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The Identification of Geothermal Reservoir from Exploration Data in Bang Hot Spring, Central Vietnam

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ABSTRACT

The previous study of geochemical analysis of hot water samples outcrop on different areas together with geological conditions and geothermal regimes entire territory of Vietnam has been identified a large number of geothermal resources in Central region with the indication on young magmatic origin is prospective as worldwide for electrical generation.

The one geothermal prospect of Bang hot spring - Quang Binh province had been selected for implementation of the exploration phase. A combination of geological, geochemical, geophysical methods, temperature measurement in shallow drilling hole (depth 250 m) has been applied in period from 2012 to 2015 for identifying the location, structure and temperature parameters of the geothermal system-reservoir.

Resistivity model from Magnetotelluric survey and Geochemical isotopic analysis has identified the location and structure of the reservoir of a typical hydro-geothermal system with magmatic origin. Temperature gradient and heat flow at the shallow drill hole are riched 4.1 ^{o}C/100 m and 83.4 mW/m^2 respectivelly. Reservoir temperature has been estimated by geochemical thermometers and temperature modelling giving values in the range of 167-200 ◦C at the depth of >2 km. The obtained data allows to determine the suitable location for test drilling to the reservoir and suggest the next phase of the Geothermal Program in the area.

1. INTRODUCTION

Up to now the world's geothermal electricity generation has in 24 countries with a capacity of 10.7 GW (2010). For electricity generation, the high temperature (>180 °C) of the geothermal resources was required, so the objects satisfying the condition can be found in only limited geological regions such as in the active young volcanoes and rift zones.

Based on the analyzed comparasion beetwen geothermal water manifestation, geochemical characteristics of water samples, geological conditions, stratigraphy, geothermal regime, ... in the territory, with the formation mechanism, and conceptual model of a prospective hydro-geothermal system can be classify geothermal sources in Vietnam on the different types, including:

Hydrogeothermal resources in tectonic fault zones are characteristic of the majority of the hot water resources distributing in the geological regions domain Pre-Cenozoic age as the North East, North West areas; geothermal resources in the form of “geopressured reservoir” are resources distributing in the Cenozoic sedimentary basins (Red River basin includes North Delta, the Mekong basin covers the Southern Delta, the continental shelf of the East Sea).These mentioned types of geothermal sources characterized low to moderate reservoir temperatures satisfying conditions only for direct use.

Hydrogeothermal resources of magmatic origin with indications on geochemical characteristics outcrop at the peripheral reservoir water are the sources distributing in geological regions with formations of younger basaltic eruption Neogen - Quaternary and Holocene in the expansion of East Sea heat flow anomaly > 80 mW/m^2 (He Lijuan, 1999), generally in Central region or in Truong Son, Kong Tum and Da Lat geological provinces (Phan Cu Tien, 1992). These geothermal resources charaterized magmatic origin with high reservoir temperature are object for surveying in order evaluate the ability to exploit for electricity generation.

Since the 1980s, both Vietnamese and foreign researchers as well as several investors (ORMAT) have been agreed that geothermal resources in Vietnam are favorable, can be exploited them for the energy development including electricity generation, but additional surveys are needed as exploration survey (Flynn, 1997). For solving this problem, in 2012 under the financial support by National Program: “Scientific Research and Technology serves disaster prevention, environmental protection and rational use of natural resources” coded by KC08/11-15 firstly in Vietnam the exploration phase has accepted and during time from 2012 to 2015 has been employed in one geothermal prospect of Bang hot spring - Quang Binh province. The important task of exploiration step is surveys to locate distribution, structure, temperature parameters of geothermal reservoir, as well as in the exploration of others mineral resources, a combinations of geological and geophysical, especially geochemical, geophysical methods (magnetotelluric survey plays a key role), drilling for temperature measurements are needed.

The geological map of Vietnam and manifestation of geothermal springs on the territory are presented on the figure 1. Chemical composition analyses, temperature of hot water samples on 287 sites archived in the monograph edited by V.C. Nghiep (1998).

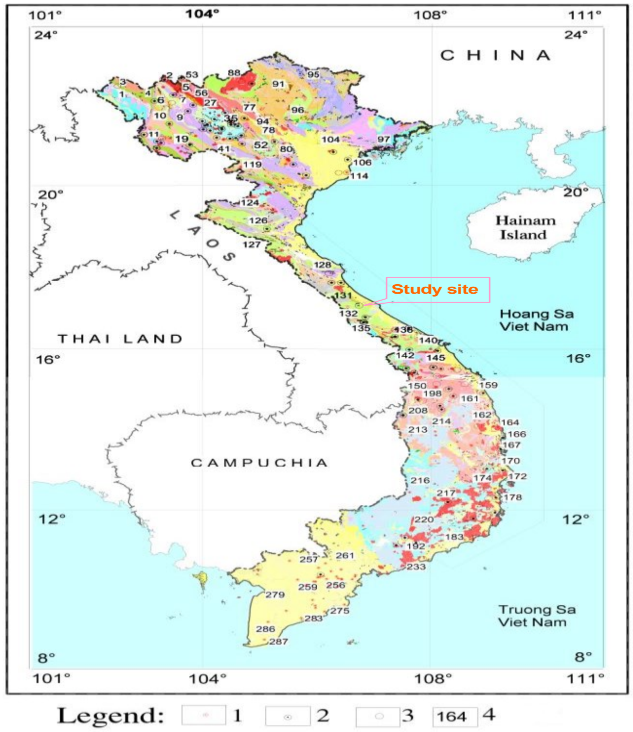


Figure 1: Manifestation of geothermal resource on the geological map of Vietnam

Legend: Temperature of water: 1- 30 -40 ^{o}C; 2- 41-60 ^{o}C; 3- >61 ^{o}C; 4- Index of water site

Successful surveyed results can give direct indication of the structure and parameters of geothermal reservoir interpreted by the criteries of conceptual model - results from detailed studies of geothermal fields have been exploited for electricity generation in the world (Di Pippo, 2012, IGA report, 2013). Based on the structural and temperature, flow rate of geothermal fluid of reservoir using simple methods such as experimental graphic (GeothermEx, 2004, Chandrakharam, 2008) can make first assessment of its possible electricity generation.

2. EXPLORATION DATA OF GEOTHERMAL RESERVOIR IN AREA BANG SPRING

The selected area for study is the Bang hot spring; it is a reveal geothermal water source with the flow rate of 40 l/s and the highest temperature (100 °C) on the territory of Vietnam, the detail geological condition of the area is presented in Fig. 2 left. In the previous studies conducted on this site, some parameters such as physical properties, chemical composition, and current hot water usage have been described in the monograph edited by Vo cong Nghiep (1998). This hot water source also is one of the selected locations of the ORMAT Group (US) for the project of investments for electricity generation (Flynn, 1997).

2.1 Methodology

To determine the parameters (indications) of a geothermal reservoir, the primary methods have been used, including (IGA report, 2013):

The geological and tectonic survey for getting information about stratigraphic features, lithological composition of geological formations, magmatic activities, distribution of faults and recent tectonic activities, as these conditions relates to the conditions and mechanism of appearance and existence of geothermal resources;

The geochemical methods based on the analysis of dissolved concentrations of the main and trace elements and the physical nature of the outcrop water samples: 20 water samples in surounding area of hot spring has collected including hot geothermal water, warm water, cold water for analyzing concentration of trace elements, 5 samples from them and rain water for isotope analyzis ^{18}O, ^{2}H, ^{3}H. Using chart-StanfordGW.xls Liquid_Analysis _v1_Powell-2010 to have results in a series of charts showing information – indication of the origin, property of geothermal liquid and temperature of reservoir (Cumming, 2009).

Geophysical surveys include electromagnetic and seismic methods, that magneto-telluric (MT) survey plays a key role with the appropriate measurement network allowing to receive information of geological structural features. Thus, the results can be used to recognize the indications of distribution, structural features and physical characteristics of the elements of a geothermal system (Munoz, 2014). The field surveys for data collection were carried out by using the MT equipment MTU2000 (made in Canada) and 150 Texas seismic instruments (USA). Survey technique, data acquisition and interpretation has anounced in previous work by Doan Van Tuyen et al. (2015). The geophysical parameters obtained from the data interpretation (mainly resistivity parameters) indicated the structural elements of geothermal system based on the worldwide conceptual model from the international literature (IGA report, 2013).

Surface geothermal survey: one drill hole of 250 m depth was conducted, site for drilling based on the received geophysical indications about location and structure of the geothermal reservoir. After finishing of drilling conduct temperature log, measurement of thermal conductivity of rocks, then calculating thermal gradient, surface heat flow,... This work has repeated after about 6 month later.

Modelling the underground temperature distribution in the area surrounding the shallow hole was conducted by software TOUTH2 (US) along the MT section: surface heat flow was determined from temperature measurements. The determination of geometric and physical parameters of environmental grid (density, porosity, thermal conductivity of the rock layers) was based on the electrical resistivity and petrologic properties of geological formations described in different sections of geological field survey and publication.

Since the surveys conducted at this stage are implemented on the ground surface, the received temperature parameters of the geothermal system/reservoir should only accepted as the indications of interest.

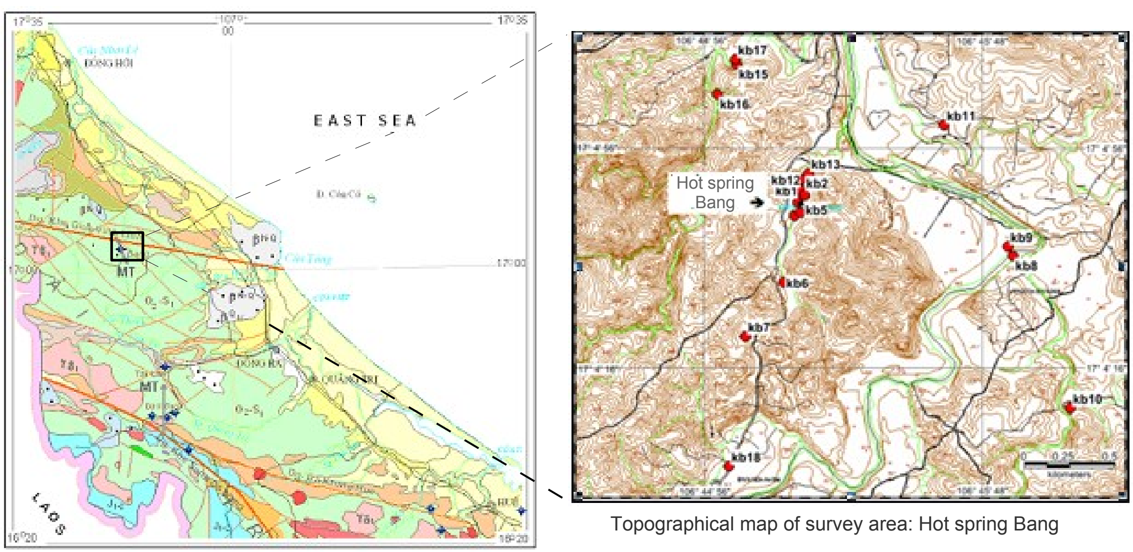
2.2 Result and discussion

2.2.1 Geological and tectonic survey (Figure 2 left)

According to the geological survey, the area Bang spring distributed in the large formations of Cambrian-early Ordovician, late Ordovician – early Silluric ages, in wich lower part of Long Dai (O_3-S_1 ld_{1-2}) and A Vuong (Є-O_1 av) subformations containing high porosity of the coarse materials (sandy, conglomerate, tuff…), which is favorable condition for circulating and accumulating geothermal water and steam flow to form reservoir and clay cap. Surface layer is middle and late Long Dai subformations (O_3-S_1 ld_{2-3}) with a sediment of claystone, siltstone,… characterizing low water proof and low thermal conductivity. Total thickness of these sedimentary formation is estimated 2-3 km (Phan Cu Tien, 1992).

Surrounding the surveyed area the product of young volcanic activity as Neogene – Quaternary basalts can be observed on the north of Bang spring in distance only about 8 km, further Neogene – Quaternary basalts and Holocene basalts in Gio Linh, Vinh Linh, Cam Lo communes, Con Co Island in east-south. Age of basaltic eruptions N-Q identified as 600,000-700,000 years ago (Phan Cu Tien, 1992), the age of basalt Q_{IV} identified 350,000 years ago is essential in creating high-temperature heat source provides heat to reservoir. In addition, there is the possibility of magmatic reactivity or basalt injection occured later, as ash eruption Tro Island on the continental shelf of Binh Thuan province had recorded in 1923 (Nguyen Xuan Han et al., 1991). This magmatic activity related to recent tectonic phase happened in late Pliocene-Quaternary time, so the hot intrusive bodies formed at shallow depth underground became heat sources.

2.2.2 Geochemical data



Topographical map of survey area: Hot spring Bang

Figure 2: Geological map (left) and network of water sampling (right) surrounding in area Bang spring

According to the chart Cl-SO_4-HCO_3, the chemical composition of water samples indicated the geothermal reservoir's peripheral zone (Figure 3), the Na-K-Mg Chart obtained from the study showed an unequilibrium condition of a large proportion of the water here, and the non-stop movement geothermal water has been rising from the space near the heat sources to surface.

The temperature of reservoir determined by the series of formula of geochemical thermometers. In this by Christobalite/Chalcedony, Na-K-Ca correct Mg, K/Mg, in general these thermometers using Mg, allway gave value lower than by other one, especially lower the temperature of revealed water on the ground surface. Therefore, this data are less reliable.

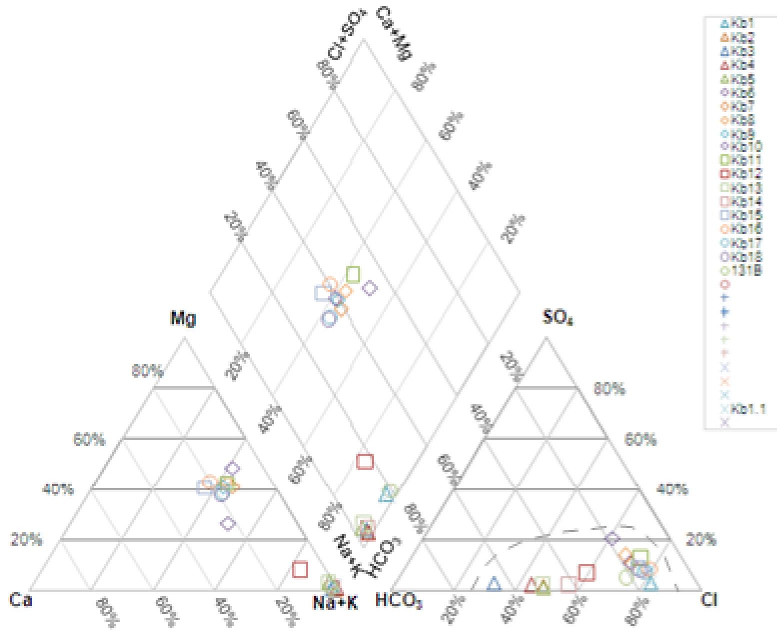


Figure 3: Chart Cl-SO4-HCO3 for water samples in Bang spring

The reservoir temperature obtained by thermometer Na-K-Ca varied in the range 167-221◦C, equivalent to the average temperature value of thermometer Na/K and mixed model silica - enthalpy (210 ◦C) is more suitable, probably reflects the temperature of geothermal reservoir (Table 1).

Table 1. The temperature of hot water samples and geothermal reservoir calculated by geochemical thermometers in area Bang

Index of water samples	Coordinats of site (latitude, longtitude)	Temperature of water at surface, T, ◦C	Calculated reservoir temperature, T◦C by geochem. thermometer						
			Cristo-balite/ Chalce-dony	Quar-tz	Na-K-Ca	Na-K-Ca Mg corr.	Na/K (*)	K/Mg Giggen-bach, 1986	Mixed model Silic-Entanpy
131B	106.83894 17.067905	100	58/79	109	167	87	137-175	93	210
KB1	106.83995; 17.068915	96.29	57/78	107	201	78	202-231	97	
KB2	106.80032; 17.076487	97,12	59/80	109	197	148	174-208	114	
KB3	106.75753; 17.09163	93.85	53/74	104	186	133	186-221	110	
KB4	106.74872; 17.093137	90.07	61/82	112	209	110	175-208	106	
KB5	106.71632; 17.096931	84.13	59/80	110	187	34	162-196	86	

Note: Data in column with symbol (*) is the range of temperature calculated by the 5 formulas of geochemical thermometer Na/K: Fournier, 1979, Truesdell, 1976, Tonani, 1980, Arnorsson, 1983, Nieva, 1987.

Result of isotope geochemistry analysis $\delta^{18}O$-$\delta^{2}H$ water samples indicating mixed geothermal water with magmatic – andesite one, confirming more information on geothermal water from magma resource (Figure 4); the cycles of rain water circulation determined by ratio $^{3}H_{0}/^{3}H$ has around 38 years.

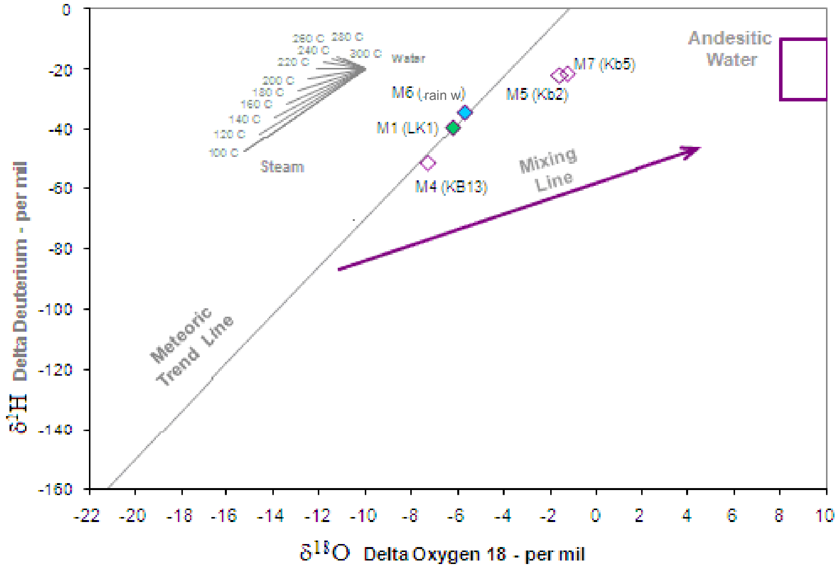


Figure 4: Diagram δ^{2}H – δ^{18}O for water samples in Bang spring indicate andesitic origin

2.2.3 Geophysical data

Network of magnetotelluric (MT) surveys in area Bang hot spring is presented on Figure 5 (left). This paper presents only results relating to indication of the geothermal reservoir. The low resistivity structure (ρ_k <10 Ohm.m) at a depth of Z = -3 km from MT data in southern part area (Fig. 5, right) although the conceptual model indicates location on plan of the geothermal reservoir.

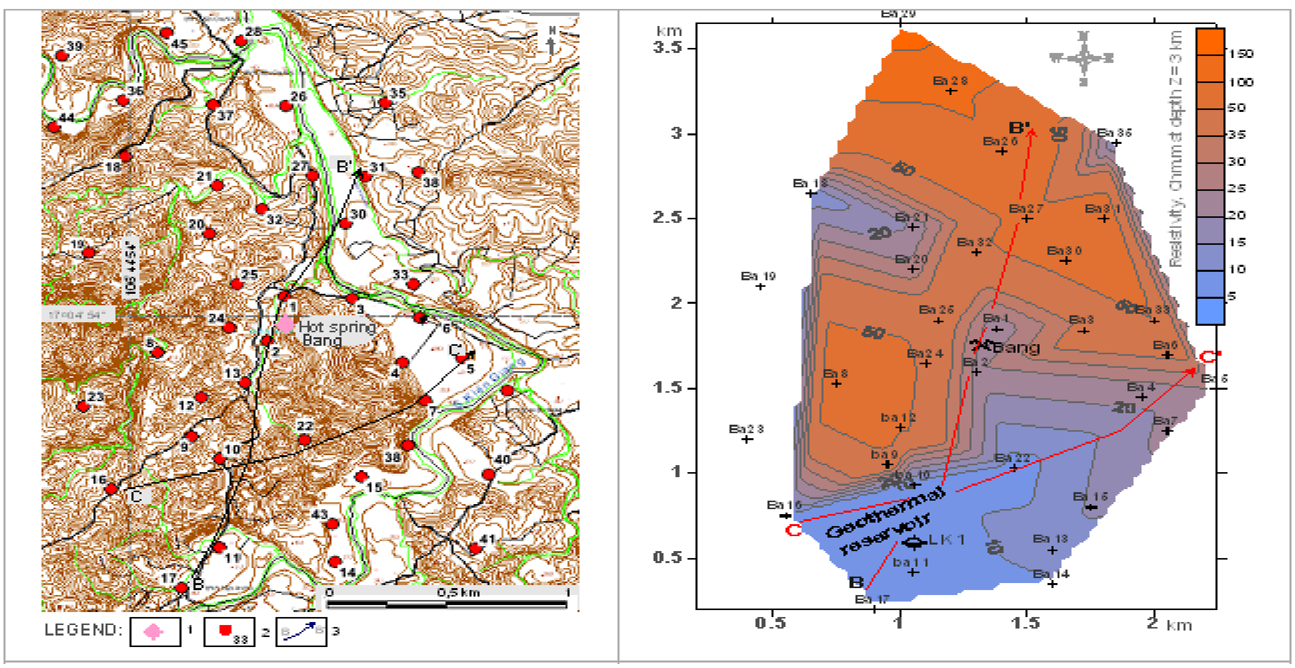


Figure 5: Left: Distribution of MT observation in area Bang hot spring (Legend: 1 – location of hot spring; 2 – location of MT surveys; 3 – MT cross-section); Right: resistivity countur at depth Z=-3km indicates geothermal reservoir in Bang area (Legend: Ba10 – Index site of MT observation; B-B', C-C': Line of MT resistivity cross-section; LK1- site of drill hole)

Two resistivity cross-sections along lines B-B' and C-C' at the Figure 5 demonstrate the deep structural features of this reservoir (very low resistivity zone) presented at the Figure 6. The structural feature of the geothermal system in Bang area identified by the geophysical surveys satisfied a worldwide conceptual model of a hydro- geothermal system with magmatic origin by both structural elements and its physical properties (Figure 6): 1) the clay cap detected at depth about 2-3 km played a role to prevent the heat transfer from the geothermal reservoir into subsurface rock layer; 2) underneath the cap is the geothermal reservoir with bottom boundary can reach the depth up to 6 - 7 km. The exposed hot water spring Bang belonged to the northern peripheral edge of the reservoir; 3) Deeper

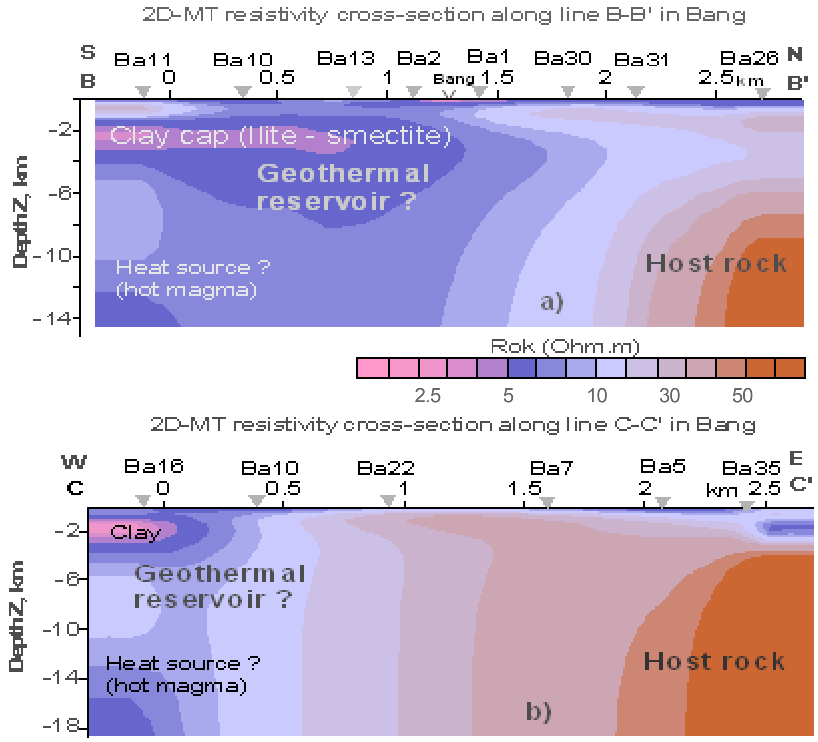


Figure 6. MT Resistivity cross-section along lines B-B' (a) and C-C' (b) reflecting structure of geothermal reservoir. Legend: Ba10- Site and number of MT survey

in the Earth crust the low resistivity structure revealed from depth about 10 -12 km can be interpreted as a intrusive body (hot magma?), which plays a role as the heat supply source for the geothermal reservoir.

2.2.4 Subsurface geothermal data

Based on the surveyed geochemical and geophysical results the site LK1 (see Figure 4 right) was choosen for drilling hole of 250 m depth and the temperature logging in bore hole was conducted, drilling cores collected. In-situ measurement temperature conducted just after end of drilling (24 November 2014) and repeated about 6 month later (9 May 2015) present on the Figure 7 left.

The thermal conductivity of core samples conducted in laboratory is with an average value of 2.1 W/m.K. The temperature gradient and heat flow caculated by repeated log has conducted after drilling termination about 6 months reached the abnormal value about 4.1 ^{o}C/100 m and 83.6 mW/m^{2} respectivelly.

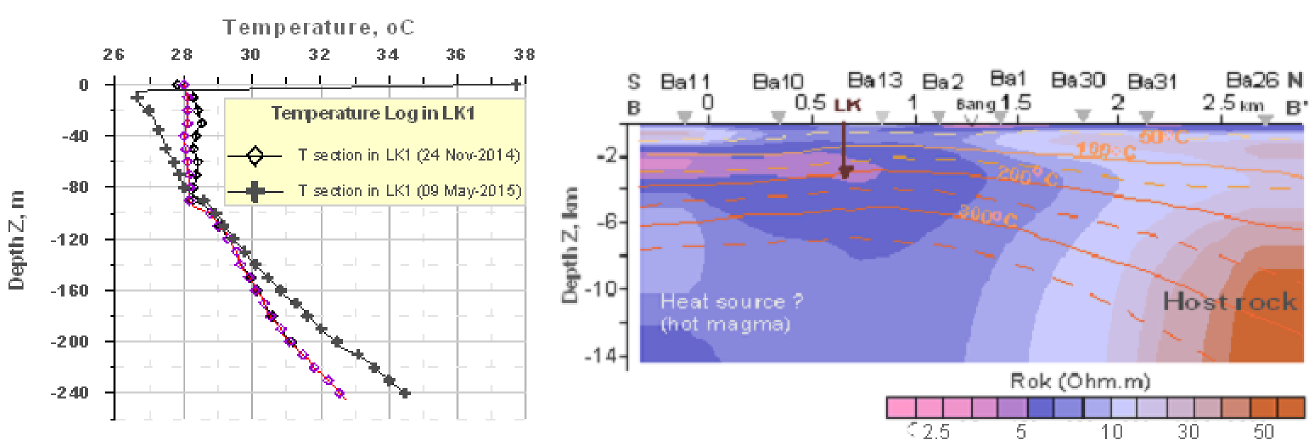


Figure 7. Temperature log (left) and model of geothermal reservoir (right) in area Bang Spring. Legend: Ba10- Site and number of MT survey; LK- site of drilling hole

Temperature modelling was implemented for one cross section B-B' based on geometric parameters from resistivity data, geothermal properties (surface heat flow, conductivity of rocks) from measurements of surface samples in shallow drilling hole LK1, and properties of deeper geological formations taken from guidebook. The obtained result of modelling which is presented in Figure 7 right has identified the model of temperature distribution in depth and at the surface of the reservoir. The temperature can reached 200 ◦C at a depth of about 3 km which is similar to the value of reservoir temperature determined by most geochemical thermometers. Based on the result, the site LK in the Figure 7 right (it's same site LK1 in Figure 5 right) has selected for test drilling in next phase to evaluate the possibility of geothermal energy exploitation.

2.2.5 Estimation of power electricity of geothermal reservoir in area Bang spring

Based on the structural and temperature of reservoir (>167- 200 ◦C by chemical thermometer and modeling results), flow rate of geothermal fluid (of 40 l/s observed in field) using simple method shuch as experimental graphic (Chandrasekharam, 2008) permite estimate power electricity by using correlation between reservoir temperatures with the flow rate of water from the source, the exploitation capacity have estimate in the range of 3-4 MWe (Figure 8).

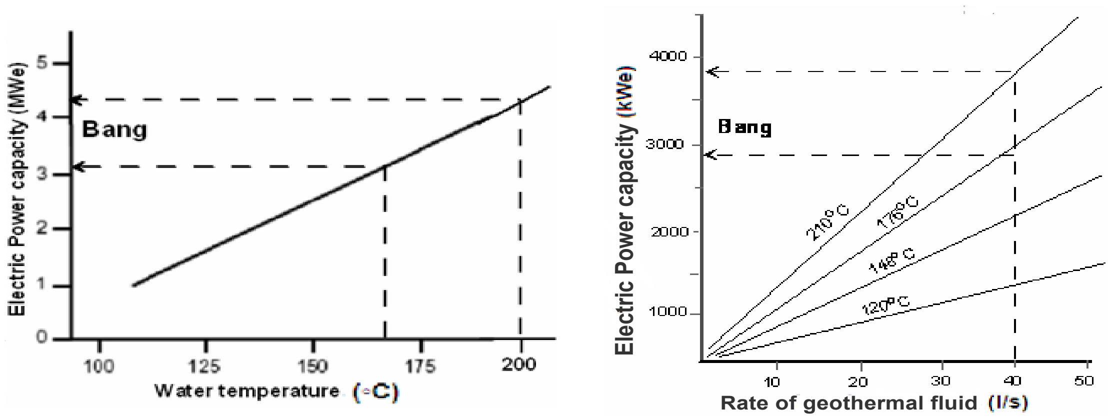


Figure 8: Estimation of electric power capacity of geothermal reservoir in area Bang Spring

Received results from exploiration step including location site, structural and temperature parameters and electricity capacity of the reservoir in the area Bang spring allow sucggest next step - test drilling for depth of 2.5 km, results will give the actual data to the propose construction of a pilot geothermal power plant.

CONCLUSSION

From more than 200 revealed hot water was discovered on the territory of Vietnam only geothermal resources in the Central region with geochemical characteristics, geological-tectonic conditions, geothermal regime indicating the magmatic source - prospect for electricity generation should be conducted the survey method to locate the site and parameters of geothermal reservoir.

The result of investigation firstly conducted in Vietnam by combining the survey methodology has identified indications of a hydro-geothermal system with magmatic origin in area Bang hot spring, The available indications of site distribution, structural features, reservoir temperature determined by the geochemical thermometer for value in the range 167-200 ◦C at a depth of 3 km of the geothermal system are interesting and sufficient databases for investment to implement for test drilling in the next phase of geothermal program.

The successful methodology, technology and practical experience conducted by domestic capacity of Vietnam for assessing the geothermal reservoir in Bang hot spring area are valuable and useful for continuing to assess the other geothermal prospects in Vietnam for establishing the potential base and proposal of strategy for geothermal energy exploitation – as a renewable resource of power in the country.

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