Preliminary Analysis of Geothermal Drilling Results in Eastern Taiwan

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ABSTRACT

Geothermal resource exploration represents the riskiest phase in geothermal development, and the results of geological drilling serve as the most crucial reference for risk assessment. These results enhance the reliability of geothermal information, reduce upfront investment risks in geothermal development, and attract as well as facilitate corporate investment.

This article presents the outcomes of a fully cored geological exploration well (referred to as CGS-YP01), drilled to a depth of 800 meters in the eastern region of Taiwan. The content includes drilling cores and logs, electric well logging, in-hole pressure and temperature measurements, rock mechanics testing, and thermal conductivity analysis.

1. DRILLING LOCATION AND WELL SPECIFICATIONS

1.1 Background

The CGS-YP01 Well, located in Yanping Township, Taitung County, Taiwan (Figure 1), is situated in an area that has undergone previous exploration activities (Huang Qiongyue, 1984; Wu Guanghong, 1985). In this region, two deep wells and five shallow wells were previously drilled. Among these, the well drilled by the CPC Corporation has a relatively shallow depth of 200 meters but exhibits favorable temperature and flow characteristics, with a wellhead temperature reaching 120°C and a flow rate of 5 tons per hour. The objective of the current drilling program is to assist in confirming the geothermal reservoir resource within this area.

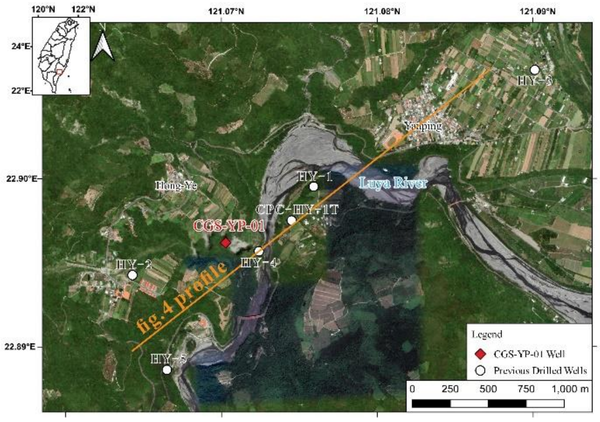

Figure 1: Location of CGS-YP01 drilling well.

The geological exploration well features a 4-inch borehole with a depth of 800 meters. The upper layer, ranging from the surface to a depth of 45.13 meters, consists of debris layers. HQ core drilling was conducted from a depth of 45.13 to 800 meters. For this drilling operation, the TEL-3 hydraulic rotary drilling rig manufactured by Japan's Tone Company was employed (as shown in Figure 2). It utilizes the wireline core retrieval method.

Figure 2: Picture of TEL-3 hydraulic rotary drilling rig.

2. DRILLING PROCESS

Throughout the drilling period, temperature measurements were conducted using a downhole thermometer (maximum registering thermometer) during the 6 to 8 hours of downtime following each day's drilling activities and preceding the commencement of operations the following day. The thermometer remained in the wellbore for approximately five minutes to capture the maximum temperature at the bottom of the well. As the drilling depth increased and fractured zones were encountered, there was a consistent upward trend in temperature.

The most notable temperature increases were observed at around 140 to 200 meters and 250 to 370 meters. Upon reaching a depth of 520 meters, the temperature peaked at approximately 141°C, marking the highest temperature recorded throughout the entire well. After descending to roughly 630 meters, the temperature displayed a minor decrease, stabilizing at around 138°C. Subsequently, an 8-hour pump stoppage led to a recording of the maximum temperature, of about 142°C, at the bottom of the hole.

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3. ROCK CORE RECORDS, WELL LOGGING, AND MECHANICAL TESTING

3.1 Rock Core Records

The rock layers adjacent to the top of the well primarily consist of interbedded sandstone and shale. The drilled rock cores also indicate a prevalence of shale throughout the well, interspersed with thin layers of metamorphic sandstone and abundant quartz veins. Quartz crystals were observed on numerous fracture surfaces. Between depths of 0 to 350 meters, shale occasionally interbeds with metamorphic sandstone and quartz-carbonate veins formed by later overpressured fluids. Below a depth of 350 meters, the cores exhibit abundant quartz-carbonate veins and a prevalence of high-angle shear zones or regional sub-horizontal foliation.

A total of 17 fractured zones, each exceeding 1 meter in length, were identified from the cores. The depths of these zones are as follows: 68.3–69.7 m, 91.9–93.7 m, 111.2–113 m, 139.1–142.6 m, 165–166.8 m, 310.4–320.1 m, 325.6–341.1 m, 357.3–358.6 m, 393.3–395.7 m, 422.9–424.6 m, 454.2–456.1 m, 473–474.4 m, 476.8–477.8 m, 602.6–604.8 m, 744–747.4 m, 753–757.7 m, and 791.8–793.4 m.

In conjunction with daily drilling records, a significant increase in downhole temperature was observed at the fractured zone located around 111 to 113 meters deep. Additionally, a notable rise in the groundwater level was measured the following day. Cement grouting was performed at this fractured zone, however, upon removing the grout, it was observed that the cement failed to bond properly and showed signs of extensive flushing, indicating fluid activity. Severe grout loss occurred at depths of 602 meters and 756 meters during drilling, suggesting the presence of water-bearing pathways near these depths.

3.2 Down hole Testing

After the completion of drilling, temperature, pressure, and geophysical well testing were conducted in Well CGS-YP01. The pressure and temperature well testing equipment utilized the Kuster K10 system, capable of withstanding temperatures of up to 300°C for up to 6 hours. The pressure sensor has a detection range of 0 to 300 bar. Analyzing anomalies in pressure and temperature within the wellbore provided insights into the locations of underground water pathways.

The geophysical well testing consisted of four components: temperature logging, natural gamma logging, self-potential logging, and resistivity logging. The temperature log assessed temperature variations, the natural gamma log evaluated natural gamma radiation, the self-potential log measured self-potential anomalies, and the resistivity log examined resistivity. However, due to the temperature constraints of the geophysical well testing instruments (limited to 120°C), resistivity logging data could only be obtained to a depth of 256 meters.

3.2.1 Pressure and Temperature (PT) Well Testing

In this well, pressure and temperature well tests were conducted at depths of 550 meters and 800 meters. The first well test was performed to a depth of 540 meters, revealing a gradual increase in temperature with depth. It started at approximately 36°C near the shallow section and reached around 139.3°C. The second well test, conducted to the bottom of the bottom at 800 meters, showed a temperature of 134°C. The highest temperature recorded in the entire well was around 136.8°C at approximately 576 meters. This peak temperature persisted within the range of 500 to 600 meters. Around the depth of 605 meters, there was a slight temperature decline, resulting in a cooling of about 2°C towards the bottom of the well (Figure 3).

From the temperature curve results, it can be inferred that there might be a cold-water layer near the surface. Additionally, the well exhibits the best geothermal potential within the depth range of 500 to 600 meters.

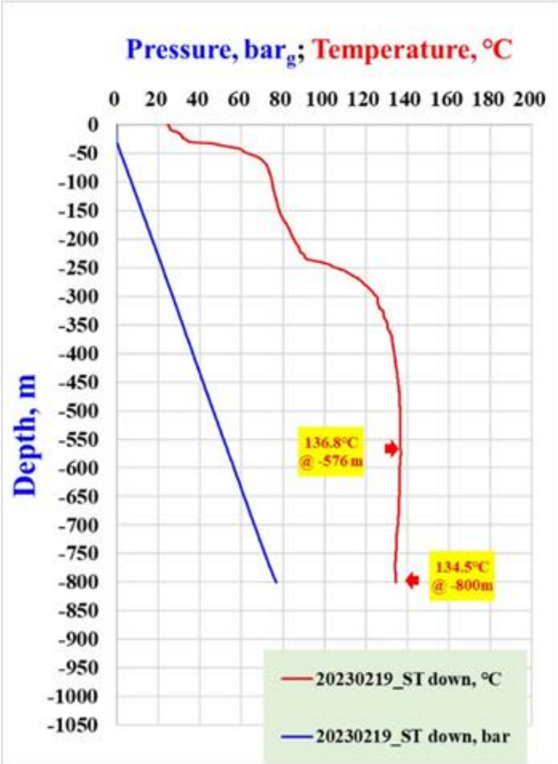

Figure 3: Pressure and temperature profiles in Well CGS-YP01

3.2.2 Geophysical Well Testing

The geological formations in the well consist of interbedded shale and metamorphic sandstone layers. Primary water-bearing fractures are often found within the metamorphic sandstone layers and at lithological boundaries. Since the resistivity values of shale and metamorphic sandstone are relatively close, initial lithological estimation can be made using the natural gamma curve. Lower natural gamma values are indicative of metamorphic sandstone. When combined with changes in resistivity values, it is possible to estimate the presence of water in metamorphic sandstone layers and fractures.

The natural gamma curve predominantly displays measurements between 30 and 150 counts per second (cps), showing a segmented distribution pattern that indicates the alternating nature of shale and metamorphic sandstone. Localized low values might correspond to metamorphic sandstone or could be related to developed fractures and fragmentation within the layers.

Single-point resistivity measurements generally fall within the range of 20 to 150 ohm-m, while long and short normal resistivity measurements are between 0 and 600 ohm-m. Based on the resistivity curves, the well is situated in a metamorphic rock area characterized by relatively high resistivity values. Localized low values could suggest the presence of water-bearing layers or fractures and fragmentation within the rock layers.

3.3 Rock Core Testing

Rock core testing involves high-temperature and ambient-temperature triaxial tests, as well as thermal conductivity assessments. The objective of rock core testing is to comprehend the behavior of rock formations under elevated pressure and temperature conditions. These parameters will serve as the foundation for numerical simulations following the development of a geothermal conceptual model.

3.3.1 High-Pressure Triaxial Testing

Ten sets of shale rock cores from various depths underwent high-pressure triaxial compression tests. The triaxial compression tests were carried out at confining pressures of 5, 10, 15, and 20 MPa, as well as temperatures of 25°C and 100°C (as shown in Table 1). Through statistical back-analysis, failure envelopes for shale at both ambient temperature (25°C) and high temperature (100°C) were determined. For shale at ambient temperature, the cohesion (C) of the failure envelope was 3.02 MPa, and the internal friction angle (φ) was 41.8°. For shale at high temperature, the cohesion (C) of the failure envelope was 3.35 MPa, and the internal friction angle (φ) was 35.35°. It is evident that the strength of the shale significantly weakens as the temperature increases.

Table 1: Downhole data for Well CGS-YP01

Sample Depth (m)	Confining pressure (MPa)	Temperature (°C)	Strength (MPa)
211.06~211.20	5	25	19.48
350.61~350.75	10	25	68.31
360.66~360.80	15	25	85.82
360.83~360.97	20	25	80.28
211.21~211.35	5	100	11.8
350.31~350.45	10	100	51.16
360.26~360.40	15	100	78.43
360.51~360.65	20	100	48.83
200.06~200.20	15	100	41.95
478.53~478.67	15	100	65.33

3.3.2 Thermal Conductivity Analysis

Thermal conductivity analysis was conducted on 10 samples at test temperatures of 23°C and 200°C. At 23°C, the thermal conductivity ranged between 2.35 and 3.74 W/m·K, while at 200°C, it ranged between 2.03 and 3.71 W/m·K.

4. DISCUSSION

4.1 Comparison between Pressure and Temperature test and Fracture Zones

Using measurements from pressure and temperature well tests and calculated temperature gradient fields, it is possible to interpret and identify potential fracture zones located at depths of 150-450m, 670-710m, and 730-755m. There are slight differences compared to the fracture zone positions observed in the core samples, highlighting the importance of core sampling in geothermal investigations. Temperature well tests indicate a geothermal gradient ranging from approximately 58.8°C/km to 91.7°C/km, with significant hydrothermal activity occurring between depths of 300 meters to 400 meters. When combined with the fracture zones observed in the core samples (figure 4), it can be deduced that this interval corresponds to a major fracture zone with a higher temperature gradient, suggesting that it represents a major feed zone for hydrothermal fluids.

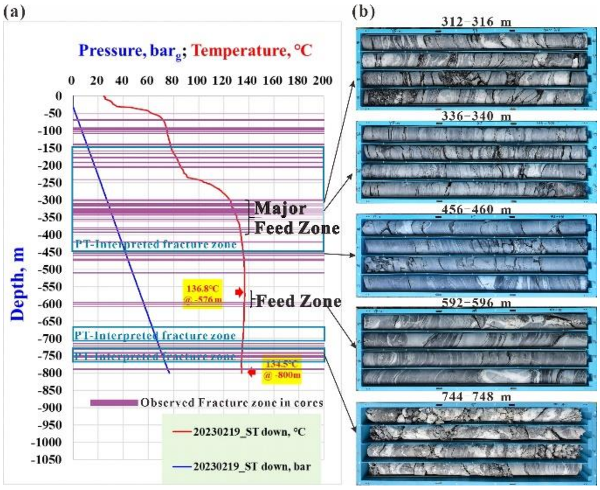

Figure 4: Comparison between pressure and temperature test and fracture zones. (a) Pressure and temperature profiles in Well CGS-YP01 combined with fracture location observed in cores. (b) Fracture zones in cores.

4.2 Geothermal Field and Conceptual model of Yanping region

In 1983, the Yanping region had a drilling record of five shallow wells with a depth of 200 meters and one deep well with a depth of 1310 meters. The drilling distribution followed a northeast-southwest direction. The temperature distribution of each well is shown in Figure 5a, and we conducted preliminary temperature field estimation using the inverse distance method. It can be observed that the heat source is primarily concentrated at the location of HY-4, where the 200-meter deep well recorded the highest temperature of 140°C. However, the CPC-HY-1T well, located 300 meters away with a depth of 1310 meters, only recorded a temperature of 95°C (Maximum temperature estimated using the Honer plot is 133°C.). After incorporating data from the newly drilled well YP-1, it can be observed that the surrounding area of this well has a higher geothermal potential, and there is a noticeable change in the estimated high-temperature range compared to the earlier period(Figure 5b).

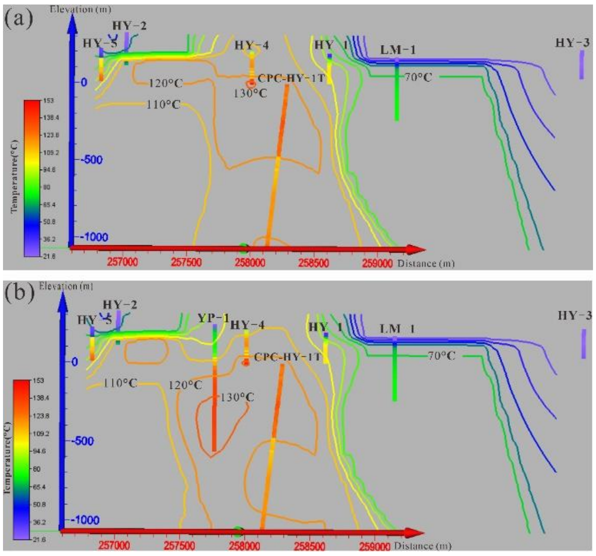

Figure 5: Preliminary temperature field estimation result. Profile location is shown in figure 1. (a) Temperature field before adding CGS-YP01 data. (b) Temperature field recalculated after adding CGS-YP01 data.

The Yanping region is located in a slate belt, and the drilled core consist mainly of slate interbedded with metamorphic sandstone and quartz veins. The geothermal system in this area is classified as an amagmatic geothermal system, which means that groundwater tends to migrate downflow along permeable faults. The fluid is heated at depth and can travel through permeable lithologies or fractures (Jolie et al., 2021). Taiwan's orogenic movements have led to rapid crustal uplift, bringing deep-seated high-temperature rock bodies closer to the surface. This has resulted in an increased geothermal gradient, with underground water infiltrating along geological structures such as fault zones or fractures, getting heated, and then rising to accumulate in shallow underground reservoirs (Figure 6).

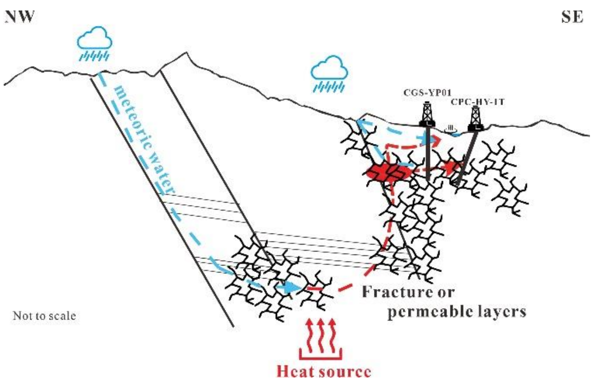

Figure 6: 2D geothermal conceptual model of Yanping region, Taitung, Taiwan.

The Yangping area is situated in the Central Mountain Range of Taiwan, which is the boundary of tectonic plates and features numerous vertical structural zones. These structure zones could potentially serve as pathways for the upward migration of deep-seated hydrothermal fluids or lateral movement channels for geothermal fluids, bring up significant geothermal potential in this region.

5. CONCLUSION

Based on the results of the full-core drilling and testing of Well CGS-YP01, it can be concluded that the formations above a depth of 800 meters are primarily composed of shale with thin layers of metamorphic sandstone and abundant quartz veins. Temperature measurements indicate that the main thermal water inflow zone is situated between depths of 300 meters and 400 meters, with the highest recorded temperature reaching 136.8°C. Single-point resistivity measurements generally fall within the range of 20 to 150 ohm-m, while long and short normal resistivity measurements are concentrated between 0 and 600 ohm-m. The rock strength displays a weakening trend with increasing temperature. In a test environment at 200°C, the thermal conductivity ranged between 2.03 and 3.71 W/m·K.

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REFERENCES

Huang, Q. Y, Temperature Well Report for the Red Leaves Geothermal Area, Taitung County, CPC Taiwan Oil Exploration Bureau. (1984).

Industrial Technology Research Institute, Regional Geothermal Exploration and Key Potential Assessment - Midterm Report for Taitung Area (Summary Version), Midterm report from the Central Geological Survey, Ministry of Economic Affairs. (2021).

Jolie, E., Scott, S., Faulds, J., Chambefort, I., Axelsson, G., Gutiérrez-Negrín, L. C., ... & Zemedkun, M. T., Geological controls on geothermal resources for power generation, Nature Reviews Earth & Environment. (2021)

Wu, G. H, Underground Geological Report of the CPC Red Leaves-1 Geothermal Well in the Red Leaves Geothermal Area, Taitung County, CPC Taiwan Oil Exploration Bureau. (1985).