Constructing geothermal conceptual model of Huangzui Volcano, Northern Taiwan

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ABSTRACT

The Huangzui volcano, situated within the Northern Tatun Volcano Group (TVG), stands as a focal point for geothermal exploration and development in Taiwan. From the 1970s to the 1980s, Taiwan CPC and the Industrial Technology Research Institute (ITRI) undertook extensive drilling campaigns, resulting in over 10 exploration wells being drilled in the region, with the deepest well reaching a depth of 2025 meters and encountering a maximum temperature of 160°C. Recently, a 1MW geothermal power plant utilizing shallow steam pockets to generate electricity was constructed in this region, marking the first geothermal power plant built in a volcanic region of Taiwan.

The magnetotelluric data, combined with geochemical analyses and drilling results, reveal that at the northern side of the Huangzui volcano's hydrothermal products in the volcanic formations are predominantly characterized by smectite and kaolinite at greater depths. Transitioning into the sedimentary basement, an alunite zone predominates, alongside ore-forming minerals such as enargite and zunyite, indicating a high acidity and high sulphidation epithermal environment, with an intrusive dike occurring at a depth of 1,000 meters. The central lava flow acts as a lateral barrier to fluid flow, while the fracture system in this region exhibits high-angle dips. As a result, temperature profiles of exploration wells away from the geothermal manifestation indicates conductive heat transfer rather than convection due to lack of fluid circulation. Subsequently, the infiltration of meteoric water into the volcanic fluid results in the production of immature, steam-heated waters sourced from a shallow low-pressure steam reservoir at 0 to 200 meters asl.

1. INTRODUCTION

The Tatun Volcanic Group (TVG) in northern Taiwan has emerged as a site of significant geoscientific interest, particularly in the realm of geothermal energy research. Located approximately 5-10 km from the densely populated urban centers of Taipei City and New Taipei City, the TVG presents a unique opportunity to study active volcanism in proximity to major metropolitan areas. The recognition of the TVG as an active volcanic system is relatively recent, with Song et al. (2000) first characterizing it as such, followed by Belousov et al. (2010) suggesting volcanic activity as recent as 6,000 years ago. Konstantinou et al. (2007), Lin (2016), Pu et al. (2020) and Huang et al. (2021) further contributed to our understanding by identifying an existing magma reservoir using seismic wave analysis.

The geothermal potential of the TVG has been a subject of increasing focus (Fig. 1), with the National Energy Program II (NEPII) estimating a potential of 2,886 MWe in 2018. Dobson et al. (2018) developed a conceptual model of the Tatun geothermal system using historical data from CPC and ITRI. Their study confirmed that in the Tatun area, specifically around Matsao, commercial temperatures can be encountered at depths of approximately 1-2 km. However, they also noted the presence of very acidic (pH <3.5) and highly corrosive fluids in some locations. Despite the challenges posed by corrosion and low pH fluids in Tatun, the significant resource estimate, coupled with the successful implementation of a 1MW pilot geothermal power plant in 2023 by Fabulous Power Co. Ltd., underscores the importance of developing a more comprehensive understanding of the geothermal system within the TVG to support further development and expansion of geothermal power plant. Nevertheless, the complex geology of the region, characterized by the interplay between volcanic processes and sedimentary formations, presents substantial challenges to geothermal resource development.

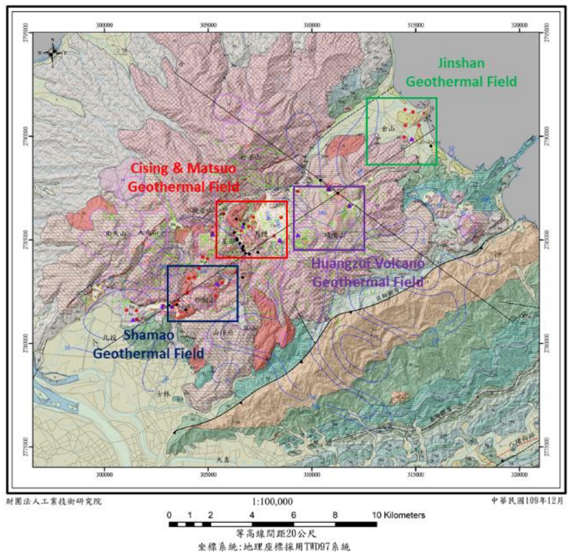

Figure 1: Geothermal field in Tatun volcanic group, northern Taiwan. (Map modified from ITRI (2021))

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Despite the growing body of research on the TVG, there remains a critical need for an integrated geothermal conceptual model that synthesizes geophysical, geochemical, and geological data. Such a model is essential for understanding the fluid dynamics, heat transfer mechanisms, and potential reservoir characteristics within this active volcanic system. Furthermore, the presence of highly acidic fluids and the potential for fluid-rock interactions in the Wuzhishan formation raise important questions about reservoir sustainability and engineering challenges and will be discuss in section 5.

This study aims to address these knowledge gaps by constructing a preliminary geothermal conceptual model of the Huangzui volcanic subgroup within the TVG. Our research integrates data from magnetotelluric (MT) surveys, fluid geochemistry analyses, and temperature profiles from two exploration wells. By combining these datasets, we seek to:

- Characterize the subsurface resistivity structure and its implications for fluid pathways and reservoir geometry.
- Elucidate the geochemical processes governing fluid-rock interactions and their impact on reservoir properties.
- Identify potential geothermal reservoirs and assess their characteristics, with particular focus on the role of the Wuzhishan formation and intrusive dykes in fluid neutralization.
- Develop a conceptual model that explains the observed shallow steam pocket and its relationship to deeper geothermal resources.

2. GEOLOGICAL SETTING

The Huangzui Volcanic Subgroup is located in the northern part of the entire volcanic group and marks the northeastern boundary of Yangmingshan National Park. This volcanic subgroup includes Huangzuishan, Dajianhoushan(also known as Winter Melon Mountain or Niubei Mountain), Chishiliushan (Laoliaohu Mountain), Lengshuishan (Bayen Mountain), Dajianshan, Zhugaoshan, Shitiling, Dingshan, and Eweishan among other peaks. Additionally, this area is characterized by numerous lava plateau, as indicated by their names on the map (Fig. 2). These lava plateau, starting from the west side of Huangzuishan and going clockwise, include Sihuangping, Xiufengping, Gengziping, Xiongjiaoping, Daping, Lukuping, and Fushiping.

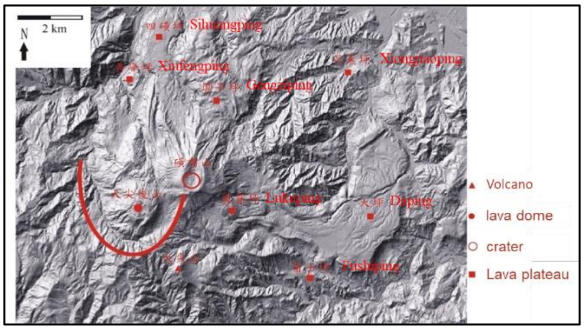

Figure 2: LiDAR map of Huangzuishan Volcanic Subgroup

Using 2m by 2m LiDAR data and through field surveys, show that the volcanic terrain of this subgroup is quite intact, as shown in Figure 2. The Huangzui Volcanic Subgroup likely includes two volcanic bodies. One is located at Dajianhoushan, an old volcano that collapsed after the eruption of large amounts of lava during the initial volcanic activity, forming a caldera. Later, due to increased magma viscosity, lava domes formed inside the caldera, resulting in Dajianhoushan. The other volcanic body is located at Huangzui volcano, which erupted to form the fourth stage of lava, creating a crater at the summit, named Huangzuichi. Additionally, there may be two smaller volcanic bodies within th**is** area.

Figure 2 show that the lava flows from the crater of the Huangzui Volcanic Subgroup are distributed in banded, tongue-shaped, and ring-shaped patterns in the lowlands surrounding the volcano. Due to differences in eruption times and the varying distances the lava traveled, different lava plateaus have formed. Generally, the lava plateau farther from the crater are older, while those closer to the crater are more recent.

Huang et al. (2021), using seismic analysis, suggested that the current magma chamber in the Tatun volcanic group is located beneath the Huangzui Volcanic Subgroup, at a depth of around 8-20 km with approximately 19% melt fraction, as determined by 3D tomographic joint inversion. This indicates that the current hydrothermal activities in the Tatun volcanic group are likely controlled by fractures and faults.

2.1 Huangzui volcano stratigraphy and age

Chen and Wu (1971) conducted a study on the stratigraphy of the Huangzuishan Volcanic Subgroup, dividing the volcanic rocks into 13 layers. However, field study and drilling data reveal that the volcanic stratigraphy of the Huangzui Volcanic Subgroup consists of multiple interbedded lava flows and pyroclastic rocks, with the lava age of the Huangzuishan Volcanic group ranging from 0.1 Ma to 0.42 Ma (Chu et al . 2018). This suggests the presence of multiple volcanic craters within the subgroup, each erupting different lava flows with significant lithological variations.

The main volcanic ejecta of the Huangzui Volcanic Subgroup are predominantly lava flows, with only a small portion being pyroclastic material. Song et al. (2011) divided the Huangzui Volcanic Subgroup into thirteen different lava flow sequences (H1-H13). The ridges extending southwest from Nanshihu and Huangzuishan consist of pyroclastic rocks. The characteristics of each lava flow layer are shown in Table 1. At least 13 layers of volcanic lava flows can be identified on the surface, interspersed with pyroclastic flows. Based on volcanic terrain profiles, the degree of erosion and preservation of lava terraces, terrain slope distribution, and detailed DTM maps, at least four major lava flow eruption periods can be identified within the Huangzuishan Volcanic Subgroup area. This suggests that volcanic eruptions in the Huangzuishan Volcanic Subgroup were quite frequent, making it a typical composite (stratovolcano) volcano.

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Sequence	Distribution	Matrix	Phenocryst Percentage		Note
			Hornblende	Pyroxene	
H13	Huangzui main peak	Grey-dark grey	10	<5	Phenocryst <0.3cm
H12	Xiufenping	Dark grey	<5	10	Phenocryst <0.3cm
H11	Dakongwei	White grey - grey	>10	<5	Hornblende Phenocryst >0.3cm
H10	Tien Lai	Dark grey	5	<10	Phenocryst <0.3cm
H9	Dajianhoushan	Dark grey	5	10	Phenocryst <0.3cm
H8	Dajianhoushan (northern side)	Grey-dark grey	>10	<5	Phenocryst <0.3cm
H7	Daping	Dark grey	1	10	Phenocryst <0.3cm
H6	Bayen	White grey	10	<5	Hornblende Phenocryst >0.3cm
H5	Dingshan	Dark grey	10	<1	Phenocryst <0.2cm
H4	Dajianshan	Grey	10	<5	Phenocryst <0.3cm
H3	Kengtou	Dark grey - black grey	<5	>10	Phenocryst <0.3cm
H2	Dalunwei	Grey	10	<5	Phenocryst <0.3cm
H1	Gongguanlun	Light grey - grey	10	5	Phenocryst <0.3cm

Table 1: Huangzui Volcanic Subgroup lava flow sequences (Song et al. 2011)

3 GEOPHYSICAL SURVEY

3.1 Magnetotelluric survey

The Magnetotelluric (MT) survey was conducted by GERD (Geothermal and Energy Research & Development Co.) to construct a 3D resistivity structure of the northern part of the Huangzui volcano. GERD conducted the survey at 38 MT stations, covering an area of approximately 4 km x 4 km, with measurements interpreted to a depth of 1,000 meters below sea level.

Figure 3 shows the map view of MT resistivity with six horizontal slices at 300, 100, -100, -300, -500, and -700 meters, respectively. The Sihuangziping steaming ground is located at 325 meters above sea level, and the Genziping steam ground is located at 440 meters above sea level. At a shallow depth of about 300 meters, low resistivity zones of 5-20 Ωm (warm colors in Fig. 3a) are interpreted as alteration zones. However, at 100 meters above sea level, there is a high resistivity anomaly (cool colors in Fig. 3b), which is interpreted as a local steam cap from which the current Sihuangziping 1.0 MW pilot power plant steam supply is sourced, the interpretation of intrusive body for the high resistivity structure was ruled out due to no lithology change at the borelog. At -100 meters (Fig. 3c) and -300 meters (Fig. 3d), a low resistivity zone with a ring-shaped alteration zone can be observed at the Huangzui volcano. The low resistivity zone occurs within the basement of the lava flow, the Wuzhishan formation, as determined by the SHP-1, E303, and LHTP-E exploration wells drilled by Taiwan CPC, ITRI, and Fabulous Power. The basement rock in this region is around 590 to 811 meters deep, dipping southwest. This layer of the alteration zone is mudstone altered to alunite in the Wuzhishan formation, which will be discussed in a later section.

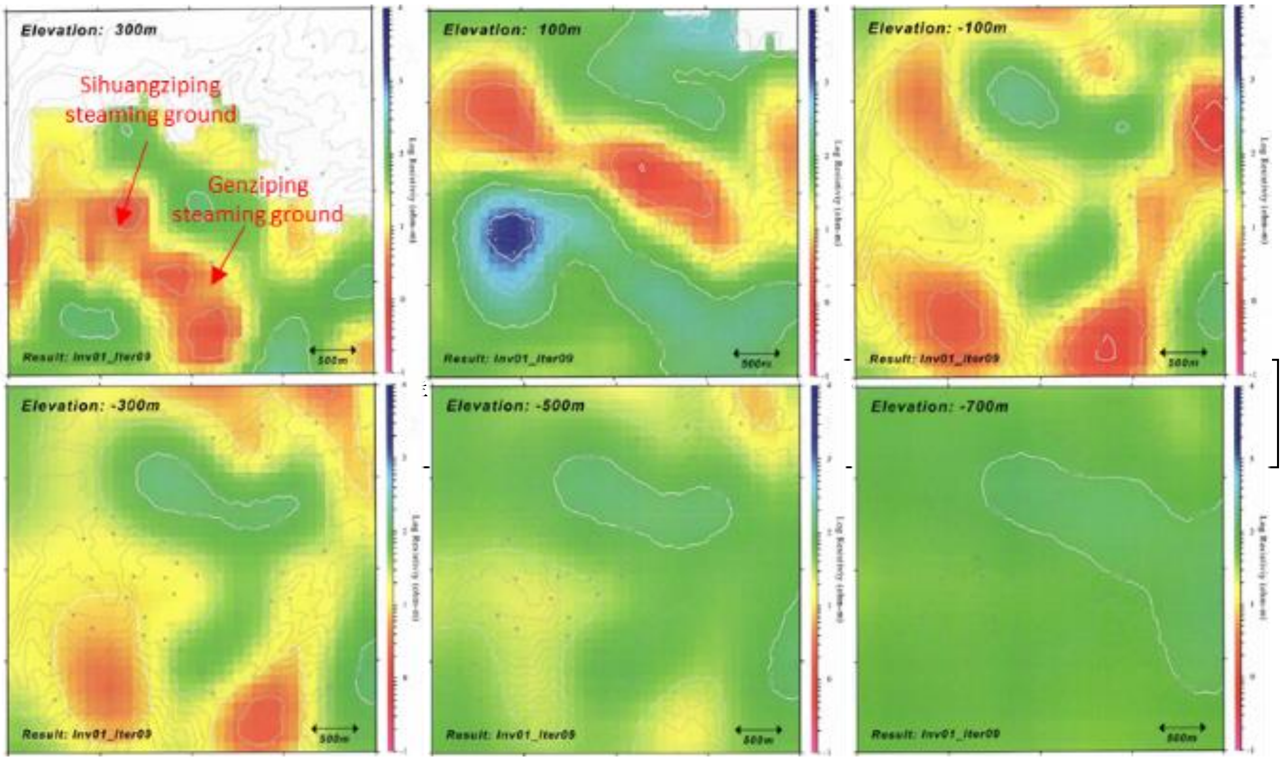

Figure 3: Planar resistivity structure of Huangzui volcano from elevation of 300 m(a), 100 m(b), -100 m(c), -300 m(d), -500 m(e) and -700 m (f).

4 GEOCHEMICAL SURVEYS

4.1 Water chemistry

The water samples collected in the steaming ground of Sihuangziping and Genziping (Fig. 4 and 5) reveals that the steam condensate from the Tianlai well for supplying nearby hot spring resort can reach a pH of 4.2, while the mixed water from the Tianlai well drainage has a pH of approximately 3.64. It is speculated that the Tianlai well is a dry steam well, resulting in a very low proportion of hydrogen sulfide dissolving into the condensate, which allows the pH to reach 4.2. At Genzing, the pH values of other steam ground are all below 3, and the pH values at the sulfur mining sites are even below 2.

The sulfate ion concentrations in field hot spring waters are very high. This is due to volcanic gases migrating upwards and encountering groundwater, where the sulphate ion dissolves into the groundwater, creating strong acids. Consequently, the hot spring waters at Sihuangziping and Gengziping, as shown on the Piper diagram in Figure 6, fall within the range of calcium sulfate springs. Only the steam condensate, which is directly condensed from dry steam, falls within the range of calcium carbonate springs.

Calcium ions are the most abundant cations, with concentrations in the two hot spring outcrops at Sihuangziping being 25 and 39 ppm, and those at Gengziping ranging between 24 and 117 ppm, as shown in appendix 1. When plotted on a sodium-potassium-magnesium geothermometer, none of the hot spring outcrops reach water-rock equilibrium, making it impossible to calculate the temperature, as shown in Figure 7.

The hydrogen and oxygen isotopes in the water samples indicate that the hot spring water at Gengziping aligns along the evaporation line, suggesting it is old water that has undergone intense boiling. In contrast, the hot spring water at Sihuangziping is closer to the meteoric water line, indicating a relatively lower degree and duration of boiling compared to Gengziping, as shown in Figure 8.

Figure 4: Sihuangziping geochemical sampling points

Figure 5: Genziping geochemical sampling points

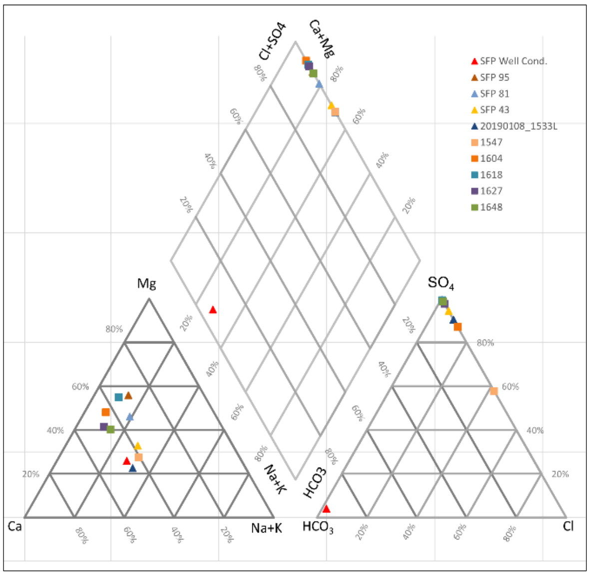

Figure 6: Piper diagram of Sihuangziping and Genziping

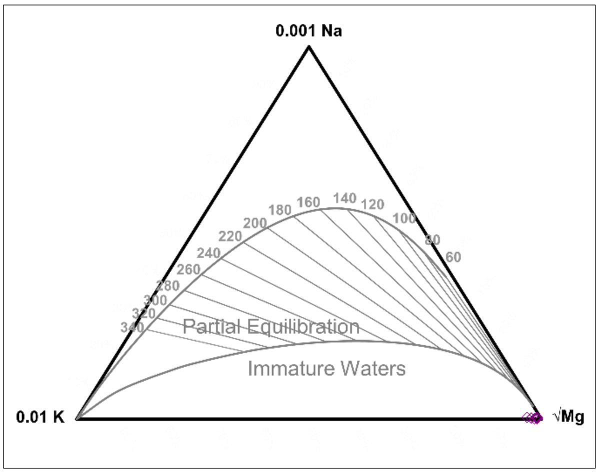

Figure 7: Na, K and Mg ternary diagram shows all the samples reach water-rock equilibrium.

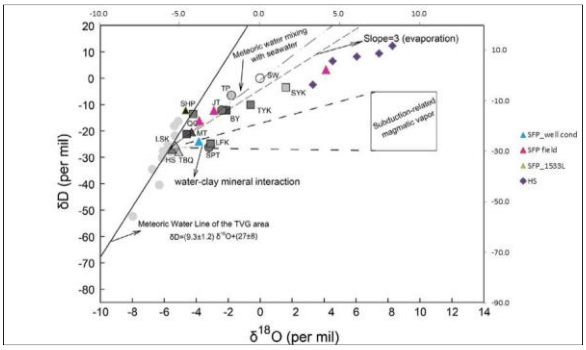

Figure 4.5: σD vs. σ18O plot of the Sihuangziping and Genziping, compared with other geothermal manifestation in Tatun.

5 EXPLORATION WELL IN HUANGZUI VOLCANO

5.1 Previous drilling result

The geothermal exploration of the Huangzui volcano began in the late 1960s, led by the MRSO, later known as ITRI. They drilled 12 shallow temperature gradient wells (labeled with "G") ranging from 60 m to 621 m in depth, and two exploration wells (E-301 and E-303) on the northern side of the Huangzui volcano (ITRI, 1994). This exploration covered three steaming grounds: Bayen, Sihuangziping, and Genziping. The well temperature at Sihuangziping steaming ground reached up to 140°C at a depth of 100 m. Due to restrictions within the national park, most wells were drilled at Sihuangziping and Genziping steaming grounds.

The drilling program ended in the late 1980s when CPC drilled a 2,200 m deep exploration well (CPC-SHP-1T) at Xiufengping (CPC, 1987). This well penetrated andesite from near the surface to a depth of approximately 810 m, followed by sedimentary rocks of the Wuzhishan Formation (811 to 2,025 m). There are records of an intrusive dyke below 1,000 m, which might indicate an historic magmatic event. The maximum temperature recorded in this well was 160 °C, but there was no record of production.

In 2016, ITRI drilled a 1,300 m deep exploration well, which reached a maximum temperature of 139°C. This well showed limited production (12.2 t/hr without airlift) and a pH of 2.5. It was later abandoned without installing a wellhead. The high acidity might due to the ground water infiltration into the wellbore, causing the sulfur and other sulphide minerals react with the heated ground water, causing the water to be acidic. It is also possible there's some pore water in the Wuzhishan formation, which may also be high acidity when react with volcanic gases and no minerals such as plagioclase, pyroxene and amphibole to assist on neutralization of the fluid, since the Wuzhishan formation is mainly consist of quartz arenite.

Cutting and core analyses of well E-303 revealed that the lithology consists of porphyritic two-pyroxene andesites (from near the surface to a depth of 620 m) and sedimentary rocks of the Wuchihshan Formation (mainly quartz arenite; 608 to 1,270 m) (ITRI, 2016). The porphyritic two-pyroxene andesites in the shallow part (above 300 m) are mainly altered to calcite and smectite. The middle section (300 m to 600 m) is altered to kaolin-smectite/illite-smectite. The sedimentary rocks are mainly altered to advanced argillic minerals, mainly alunite, quartz and cristobalite (ITRI, 2020).

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Table 2 List of geothermal gradient wells and exploration wells drilled in Huangzui volcano area.

Well ID	TWD97(WGS84)_Long.	TWD97(WGS84)_Lat.	Depth (m)	Max Temp.(°C)	Owner
E-301	121.6094795	25.18532688	474	103	MRSO / ITRI
E-302	121.6062403	25.19035966	60	nd	MRSO / ITRI
E-303	121.6077201	25.19266471	1300	139	ITRI
G-301	121.6025879	25.19214404	147	134	MRSO / ITRI
G-302	121.6050639	25.19123115	104	140	MRSO / ITRI
G-303	121.6077363	25.19191534	150	28	MRSO / ITRI
G-304	121.5991166	25.19242897	132	23	MRSO / ITRI
G-305	121.6039836	25.19349252	89	98	MRSO / ITRI
G-306	121.6029736	25.18988551	100	38	MRSO / ITRI
G-308	121.6023026	25.19467299	144	116	MRSO / ITRI
G-310	121.6037976	25.19602107	124	102	MRSO / ITRI
G-312	121.6209776	25.1821858			MRSO / ITRI
G-313	121.6239776	25.18256899			MRSO / ITRI
G-307	121.6136673	25.18550818	41	87	MRSO / ITRI
G-309	121.6159655	25.18874865	129	29	MRSO / ITRI
G-311	121.6130615	25.18936557	134	63	MRSO / ITRI
G-501	121.5933683	25.19582855	621	140	MRSO / ITRI
CPC-SHP-1T	121.5994629	25.19831371	2025	160	CPC
LHTP-1	121.60707	25.190968	1100	122.2	Fabulous Power
GZP-E	121.612965	25.189732	500	175	Fabulous Power

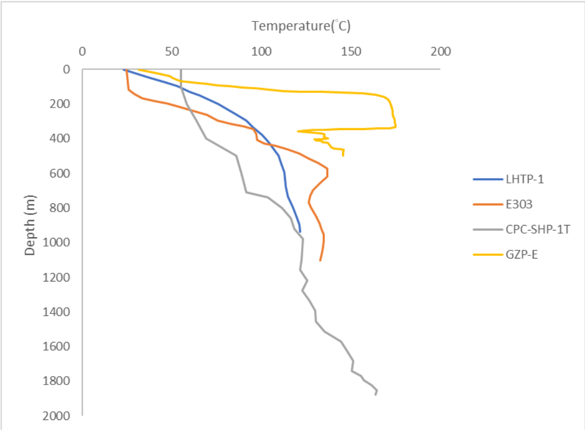

Figure 8 Temperature profile of LHTP-1, E-303, COC-SHP-1T and GZP-E exploration wells.

5.2 Fabulous Power exploration well LHTP-1

The drilling of the LHTP-1 exploration well commenced after the company won the bid for the "Liuhuangziping, New Taipei City Geothermal Power Generation Demonstration Area" project from the Bureau of Energy (later called the Energy Administration) in 2018, following the completion of the E-303 exploration well by ITRI. The LHTP-1 well is located 200 m away from E-303. Initially, LHTP-1 was targeted to reach a depth of 1,800 m, but due to various reasons, it was completed at 1,123 m. The transition from andesite to sedimentary basement occurs at 600 m.

Preliminary analysis of the alteration minerals in the andesite lava flow shows similarities to those in the E-303 well, with no acidic alteration minerals. Near the boundary of the sedimentary basement (around 500 m to 600 m), native sulfur appears, indicating the presence of acidic fluid in this region. Below 600 m, in the sedimentary basement, native sulfur predominates as the alteration mineral. After 1,000 m, alunite alteration becomes the dominant alteration mineral, and the quartz grains in the cuttings become coarser. The core sample between 1,050 m and 1,073 m shows interlayers of alunite-altered formation and quartz sandstone, which appears to be slightly metamorphosed. The core sample from 1,060 m to 1,065 m also shows the presence of intrusive rock, similar to that found in the CPC-SHP-1 well but not in the E-303 well. The intrusive rock in the sedimentary basement further indicates that the quartz arenite underwent contact metamorphism. The core sample shows a zunyite vein with presence of enargite, confirmed by SEM and XRD analysis at 1,062 m, suggesting that the fluid temperature in the sedimentary basement might have exceeded 200°C in the past (Hedenquist and Arribas, 2021). The PT diagram in the Figure 5.1 shows the maximum temperature of this well is 122.2°C, with limited production.

5.3 Fabulous Power exploration well GZP-E

Fabulous Power just finished drilling a 500 m exploration well at Genziping. Preliminary data shows that the shallow section (above 375 m) encountered a 170°C to 175°C steam pocket. Below 400 m, the well enters the liquid phase, with the temperature around 150°C and still rising. The entire section is still within the andesite formation.

6 GEOTHERMAL CONCEPTUAL MODEL OF HUANGZUI VOLCANO

By integrating previous and new results from geophysical data, geochemical data, and drilling data, we have reconstructed the geothermal geological model for the Huangzui volcano geothermal field (Figure 9). We have listed several notable points for the current model.

- All the surface geothermal manifestations and steam grounds are fault-controlled, and it is where the main upflow zone occurs in this region. As a result, all three deep exploration wells in this region (CPC-SHP-1T, E-303, and LHTP-1) did not encounter the reservoir (steam or brine).
- Magnetotelluric results showed that the Sihuangziping steaming ground has a shallow steam pocket, confirmed by the drilling of three production wells in the Sihuangziping geothermal power plant. Due to its shallow depth, the pressure of the steam is relatively low, which keeps the steam in a high dryness fraction. The high steam dryness fraction in Sihuangziping might also be due to the low natural recharge of meteoric water in this region.
- At Genziping steaming ground, the high resistivity anomaly is not as apparent. However, with the recent drilling data from GZP-E, we suggest that the high resistivity anomaly might be mixed with low resistivity brine fluid at the lower levels of the formation, resulting in lower resistivity than the Sihuangziping steam ground.

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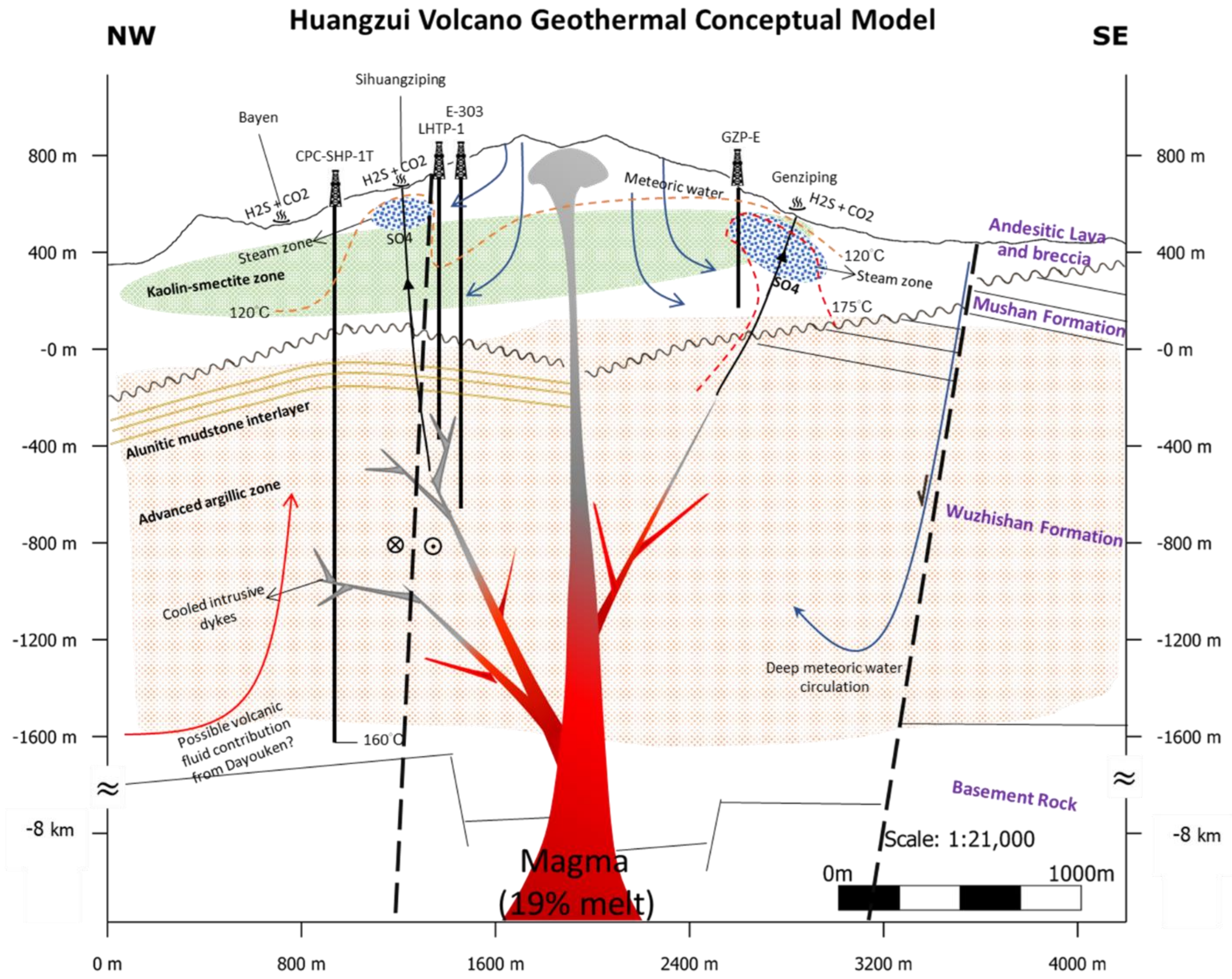

Figure 9 Geothermal conceptual model of Huangzui Volcano

7. CONCLUSION

In this study, we combined previous and recent geophysical, geochemical and drilling data in Huangzui volcano region, northern Taiwan to build a geothermal conceptual model.

The geothermal system at Sihuangziping and Genziping is characterized by steaming ground, indicating significant subsurface thermal activity. Our model reveals a shallow steam pocket beneath these areas, with temperatures ranging from 95°C to 130°C, corresponding to a high resistivity zone identified through magnetotelluric (MT) survey data. The main upwelling zone is located directly beneath the steaming ground, with minimal lateral fluid movement, suggesting a relatively confined and vertical flow system.

In the andesite formation, kaolinite-smectite alteration and calcite veining are dominant, indicating that the fluid has undergone propylitic alteration, typically occurring in cooler, peripheral parts of hydrothermal systems. The Wuzhishan formation exhibits more intense alteration patterns, with advanced argillic alteration predominating. Alunite is the main alteration mineral, with zunyite and enargite also present. This mineral assemblage is characteristic of high-sulfidation environments, suggesting more acidic and oxidizing fluid conditions in this formation.

The shallow fluid in the system is primarily steam-heated, with temperatures consistent with the steam pocket. Its source is mainly meteoric water that has penetrated the shallow formation and rapidly boiled due to interaction with volcanic gases, explaining the steam-dominated nature of the shallow system and its relatively low temperature compared to deeper geothermal reservoirs.

The high-sulfidation environment indicated by the mineral assemblage suggests magmatic input into the system, likely providing heat and sulfur-rich fluids. This has important implications for the potential longevity of the geothermal resource, the possibility of associated epithermal mineral deposits, and environmental considerations due to potentially acidic and metal-rich fluids.

To support the sustainable expansion of the power plant in the Hunagzui volcano region, further work is planned to exploit the deeper parts of the geothermal reservoir, as the current low-pressure and low-temperature steam pocket maybe insufficient for our goals. Our ultimate objective is to construct a 20 MW geothermal power plant in the Sihunagziping geothermal area. To achieve this, we are implementing several strategies: conducting a micro-gravity survey to better understand the fault structure in this area;

expanding the magnetotelluric (MT) survey from 3 to 5 days, aiming to reveal the resistivity structure up to 3000 m below sea level; planning an exploration well equipped with Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) systems to monitor micro-seismic activity and temperature changes in the reservoir; and performing well logging to further enhance our understanding of this geothermal field.

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Sample Name	T (°C)	pH	F	Cl	Br	NO3	PO4	SO4	CO3	HCO3	Li	Na	NH4	K	Ca	Mg
SFP Well Cond.	42.8	4.2	0.52	1.21	ND	0.9	ND	3.69	ND	110	ND	0.29	ND	0.97	1.23	0.42
SFP 95	95.3	2.83	0.75	8.1	ND	0.9	ND	1249	ND	ND	ND	9.91	ND	5.33	25.1	28.1
SFP 81	81.5	2.28	ND	4.29	ND	0.9	1	1692	ND	ND	ND	17.8	ND	11.7	39.1	31.4
SFP 43	43.1	2.96	0.48	8.78	ND	1.3	ND	199	ND	ND	ND	7.21	ND	1.61	9.38	4.89
20190108_1533 L	56.9	3.64	0.43	7.22	0.86	ND	ND	92.2	ND	ND	ND	5.48	0.08	1.46	7.8	2.35
1547	96.5	1.23	0.83	1458	ND	ND	ND	2701	ND	ND	ND	16.5	3.31	9.4	24.2	10
1604	91	1.92	0.91	224	1.17	ND	ND	2012	ND	ND	ND	19.4	1.06	5.73	98.6	66.3
1618	86.6	3.05	0.62	1.88	0.91	ND	ND	307	ND	ND	0.29	7.33	1.35	4.97	29.7	28.5
1627	81.5	2.08	0.86	36.9	2.05	ND	ND	2025	ND	ND	0.32	29.2	1.94	5.15	117.3	62.4
1648	69.5	2.05	0.76	17.9	1.78	ND	ND	1700	ND	ND	ND	23.3	1.28	6	73.1	39.1

Appendix 1: Geochemical analysis result of the northern Huangzui Volcano area.