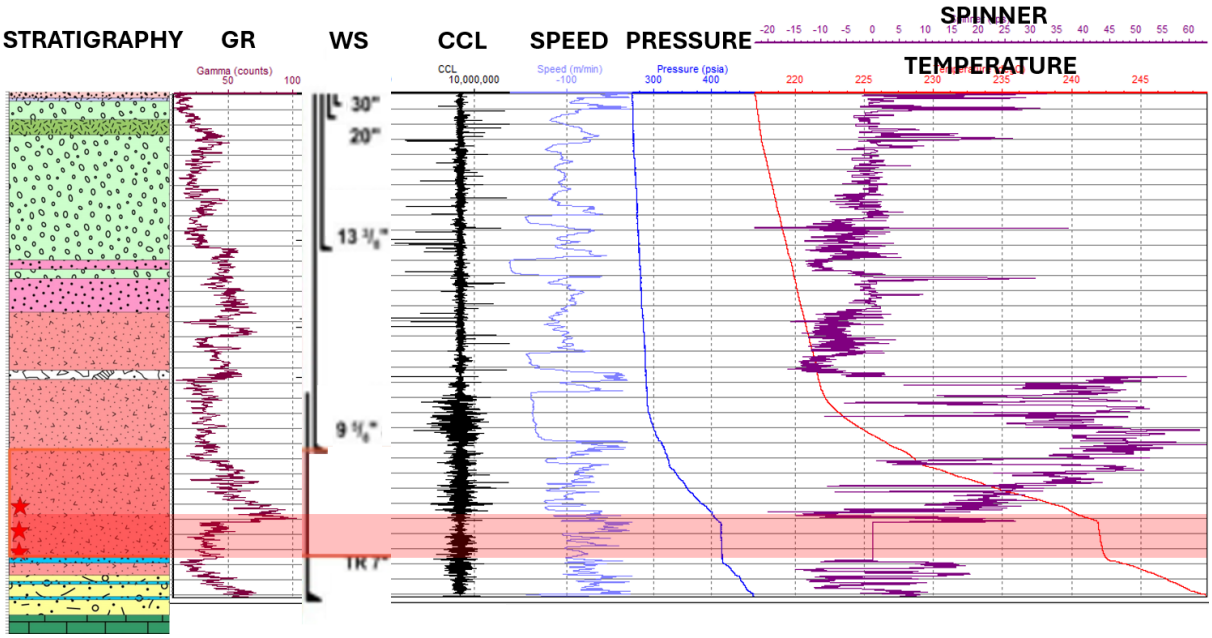


Figure 5. Lithostratigraphic column and Well Sketch (WS) fitted against PTS-CCL-GR down log results. CCL responds accordingly to diameter changes in the WS, spinner flow-regime corroborates such reductions, like the entry into the 7" liner. GR demonstrates corresponding activity to lithostratigraphic boundaries. Notice PTS behavior in the shaded interval which highlights the feed zone in the 7" slotted liner. This behavior is similar to the one observed in Case 3 – Figure 6.

The well lithostratigraphic column and the well casing diagram are fitted against the log: CCL correlates accurately with the well-casing diagram, GR responds adequately to the local geology, and the PTS profile identifies the main production feed zone. The core lesson learned came from an unstable velocity curve (trip speeds 50-100m/min) which impacted depth control. Data quality was safeguarded by programming the tool logging rate at 0.1 samples / second. Still, quality control required some work to fix depth-related issues. As the slickline relied on a derelict winch to lower and raise the tool, the issue was clearly out of our hands. However, this was foreseen from the training phase and we prepared accordingly: cross-sector know-how transfer.

3.3 Case 3: northern México

The tectonic evolution of this Geothermal Field is controlled by continental rifting, currently affected by a regional scale, dextral trans-tensional regime. Gallardo, et al. (2012), proposes that the geothermal field is found within a regional semi-graben transfer zone, flanked by oblique regional faults, which intersect relatively shallow intrusive bodies that provide the heat source for the geothermal system. Hydrothermal fluids migrate along this fault network, and are hosted by continental, detrital sedimentary sequences, such as fluvial, deltaic and/or alluvial deposits.

Access to sensitive background information on well activity provided context and was key to develop a corresponding strategy for safely logging the well. Previous milling operations to open a sidetrack in 2012 damaged the 7" casing, as corroborated by an ultrasonic caliper log, which also found degraded and invaded

cement with drilling mud, channelized behind the casing (yellow box on Well Sketch **Figure 6**). Also, earlier wiper trips could not reach the wells total depth in the side track. Therefore, we stayed 5 m above the last wiper trip total depth, which coincided with the entrance into the sidetrack. Slickline conveyance with a robust winch guaranteed a stable steady logging speed of 30 m / min.

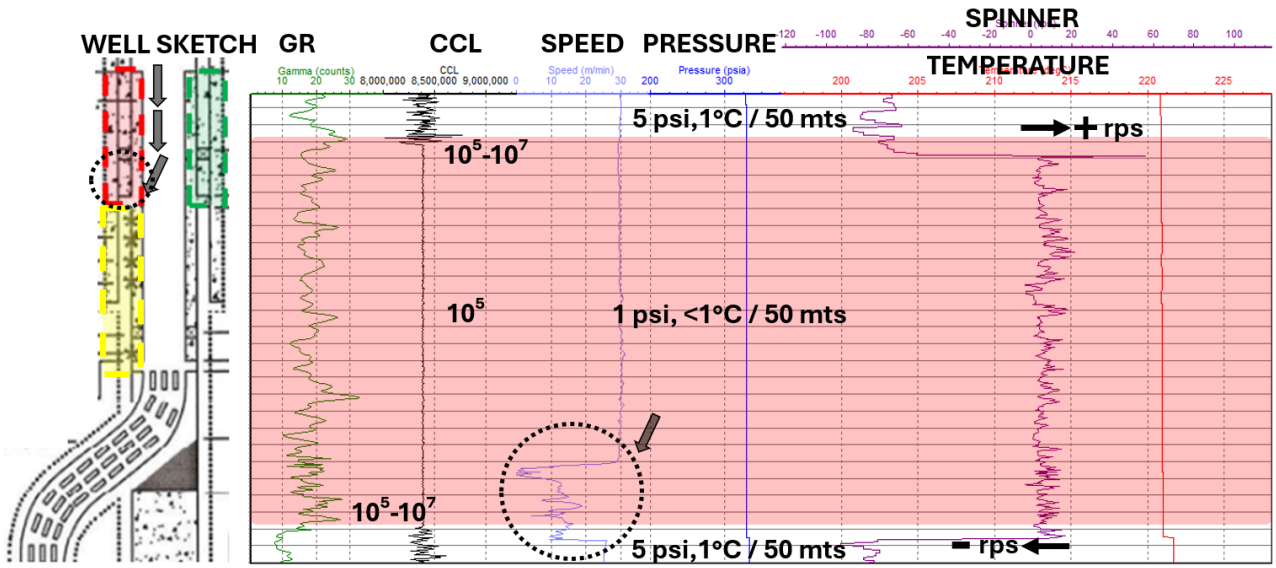


Figure 6. Well sketch: green box no damage; yellow box 2012 damage; red dashed box recent damage. Circle indicates near-miss location. PTS-CCL-GR down log track showing 50m of data: notice CCL flatlining with a 10^5 voltage variation in the shaded interval. Modified from Cerón, et al. (2022).

All precautions were taken, and we still had a near-miss when we completely lost tension and cable speed, as we were about to reach the previously identified damaged zone while tripping down. As from **Figure 6**, the location of the near-miss is pointed at by a circle in the red box on the well sketch. This location coincides in depth with the circle on the log track, which illustrates a complete loss of cable speed and efforts made to slowly and safely log this interval and finish the logging program. Indeed, as Marbun, et al. (2019), confirms: it is risky to run a PTS log in casing with severe damage.

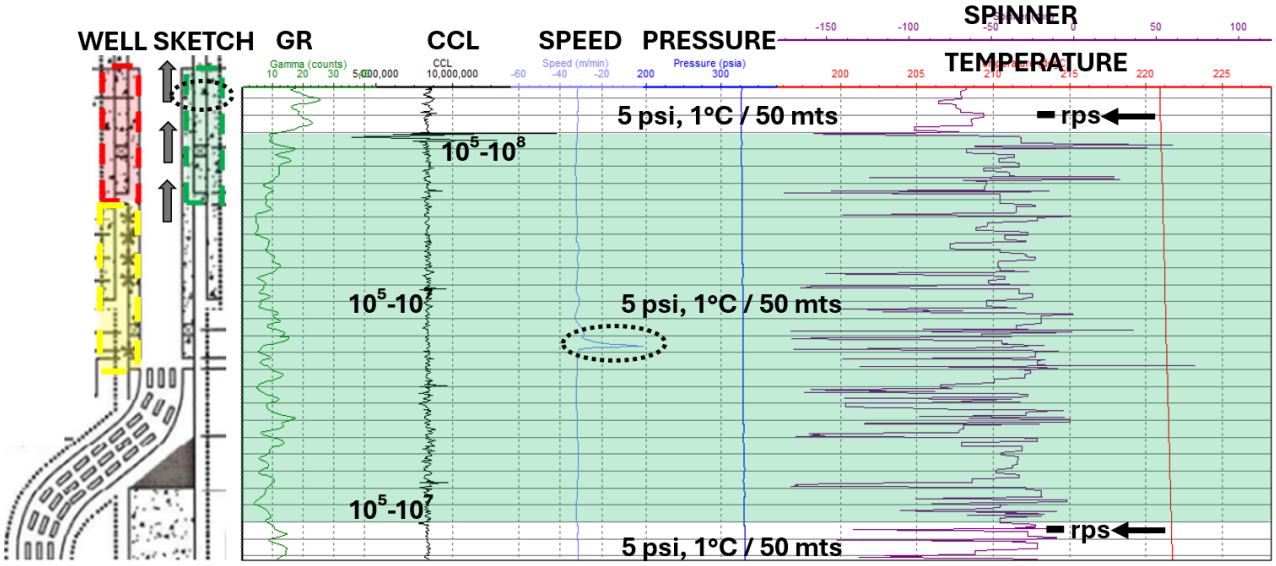


Figure 7. Well sketch: Circle indicates programmed stop before exiting the 7" liner. PTS-CCL-GR up log track showing 50m of data across the highlighted interval: notice CCL voltage variations, PT steady rate of decrement above and below damaged area, and stable spinner flow regime inside the damaged area. GR counts are attenuated. Tool compound measurement behavior is opposite of what was demonstrated during down log. Modified from Cerón, et al. (2022).

After the tool was recovered and data downloaded, QC revealed a shocking image of unexpected compound measurement behavior. Tool failure was discarded once we realized all measurements were affected in this

interval. While on surface, baseline CCL counts have a stable raw voltage variation within the order of 10^4. Inside the well the variation is in the order of 10^5-10^8. However, there is a 46m interval (shaded red) in which CCL readings flatline in the order 10^5. No variation at all. Towards the end of the flatline interval is where the near miss event occurred. Regarding pressure and temperature, there is a normalized 5psi and 1°C / 50m rate of increment above and below the problem interval. Yet inside the problem interval, this rate is 1psi and <1°C / 50m. Also in the same interval, GR counts duplicate while tripping down when compared against GR counts while tripping out, GR activity attenuation is observed. Finally, the spinner experiences sustained flow inversion.

The basic interpretation is the absence of metal. Since all curves respond as a function to the absence of it, two explanations are proposed: (1) the entry of fluids into the hydrostatic column (similar to **Case 2** – **Figure 5**) or (2) the expulsion of native fluids out of the hydrostatic column through the damaged interval. We choose (2), given the near-miss event at this precise depth, and the fact that the well is reportedly experiencing pressure loss, we construe the tool was sucked towards the damaged sector causing sudden loss of tension and cable speed.

Surprisingly, as seen from **Figure 7,** while tripping out we did not find the same behavior in the damaged interval. We expected problems but found none. CCL data interpretation revealed no damage on the casing (green square on Well Sketch **Figures 6** – **7**) and all other measurements remained stable in the same interval. We therefore conclude that slickline conveyance inherently runs the tool eccentralized, explaining why the up log did not see the same damage as the down log; and, the damaged interval is in the same azimuthal sector in which the 2012 side track is oriented. For further detail on this case study, see Cerón, et al. (2022).

4 FUTURE WORK

The three case studies presented herein validate both the technical feasibility and economic viability of deploying what is considered conventional O&G technology: a PTS-CCL-GR logging suite for reservoir monitoring and workover characterization. However, it must be perfectly clear that said tool is un-conventional for O&G simply because it was designed and born for geothermal applications, not the other way around. We foresaw a niche in O&G wells under extreme thermobaric conditions and we have demonstrated its applicability in said industry. Our workflow establishes a cost-effective and tailor-made operational approach for acquiring high-resolution downhole data, establishing a foundation for broader cross-industry integration, as we catch-up to a decarbonized future.

Contextualizing the above statement, the geothermal heat flow map by Prol-Ledesma et al. (2018) as seen in **Figure 8A**, lays the foundation for future geothermal exploration, pointing from early on, the high flux values in the eastern seaboard where the oilfields are located. From this resource, Félix and Gutiérrez (2023) highlight that heat flow in O&G regional basins is greater (>100 mW / m2) than the average continental heat flow (65 mW / m2). When visualizing on-shore wells coupled with the heat flow map (see **Figure 8B**), we gain insight into the vast potential for reconversion of O&G infrastructure into direct and indirect (80-150°C) geothermal applications, when >28 million liters of water are produced daily from land wells alone.

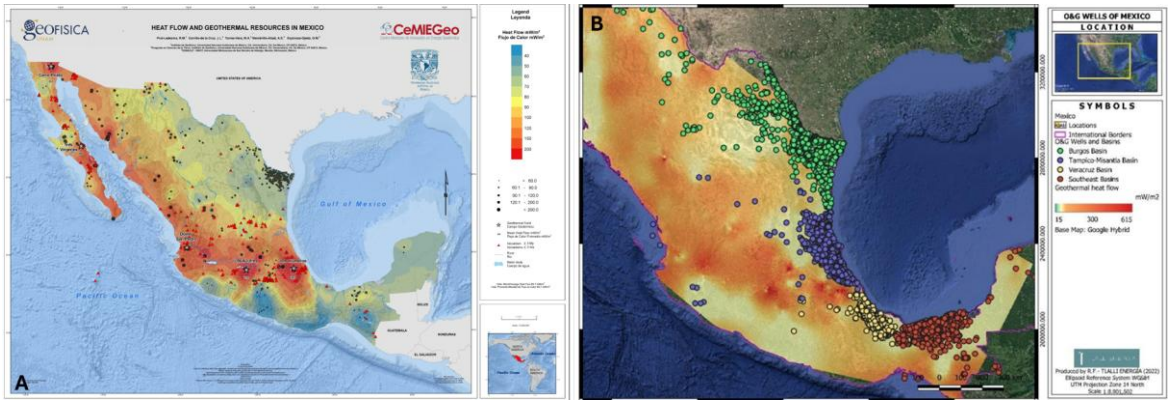


Figure 8: A) Geothermal heat flow map of continental México, modified from Prol-Ledesma et al. (2018); B) Felix and Gutiérrez (2023) zoom in on the eastern seaboard and overlay land wells on the heat flow map, color coded according to regional O&G basin.

The task seems daunting. However, the body of technical knowledge acquired in the last decade, is setting the stage to increase the financial viability for stand-alone geothermal (Marbun et al. 2019), or fully integrated geothermal-O&G projects, as shown by punctual discourse from Caulk, R.A. and Tomac, I. (2017), Bujakowski, et al. (2020), and Nassan, et al. (2024).

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Jácome-Paz et al. (2023), while conducting upstream surface prospecting, reminds us of the social dimension upon which geothermal resources are found: analysis of social impacts and perception studies empower communities for the socio-economic appropriation of the resource. A social approach is also perceived in the analysis by Chen et al. (2025), in the depleted Beaver River gas field, Canada, which serves as frontier scrutiny for geothermal exploration within dolomitized aquifers in deformed foreland basins.

The local analog is one of México's premier hydrocarbon producing horizons: found within buried fold and thrust belts along the south-eastern gulf coast (on-shore, Martinez 2012 and off-shore Perez, et al. 2016), it contains the triad of conditions required for viable geothermal-O&G engineering solutions: high heat flow, dolomitized and permeable reservoir (Chen et al. 2025).

Framing it all up, geothermal policy in México changed early 2025 (Gutiérrez-Negrín 2025) when the Mexican Federal Congress approved constitutional changes and established the Geothermal Law (Ley de Geotermia) which replaces the 2014 Geothermal Energy Law (Ley de Energía Geotérmica). By providing a foundational legal framework, the new law is simplified and clear regarding electricity generation and co-participation, as well as for diverse direct and indirect uses.

Montaño (2025), argues that the new law is agile, it removes bureaucratic hurdles and operational bottlenecks, offering financial mechanisms to promote investment, and the bankability of geothermal projects. Diez (2025), lays out a comprehensive decarbonization road map with geothermal energy as its financial engine. He explores the Mexican and global energy sector and proposes incentivizing cross-industry synergy within, and outside the energy sector, for effective investment and funding of geothermal projects. This is the blue print for the future: resource availability, technical aptitude, legal certainty and economic capacity.

5 CONCLUSION

The O&G workover intervention (**Case 1**) established baseline operational accuracy by achieving depth correlation within ± 0.7 m, and saving the field operator one additional coiled tubing run, had he employed conventional O&G technology and workflows. From procurement to deployment in a geothermal environment (**Case 2**) confirmed tool reliability under extreme thermobaric conditions, delivering internally consistent data that identified the main feed zone, verified casing depth through CCL correlation, and delineated lithological boundaries via gamma-ray stratigraphy. The high-risk intervention (**Case 3**) localized a 46-metre casing integrity anomaly.

Field-wide deployment of proven JT technology and workflows, has demonstrated cost and time savings against conventional multi-tool programs in O&G fields (**Case 1**), as well as proven its technical soundness in geothermal fields with the introduction of the CCL-GR combo in the same PTS HPHT monel (**Cases 2** and **3**). This provides a high-value logging suite for reservoir management in capital-constrained contexts.

Collectively, these results establish an empirically validated, operationally replicable framework for synergistic implementation across sectors by JT specialized personnel. The results presented form part of a broader technical ecosystem aimed at optimizing geothermal and hydrocarbon resource development. JT advocates a collaborative, evidence-based approach: leveraging validated technologies, fostering transparent technical dialogue, and strengthening partnerships that advance Mexico's energy transition while creating local analogs and replicable models for global adaption.

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