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Quynh Phu – Hung Ha Geothermal System in Red River Delta, Vietnam: Geothermal Potential and Conceptual Model

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ABSTRACT

Quynh Phu – Hung Ha geothermal resource is located in the centre of the Red River Delta in northern Vietnam, in an area of about 25 km^2, the local people can easily get hot water of 45^{o}C when drilled to the depths of 70 m. There are applications of geothermal water for swimming pool, spa, aquaculture, and breeding farm here.

The Red River Delta is covered by Neogene and Paleogene sediments, with the varied thicknesses, ranging from 0 to a few dozen, several hundred, some places to thousands of meters. The main fault systems those control the structure of the Red river plain are the horizontal sliding normal faults of Red river and Lo river; the reverse fault of Vinh Ninh and Thai Binh, and the normal faults Chay river.

The geothermal system here is believed to be convective - that is, meteorological water flows downward along Thai Binh fault and encounters a high-temperature zone due to the cooling process of a magma block located deep below. After that, the water is raised following Vinh Ninh fault channel and appeared in the Pleistocene aquifer at a depth of more than 70m. Due to the upper confining bed of the Pleistocene layer, hot water is spread only below the confining bed of Pleistocene aquifer. A conceptual geothermal system has been trying to make for a better understanding of geothermal resource and future exploration orientation.

1. INTRODUCTION

With an area of over 14,000 km^2, the Red River Delta has been found to have 22 mineral hot water sources with temperature from 32^{0}C to 137^{0}C. All of the hot water sources in this area appear in the shallow and deep wells, and the deepest well is 3,100 m. In these deep wells, the hot water temperature is high due to the geothermal gradient. This is also consistent with a study on the heat flow in the area. The study shows the Red River Delta has the hottest heat regime in four sedimentary basins in Vietnam territory with thermal conductivity: 3.37W/mk; thermal gradient: 35.9K/km and heat flow: 118mW/m^2 (GSJ, 1997). About recent 30 years, the people living in an area of about 25 km^2 of Quynh Phu and Hung Ha district of Thai Binh province and Phu Cu district of Hung Yen province have used water from the wells to supply for daily domestic uses. When the people drilled to a depth of more than 60 m, they all got 37-50^{0}C hot water. Although the temperatures of hot water here are not very high, the hot waters appear in a very large area and can be assessed that this area is the highest geothermal potential in the Red River Delta (Fig. 1). Currently, people here use geothermal water for bathing, spa, physiotherapy, swimming pools, aquaculture and breeding farm. The authors have conducted a survey, collected water samples combining with the existing data of geology, geophysics and hydrogeology for the purpose to research and evaluate the geothermal potential as well as to create the conceptual model for Quynh Phu – Hung Ha geothermal system in order to serve socio-economic development in the region and orientation for development of this geothermal resource in the future.

2. GEOLOGICAL SETTING

2.1 Geology

Most of the Red River Delta surface area exposes the Quaternary sediments, underneath the Neogene and Paleogene sediments with unstable thickness, ranging from a few to ten, several hundred and some places to thousands of metres.

The basement of the Red River basin has been encountered in many wells. The basement is found to be diverse and heterogeneous (Fig. 2). At the North-eastern edge and the Northside of Song Lo fault is metamorphic rocks such as sericite schist, quartzite, and Carbonate – Permian carbonate. At the centre of coal basin in Red River Delta and in between the Song Chay and Song Lo faults, there are eruptive rhyolite rocks aged Triassic and Palaeozoic metamorphic rocks. At the Southwestern edge, in the south of Song Chay fault, Permian eruptive rocks and Proterozoic metamorphic rocks are belonging to Red River complex.

Based on the study of sedimentary petrography of oil drilling holes in Red River Delta, Glovenok V.K., Le Van Chan (1966) divided Cenozoic sediments in the Red river basin area including Neogene sediments of five layers: Phu Tho, Phan Luong, Phu Cu, Tien Hung, Vinh Bao and Quaternary sediments including two layers of Hai Duong and Kien Xuong. Meanwhile, Vu Xuan Doanh (1986) divided Cenozoic sediments starting from Paleogene with Dinh Cao suite aged Eocene - Oligocene, above which were Neogene formations of Miocene series, including the suites of Phong Chau (N_1^1), Phu Poles (N_1^2), Tien Hung (N_1^3) and Pliocene series including two suites of the same age as Vinh Bao and Hoa My (N_2). Covering on these formations is the Pleistocene sediments with Hai Duong suite and the Holocene with suite Kien Xuong.

Summary of the research results of geological sections of the boreholes in Red River basin, the Cenozoic sediments here include the following formations: Paleogene system (E), Neogene system (N), Quaternary system (Q).

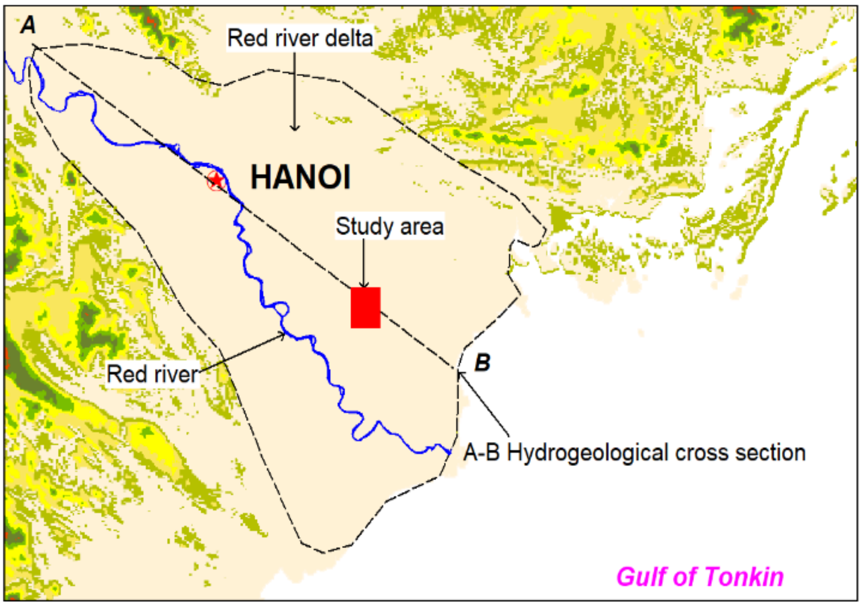

Figure 1: Location of the study area.

2.2 Tectonic

Macsiutova et al., 1969 used the geophysical methods (electricity, bouget gravity (Δg), seismic) were able to draw the geological structure of Cenozoic sediments in the Red River Delta to a depth of 3,000 m with structural zones: North-eastern Zone, Central Zone and Southwestern Edge. In which, the study area is located in the Central Zone, which is limited by two main faults, namely the Song Lo fault in the Northeast and Song Chay fault in the Southwest. This is a large subsidence area, with very complex geological structure and tectonic characteristics. The thickness of Cenozoic sediments here is very large, and the thickest place reaches over 5,000m, tends to sink gradually into the Gulf of Tonkin. This area is strongly compressed because tectonic activity phases occur at the end of the middle Miocene until the end of the late Miocene.

The impact of compression phase caused strong folds, creating a series of reverse faults, of which the most typical is the Vinh Ninh fault (reactivating and becoming reverse fault), and forming a series of flower structures.

The study area developed many different fault systems. The main fault system is regional characteristics with the direction of Northwest – Southeast. The less-developed fault systems are Northeast – Southwest direction.

- The system of Northwest - Southeast faults: is the main fault system controlling the structural framework of Red River Delta including the faults with horizontal flat sliding Red river and Lo River; Vinh Ninh fault, Thai Binh reverse fault, Song Chay normal fault. The faults have a dip angle of 70 – 80^{o} with a displacement of 100 - 1,000 m, a destructive zone of over 100 m. In addition, there are many small faults with reverse mechanism appeared in the late Miocene compression phase such as Tien Hai fault, Kien Xuong fault and F1 fault, ... with smaller displacement amplitude and smaller destruction zone. Here are some main systems:

+ Song Lo fault system: This is an ancient fault system that was born in the Cambrian period deeply embedded in the foundation to the face of Moho surface, in the West and Southwest direction, re-operating in the early Eocene - Oligocene rift period (separation zone) and stop working during the late rifting period (Late Oligocene, Early Miocene). The Song Lo fault system is important to play a role in the formation of Red River sedimentary basin, controlling the eastern part of the central zone.

+ Vinh Ninh fault system: It is a relatively young fault system compared to the Song Lo fault system, possibly in the early period of subsidence of Song Hong basin and plugging deeply into the basement in the Western and Southwestern direction. It is because of the compression phase at the late middle Miocene – early late Miocene has left a series of negative and positive structures in the form of flower form attaching with the reverse faults and forming traps capable of accumulating petroleum-like Tien Hai mine. This deep and young fracture is also very likely a circulation channel for water from sedimentary layers near the surface to the depths of the earth's crust in the area.

+ Thai Binh fault system: This is a reverse fault and a part of the Song Chay fault system, with the Northwest - Southeast direction, the penetrating direction of East and Northeast. The depth of influence is relatively large of about 25 km, cutting through the crust.

+ Song Chay fault system: The Song Chay fault system has a relatively large displacement amplitude, some places reach to more than 3,000m, penetrating into the basement until Moho surface with the directions of East and Northeast. This is the main fault system controlling the western part of the Central zone of Red River basin. The Song Chay and Red River fault systems have created a very important suture zone of Red river in the geological formation and development of the Red river sediment basin.

- The systems of Northeast – Southwest fault: This fault system divides the architectural blocks into small blocks of terraced form, gradually descending towards the sea, interrupting or moving the Northwest - Southeast fault system. The displacement amplitude of these faults is not large ranging from tens to hundreds of meters. The characteristics of this fault system are strongly developed in the Paleogene period and reactivated in the early period of Neogene.

- The system of sub-latitude fault: These are individual faults which are not large in both length and displacement amplitude, they do not play a big role in the formation of the main structure of the basin but only complicate the structure. The formation of the Red river basin is closely related to the activity processes of the Ailao Shan – Red River fault zone. Geologists also know it as Ailao Shan – Red River shear zone. The width of Ailao Shan – Red river sliding shear zone is several tens of kilometres, and the length is longer than 1000 km, the slipping operation of the Ailao Shan – Red river shear zone is caused by the collision between the Indian Plate and the Asian plate in the Himalayan phase. Along the fault zone, there are sections with different geodynamic regimes: squeezing zone, flat sliding area and extension zone creating many large and small Neogene sedimentary basins, of which the most typical is Red river basin.

Overall, the Red river basin may be one of the Cenozoic basins overlapped on the continental crust basement, formed by the activities of the Ailao Shan – Red River shear zone, the result of the Himalaya collision, further constrained by the heat up activities due to the lower mantle lifting (Fig. 2).

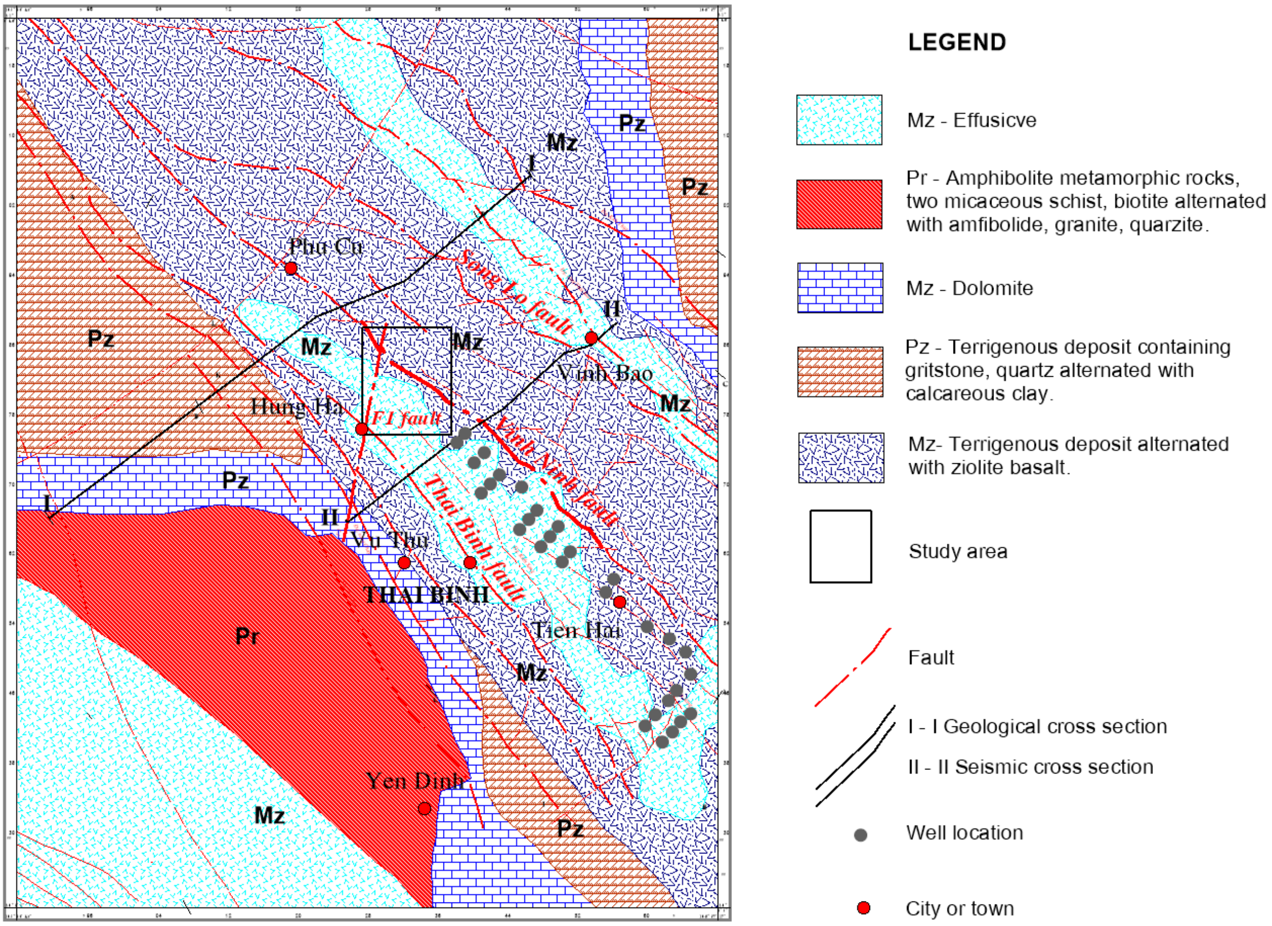

Figure 2: Quynh Phu – Hung Ha geothermal area in relation to the geological setting.

2.3 Hydrogeology

The study area constituted by the Quaternary unconsolidated sedimentary layers with the thickness ranging from a few to over 100 meters, and the underneath masses are the weakly aggregated Neogene rock with a thickness up to thousands of meters and crystalline basement below. Because of this structure, the geohydrological conditions here are very complicated. In unconsolidated soils and rocks, groundwater exists in the form of holes, according to the cross-section from top to bottom, it is possible to divide several aquifers alternated with aquiclude layers (Fig. 3).

The aquifers:

- Qh aquifer in Holocene sediments: This is the first aquifer from the ground and has the youngest age. It is widely distributed from Hanoi to the sea but from the angle of the Red River delta to Hanoi only exists along the Red River or other small rivers such as Cau river, Ca Lo River and Day river. The average thickness of the Holocene aquifer throughout the delta is 13.6m. General characteristics of water: light water, mineralisation ranges from 0.189g/l to 0.445g/l, especially 0.58g/l, medium soft to medium water, calcium-magnesium bicarbonate type, pH = 6.9-8.0. The main source of Holocene aquifer is the infiltration of rainwater and the infiltration of river and lake water.

- Qp aquifer in Pleistocene sediment: This is a product aquifer, used to exploit water to supply for domestic use of the people in the urban areas, villages and industrial zones in the Red River Delta. Pleistocene aquifer is widely distributed throughout the Red River Delta and is mostly covered by sediments with younger age. Due to the influence of geological processes, the order of aquifers in Quaternary sediments has special features: from Hanoi to the sea, and the qp aquifer is located underneath the qh aquifer and between them, there is a layer aquiclude. The thickness of qp is from 0.6m to 55m. The groundwater geochemistry of qp is mainly bicarbonate-calcium, bicarbonate-chlorinated water, calcium-sodium or colloid-bicarbonate, sodium-calcium. The main source of supply for qp aquifers is surface water, rivers, lakes, seepage through the hydrogeological "window" zone, water from the inlet boundary and infiltrating water from the above Holocene aquifer. The source drains mainly to the sea, penetrates to the upper aquifer and supplies for the people.

In addition to porous aquifers, there are fissured aquifers and poor-water aquifers in the area such as Fissured aquifer - Neogene porous sedimentary; cracked aquifer of the Jurassic system; Cracked aquifer, cracks - karst in limestone and geological formations of very poor in water or aquiclude.

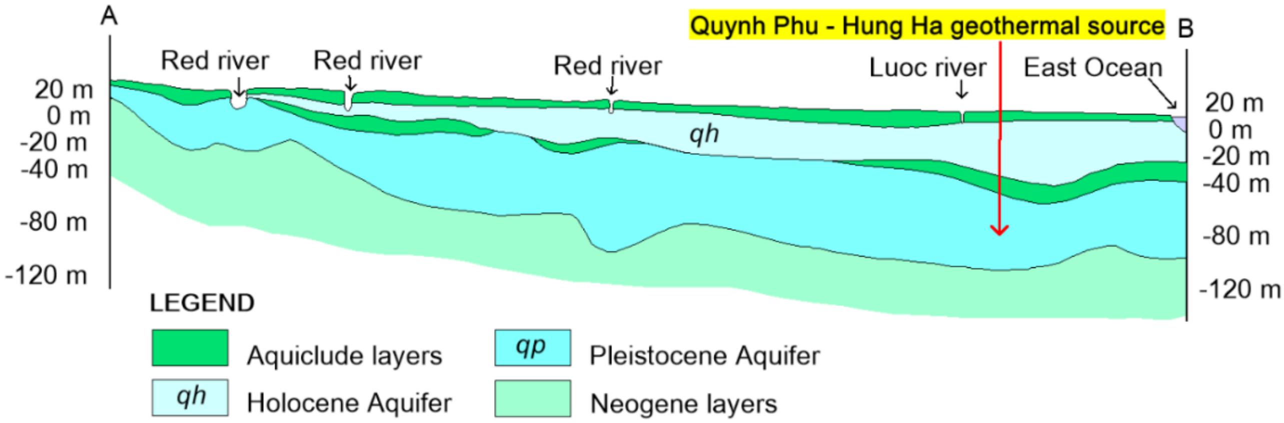

Figure 3: A-B Hydrogeological cross-section *(Source:* Nguyen Thi Ha, 2006-2010).

3. CHARACTERISTICS OF QUYNH PHU – HUNG HA GEOTHERMAL RESOURCES

3.1 Geothermal Sampling

The appearance of hot water on a large area is very rare in Vietnam, and especially hot water appears in underneath aquifer. Due to the flat plain terrain, thick sediment coating, hot water is ascended from below layers through the channel as faults or cracks and retained in this Pleistocene aquifer. Therefore, collecting this geothermal water sample is completely from shallow boreholes that were extracted to supply water for the villagers here. These boreholes have depths from 60 to 110m. Each family has one borehole, so the borehole density is very thick. Through the survey by measuring the temperature, pH, conductivity and TDS of 80 selected wells in the study area (Fig. 2), from the well with the highest temperature in the centre to the wells with normal temperature in the periphery. Of the 80 wells surveyed, 55 have hot water at temperatures between 40 and 50oC. Of the total 80 survey wells, water samples were collected from 14 wells for analysis, in 14 samples, there was 1 sample collected from a common water well, and 1 sample was surface water from the pond. Analysis criteria: Na, K, Ca, Mg, SiO2, CL, SO4, HCO3, CO3, NH4, Fe, Mn, Ba, H2S, Cs, Sr, Li, Rb, B, As, F, Hg, Br and stable isotopes D, O^{18}.

Because the study area is located in the large Red River Delta, the characteristics of Neogene sediment layers are hardly changed much in a relatively close distance. Therefore, the research team used drill core samples at 19 boreholes up to 1,200m (Fig. 2) in the area about 10 km away from the Quynh Phu - Hung Ha geothermal study area for analysing the U, Th and K radioactive elements; measure the porosity and thermal conductivity of these core samples. The core samples are collected at three positions in each borehole. Particularly, the borehole is located near the study area was collected at six positions so that there would be more data for the geological assessment for the geothermal reservoir of Quynh Phu - Hung Ha. In total, 60 rock samples were collected and analysed for the content of U, Th, and K.

3.2 Characteristics of Geothermal Fluid Chemistry

In order to classify geothermal waters, the results of chemical composition analysis of geothermal water samples in Quynh Phu - Hung Ha area were used, and the three HCO_3-CL-SO_4 constituents (Fig. 4) show all of the geothermal waters here are positioned at the HCO_3 corner, indicating that the samples are all bi-carbonate. This proves that there is no sign of magmatic water. Moreover, the study area is at about 30 km from the sea, the groundwater here is almost salinisation with higher Cl content, but the hot water is not Cl. So, geothermal water here is bi-carbonate.

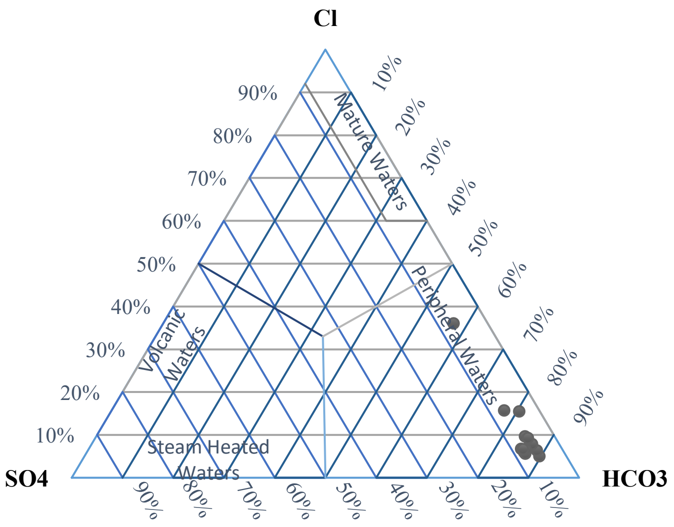

Figure 4: Cl-SO_4-HCO_3 triangular diagram of Quynh Phu - Hung Ha geothermal field.

The K-Na-Mg diagram (Fig. 5) shows that geothermal fluids in Quynh Phu - Hung Ha are immature and have a temperature of 120^0C to 180^0C at the reservoir.

The Na-K / Mg-Ca diagram (Fig. 6) of Giggenbach and Goguel (1989) is also another address to support the Na-K-Mg diagram in which it complements the use of the K-geothermometer of K/Na with balanced Mg-Ca system. This diagram is applied appropriately to geothermal reservoirs affected by low temperature and shallow processes rather than to balanced geothermal systems, suitable for the reservoirs in carbonate rocks or solutions dominated by water-rock chemical balance rather than geothermal equilibrium. From this diagram, it can be seen again that the temperature in the reservoir of the geothermal waters those were collected from the hot water wells in Quynh Phu - Hung Ha ranged from 12^0C to 200^0C.

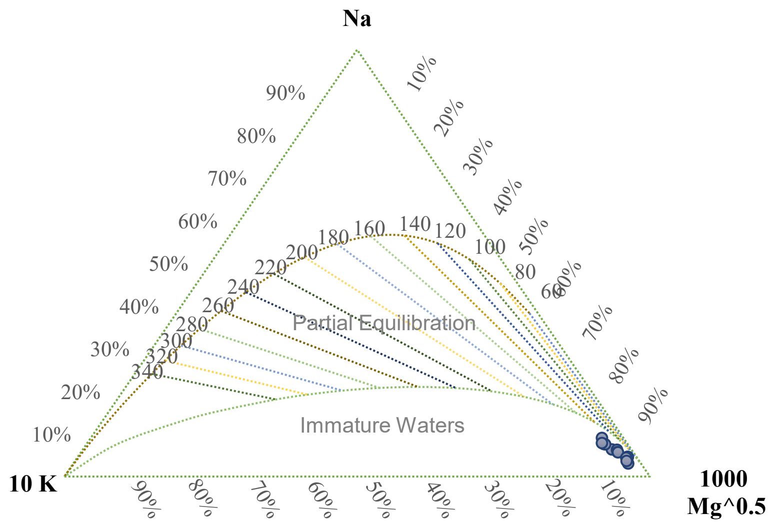

Figure 5: K-Na-Mg triangular diagram of Quynh Phu - Hung Ha geothermal field.

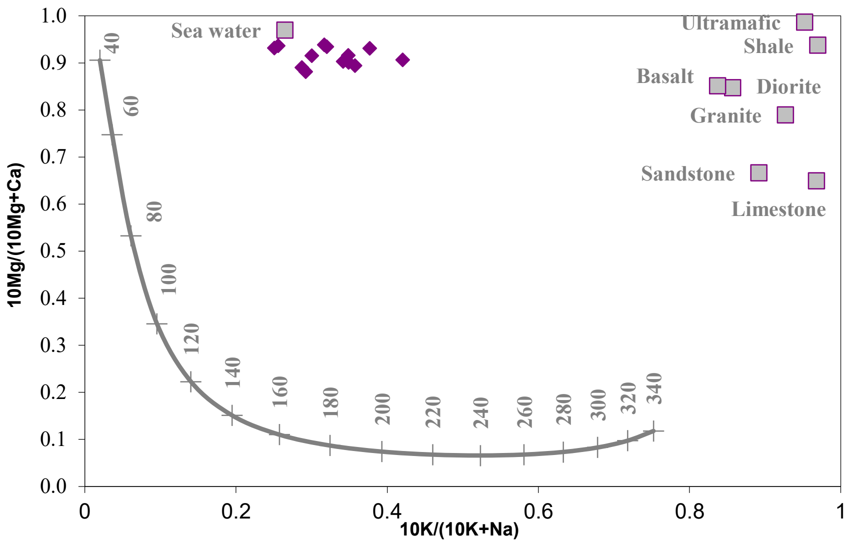

Figure 6: Na-K/Mg-Ca diagram of Quynh Phu - Hung Ha geothermal field.

Triangular diagrams of Chloride, Lithium and Bo are presented in Giggenbach (1991a) to distinguish liquids from different sources, to distinguish segments related to boiling or mixing with boiled liquid or Liquid generated by different high-temperature sources. According to Powell (2001), it is used to distinguish geothermal waters affected by high-temperature vapour absorption from different sources. The results shown in the diagram (Fig. 7) show that geothermal sources are mostly about the corner of Cl, close to seawater, so it can be concluded that there are no such properties.

The diagram of the relationship between the stable O^{18} ratio and Deuterium (Fig. 8) shows that the water samples analysed for this stable isotope pair are close to the meteorological water line. Since they are all above the meteorological waterline, the chances of these waters being less mixed by the process of ascending from deep layers. This confirms that the Quynh Phu - Hung Ha area belongs to the discharge area**.**

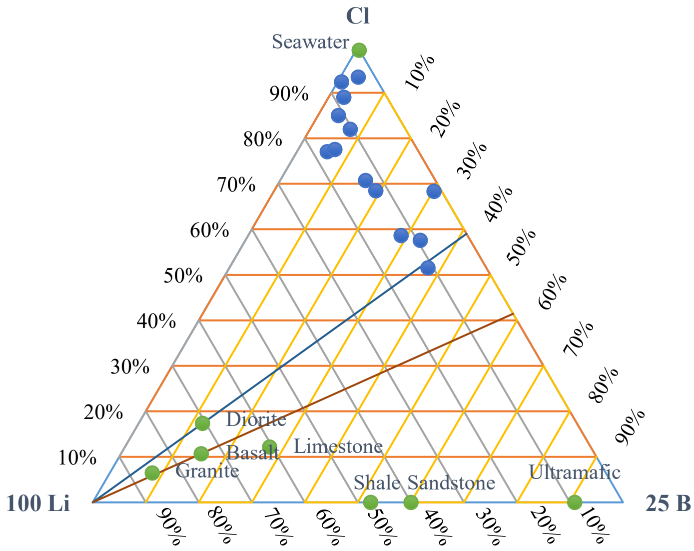

Figure 7: Cl-Li-B correlation diagram.

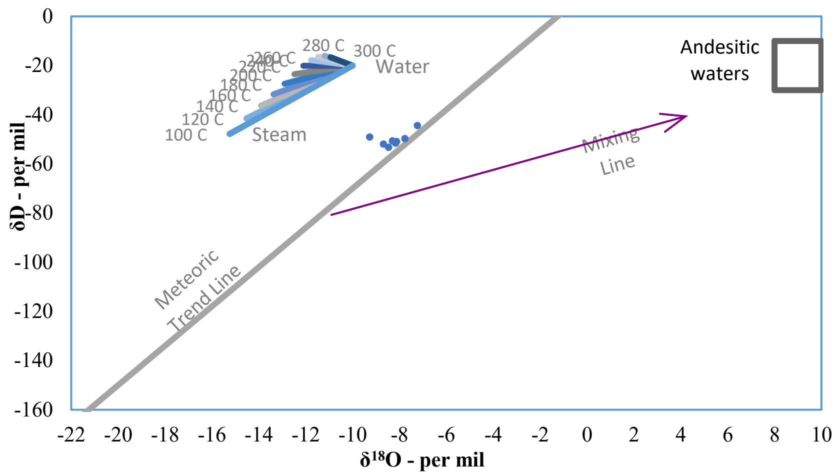

Figure 8: $\delta^{18}O$ and δD stable isotope plot of Quynh Phu - Hung Ha geothermal water.

3.3 Geothermometers of Quynh Phu - Hung Ha

There are many geothermometer formulas, however, according to the above explanation, this geothermal source is not a volcanic origin, so it is suitable with using the cation geothermometers to estimate the temperature in the reservoir. The K/Na geothermometer have been applied to for Quynh Phu - Hung Ha geothermal resource. The temperature those were computed by geothermometers for the wells is varied but not much. The temperature of each drilled well varies from 121°C to 162°C. Because this is a preliminary assessment, so the average method can be used to get the final result of reservoir temperature of Quynh Phu - Hung Ha geothermal resource. It is 140.3°C (Table 1).

Table 1: The result of geothermometer computation for Quynh Phu - Hung Ha geothermal resource.

No.	Sampl e	T bet a = 4/3	Na-K-Ca	delta T R<5	delta T R>5	Na/K Fournier 1979	Na/K Truesdell 1976	Na/K Giggenbac h 1988	Na/K Tonani 1980	Na/K Nieva & Nieva 1987	Na/K Arnors son 1983	Ave.
1	HH02	138	150	96,0	118,7	151	109	170	135	140	119	132,7
2	QP04	105	161	128,8	147,1	191	155	208	187	178	164	162,5
3	HH05	108	135	100,1	124,2	140	95	159	120	128	107	121,6
4	HH08	138	159	110,4	131,6	169	129	187	157	157	139	147,7
5	HH12	145	161	103,9	124,8	169	129	187	157	157	139	147,3
6	HH14	144	160	104,0	125,1	167	126	185	154	154	136	145,5
7	HH15	146	163	102,6	123,1	171	132	189	161	159	142	148,9
8	HH17	117	143	92,4	116,7	150	107	169	133	138	118	128,4
9	HH18	134	154	117,7	138,2	160	119	179	146	148	129	142,5
10	HH19	134	153	118,8	139,0	159	117	178	145	147	128	141,9
11	HH58	104	134	96,0	121,3	138	94	158	118	127	105	119,5
12	PC72	106	142	103,4	126,8	154	111	173	138	142	122	131,8
13	PC73	115	157	127,8	145,8	177	139	195	169	165	149	154,0
Average		125,7	151,7	107,8	129,4	161,2	120,2	179,8	147,7	149,2	130,5	**140,3**

3.4 Heat Generated by Radioactive Decays in the Study Area

Due to the absence of deep drilling conditions inside the study area, the research team used 60 drilling cores samples of 19 deep drilling holes of the coal assessment project in Red river coal basin to analyse the content of U, Th. and K in order to calculate the amount of heat generated by radiation from these three radioactive elements. Based on the results of the analysis, the team used the formula for calculating the radiogenic heat generation (Rybach, L., 1976). Calculation results show that the soil types on the investigation area have radiogenic heat energy varying from 0.456 Kw/m^3 to 2.7 Kw/m^3, which is smaller than the average heat flux of the earth's crust (the average earth's flux is over 10 Kw/m^3), there is no possibility of heating water but only contributing to the heat loss of the earth crust. Thus, the high temperature of Quynh Phu – Hung Ha geothermal reservoir is not caused by heat generation from radioactive elements.

4. CONCEPTUAL MODEL OF QUYNH PHU – HUNG HA GEOTHERMAL SYSTEM

Although the conceptual model is mainly qualitative, it is very important for further research on the Quynh Phu – Hung Ha geothermal field and especially the orientation of geothermal exploration for this geomagnetic field in the future.

Based on the available data about the Quynh Phu – Hung Ha geothermal field, such as Characteristics of geothermal fluids, the subsurface geothermal phenomena, geological characteristics of geothermal fields, tectonic faults, geological structures and deep drilling well materials near the study area, seismic data, hydrogeological documents, geological cross-sections, hydrological cross-sections, the conceptual model of Quynh Phu - Hung Ha geothermal system was built.

Quynh Phu - Hung Ha region is completely plain. The terrain surface is almost flat. The entire land area is farmland, residential land, ponds, rivers and canals.

The Quaternary sediment layer's thickness is more than a hundred meters. The top layer is an aquiclude with a few meters of thickness. The next layer is the Holocene aquifer (qh) with the thickness to a depth of 25m. Under the qh aquifer is an aquiclude layer up to a depth of about 50m before down to Pleistocene aquifer (qp) with a thickness of up to 100m (Fig. 3).

Located under the qp aquifer is the Neogene sediments with a thickness of 4 km and then the Paleogene formation (E) to a depth of nearly 6 km. Finally, the crystalline basement rocks are Mesozoic eruptive rocks (Fig. 2).

Through observing the geologic section (Fig. 9) as well as studying the formation time of the Vinh Ninh fault, it can be seen that the fault only cuts to the end of the Neogene layer. This is consistent with the conclusion that the Vinh Ninh fault was formed during the middle Miocene - late Miocene, as mentioned in the geological characteristics of the study area. Therefore, it can be assumed that hot water is brought up from the depth through the Vinh Ninh fault and flows out in the qp aquifer and then spreads in this aquifer.

Looking at the geological map, the Vinh Ninh fault has been fractured by F1 fault to make Vinh Ninh fault into two sections, intersecting with Luoc river on the surface, moving the northwest part of Vinh Ninh fault to the southwest direction (Fig. 2), this is completely coinciding with the movement of geothermal field that can be seen through the manifestation of hot groundwater in Tra Duong village, Tong Tran commune of Phu Cu district, showing signs of Vinh Ninh fault. This further confirmed that hot water was brought from deep up to the Vinh Ninh fault.

As shown in the characteristics of geothermal liquid chemistry. Quynh Phu - Hung Ha hot water is completely bi-carbonate. Although at similar depths in hydrogeological boreholes in the surrounding areas, groundwater is mostly Chloride due to salination by seawater intrusion. This further confirms that hot water is caused by deep water ascending through the Vinh Ninh fault while these geothermal fields are meteorological waters that have no relation with magmatic waters or other origins.

The Quynh Phu - Hung Ha geothermal field developed in the direction of NW-SE, along the Vinh Ninh fault and is appeared completely to the southwest of the fault, the angle dip of the fault (Fig. 9). Vinh Ninh fault has an angle of 70 - 80o with a displacement range of 100 - 1,000 m, a destructive zone of over 100 m.

Situated at the location from Vinh Ninh fault about 10 km to the Southwest is the Thai Binh fault (Fig. 2 and 9) with the opposite dip direction to the Vinh Ninh fault and also the dip angle, displacement amplitude and fractured zone similar to Vinh Ninh fault,

Located between the Vinh Ninh fault and Thai Binh fault in the area below Quynh Phu - Hung Ha geothermal field is the inverse lifting axis (Fig. 2, 9 and 10), situated in the Miocene inverse range. The thickness of Cenozoic sediments in this zone is very large; the deepest place reaches 7,000m, including Eocene to Quaternary formations. The area is strongly compressed because tectonic activity phase that occurs at the late of the middle Miocene until the end of late Miocene. Due to the impact of this compression phase, it has caused strong folds, creating a series of reverse faults, of which the most typical is the Vinh Ninh fault (reactivating and becoming reverse fault), and forming a series of flower structures such as Khoai Chau, Phu Cu, Tien Hung, Kien Xuong and Tien Hai structures.

According to the results of stable isotope analysis of $\delta^{18}O$ and δD pair, it is clear that hot water is of meteorological origin. In addition, this is completely bi-carbonate water, so it is not related to magmatic or peripheral groundwater etc. The water supplied to the geothermal reservoir is the rainwater from the ponds that flows down along the fault then moves to the hot rock area, in this case, from the regional geological documents such as activities of the inverse axis (Fig. 2, 9 and 10) lying between the Vinh Ninh and Thai Binh faults (Fig. 2 and 9), so the water heats up, then ascends along the Vinh Ninh fault and then appeared on the surface of the Neogene layer - at the junction of the qp aquifer and the Neogene layer. From there, geothermal water is continuously supplied to the qp aquifer in the area (Fig. 3). Therefore, in the study area, when drilling to qp aquifers, water often has great pressure to maintain for a long time and then return to the normal state. The emergence of hot water at a depth of up to a few kilometres was completely proven as in the oil and gas borehole from the 1960s. The engineers met the hot water of 140°C in a deep well of 4,100m or 115°C in a deep well of 3,200m (Fig. 9).

The seismic cross-section is perpendicular to the Thai Binh and Vinh Ninh faults in the location that far from Quynh Phu - Hung Ha geothermal area about 5 km, see Figure 10 (Intergeo, 2017) has shown the structure of rock layers in the study area. However, this cross-section is not able to show the depth of less than 3,300m in the place between the two faults while the place immediately below the depth of 3,700m may have a fractured zone whereby water is moved from the Thai Binh fault demolition area to Vinh Ninh fault area and then goes up to qp aquifer.

Combining the above analysis can generalise a conceptual model of Quynh Phu - Hung Ha geothermal system that is presented in Figure 11 and explained as follows: Rain or lake water descends to the deep zones of the earth crust following Thai Binh fault to the depth of about 2,500m to 3,000m meets a rock layer with high porosity, below this rock layer, is a basement rock that heated by a underneath cooling down magmatic blocks. At a depth of 2,500 – 3000m, the water is heated by surrounding rocks as well as by thermal gradient. After that, the water ascends following Vinh Ninh fault and appears on the upper surface of Neogene layers supplying geothermal water for the qp aquifer in Quynh Phu - Hung Ha area.

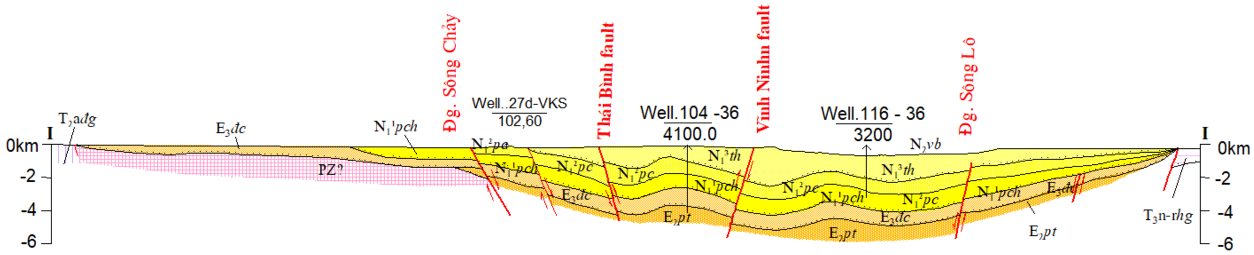

Figure 9: Geological cross-section through Quynh Phu – Hung Ha geothermal area.

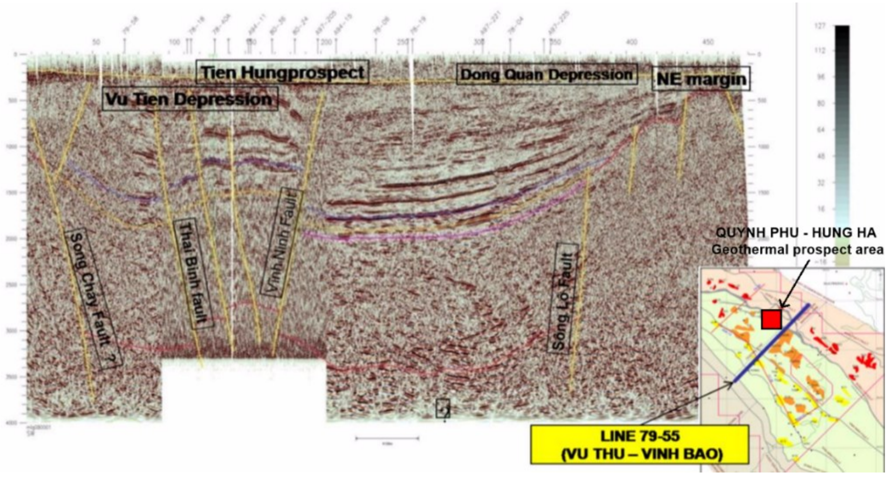

Figure 10: Seismic Cross-section through Quynh Phu – Hung Ha geothermal area.

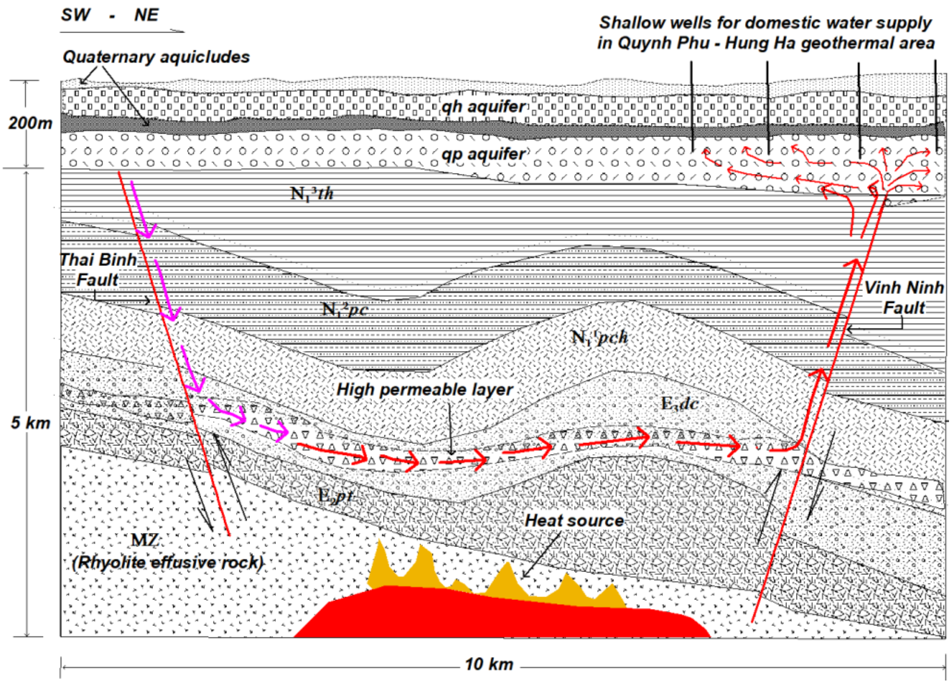

Figure 11: Conceptual model of Quynh Phu – Hung Ha geothermal system.

5. CONCLUSIONS

Direct use of geothermal water: Through the works of the wells for domestic use, the hot water area with temperature from 37^0C to 50^0C is about 25 km^2. The thickness of the hot water aquifer (qp) is about 50m, the porosity is about 30% (Results of analysis of porosity from drilling core samples in the qp aquifer in the Red River delta), and so the volume of hot water in this area is about 375,000,000 m^3. With a large volume of hot water continuously recharged from the deeper fractured zone through the Vinh Ninh fault, if this hot water is developed for direct use, it can bring about great economic value for local people. The current utilisations have brought about certain economic efficiency, but if the local people boldly invest in hot water exploitation for heating, bathing, swimming pools, aquaculture and animal husbandry in a larger scale, this investment will bring higher economic efficiency.

The prospect of power generation: According to the estimate of the temperature in the reservoir of Quynh Phu - Hung Ha geothermal system as mentioned above, the temperature of the geothermal can reach 140^0C. With this temperature, it is possible to use this hot water resource to generate electricity using binary cycle technology. However, how are the depth and the volume of Quynh Phu - Hung Ha geothermal reservoir? Is a problem and need to be invested for geothermal exploration. According to the conceptual model of Quynh Phu - Hung Ha geothermal system, the geothermal reservoir is possible situated at a depth of 2.5 to 3 km. This is also the usual depth for a sedimentary geothermal reservoir.

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