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Active Faults and Geothermal Potential in Vietnam: a Case Study in Uva Area, Dien Bien Phu Basin, Along Dien Bien -Lai Chau Fault

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ABSTRACT

In Vietnam, most of the active fault zones have been intensely studied in terms of seismic probability assessment or landslide along the faults as a part of geo-hazard projects but research on geothermal energy relating to these fault zones is lacking. This study aims to evaluate the geothermal potential based on the geological, geochemical, and geophysical data and shows for the first time the geothermal potential relating to Dien Bien Phu Fault Zone in northwestern Vietnam. The study is based on the hot springs in the southern part of Dien Bien Phu Basin, an area that is referred to as the Uva hot spring area. The study concentrates on the deformation characteristics of the faults, determination of the heat source based on electrical geophysical data and geothermometric calculations using K^+-Na^+ cations, in combination with the assessment of groundwater potential by hydrogeological survey. The results show that the hot spring in Uva area is related to the Dien Bien Phu deep fault, and that the geothermal potential in the Uva area could be ranked at a medium level with the geothermometer of up to 150°C. Considering the restorable capability and the heat potential of the groundwater, the results suggest that the Uva geothermal resource can be developed for constructing a small-scale geothermal power plant.

1. INTRODUCTION

Vietnam lies in a tectonically active area, which is strongly affected by the collision between Eurasia and India. The tectonic regime caused formation of a series of active fault zones in Vietnam (Fig. 1). These fault zones, including the Red River Fault Zone and the Dien Bien–Lai Chau Fault Zone, are mainly in the northern part of the country (Taponnier et al., 1986; Zuchiewicz et al., 2004).

The active Dien Bien–Lai Chau Fault Zone was previously studied in terms of its earthquake and landslide potential (Nguyen et al., 2008). However, the degree of deformation, which can be used to assess the geothermal potential, has not yet been discussed. There is no study on this fault zone relating it to the geothermal systems in Vietnam. The explanation of geological and hydrogeological conditions that is in combination with the interpretation of the geothermal reservoir based on the electric resistance survey as well as other geothermal methods (e.g., isothermal mapping and geothermometers) show that the potential of the Uva geothermal area is certainly related to the Dien Bien-Lai Chau Fault Zone. In addition to assessing the geothermal potential in the Dien Bien Basin and the analysis of the Dien Bien–Lai Chau Fault Zone, this paper further aims to evaluate the possibility of constructing a geothermal power plant in the Dien Bien Phu area.

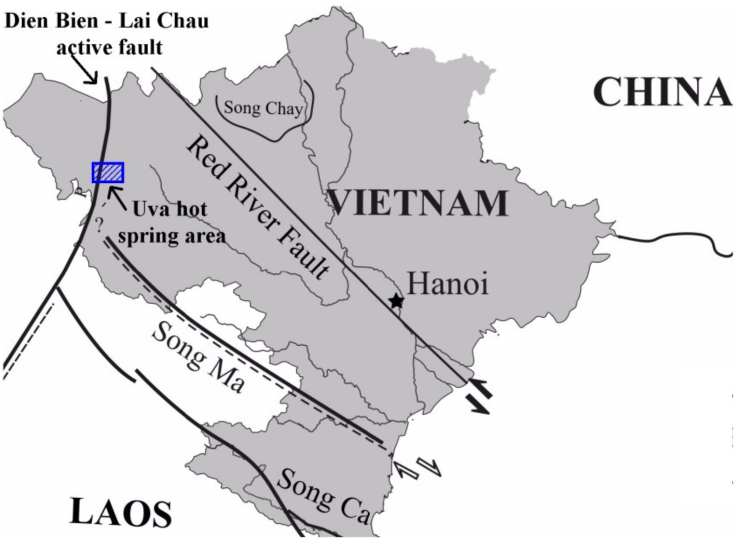

Figure 1: Map showing the main active faults in northwest Vietnam

2. GEOLOGICAL FEATURES OF DIEN BIEN – LAI CHAU FAULT ZONE

The N–S-trending Dien Bien–Lai Chau Fault Zone (Fig. 1 and 2A) is located in northwestern Vietnam, extending for about 500 km in length between China through Vietnam and Laos. The movement of this fault has caused deformation of the crust and a large (10 km-long) destruction zone in the Dien Bien Basin (Zuchiewicz et al., 2004). Besides the Dien Bien–Lai Chau Fault Zone, the width of the deformation zone also depends on the NW–SE-trending faults observed in the study area. Movement along these two structural zones has created a large deformation (Fig. 2B).

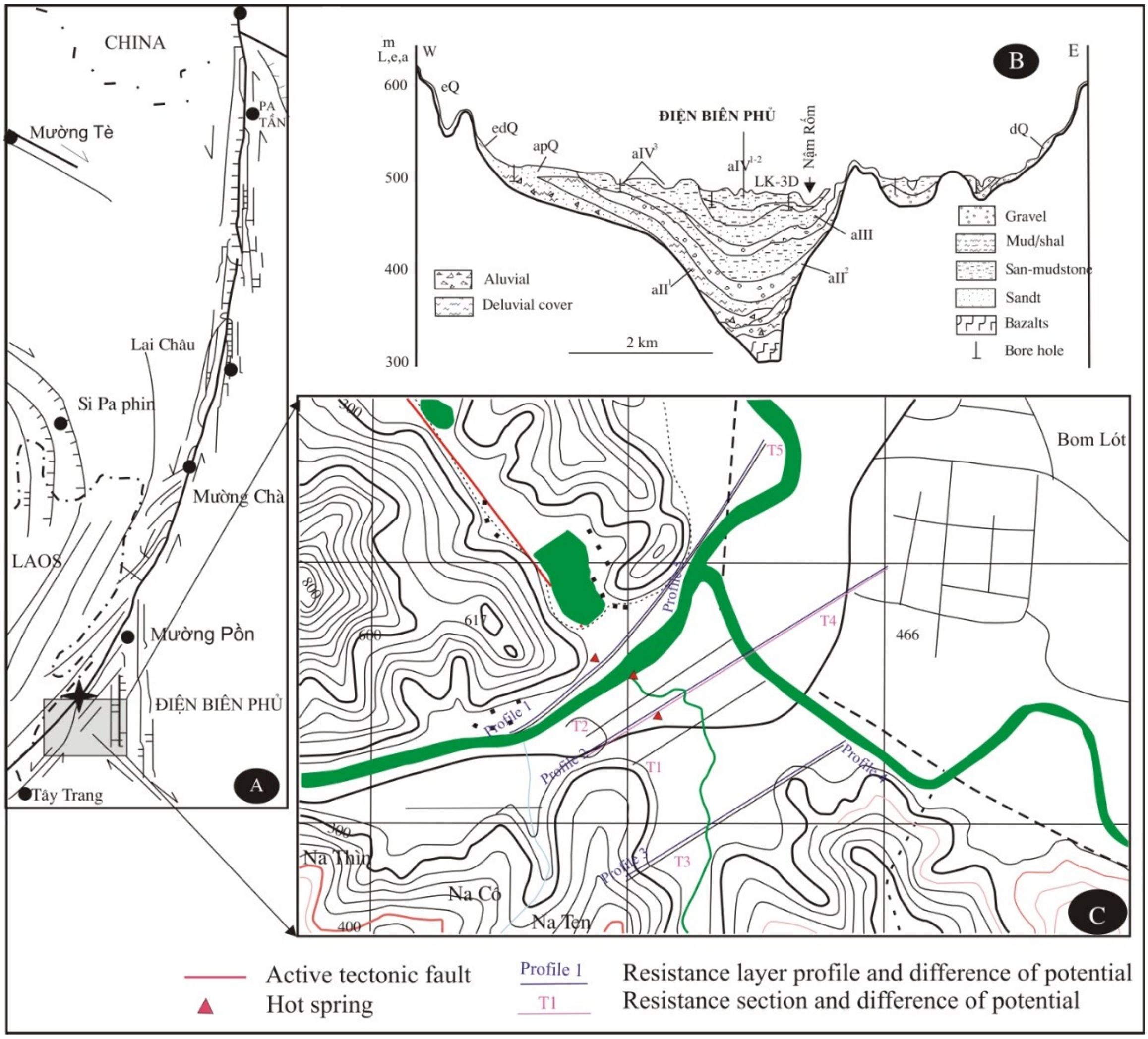

Figure 2: (A) The Dien Bien–Lai Chau Fault Zone (Nguyen et al., 2008); (B) The Dien Bien Basin section (Nguyen et al., 2008); (C) studied area and geophysical survey alignments (Chu et al., 2006).

The degree of active deformation of the Dien Bien–Lai Chau Fault Zone is clearly shown by deformation and distribution of the geological formations along the fault zone (Fournier, 1979). During the Cenozoic, extreme tectonic activity resulted in two main deformation phases (Nguyen and Hoang, 2005): (a) the Oligocene–Miocene deformation phase developed in response to tectonic forces oriented sub-parallel to the compressive axis. Impacted by this force, the deep NW–SE fault sinistrally moved and oriented in a sub-parallel trend with the latitudinal dextral fault. Different movements of these fault systems resulted in compression, separating the blocks. Along the faults, the geological formations were broken, developing a shear zone at different scales, (b) the late Pliocene–Quaternary phase during which the tectonic activity was impacted by tectonic forces with maximum stress direction oriented sub-parallel to the compressive axis. Along the faults, deep NW–SE-oriented structures moved dextrally and the sub-parallel faults moved sinistrally. The interaction also formed a Quaternary basin alongside with other compressed/crushed areas.

The activity of deformation phases that formed young sedimentary basin with low degree of consolidation and high efficient porosity, is good for water storage, has been shown through the Dien Bien basin and lithological properties (Fig. 2B). Considerable depth of the basin can reach to 200m. The width of the basin is about 8 km. The asymmetrical reservoir bottom is filled by Quaternary unconsolidated deposit (Zuchiewicz et al., 2004). Two factors have been interpreted from basin construction: (i) basin with good water storage potential and (ii) basin with good condition for heat potential from underneath magma. The two factors are the conditions to create a large amount of hot water in Dien Bien basin (Fig. 2C).

3. GEOTHERMAL INVESTIGATION IN THE UVA HOT SPRING AREA

3.1 Geological and hydrogeological features

The Dien Bien Basin is an ellipsoidal-shaped valley with elevations of 400–700 m a.s.l. and is surrounded by high mountain ranges (over 1000 m). The Dien Bien Basin is wider in the middle and narrower in the north and south sides. The mountains on the eastern and western sides of the basin are higher, and the high relief areas are cut by numerous rivers and streams. According to hydrographic, geological, and shallow borehole network data, some water storage units were identified in the Dien Bien Basin: (1)

pore water-bearing formations in the valley and river bank, which are covered by Quaternary clay, silt-clay, and sand-clay, and (2) joint water; there are only 2 joint rock bands aged T_3 n-r*sb* with moderate degrees of water storage (Nguyen and Hoang, 2005).

A shallow borehole and pumping test was attempted to explore the geothermal potential in the Uva area, in the tectonic mould zone. In this borehole, the static water level was 1.8 m at a depth of 14 m. From the ground surface to the depth of 13.7 m, the temperature increases from 48° to 60°C. When drilled to the depth of 14 m, the water level increased to 0.5 m and the temperature to 59°C. As a result, from this depth, the ground water 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 above 1.3 m (1.8 – 0.5 m). When drilling to a depth of 21.3 m, the temperature decreased to 51°C. In the section, from 21.3 m to 36.9 m depth, the water is lost. As the drilling continued to a depth of 37 m, the water blew to the surface, and with drilling another 2 meters the water kept on blowing with a flow rate of 0.33 l/s at a temperature of 74°C. The natural flow rate is 0.228 l/s (19.8 m^3/day) when the water level is down to 0.81 m.

Structural and hydrogeological data revealed that the water-joint 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 different between the deep and surface zones. Three pumping times were implemented. 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, the difference between discharging and recharging flow rates was small. According to the close correlation between the calculated values shown in the quadric diagram (Fig. 3), 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.

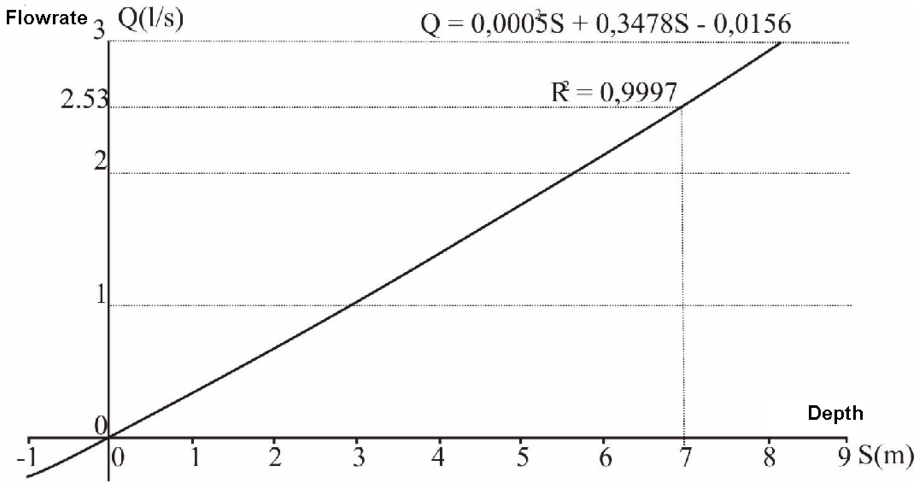

Figure 3: Relationship between capacity and water level decrease.

However, due to the structure of the well (high steam filter tube), the steam tube can be put down to a depth of 9 m. As a result, if we choose a lower depth of 8 m (active water level is estimated as 7 m), it will be difficult to set the steam tube while using pressure pump machine to exploitation. If we choose the depth of water level as 7 m, the active water level would be about 6 m, which is suitable to use the pump in two ways (pressure and centrifugal). On the diagram in Figure 3, if the depth of decreasing water level is 7 m, the reasonable exploitation flow rate will be 2.5 l/s, which is equal to 216 m^3/day. Thus, the defined rate of 216 m^3/day is reliable and reasonable with different types of exploration. In fact, in order to use this geothermal resource for constructing a power plan, it is necessary to drill deeper wells to obtain higher temperatures.

3.2 Isothermal mapping

Surface geothermal investigation shows the distribution of the thermal source. The results of isothermal measurements are presented in the Figure 4. Geothermal field in the area can be divided into three separate zones: the Northwest Zone, the East Zone, and the South West Zone.

The Northwest zone is limited by a 29°C isothermal line and is an abnormal geothermal zone as shown by 3 abnormal peaks. These peaks have great amplitudes (over 12°C). The abnormally exposed feature includes the underexploited hot spring and its influenced zone in the Uva valley. The abnormal peak is located in the middle of the Nam Rom River. The Pa Nam abnormal peak is in ellipsoid shape with NW–SE-directed stretching axis coinciding with the fault direction.

The East Zone geothermal field is quite stable and the temperature gradient is not highly varied. However, this zone can be divided into 2 different areas; the northern part has gradually increasing temperatures, whereas the southern part is quite stable. The boundary between these two parts is related to a change in lithologic properties of the sedimentary cover, or there may be a NE–SW-trending fault.

The Southwest Zone is a low activity geothermal zone with a stable geothermal field and low temperatures due to bulging of the basement rocks.

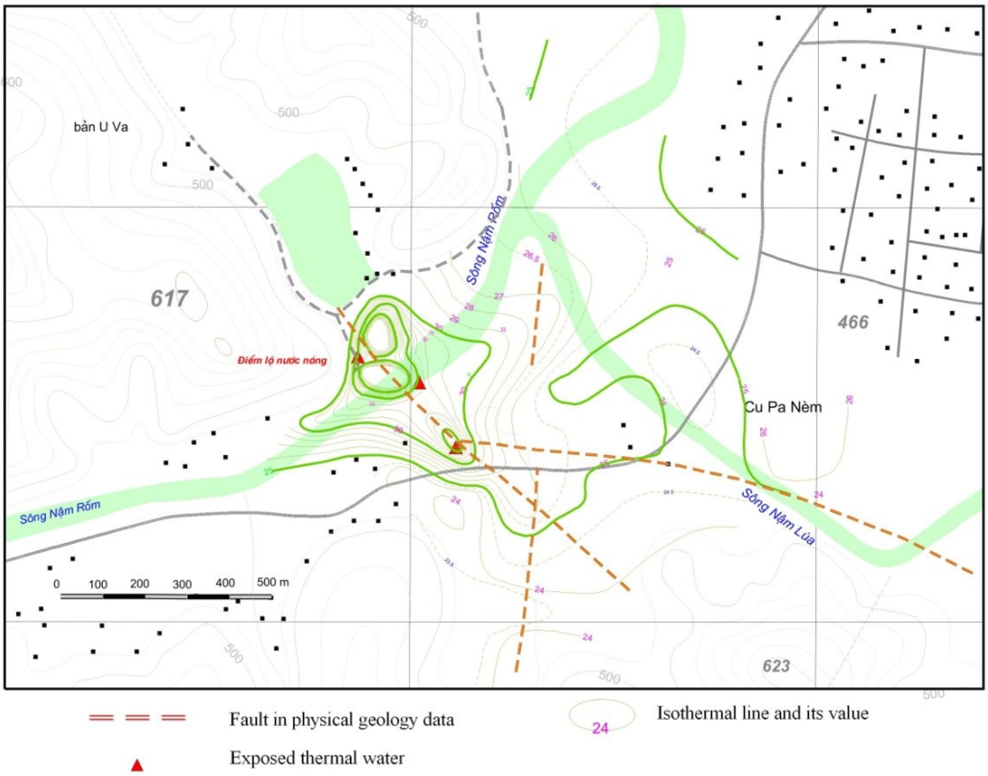

Figure 4: Geothermal field in the Uva area.

3.3 Electric resistance survey

Three electric resistance lanes and five cross sections were investigated. Positions of lanes and cross-sections are shown in Figure 2C and the results of the surveying lanes are given in Figure 5. Results of this analysis provided information on geological structures, tectonic features, and water storage as well as on mineral water potential. Weathered rocks have high electric resistance values (from 100–200 Ohm) and they are distributed 20–40 m below the surface (shown by black spectrum in the map). In this area, thicknesses of the layers vary depending on the basement rock surface. The basement rocks are siltstones with high electric resistance (>300 Ohm; shown by black spectrum on Fig. 5). The solid basement rock is the foundation of dry weathering layer. In practice, studied rocks on three sides form a small valley and segmented relief.

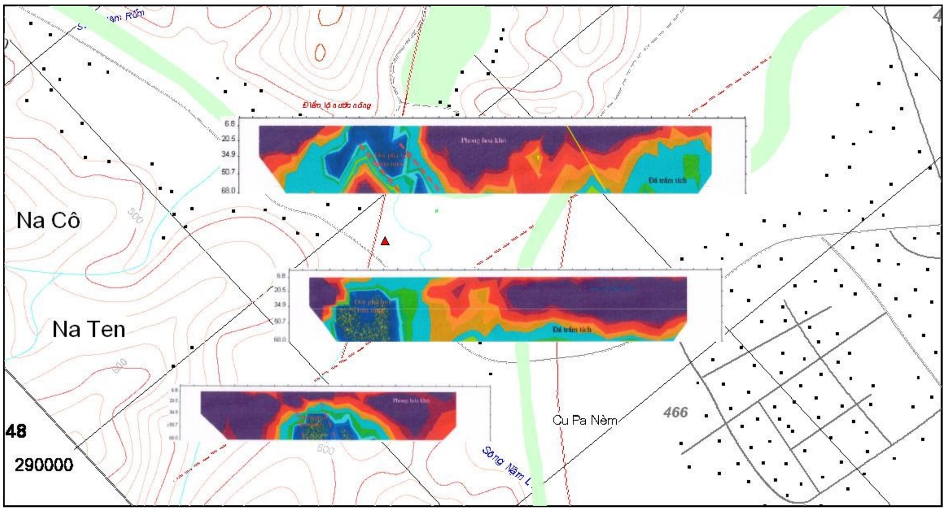

Figure 5: Sections of electric resistance field in the Uva hot spring area.

The mineral water has higher conductivity (low electric resistance) than other rocks. Electric resistance values can be determined from resistance scanning data. Analysis of rock structure will provide clues on mineral water source. The assessment and correlation of the resistance features and distribution of sedimentary structures and water, solid basement rock, weathering layers, and deformed zone have been completed. Low resistance layers lie in between the basement rocks and the sedimentary or weathered dry layers. This structure is presented in 3 electric measure lanes. On the first lane, low electric resistance appears to be 100 m-wide and over 60 m-deep. This is the drainage zone that helps thermal waters to come up to the surface in the Uva area. In cross-sections 2 and 3, this structure tends to sink or is blanketed by weathering layers. The analyses of the structural section can help identification of the thermal water drainage along discontinuous veins of the basement rocks and tectonic features relating to deep fault movement. Combination of the obtained results indicated that the thermal waters identified on the surface in Uva area came from this source. However, the actual origin of the thermal waters is not identified at a depth of 60 m in the study area. Therefore, it is necessary to apply additional methods to evaluate the geothermal potential in this area.

3.4 Geochemistry and geothermometry

There are two hot springs, named Pom Lot and Na Hai, in the Uva area. The distance between these springs is only a few hundred meters and both hot springs are located on different sides of the Nam Rom river. The hot spring waters are very clear, but have sulfur odor. The temperatures were measured from 74° to 78°C. The natural flow rate of the hot springs varies from 0.8 to 3.0 l/s. The TDSs are range from 410 to 510 mg/l. The Na Hai hot water is of bicarbonate-sodium-type and the Pom Lot hot water is of bicarbonate-sodium-potassium-type. The H_2SiO_3 contents of waters from both hot springs are over 60 mg/l. These hot waters are manifestations of the active fault because the fault zone formed some the unconsolidated areas and favorable conditions for heat coming from the magma underneath. The high thermal gradient causes heating of the waters in the lower basin, while the active faults are draining hot waters to the ground surface.

Two sets of hot water samples were individually collected; one from the Pom Lot and Na Hai hot springs and another from a shallow borehole in the Uva area. The analyses were carried out in different laboratories in Hanoi, Vietnam. The analytical results for the natural hot springs are presented in Table 1 and the analytical results for the shallow borehole waters are presented in Table 2.

Table 1: Chemical compositions of thermal waters in the Uva hot spring area

Chemical component	Na Hai hot spring (mg/kg)	Pom Lot hot spring (mg/kg)
pH	7.3	6.8
Na^+	130.4	119.3
K^+	15.6	8.5
Ca^{2+}	10.0	46.0
Mg^{2+}	1.8	7.2
NH_4^+	0.62	1.0
HCO_3^-	319.7	518.5
SO_4^{2-}	81.0	37.9
Cl^-	12.1	27.6
H_2S	0.01	0.01
NO_2^-	0.01	0.01
NO_3^-	0.24	0.49
SiO_2	125.8	66.8
Hg	0.0001	0.0001
As	0.003	0.004
Mn	0.040	0.170
B	0.720	1.370
F	2.150	1.300
Li	0.244	0.336
Rb	0.0780	0.0280
Br	0.05	0.05
TDS	410	510

Table 2: Results of mineral component analysis of thermal waters in the Uva area.

Component	Number of samples	Content (mg/kg)		
		Max	Min	Mean
Fe	20	0.40	0.29	0.36
As	20	0.0024	0.0008	0.001
Hg	20	0.00085	0.00055	0.0006
Na^+	20	160.7	159.6	159. 9
K^+	20	8.8	6.3	6.95
Ca^{2+}	20	88	85.4	86.1
Mg^{2+}	20	17.1	15.9	16.2
Al^{3+}	20	0.093	0.070	0.076
$Mn2^+$	20	0.510	0.420	0.442
Zn^{2+}	20	0.1241	0.0063	0.0489
$Pb2^+$	20	0.0025	0.0012	0.0015

The Na-K, Na-K-Ca, and silica geothermometers were applied using the chemical compositions of Na Hai and Pom Lot thermal waters for calculating the geothermal reservoir temperatures (Table 3). The calculated temperature values for the silica geothermometer are quite low possibly due to mixing of thermal and subsurface waters during their ascent to surface. Results of the Na-K geothermometer are very high and results of the Na-K-Ca geothermometer are 150°C for Pom Lot and 192°C for Na Hai.

As for the set of thermal water samples collected from the borehole, various Na^+ and K^+ cation geothermometers were used, and the calculated temperatures of geothermal fluid in the reservoir ranged from 112° to 173°C (Table 4). These temperatures are much higher than that the ones that were measured directly at the surface or in the well. However, calculated temperature values are different from each other. Therefore, it is necessary to apply different geothermometers with correct interpretation in order to obtain more accurate results. In this paper, we simply take the mean value of the calculated results, which is 145.3°C. In summary, geothermometry applied for two sets of samples yielded different results and different geothermometers also gave different temperatures in the same hot spring area.

Table 3: Geothermometers calculated for water samples from the Na Hai and Pom Lot hot springs

Hot spring	Geothermometer (°C)		
	K-Ca	Na-K-Ca	SiO_2
Na Hai	-	192	150
Pom Lot	240	150	116

Table 4: Geothermometers calculated for water samples from shallow boreholes in the Uva hot spring area

Geothermometer formula	Temperature (°C)
Truesdell (1976) for temperatures around 100–275°C	112.6
Tonani (1970)	139.1
Arnórsson (1983a) for temperatures around 25–250°C	133.4
Arnórsson (1983b) for temperatures around 250–350°C	157.7
Fournier (1979)	154.6
Nivea and Nieva (1987)	146.0
Giggenbach et al. (1983)	173.5

4. DISCUSSION AND CONCLUSION

The active Dien Bien–Lai Chau Fault Zone is affirmed to have some geothermal potential as can be seen in the Uva area in the Dien Bien province. The geothermal field is situated in a considerably large area with varied temperatures. The highest surface temperature of the hot springs is 76°C and the geothermal temperature in the deep reservoir is about 150°C.

Geothermal sources are closely related to activities of the Dien Bien–Lai Chau Fault Zone and the adjacent areas. The deep Dien Bien–Lai Chau Fault Zone plays an important role in supporting the heat flow. The NE–SW fault system controls the basin 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 in 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.

According to a comparison between the results mentioned above and the requirements of some geothermal power plants in the world, this area could be ranked as a small to moderate geothermal potential for developing a low-capacity geothermal power plant.

A more detailed research and investment on exploration are necessary. The geothermal power plant should be constructed to support the energy demand of the Dien Bien Phu city with a note that the Dien Bien–Lai Chau Fault Zone is still active and has seismic potential. Therefore, if the geothermal power plant is constructed, it is necessary to take the earthquake risk into account.

5. REFERENCE

Arnórsson, S., Gunnlaugsson, E., and Svavarsson, H., 1983a: The chemistry of geothermal waters in Iceland II. Mineral equilibria and independent variables controlling water compositions. *Geochim. Cosmochim. Acta*, *47*, 547-566**.**

Arnórsson, S., Gunnlaugsson, E., and Svavarsson, H., 1983b: The chemistry of geothermal waters in Iceland III. Chemical geothermometry in geothermal investigations. *Geochim. Cosmochim. Acta, 47*, 567-577.

Cao D. G. et al., 2004: Research and evaluation of the geothermal potential in the Northwestern Plain of Vietnam and It's prospect for economic and social development. *Project Report*. Institute of Geosciences and Mineral Resources, Hanoi.

Chu V. Ng. et al., 2006: The study of geological structure for foundation of controlling and developing safety level of traffic system in mountainous area and midland in Vietnam, project of VNUH. 05-29.

Giggenbach, W.F., Gonfiantini, R., Jangi, B.L. and Truesdell, A.H. 1983: Isotopic and chemical composition of Parbati valley geothermal discharges, NW-Himalaya, India, Geothermics, 12: 199-222.

Fournier, R.O. and Potter, R.W. 1979: Magnesium correction to the Na-K-Ca chemical geothermometer, Geochim. Cosmochim. Acta, 43: 1543-1550.

Fournier, R.O., 1979: Textbook for the geothermal energy. In: Koga, A., Editor, 1979. Hydrothermal Geochemistry, Kyushu University, Japan, p. 1993.

Jörg M., Emmanuel G., Thomas K., Jens C. G. and Eva S.: Slip- and dilation tendency analysis: Implications for geothermal exploration in the Upper Rhine Graben.

Nguyen T. Th., Pham D. D., Hoang Th. Th. B., Chu V. Ng., Vu V. T., Chu V. Q., Do M. D., Nguyen Th. Th. Hu., Luong Th. Th. H. and Pham B. Ng., 2008: General report of investigated project, assessment of quantity and quality of thermal water in Uva, Dien Bien.

Nguyen V. H. and Hoang Q. M., 2005: Moving characteristics of the Lai Chau - Dien Bien fault zone during Cenozoic. J. of. Geology. Serie B. Hanoi.

Nieva, D. and Nieva, R. 1987: 'Developments in geothermal energy in Mexico. XII. A cationic composition geothermometer for prospection of geothermal resources', Heat Recovery Systems & CPH, Vol. 7, pp. 243-258

Tonani, F. 1970: Geochemical methods of exploration for geothermal energy, Geothermics, Sp. Issue, 2 (1), 492-515.

Truesdell, A.H., 1976: Summary of section III - geochemical techniques in exploration. *Proceedings of the 2nd U.N. Symposium on the Development and Use of Geothermal Resources, San Francisco, 1,* liiilxxix.

Taponnier, P., Peltzner, G., and Armijo, R., 1986: On the mechanism of the collision between India and Asia, in Coward, M. P., and Ries, A. C., eds., Collision Tectonics: Spec. Pub., Geological Society of London, p. 115-157.

Zuchiewicz W. , Nguyen Q. C., Andrzej B. and Marek M. 2004: Quaternary sediments in the Dien Bien Phu fault zone, NW Vietnam: a record of young tectonic processes in the light of OSL-SAR dating results. Geomorphology, 60 (2004) 296-302.