Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Structural Features of Geothermal Field from Magnetotelluric Survey in Northern Central Region of Vietnam

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Keywords: Magnetotelluric, Geothermal, Reservoir, hot water, Vietnam, Northern – Central region, Quang Binh province, Quang Tri province, Bang, Da Krong.

ABSTRACT

The first result of Magnetotelluric survey for geothermal investigation in Vietnam is conducted in 2013 and presented. The fifteen MT data collected mainly between 0.001-500 Hz by MTU 2000 equipment is of useful quality and provides good control on the surface layers in two high hot water 75-105◦C areas Bang (Quang Binh province) and Da Krong (Quang Tri province) belong Northern-Central region of Vietnam. It means that reliable modeling should be possible to a depth of 10,000 m depending on resistivity distribution. The data was processed and modeled using an improved modeling method by WinGlink software. The resulting 1D and 2D models show a high–very low–very high resistivity sequence with depth. The second layer is a very conductive layer distributing at a depth range from 1.2 – 3.5 km and is interpreted as the reservoir that has thermal convection and hot fluids contained in its fractures and pores. The resistive basement is a hot and solid magmatic intrusion and is interpreted as a heat source that produces a conductive heat flow towards the reservoir. As a result, the shallow resistivity model of the areas is in a good correlation with the geological features. This result allows explain the common conceptual resistivity model which has been presented for the geothermal reservoirs.

1. INTRODUCTION

On the world map, Vietnam is not lying on high heat flow anomaly of the Earth. However, across the country with over 200 geothermal hot water outcrop or discovered in boreholes had temperatures ranging from 30˚C to 100˚C, some regions of high heat flow anomaly on land and continental shelf had identified, young volcanic activity has been recorded in 1923 at Tro Island, Binh Thuan province, ... It proven geothermal resources in the country are distributed widely, is the object of interest in studies to evaluate potential geothermal resources for energy development (Nghiep, 1998).

Until now day, the results in geothermal study in Vietnam based mainly on geochemical methods for several geothermal water on the territory are showed indication on peripheral origin and relatively high reservoir temperature of some geothermal hot water sources in central regions in comparison with the northern and southern one are perspective object for more detail and extensive investigation (Flynn and Quy, 1997, Mathews, et al., 2008, Doan et al., 2014). For qualitatively assessing geothermal potential of this perspective resource, in most worlds practice necessary to carry out the new methods in order to receive structural characteristics of the specific geothermal systems.

Over the last years, there has been an important increase in the use and development of several exploration methods for geothermal resources, seismic as well as electromagnetic (EM); but while the former (like repeated 3D surface seismic, surface-to-borehole vertical seismic and borehole-to-borehole cross-well seismic profiling) have not always led to better understanding of the geothermal systems, the latter have become very popular due to improved equipment, methodologies and processing and modeling software. The electromagnetic method (magnetotelluric method – MT is used widely, the only method to reliably reach depths of several kilometers needed for some geothermal targets) provides a useful contribution to geothermal exploration and exploitation, through careful data acquisition, processing, modeling and interpretation. Its integration with other geological and geophysical data, in particular seismic, will improve the imaging of static and dynamic processes of geothermal systems (Spichak and Manzella, 2009).

The electrical conductivity of the subsurface is known to be a crucial parameter for the characterization of geothermal settings. Geothermal systems are in general composed by a region or system of faults and fractures filled with geothermal fluids, which can have high concentrations of dissolved salts, thus resulting in conducting electrolytes in a rock matrix. Both fluid and matrix (to a lesser extent) conductivities depend on temperature, and the geothermal system exhibits, generally, higher conductivity values than the host rocks. Clay mineral alterations resulting from the hydrothermal processes that take place in geothermal systems also have a high conductivity signature. Based on the series of the material fact, researchers have established relationships between the elements of a geothermal system with the electromagnetic parameters to construct an ideal - conceptual model of the convective hydrothermal systems is related to the most common type of magmatic geothermal systems (Pellerin et al., 1996, Anderson et al., WGC2000, Cumming, 2009). This makes geothermal systems ideal targets for EM methods, which have become the industry standard for exploration of geothermal systems in many countries. In the practice, the relatively easy to identify low resistivity zones produced by brines and clays that cap a geothermal system represent attractive targets for exploration (Munoz, 2013), in general case EM data is useful for better understanding the geothermal system in an area.

In 2013 under the financial support by the Ministry of Science and Technology of Vietnam and provided MTU equipment from Chung Cheng University (Taiwan) scientists of Institute of Geological sciences - Vietnam Academy of Science and Technology made magnetotelluric measurements on one line in the hot water 50-75˚C DaKrong (Quang Tri Province) and on an area of 4 x 2.5 km^2 in hot water 100˚C Bang (Quang Binh province). The paper presents results of imaging of geothermal targets in the perspective geothermal resources are distributing in Northern-Central region of Vietnam (fig.1). This first result allows explain the common conceptual resistivity model in this region, as possible in order to obtain a better understanding of the geothermal system as a whole, which is the present technique needed for assessing geothermal potential in other parts of the country in future.

2. GEOLOGICAL SETTING

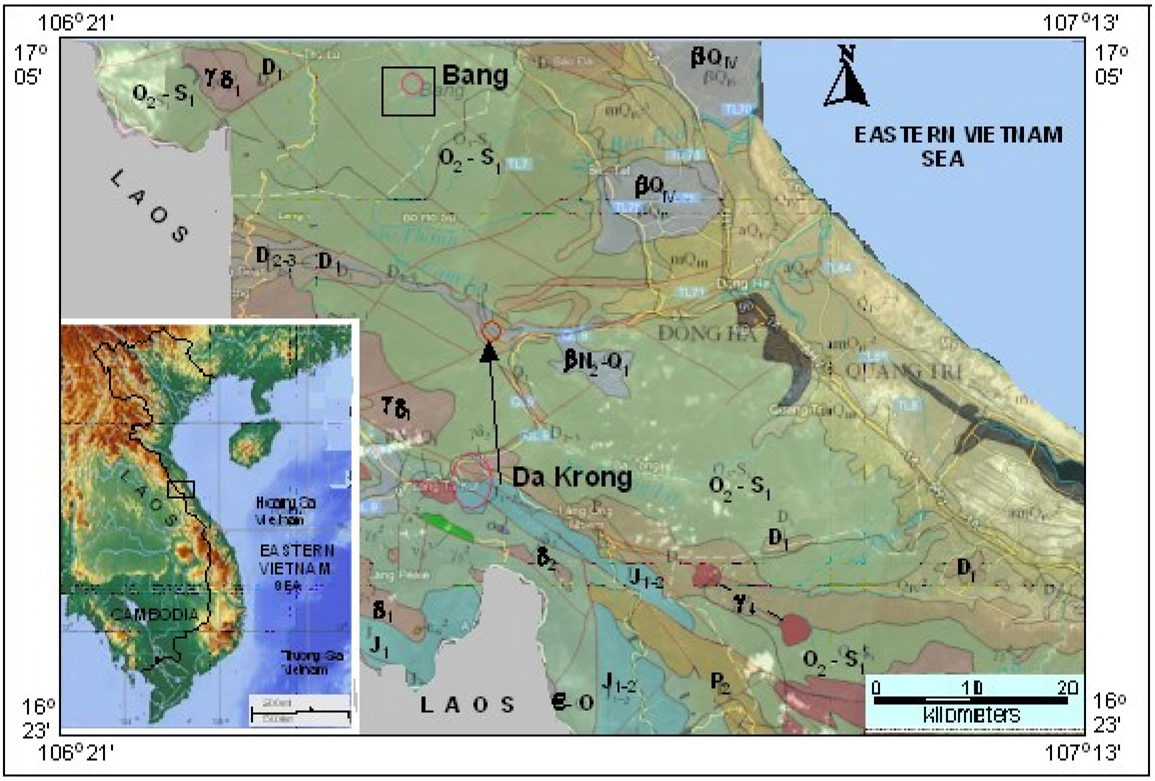

Figure 1: Geological map of North-central region of Vietnam in scale 1:1000000 and location of magnetotelluric surveys

Explanations of symbols in Fig.1 (after Tien et al., 1992, Geological map of Vietnam, 1996) are distinguished the stratigraphic features in the region:

aQ – amQ: Quatenary sediments of different origin and ages with very thin thickness is distributed mainly along sea coast;

βQ_{IV} / βN-Q: Igneous rocks of Quartenary and Neogen – Quartenary ages: Basalts are crop out in form asymmetrical body;

γδ: Magmatic intrusive rocks of Paleozoic ages: Biotite-hocblend granites, granodiorite, diorite, gabrodiorite;

P_1: Sediment rocks of Permian age: Limestones, siliceous limestones;

C-P: Sediment and metamorphic rocks of Carbonian – Permian ages: Limestone, siltstone, sandstone,…

D_1: Sediment rocks of Silurian – Devonian ages: Siltstone, sandstone, limestone;

O_2-S_1: Sediment rocks of Ordovician- Silurian ages: andesite, siliceous schists, sandstone, tuff,… largest distribution in region, its total thickness is exceed about 2,000 m.

€ - O: Rocks of Cambrian-Ordovician ages: Quartz, sericite schists, quartzitic sandstone;

System of red lines is manifestation of tectonic faults. Red rounds: Manifestation of hot water resources.

Symbols of magnetotelluric measurements: The arrows (→) is location of profile and square (□) is the area of magnetotelluric survey at Da Krong and Bang sites respectively.

The previous analysis showed that recent tectonic and magmatic activities in Southeast Asia are the main factors that affect the geothermal regime and the chemical characteristics as well as the manifestation of hot water in the different regions of the Vietnam territory (Doan et al., 2014). The overview of distribution of tectonic faults and igneous rocks, especially Neogene-Quaternary and Quaternary igneous rocks close intensively relationship with the distribution of the revealed hot water in this region. System of tectonic faults in the surveyed region is the response of two recent tectonic events in the Cenozoic time: 1) The collision between two lithosphere plates of India and Asia occurred in the period 32-5 million years ago (Oligocene-Miocene) caused slip movement along northwestern - south eastern faults. A number of these sedimentary formations and fault zones have conditions for water accumulation and heat storage, there anomalous heat flow and hot water production in favorable case may also be observed; 2) The floor spreading of Eastern Vietnam sea causes for the eruption magmatic activity in Pliocene - Quaternary happen strong, they are taken up mainly by the sub-meridian and northeastern - southwestern faults. Part magma intrusion beneath the late eruption of basalt is plying the high temperature source of heat. In places where young tectonic faults reach developing in depth exceed intrusive source will facilitate water circulation generated hot water sources, some of them revealed on the territory.

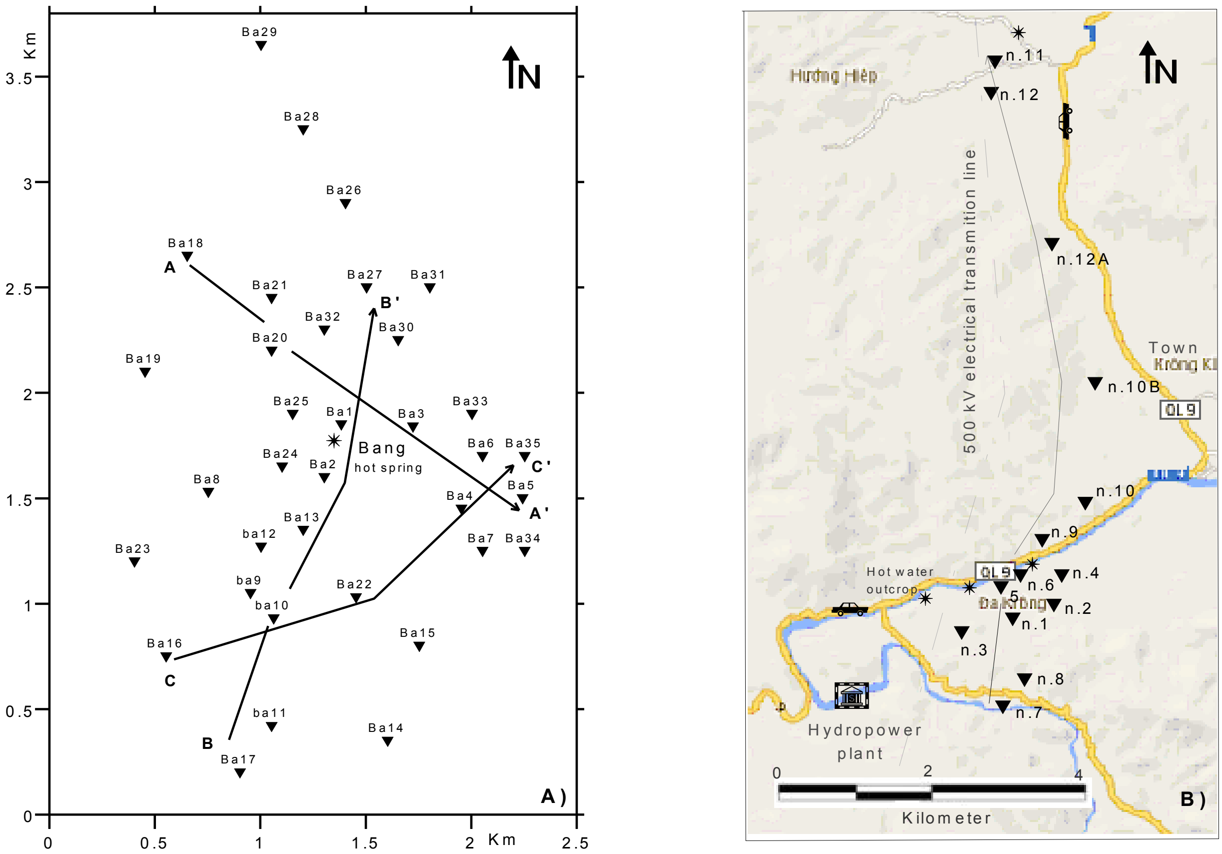

Figure 2: Sketch map of distribution of MT stations in areas Bang (A) and Da Krong (B) and profiles for presenting interpretation results. Symbols: ▼- MT station; * - location of hot water source.

3. MAGNETOTELLURIC (MT) SURVEY AND RESULT

3.1. MT data acquisition and processing

The distribution of MT stations in each area is presented in fig.2.

The field survey is carried out by the system MTU2000 to record at each station MT variations includes 2 electrical components Ex, Ey, and 3 magnetic components Hx, Hy, Hz in single site measurement. The lines for electrical components is 50m long are placed in T configuration (due to limit of topographic conditions cannot place the lines a longer). Frequency of electromagnetic variations recorded in range 500 Hz – 0.001 Hz, recorded time at each station MT is 8-10 hours. In each area made two MT stations with longer record time 20 hours.

The observation of electromagnetic signal in these areas is difficult because of both complicated topography conditions (terrain cleaves by high mountain with strong dipping slopes) and the high level of industrial and civil noises (near the 500 kV electrical power transmission lines, high traffic activity, telecommunication system, in area Da Krong there are two hydropower plants in operations, ...) so the quality of the field data is good only in frequency range 5000 Hz – 0.1 Hz. The data is good quality received in frequency exceed 0.01 Hz for stations with recorded time 20 hours.

The result of field survey is database of total 35 MT stations in Bang area and 15 MT stations in Da Krong one. The **SSMT2000** and **NPIPlot** software is used to process the MT variations and view raw MT data including series of MT cross-power curves and parameters (impedances, Resistivity and phase curves for TE and TM modes, Skew, Tipper, Coherency between channels, Conductive arrow vector, Bostik inversion curves,…) at each station in whole areas are important data for investigation goal. Due to limitation of finance for MT survey (only 50 MT stations are planed) and main goal in this stage is choice one of these two areas for detail investigation, this first result of data processing is performance in beginning of field survey allowed us have highlight indication of low resistivity at depth 1 – 5 km on Bostik inversion curves in area Bang, thus area is choice for more detail MT measurements (Fig.2A). Typical MT resistivity and phase curves at one station of the survey are presented in Fig 3. Then **MT-Editor** software is used to calculate and take out (automatically and manually) affect by noise from resistivity and phase curves as well as the individual cross-power curves. In result the series of MT curves and parameter with better quality at each station (example in Fig.4) are saved in files with needed format can be used for MT interpretation software in next step.

3.2. MT inversion and imaging

The pair of resistivity and phase curves ρ_{xy}, φ_{xy} and ρ_{yx}, φ_{yx} at each station are used for 1D inversion by TE and TM modes respectively, a few of them are used for 2D inversion along two perpendicular lines (B-B' and C-C' on fig. 2A) in Bang and one line in Da Krong area (fig. 2B).

One-dimensional of MT data: The TE resistivity cross-section from 1D inversion result from surface to 5 km of depth showed that at all stations in the area Bang characterized a high–very low to low–very high resistivity sequence with depth, presence of

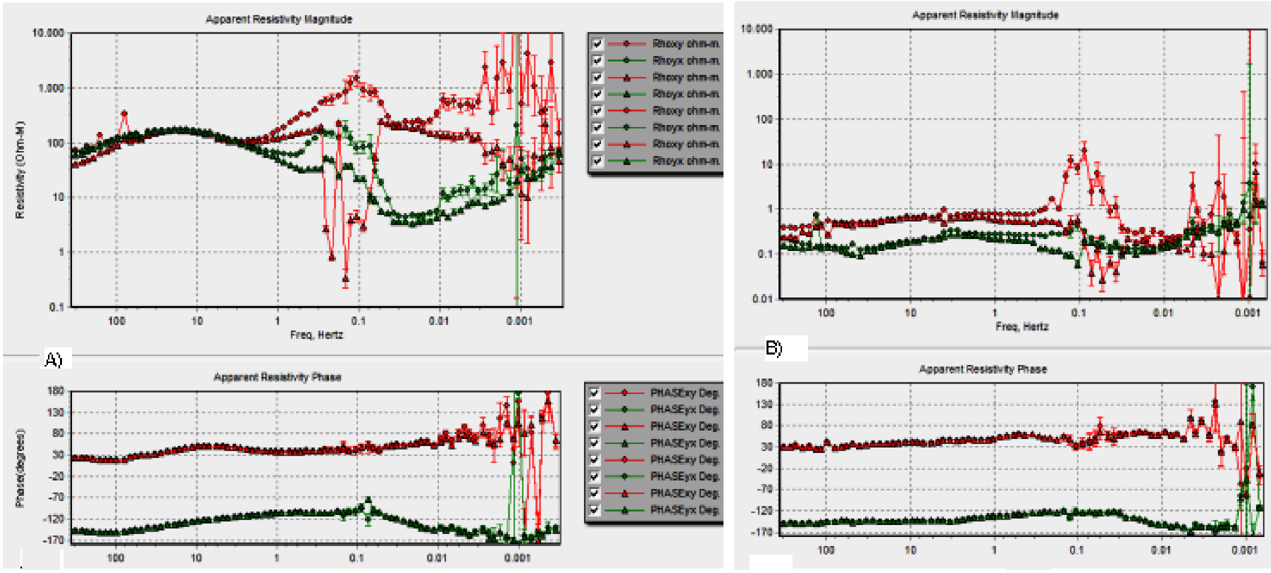

Fig.3. Example of the raw MT resistivity and phase curves in Bang (A) and Da Krong (B) areas

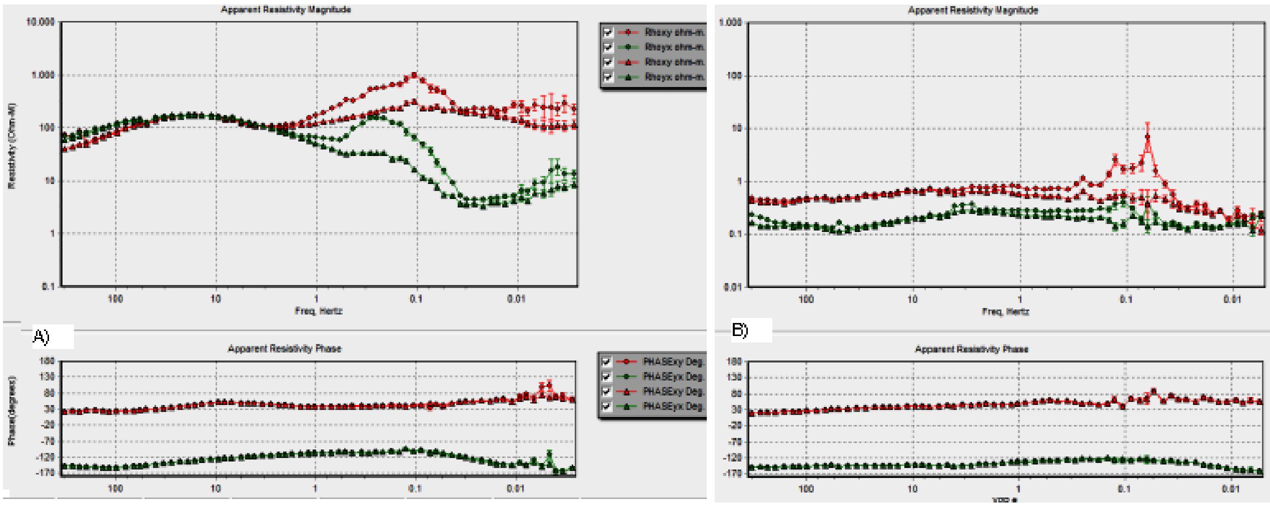

Figure 4: The MT resistivity and phase curves after data processing by MT-Edit software in Bang (A) and Da Krong (B) areas

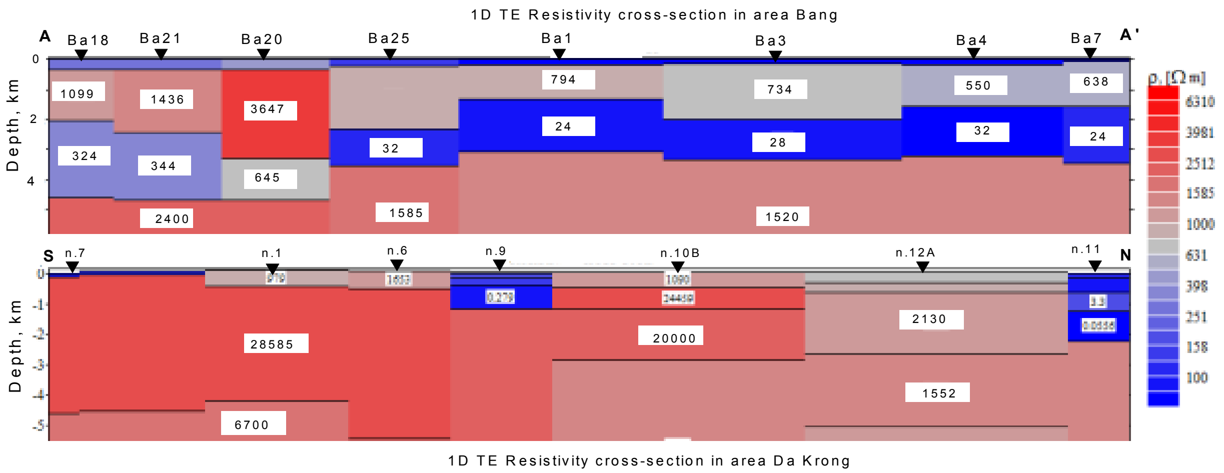

Figure 5: TE Resistivity cross-section from 1D-MT inversion results in Bang (along the line A-A') and Da Krong (S-N). Numbers in the white windows are resistivity values of layer

conductive to low resistivity layer with thickness of 1-2 km distributing at a depth range from 1.2 to 4.5 km, while in DaKrong area its presence only under two stations MT n.9 and n.11 (fig. 5). This low resistivity layer is developing into depth under the hot spring Bang, thus it is interest for geothermal investigation in this area. Based on the 1D inversion result we can map a resistivity contour of this layer in the surveyed area Bang (Fig. 6A). In this region without deep well for controlling and correcting the electrical parameter with the geological – stratigraphical formations, but in principal, the blue region including hot spring Bang in

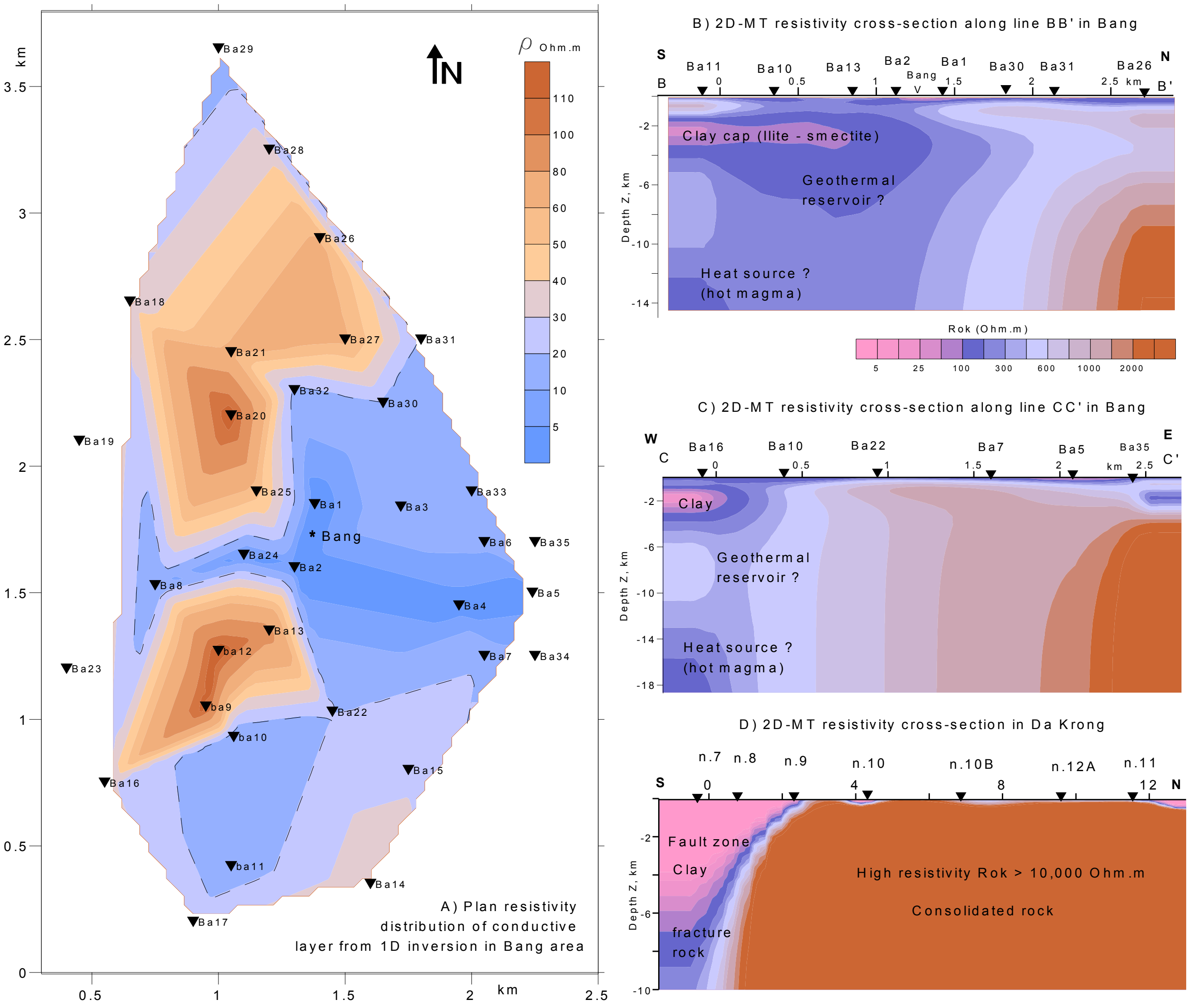

Figure 6: MT imaging in areas Bang (A-C) and Da Krong (D)

fig. 6A with low resistivity of about 20 Ohm-m distinguishes and recognize structural distribution of the reservoir or mineral alteration of the geothermal system in surveyed area.

Two-dimensional of MT data: The MT data along the lines B-B' and C-C' crossing the low resistivity region in Bang and S-N in DaKrong (Fig.2) was used for 2-D inversions using Occam 2-D algorithm and inverting for the apparent resistivity and phase of the determinant of the impedance tensor, a priori models with an uniform earth resistivity 300 Ω-m. Depth for inverting is limited 20 km. The resulting inversion models were obtained at the tenth iteration with an RMS error in range 0.05 – 0.1.

The inversion models (fig. 6B-6D) show the distribution of sub-vertical structure of low resistivity varies from 10 Ohm-m to several hundreds of Ohm-m in the left part of all cross-sections of both two areas. There is tendency increasing resistivity toward end of profiles reach some thousands of Ohm-m in Bang and more higher in Da Krong. In the left part of cross-section from hot spring Bang towards south and south-west down to depth 15 km is characterized very low – high – low resistivity sequence is an interest for geological and geothermal interpretation of the MT data in the area.

4. GEOLOGICAL-GEOTHERMAL INTERPRETATION AND DISCUSSION OF THE MT DATA

The obtained resistivity sections from MT data (Figure 6) reflects not only the geological characteristics, it also contains information relating to geothermal resources in the surveyed area. Due to without drill holes to establish the relationship between the electrical parameters with the geological formations, so just based on morphology and resistivity values of structures obtained from MT and the revealed formations of the rocks on geological maps and hot water manifestation, as well as resistivity models was associated in the literature allow interpret the nature of the rocks and recognize some elements of a geothermal system.

Resistivity of rocks beneath the surface to a depth of 15-20 km generally have very high value from thousands to tens of thousands of Ohm-m reflecting high consolidated and dry rocks, perhaps undersurface part of it includes all metamorphic and igneous formations are occurring on geologic maps, while the lower part related to granite crust.

Structures of medium resistivity (hundreds Ohm-m) to low (tens of Ohm-m) zones are dyke form or divided from host rocks of high resistivity by vertical boundaries seams are fractured rocks containing water concerning to tectonic fault zone, often associated in the place of identified tectonic faults on geological maps (Fig. 1). Based on the distribution of revealed hot water resources and resistivity distribution in this structure and compare with the conceptual model has been studied (Cumming 2009) can interpret the geothermal system model in observed area.

In the area Bang the structure of low resistivity zone in two directions (Figure 6B-6C) shows relatively complete indications of a probable magmatic hydro-geothermal model including: the low resistivity layer (10-20 Ohm-m) at a depth of about 2 km reflecting clay cap; head of a structure with relatively low resistivity (100-200 Ohm-m) at a depth of more than 12 -14 km can be interpreted as magmatic intrusions acting as the heat source of the geothermal system; medium resistivity zone (hundreds Ohm-m) distributing in the area between the two mentioned above structures is interpreted as fractured rock of reservoirs and upflow and outflow of heat. The revealed hot water point Bang (100˚C) is located at the edge of a low resistivity zone, where clay cap thickness was thin is one more indication of the proposed geothermal system.

In the area Da Krong the low resistivity zone including only two layers: above layer is very low resistivity with great thickness can be interpreted as the clay alteration, the low resistivity is lying below probably is the fractured rock containing hot water (Figure 6D). The hot water in revealed points (50-75˚C) distributing at the northern edge of the structure, which subsurface is much consolidated bedrock (very high resistivity >10,000 Ohm-m). This structural feature allows explain the revealed hot water in the area probably is outflow from the heat source in tectonic faults to surface without indication of magmatic hydrothermal system.

On models received from MT-2D data in the Bang area the resistivity of clay cap and reservoir is relatively higher than in the conceptual models published in the literature (Cumming, 2009, Anderson et al., 2000) can be explained by clay and geothermal fluid filled in the matrix rocks here having very high resistivity (thousands Ohm-m) than resistivity in rock of mentioned models.

In practical analysis of electromagnetic use have shown that the existence of low resistivity zones in geothermal areas often caused by geothermal salt in fluid, but in many cases can also be produced by conductive minerals in the rocks or ore, but there is no data to exclude them. Thus several papers (Cumming, 2009) note that, the relatively easy to identify low resistivity zones produced by fluids and clays that cap a geothermal system, however, this electromagnetic conductive anomaly can sometimes be misleading, because clay caps produce high conductivity anomalies but the opposite is not true, not all conductive anomalies are clay caps.

5. CONCLUSIONS

This paper presents the first in Vietnam results of magnetotelluric survey in two geothermal areas; it has new information to better understand a geothermal system compared with the available before results of geological and geochemical investigations alone.

The results of our study indicate that the electrical model in Bang area is an agreement deduced from 2D MT data and the global conceptual resistivity model reported for magmatic hydrothermal system. Resistivity model in Bang shows all three main indicators of a system as a conductive layer at the depth of 2 km which plays the role of the clay cap, and as immediate conductive zone interpreted as the reservoir and a deep relative conductive structure at 12-14 km in south-west from hot spring Bang is interpreted as magma intrusion forming the heat source of the geothermal reservoir. This data is useful to take rational place for a shallow exploration well to obtain water samples from the outflow zone (aquifer) and a shallow seismic survey to localize fractured regions in next step, as possible in order to establish a complete conceptual model. In the area DaKrong MT data showed probable geothermal model in tectonic fault.

ACKNOWLEDGEMENTS

This work was supported by the scientific programs on disaster prevention and rational use of natural resources KC08/11-15 of Ministry of Science and Technology of Vietnam. The authors acknowledge Prof. Chau-Huei Chen from Chung Cheng University (Taiwan) for providing magneto-telluric system MTU2000 and software for data acquisition and processing.

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