Active Tectonic Controls on Hydrothermal Flow in the Northern Part of Vietnam: Implications for The Geothermal Exploration at Uva geothermal reservoir in Dien Bien Phu Basin

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Abstract: Geologic characteristic controls the development of high-flux hydrothermal conduits that geothermal system formation which is evaluated at large and small scales in the Northern part of Vietnam. There are also several active fault zones here including the Red River fault zone (RRFZ), and Dien Bien-Lai Chau fault zone (DBLCFZ) which have been shown by the previous study. However, the investigation for geothermal potential relating to these fault zones has not been implemented yet. Therefore, this work has made a synthesis of geothermal potential in Northern part of Vietnam basing on the geostructural, geochemical and geophysical data. It shows the first study for the assessing of the geothermal potential of DBLCFZ which is based on the presence of hot springs at the southern DBPB (Uva geothermal reservoir). This study focuses on the deformation characteristics of fault, determining the heat source basing on both electrical field geophysical data and geo-thermometric calculations of K+Na+cations from thermal water in this area, in combination with the assessment of groundwater potential by the hydrogeological survey. The result shows that firstly the hot spring phenomenon at Uva geothermal reservoir (with flow rate attending to 216 m³ per day) which is related to the DBLCFZ, and secondly, the geothermal potential in Uva area belongs to medium level in the worldwide classification grade with the calculated heat source is up to 145,3ºC in average. Considerations on the restorable capacity of groundwater and its geothermal potential, this result suggests that the geothermal source of Uva can be used to build a geothermal power plant on a small scale.

Keyword: Active tectonics, geothermal potential, Vietnam, Dien Bien Phu basin, Uva geothermal reservoir.
1. Introduction
The geothermal is one of the important kinds of clean and renewable energy. Vietnam has had a green development strategy since 2014, but the advantage of this energy has not been known by the Vietnamese government. Although Vietnam has a high demand for energy such as heating at the high mountainous regions in winter, especially for generating electricity. We have known that geothermal is the heat which is discharged from the inner earth by magma activities or relating to active fault activities, it will create the condition for the amount of heat escaped from the inside of the earth.

Vietnam is probably the finest natural geological laboratory, but the geothermal of Vietnam has not been known yet (Fig 1). It is a spectacular region in which the manifestations and processes of geothermal relating active fault zone can be observed at present. It is a region that must be understood if we are to understand active fault, sedimentary basin evolution and, more generally, the behavior of the geothermal fluid in active tectonic settings. Furthermore, the region is developing rapidly on the economic front, and a major part of this rapid development is built on natural resources, in which natural energy is playing an important role. The geological reasons for the distribution of these resources are therefore of major importance for the inhabitants of the region and for attempts to discover and exploit them. In order to understand the development of this complex region, the first essential step is to identify the key features of the active tectonics and determine how to find the geothermal reservoir.

Study area (Fig 1) lies in the areas of the active tectonic regime. This tectonic regime has caused a series of active fault zone in Vietnam, which is dominated mainly in the northern part of the country such as the Red River fault zone (RRFZ), Dien Bien-Lai Chau fault zone (DBLCFZ) ... [45]. DBLCFZ has been studied with many aspects such as earthquake potential... (Nguyen T Th et al., 2008). However, the study of deformation level with the purpose of assessing the geothermal potential has not been discussed. In Vietnam, there is not any study of active fault role in supporting geothermal system. In term of the assessment of geothermal potential in Dien Bien Phu basin (DBPB) as well as the study of DBLCFZ, this article is considered as the potential of building a geothermal plant at Dien Bien province area.
The manifestation of hot springs along the active fault zones, which are related to the active tectonic activity [25]. In this paper, we examine the physical controls on hydrothermal fluid flow for geothermal systems of the DBPB at Uva hot spring site and interpret their significance relating to the geothermal potential of the Northern part of Vietnam (Fig 1).

The data comprise resistivity and geologic maps, which show the locations and extents of the geothermal system and their relationship to active tectonic activities, plus hydrologic information on deep flow rates, stratigraphic and structural controls on the permeability, and the locations, discharges, and extents of surface hot spring activity. We use these for some purposes: (1) assessing the regional factors that localize geothermal systems; (2) showing how lithology, structure, and hydrothermal flow control fluid movement through the epithermal environment; and (3) evaluating factors which are conducive to the development of permeability fault-fracture in an extensional environment; and the last purpose focuses on suggestions for exploration in Uva hot mineral spring site.

2. Geologic, tectonic setting and geothermal potential of the Northern part of Vietnam
2.1. Recent tectonic setting and active fault zone in the Northern part of Vietnam
Vietnam has situated approximately 1000 km from Himalaya, at which the Indian Plate is subducting to the Eurasian Plate. Subduction in this zone is increasing: thus, whereas there is a substantial component of N-S convergence, plate interaction is almost purely strike-slip to the west. The convergence of these plates resulted in an Eocene-to-present collision of the Indian subcontinent with Eurasian continental lithosphere [27] (Fig 2).

Active faults in the Northern part of Vietnam, which are mostly controlled by the RRFZ extending in the Yun-Nan province in China and in Northern Vietnam, and up to 10 km wide, is one of the main strike-slip fault zones in SE Asia that separates the South China and Indochina blocks (Fig 2). The structural evolution of the RRFZ has been dealt with by a number of authors [4], [9], [28]. The RRFZ is considered to have evolved in two phases: (1) an episode of sinistral ductile shear active between 27 and 16 Ma, followed by (2) a period of exhumation and uplift from depths of 20-25 km, accompanied by dextral, predominantly brittle shear active during the Plio-Quaternary [1], [12], [14], [28] and references therein). According to Jolivet L et al. [11], the RRFZ is rooted in a horizontal shear zone, at the brittle/ductile transition separating the upper and middle crust from the lower crust, and the sinistral strike-slip motion was first transpressional (40-25 Ma), and then transtensional, leading to fast exhumation between 24 and 17 Ma. Wang P L et al. [43] maintain that the sinistral shearing took place between 27 and 17 Ma. New structural and geochronological data appear to document the polyphase, ductile shear active between the Early Cretaceous and the Miocene, which included dextral, sinistral and dextral transpression, and sinistral_transtension regimes [46]. The Late Miocene change of the sense of motion is commonly related to the history of collision between India and Eurasia [9], [24], [28].

As compared to the recently dextral RRFZ, the DBLCFZ is a sinistral, probably conjugate fault (Fig 1). Both the RRFZ and DBLCFZ are very important strike-slip fault zones of SE Asia, whose Quaternary structural history has not been fully recognized. During this movement, the DBPB was formed [44].
2.2. Geothermal potential of Northern part of Vietnam

Active Fault zones commonly have great effects on fluid transportation in geothermal reservoirs. During fault movement, all the pores and small fractures that meet with the fault plane become interconnected so that the inner part of the fault, the fault core, consisting of breccia or gouge, may suddenly develop a very high permeability. This is evidenced, for example by networks of mineral veins in deeply eroded fault zones in geothermal fields. Inactive faults, however, may have low permeabilities and even act as flow barriers. In geothermal reservoirs, the orientation of fault zones in relation to the current stress field and their internal structure needs to be known as accurately as possible. One reason is that the activity of the fault zone depends on its angle to the principal stress directions. Another reason is that the outer part of a fault zone, the damage zone, comprises numerous fractures of various sizes.

Here we present field examples of faults, and associated joints in geothermal fields, and potential host rocks for geothermal reservoirs, respectively. We studied several localities of different stratigraphies, lithologies and tectonic settings: fault zones in outcrops from the DBPB. Geothermal activity in the DBPB has long been associated with transport and deposition of sediments, hot mineral springs appearance, making the zone become an important setting for investigating thermal processes. Most studies have focused on fluid chemistry, the applicability of geothermal fluid [6], [20]. Epithermal deposits nonetheless form in zones of high permeability in relatively shallow parts of geothermal systems, along steeply dipping faults, fractures that were clear channels of strongly focused hydrothermal fluid flow (Sillitoe R H., 1993).

Although only the reservoir temperature data is computed by the geothermometers through geochemical surveys for geothermal fields. Parameters of geothermal reservoirs are estimated relatively based on geological maps, tectonic structures, and international references. The thickness of each reservoir is estimated to be 2m and the reservoir areas are 2.5 km$^2$. Applying the computing methods for the potential of geothermal energy [19]. Among 100 geothermal resources, there are 18 ones those can be directly applied to energy application and can be also developed for electric generation (Fig 3 and Fig 4). The surface temperature and flow rate of geothermal water in the hot
spring are used to calculate the natural thermal power that is waste heat if is not applied to human uses. The results show that it is 8,960 ton of waste heat annually (Table 1). With the deep temperatures of reservoirs are varied from 136°C to 170°C, these geothermal resources can be developed for electricity generation of the capacities from 4.2 MWe to 17.4 MWe. Total electric generation capacity from 18 geothermal prospects is estimated to be about 170 MWe (presented in Fig 4).

**Figure 3.** Location map of geothermal manifestation. Numbers in the green cycle symbolizes the sources: 1- Pe Luong, 2- Na Hai, 3- Uva, 4- Pa Thom, 5- Pa Bat, 6- Pac Ma, 7- La Si, 8- Sin Chai, 9- Nam Cai, 10- Lang Sang, 11- Nam Pam, 12- Lung Po, 13- Bo Duot, 14- Quang Ngan, 15- Quang Nguyen, 16- My Lam, 17- Nam Ron, 18- Kim Da.
Figure 4. Location map of potential geothermal sources related to the surface geothermal field (Numbers in the green cycle symbolize the sources refer to Fig 3).

Table 1. Characteristics of potential geothermal sources in the Northern part of Vietnam [30].

| Name     | Location          | Surface T ($^\circ$C) | Deep T ($^\circ$C) | Flow rate (l/s) | Waste heat (KJ/s) | Achievable temperature with 30°C - output T (KJ/s) | Criterion energy with 30°C - output T (KJ/s) | Geothermal energy potential for exploration (ton/yr) | Electric generation capacity estimation (10$^{14}$ KJ) (MW) |
|----------|-------------------|-----------------------|-------------------|-----------------|-------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Pe Luong | Thanh Luong, Dien | 53.80                 | 151.00            | 1.70            | 205.14            | 169.53                                          | 182.28                                          | 1.50                                            | 4.20                                            |
| Pa Thom  | Pa Thom, Dien     | 57.00                 | 146.00            | 0.40            | 53.63             | 45.25                                           | 48.66                                           | 2.23                                            | 6.20                                            |
| Uva      | Dien Bien         | 74.00                 | 161.00            | 2.53            | 164.25            | 147.49                                          | 158.58                                          | 2.36                                            | 6.60                                            |
### Characteristics of DBPB geothermal systems

DBPB was created by DBLCFZ, which is one of the most active fault zones in Indochina (Fig 5). The movement of this fault has caused deformation of the crust and a large (8 km-long) destruction zone in the Dien Bien Phu basin [45]. According to Wang P L et al., [43], the N-S-trending DBLCFZ is located in Northwestern Vietnam, extending about 500 km in length between China through Vietnam and Laos, probably continuing as far as the Gulf of Thailand. It cuts late Paleozoic-Triassic sediments and granitoids (Fig 2; [13], [35], [45].

The DBLCFZ crosscuts a late Paleozoic to Early Triassic granitic complex (the Dien Bien Complex) that is unconformably overlain by upper Triassic classics of the Lai Chau and Suoi Bang formations (Fig 3). The main fault zone and associated subsidiary faults record strike-slip and oblique-slip displacement, with the principal fault plane dipping 60°-70° to the west and steepening to 70°-80° (and even vertical) in the south [10].

### Table 1: Geothermal Characteristics of DBPB Geothermal Systems

| Name          | Location                  | Surfacing T°C | Deep T°C | Flow rate (l/s) | Waste heat (KJ/s) | Achieved temperature with 30°C T°C output T | Criterion energy with 30°C T°C output T | Geothermal energy potential for exploration (10^4 KJ) | Electric generation capacity estimation (MW) |
|---------------|---------------------------|---------------|----------|-----------------|-------------------|---------------------------------------------|-----------------------------------------|-------------------------------------------------|-----------------------------------------------|
| Na Hai        | Dien Bien Sam Mun, Dien Bien Muong Te, Lai Chau | 78.00         | 170.00   | 3.00            | 666.21            | 603.36                                      | 648.74                                  | 10.64                                           | 11.40                                         |
| Pa Bat        | Luan, Dien Bien Muong Te, Lai Chau | 61.50         | 143.00   | 0.10            | 21.41             | 18.48                                       | 19.87                                   | 2.05                                            | 5.70                                          |
| Pac Ma        | Muong Te, Lai Chau        | 62.50         | 147.00   | 1.20            | 188.55            | 163.41                                      | 175.70                                  | 2.88                                            | 8.00                                          |
| La Si         | Muong Te, Lai Chau        | 54.00         | 152.00   | 25.00           | 3,037.7           | 2,514.00                                    | 2,703.09                                | 4.23                                            | 11.80                                         |
| Sin Chai      | Phong Tho, Lai Chau       | 74.00         | 151.00   | 5.00            | 1,026.5           | 863.97                                      | 991.13                                  | 2.21                                            | 6.20                                          |
| Nam Cai       | Sin Ho, Lai Chau Mu Cang Chai, Yen Bai | 62.00        | 162.00   | 3.00            | 465.09            | 402.24                                      | 432.49                                  | 1.72                                            | 4.80                                          |
| Lang Sang     | Muong La, Son La          | 53.00         | 139.00   | 0.70            | 82.12             | 67.46                                       | 72.53                                   | 4.23                                            | 11.80                                         |
| Nam Pam       | Muong La, Son La          | 55.50         | 139.00   | 0.80            | 102.24            | 85.48                                       | 91.90                                   | 4.10                                            | 11.40                                         |
| Lung Po       | Bat Xat, Lao Cai          | 53.00         | 136.00   | 3.00            | 351.96            | 289.11                                      | 310.85                                  | 1.63                                            | 4.50                                          |
| Bo Duot       | Vi Xuyen, Ha Giang        | 71.00         | 181.00   | 1.00            | 192.70            | 171.80                                      | 207.80                                  | 2.10                                            | 17.40                                         |
| Quang Ngan    | Vi Xuyen, Ha Giang        | 62.00         | 170.00   | 5.00            | 775.20            | 670.40                                      | 810.90                                  | 1.80                                            | 15.30                                         |
| Quang Nguyen  | Xin Man, Ha Giang         | 56.00         | 144.00   | 5.00            | 649.50            | 544.70                                      | 658.90                                  | 1.20                                            | 10.40                                         |
| My Lam        | Yen Son, Tuyen Quang      | 65.50         | 143.00   | 6.30            | 1,065.7           | 934.10                                      | 1,129.90                                | 1.20                                            | 9.70                                          |
| Nam Ron       | Tan Ky, Nghe An Tuong Quang | 57.00       | 138.00   | 1.00            | 134.08            | 113.13                                      | 121.64                                  | 5.40                                            | 9.00                                          |
| Kim Da        | Muong, Nghe An            | 73.50         | 163.00   | 1.00            | 203.22            | 182.27                                      | 195.97                                  | 8.30                                            | 13.80                                         |

**Total**: 9,385.3  0  8,044.01  8,960.93  51.01  168.10

T°C: Temperature (Degrees Celsius-°C)
Besides the DBLCFZ, the width of the deformation zone (DBPB) also depends on the NW-SE-trending faults observed in the study area. Movements along these two structural zones have created a large deformation (Fig 5), they formed pull-apart basins filled by Quaternary fluvial sediments [10], [45]. Sizes of these basins increase southwards. The basin’s sediments are cut by faults, clasts composing alluvial fans are fractured parallel to the fault traces. These observations contribute to proving strike-slip motion of the DBLCFZ.

![Figure 5. Structural sketch of Dien Bien-Lai Chau Fault Zone (modified after [10]).](image)

Morphotectonic indicators of sinistral and sinistral-normal faults bounding pull-apart basins in the southern portion of the DBLCFZ include well-developed triangular facets and shutter ridges [45]. Triangular and shutter ridges are of relatively small height at least in the DBPB, and NW of Dien Bien city. Furthermore, the evidence of active strike-slip movement is also found on the conjugate DBLCFZ by the river features. The measured left lateral offsets of tributaries, river and drainage channels range between 270 and 790 m [39].

Studied geomorphic features indicated the amplitude of sinistral strike-slip around 500-2,200m in many locations (Fig 5). The age of deformation may be Quaternary (1 million years) with rates of sinistral strike-slip ranging from 0.5 to 2.2 mm/yr. The results are similar to which obtained by Zuchiewicz [45], who investigated amplitudes and rates of faults distributed in some valleys along the
DBLCFZ. The displaced Quaternary alluvial sediments in DBPB indicate that sinistral strike-slip faults reveal minimum rates ranging from 0.6 to 2 mm/yr in Holocene and 2 to 4 mm/yr in middle-late Pleistocene times [45].

The action of deformation phases created young sedimentary basin with a low degree of consolidation and high efficient porosity that have good water storage, which has shown through the DBPB section and lithological properties [36]. Considerable depth of the basin can reach by 200m, in width: 8 km, asymmetrical reservoir bottom, is filled with Quaternary unconsolidated deposit. Two factors have been interpreted from basin construction: (i) basin with good water storage potential and (ii) basin with good heating escaping from inner mantle potential. The two factors are conditions to create the amount of hot water source in DBPB which will be shown below.

The field studies in the DBPB [36] show pronounced differences between normal-fault zones in clastic rocks. In clastic rocks, clear damage zones occur that are characterized by increased fracture densities and higher percentages of fractures with large apertures. In the damage zones in Cenozoic sediment [36] are well developed even in fault zones with dm-scale displacements. Their fault cores, however, are narrow compared with that of fault zones with larger displacements and comprise a brecciated material, clay smear, host rock lenses or zones of mineralization. Fracture apertures are larger parallel or subparallel to fault zone strike. A large fault zone footwall in Triassic and Cenozoic clastic sediments shows a clearly developed fault core with fault gouge, slip zones, deformation bands and host rock lenses, a distal fault core with disturbed layering and high fracture density and a damage zone with increased fracture density compared with the host rock. In the study areas, all the mineral veins are clearly related to the faults and occur almost exclusively in the damage zones, indicating that geothermal water was transported along the then-active faults into the host rocks. Field measurements indicate that in all the localities, a large majority of the fractures in the fault damage zones are extension fractures, fewer are shear fractures. In the Triassic clastic rock, there is evidence that the veins were injected as hydro-fractures from fault planes into the clastic layers. In the Cenozoic, most veins were arrested during their propagation by layers with contrasting mechanical properties. Some veins, however, propagated through the barriers along faults to shallower levels.

4. Characteristics of Uva geothermal reservoir

4.1. Geological structure controls on Uva geothermal reservoir

Uva hot spring is located in the southwestern part of DBPB ([36], Fig 7), where was the lowest in DBPB. According to hydrographic, geological, and shallow borehole network data, some water storage units were identified in the DBPB: (1) pore water-bearing formations in the valley and river bank, which are covered by Quaternary clay, silt-clay, and sand-clay, and (2) fracture water; there are only 2 types of fractures Tn-rsb, rock with moderate degrees of water storage (Fig 6).

Within the main fault zone of the Uva geothermal reservoir, the stratigraphy is dominated by DBLCFZ which favors the development of clay-rich cores in the main fault zone (Fig 6). In general, faults in this zone will behave as baffles causing compartmentalized fluid flow, which is distributed within fault blocks and accounts for large volumes of hydrothermal alteration. The development of vertically contiguous and increased permeability is possible following large seismic events that rupture the entire thickness of the convective zone. However, with the exception of a few locations dominated by sediment materials, and in the absence of large-volume silicification, it is doubtful that the permeability contrast between the host rock and the fault zone would be sufficient to maintain focused and high flux flow across the full vertical interval of the cover sequence for time periods much in excess of the postseismic phase. Well injections into and across this depth interval additionally may drive the development of high-permeability pathways.

Structural and hydrogeological data revealed that the water-fracture system including steep and near opening cracks created the channel for mineral-hot water to come up faster and the water temperatures are not much difference between the deep and surface zones.
Geothermal sources are closely related to activities of the DBLCFZ and the adjacent areas. The deep DBLCFZ plays an important role in supporting the heat flow. The NW-SE fault system controls the Uva geothermal reservoir and the thermal waters exposed in the surface. The area has a cauldron-shaped relief lying along the fault with highly deformed rocks, a thick sedimentary layer and high potential for water storage. The water flow rate in the area is high because the rock is heavily deformed, so the ability of deposit recovery would be very fast. And therefore, in this section we analyze how active tectonic factors influence the fluid flow and heat transfer regimes within a fault zone:

However, gouge development, redistribution of material and sealing of gouge by pressure solution, and local redeposition of the dissolved material act to reduce permeability within the core of fault zones [3], [18]. Results of the fracture sealing experiments and observations of phenomena related to co-and postseismic fluid redistribution provide independent evidence to support the notion that seismically enhanced permeability is reduced over geologically short periods [18].

The distribution of geothermal fields within the DBPB suggests structurally influenced directional permeability, at least to some extent. The Uva geothermal reservoir is optimally positioned for the localized and tectonically maintained development of high flux conduits. However, structural influence is obvious within the DBPB, which is notable for its lack of rift structure, extraordinarily high natural heat output, and thick accumulations of weak and porous pyroclastic deposits and their reworked equivalents. There is a higher density of geothermal fields within and more generally on the periphery of this basin than anywhere else in the DBPB. The lack of obvious structural control at the surface may reflect the masking effect of the basin fill, which in this region comprises much of the stratigraphic pile within the convective regime.

The epithermal zone is the depth interval in which boiling conditions develop and high-flux conduits form, and additional fluid buoyancy can derive from fluid flow in narrow. Accepting these conduits are analogous to a geothermal well, they are likely to open over a long vertical interval (up to 1 km), and they must be isolated from shallow-water inflows with running casing in shallow section. High-flux conditions are likely short-lived and transient. For much of the duration of hydrothermal fluid flow, however, the main controlling factors are (1) presence and/or development of a vertically extensive fault-fracture network; (2) the primary porosity-permeability of host lithologies; (3) heterogeneities in the tensile strength of the host rocks and their ongoing transformations (both weakening and strengthening) due to hydrothermal alteration, which affect the mode of brittle failure; (4) the basement faults which localize growth faults in the cover layer; and (5) complexity arising from interplay of lithological and structural controls on fluid movement.

4.2. Drilling and geophysical investigation results
Three resistance lanes and 5 resistance section achieved. The navigations of those lines are shown in Fig 8 and results of the cross section measurement are given in Fig 8. Analysis results show information of the geological structure and tectonic features as well as water storage capacity and mineral water structure. Weathering rock: these rocks are in high electric resistance (from 100-200
Ohm), distributed from the surface to the depth of 20-40m (which is shown by black spectrum on the map). In this area, thick layers which are dramatically changed because they are influenced by the basement rock surface. In the investigation area, basement rock is silt, which has high electric resistance (>300 Ohm), shown by black spectrum on the map. Solid basement rock is the foundation of dry weathering layer. In fact, investigated rock area is on three sides, forming a small valley, and segment relief.

Mineral water has a higher conductance (low electric resistance) than other rocks. Electric resistance value can be found from resistance scanning data. We can analyze the rock structure properties which will be a sign that water source. We assessed and connected the features of resistance and distributing structures sedimentary including water, solid basement rock, weathering layers, destroyed zone. Low resistance forming a layer between basement rock and sedimentary, as well as dry weathering layer has been shown in the document. It is also the expression of mineral thermal water source from a deep position which is the careful object.

![Figure 7. The geothermal field in Uva’s area.](image)

Four shallow boreholes and pumping tests were attempted to explore the geothermal potential in the Uva area, in the active tectonic zone. In an average of this four boreholes, the static water level was 2m at a depth of 14m. Under the observation of the water level from the ground surface to the depth of 13.7 m, the temperature increased from 50°C to 65°C. When we have drilled to the depth of 14 m, the water level increased up to 0.5 m from water level to the surface and the temperature growth up to 67°C. As a consequence, from this depth, the groundwater shows a pressure difference of 13.5 m (14 – 0.5 m). The mineral water storage zone can be determined from this depth. The groundwater created a higher lens than the groundwater by 1.5 m (2 – 0.5 m). When we drilled to a depth of 50 m,
the temperature decreased to 85°C and the water kept on blowing with a flow rate of 0.355 l/s with the hole diameter is 110 cm. The natural flow rate is 2.53 l/s (216 m³/day) when the water level is down to the depth of 7 m (Fig 6).

This structure is given in 3 electrical measurement section (Fig. 8). On the first section, low electric resistance has 100m wide continuously in the depth of over 60 m. It is the drain, creating a condition to expose thermal water in U Va. In the section of geo-electric No 2 and 3, this structure tends to sink or is covered by weathering layer. Structural section analyses can realize thermal water drains to the discontinuous spring of basement rock, features for tectonic deformation relating to deep fault movement from the deep position. With the total investigated result, we consider: exposed thermal water in the surface is from this source. However, in the depth of 60m, it does not identify the real origin of thermal water in this area. To know the temperature of the basin, it is necessary to use another tool introduced below.

![Figure 8. Sections of resistance field in Uva’s area.](image)

### 4.3. Geochemistry of hydrothermal fluid

In this work, only small sample volumes (a few milliliters) are required in order to determine the stable isotopes deuterium and oxygen-18 from the hot mineral water. After preparation of the sample, in which the sample is transferred to a suitable sample gas, the isotope abundances are analyzed in a mass spectrometer-the IRMS instrument (Thermo Delta V Advantage) at the Institute of Earth Sciences, University of Iceland (Table 2); and as a consequence, all the results (cations, anions, isotopes which was analysed) was modeling in the ternary diagrams and stable isotopes diagrams based on Powell T and Cumming W’s model [22].

| Table 2. Analyzed results of cation components of thermal water in Uva’s area |

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### Component and Sample Content (ppm)

| Component | Sample | UVn-01 | UVn-02 | UVn-03 | UVn-04 |
|-----------|--------|--------|--------|--------|--------|
| Fe        |        | 0.087  | 0.082  | 0.116  | 0.121  |
| Hg        |        | 0.008  | 0.002  | 0.006  | 0.003  |
| Na⁺       |        | 148.600| 73.800  | 106.500| 98.900  |
| K⁺        |        | 6.190  | 3.080  | 4.440  | 4.120  |
| Ca²⁺      |        | 135.900| 67.090  | 96.820  | 89.910  |
| Mg²⁺      |        | 3.800  | 7.100  | 6.200  | 5.700  |
| Al³⁺      |        | 0.091  | 0.152  | 0.122  | 0.233  |
| Mn²⁺      |        | 0.031  | 0.033  | 0.091  | 0.025  |
| Zn²⁺      |        | 0.042  | 0.028  | 0.036  | 0.038  |
| Pb²⁺      |        | 0.0017 | 0.0013 | 0.0015 | 0.0012 |
| HCO₃⁻      |        | 453.900| 261.000| 338.000| 314.000|
| Cl⁻        |        | 22.970 | 11.410 | 16.460 | 15.280 |
| SO₄²⁻      |        | 8.943  | 6.267  | 4.712  | 4.933  |
| NO₃⁻      |        | 0.729  | 5.848  | 0.744  | 0.500  |
| SiO₂       |        | 61.910 | 43.220 | 46.180 | 46.410 |

On the other hands, all the evaluating origin results show that Uva’s geothermal fluid was created by surface meteoric sources (Fig 9 and Fig 10). It can be understood by some reasons (1) In the Cl⁻-SO₄²⁻-HCO₃⁻ ternary diagram, all the samples which plot in the area of HCO₃⁻ are cold groundwater. Generally, this diagram classifies geothermal waters using the major anion concentrations (chlorides, sulfates, and bicarbonates) [8] and also helps distinguish the waters as mature, peripheral and volcanic and steam-heated waters. Waters from the thermal springs have high chloride concentrations and plot in the mature water field or close to it, albeit with mixed chemistry as indicated by the significant HCO₃⁻ and SO₄²⁻ (Fig 9a). The chloride may have a source in a deep, high temperature, neutral chloride reservoir although, in magmatic environments, the water may also represent a neutralized outflow of acidic condensate formed from the absorption of HCl and steam in shallow groundwater. (2) When we used the Na-K-Mg triangular diagram [8] for evaluating equilibrium between the hot waters and rocks at depth and to estimate reservoir temperature (Fig 9b), all samples plot in the area of immature waters with an orientation to Mg corner. This is suggestive that the Uva hot spring is the product of deep with high Mg geothermal waters being cooled and quenched by mixing with groundwater associated with country rock and surface sediments.

![Figure 9. The geochemical origin of Uva geothermal fluid.](image)

| Sample | pH | d¹⁸O   | D    | d (WMWL) | d (ASIA) |
|--------|----|--------|------|----------|----------|
|        |    |        |      |          |          |
And finally, the stable isotope data for geothermal fluid (Table 3) proved that it began from surface natural sources. The positions of thermal fluids of geothermal sources are presented sitting near the meteoric line showing that the origin of thermal fluids is meteoric (Fig 10). This means that the thermal fluids come from surface waters infiltrated into the deeper layers then deep circulating.

| UVn-01  | 8.08 | -9.12 | ±0.06 | -67.04 | ±0.57 | 5.92 | 7.20 |
| UVn-02  | 8.14 | -6.68 | ±0.02 | -48.93 | ±0.45 | 4.51 | 5.45 |
| UVn-03  | 8.54 | -8.95 | ±0.03 | -63.03 | ±0.16 | 8.57 | 9.82 |
| UVn-04  | 8.66 | -8.91 | ±0.00 | -63.99 | ±0.51 | 7.29 | 8.54 |

**Figure 10.** The geochemical origin of Uva geothermal fluid.

### 4.4. Geothermometer of the heat source of hydro-geothermal

The study of the relationship between the flow rate and the degree of decreased water level allows prediction of the exploitation of the deposits. According to the study, water recovery time is very short; suggesting that the possible time to recover the deposit is very short. Exposed springs did not change during three pumping cycles so that the difference between discharging and recharging flow rates was small. According to the close correlation between the calculated values shown in the quadric diagram, the extrapolation number was determined as 1.75 using Altopsky’s extrapolation method. This means that if the water level was 8 m, the flow rate would still be reasonable [32]. Besides, the Na-K, Na-K-Ca, and silica geothermometers were applied using the chemical compositions of Uva’s thermal water sample for calculating the geothermal reservoir temperatures (Table 5). The calculated temperature values for the Na-K-Ca geothermometer are quite low possibly due to the mixing of thermal and subsurface waters during their ascent to surface. Results of the Na-K geothermometer are very high, and as a consequence, the depth average temperature of all these geothermometers is nearly 145.3°C for Uva geothermal source.

Geothermometer is a method that calculates the temperatures of the geothermal fluids in the basin by using formulas. These formulas are based on element’s content in the thermal fluid. This method is applied to all activities, exploratory and geothermal exploitation in the world. Foundation of this method is not only relied on mineral dissolved property in water but also reactions between round rocks and geothermal water. At a temperature or a pressure, the mineral dissolution or reactions
between minerals or round rock and water is different. Although the temperature and pressure conditions change, geothermal water in the surface keeps initial components when we take it to analyze. Most of the geothermometers are used, depending on Silica concentration, cation rates. Silica geothermometer is easy to calculate, basing on the silica concentration in the thermal fluid. There are many different geothermometer formulas, depending on features of each geothermal source. These formulas have been developed by Fournier R O [5] or Arnórsson S [2]. In the framework of analyzing data in Uva’s area (Table 4), we only use cation geothermometer and formulas with cation Na⁺ and K⁺ to calculate basin’s temperature.

| No. | Component | Unit | Number of sample | Max   | Min   | Average |
|-----|-----------|------|-----------------|-------|-------|---------|
| 1   | Fe        | mg/l | 20              | 0.40  | 0.29  | 0.36    |
| 2   | As        | mg/l | 20              | 0.0024| 0.0008| 0.001   |
| 3   | Hg        | mg/l | 20              | 0.00085| 0.00055| 0.0006  |
| 4   | Na⁺       | mg/l | 20              | 160.7 | 159.6 | 159.9   |
| 5   | K⁺        | mg/l | 20              | 8.8   | 6.3   | 6.95    |
| 6   | Ca²⁺      | mg/l | 20              | 88    | 85.4  | 86.1    |
| 7   | Mg²⁺      | mg/l | 20              | 17.1  | 15.9  | 16.2    |
| 8   | Al³⁺      | mg/l | 20              | 0.093 | 0.070 | 0.076   |
| 9   | Mn²⁺      | mg/l | 20              | 0.510 | 0.420 | 0.442   |
| 10  | Zn²⁺      | mg/l | 20              | 0.1241| 0.0063| 0.0489  |
| 11  | Pb²⁺      | mg/l | 20              | 0.0025| 0.0012| 0.0015  |

With the analyzed results and geothermometer formulas of the author above, the temperature of geothermal sources can be calculated (Notice: cations in the formulas are concentration, calculating by ppm) (Table 5):

| No. | Geothermometer       | Range of Temperature | Result T°C |
|-----|----------------------|----------------------|------------|
| 1   | Truesdell A H (1976) | 100 - 275°C          | 112.63     |
| 2   | Tonani F (1980)      | -                    | 139.10     |
| 3   | Arnórsson S (1983)   | 25 - 250°C           | 133.41     |
| 4   | Arnórsson S (1983)   | 250 - 350°C          | 157.77     |
| 5   | Fournier R O (1979)  | -                    | 154.64     |
| 6   | Nivea D and Nieva R (1987) | -  | 146.00     |
| 7   | Giggenbach et al (1983)| -  | 173.53     |
| 8   | Average value        |                      | **145.30** |

Through geothermometer calculations mentioned above, the temperature of geothermal fluid of the basin change in the field of 112°C to 173°C. The temperature is higher than other which is measured on the surface or in the well. However, temperature values are different, so that applying various thermometers are needed to have more exact results. In the field of this activity, we take the mean value of calculated results is 145.3°C. So, the temperature of this thermal water source in the deep geothermal reservoir is 145.3°C. In the world, based on the temperature of the thermal fluid in the basin, it can be divided potential of geothermal sources. After that, there are 3 levels: high - temperature is over 180°C, moderate - temperature is about 100°C - 180°C, and low - temperature is under 100°C. So, Uva’s geothermal source (145.3°C) is put in the type of moderate geothermal potential source.

4.5. Implications for the geothermal energy exploration at Uva geothermal reservoir
After gaining the results of calculating the temperature of geothermal sources in the Northwestern for the energy exploitation purpose of power generation, we propose using the binary cycle technology in order to ensure exploitation energy from geothermal resources. The geothermal potential is not high but it can protect the environment. Besides, thanks to researching and assessing the potential of geothermal reservoirs in the Northern part of Vietnam, DBPB where the three geothermal sources Pe Luong, Uva and Pa Thom were evaluated is the most potential geothermal basin in terms of geological features of geothermal (sediment, magma, active faults, hydrogeology, etc. As a result of this study, the Uva geothermal source was selected for the purpose of constructing a geothermal power plant with an exploitation capacity of 200-300 KW. This is considered as the result of evaluation and construction of the first geothermal power plant in Vietnam which according to assessment using vaporization technology of Isopentane (or Butane) for electric power generation (Fig 11).

![Power Generation using Binary cycle technology](image)

**Figure 11.** Presentation model of binary power generation in Uva geothermal reservoir.

This geothermal power plant is located in Uva village-Noong Luong commune and next to the Nam Rom river, which flows through Laos. The geothermal site is bordered by mountains in the Northwest and the Nam Rom river in the Southeast. The expectation area for the site selected for the power plant construction associated with the proposed mining design (Fig 11), of which the total area is estimated at nearly 5.6 ha. There are three wells (two production wells and one injection well) designed in the appearance area. The depth of these boreholes is nearly 200m and it is considered as a suitable area for the geothermal reservoir layers based on results from geophysical methods.

5. Conclusions
Hydro-geothermal is the use of natural resources of hot water in the sub-surface. Sedimentary reservoir formations for hydro-geothermal projects are siliciclastic rocks like sandstones, arkoses, greywackes, and conglomerates. Only for limited regions, the primary or the secondary porosity (fracture and/or porosity) is that deep groundwater for geothermal use can be directly pumped from the reservoir formation. With the Triassic formation and Quaternary formation, the DBPB has such
high porosity and high permeability formations. However, in most cases, the permeability of reservoir formations is not sufficient for economically interesting pumping rates in the range of 40, 60, 80 liters/sec or even higher than expected. In this case, active fault zone systems are helpful for the development of sedimentary reservoir formations for hydro-geothermal use.

DBLCFZ is an important geothermal potential zone. Uva is the geothermal area of DBPB, the field of geothermal distribute considerably large, the temperature is complicated with high amplitude. The highest temperature in the exposed thermal water is 76°C and mean value of deep geothermal temperature is 145.3°C.

Geothermal sources are closely related to the action of DBLCFZ zone and adjacent areas, that is deep DBLCFZ (nearly North-South direction) playing a role to support heat, Song Ma Northeast-Northwest fault system controls the basin and exposed thermal water. The activity area’s relief is hollow, along with the fault, rock is strongly deformation, the sedimentary layer is thick and water storage potential is high. Water discharge from the area is great. Because of rock deformation property in the area, received recovery potential is fast.

According to the above results and comparing to demand of design using geothermal energy in the world, this is a moderate geothermal potential area (mean temperature in Uva’s area is estimated 145.3°C). It is the scientific foundation to build a pilot of the geothermal power plant, ensuring maximum geothermal potential in this place.

It is widely accepted that geothermal activity is largely associated with areas of active faulting. It illustrates that the spatial correlation between thermal springs and late Quaternary faults in Northern part of Vietnam is quantitatively robust. It is commonly accepted that faults play a role in this association by sometimes forming conduits for upward movement of groundwater. Similarly, in geothermal reservoirs, it is thought that it is necessary to have recent fault movements in order to maintain open fractures and permeability. However, the question of how the mechanics of the faulting process may play a causative role in the factors that influence geothermal.

In summary, hydro-geothermal depends on the availability of natural hot water reservoirs in the deep sub-surface which allows persistent high-capacity pumping. For this purposing large active fault systems with large damage zones developed in the thick reservoir, formations are the primary target. Most likely they guarantee high permeabilities and efficient heat exchange in highly fractured rocks which are needed for the energy gain from hydro-geothermal heat extraction from the deep subsurface. Large geothermal fault systems are present within the Northern part Vietnam. A hydro-geothermal type of project would increase the feasibility in several areas of the Northern part Vietnam.

It is necessary to have a detailed study and need to have investment for exploration, then to build geothermal plan as well as support demand at this place and develop using clean energy in Viet Nam.

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