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Geochemical Characteristics of Geothermal Hot Water Sources on the Territory of Vietnam

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ABSTRACT

Main results in geothermal study in Vietnam until today is the archive of manifestation and chemical compositions, temperature of the water samples in over 200 outcrop hot water sites and in drill holes has a temperature >30°C distributing in the entire territory. They are collected during the geological and hydro-geological, oil and gas exploration since 1954 (mainly from 1975) today. The results of some approach and applies common worldwide methods for identifying the characteristics of hot water resources are presented. By using series of chart SO_4-HCO_3-Cl, Na-K-Mg, correlations between log (SiO2) with log (K^2/Mg), between the levels of pH and temperature-dissolved silica, between the concentration of dissolved silica and chlorine, for the available data allowed classify nature of each hot water sample such as in every region on territory. The sources distributing near the sea coast with high chlorine indicate sea water. Most sources in Northern territory characterized a high HCO_3 - SO_4 and low Cl indicating heated and mixed with the near surface water-rich HCO_3. Conversely, in the Central and Southern parts of territory, almost sources water distributing along the HCO_3 - Cl axis with low SO_4 indicating water rising from periphery of hot granitic source. Eight formulas of geochemical thermometer as the silica - quartz, silica-chalcedony, the cation thermometers Na-K, Na-K-Ca, mixing model silica – enthalpy were applied at available 50 sources entire territory giving values of reservoir temperature, that concentrated around 80-200°C, a few values >200°C to 400°C at a small number of sources received from the Na-K thermometers may not ensure reliability. The average values of the reservoir temperature from the all applied thermometers concentrated in range 120°C to 160°C. In comparison between regions, the reservoir temperature in Central part of territory has higher, than in the Northern and the Southern one.

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.

Geothermal research in Vietnam so far is mainly the result of chemical composition analysis, temperature measurement of hot water samples on 287 sites is archived in the book "List of sources mineral and hot water in Vietnam" published by the Vietnam Department of Geology and Mineral Resources in 1998 (ed. by Vo Cong Nghiep). The hot water sources are divided into the level and total number of sources: warm water (30-40˚C): 131 source, medium hot (41-60˚C): 77 sources, very hot (61-100˚C): 41 sources, extremely hot (> 100˚C): 4 sources (including 1 reveal source and 3 resources in drilled holes in Northern Delta). The presence of hot water is divided in geographic regions: North-East, Northern Delta, Northwestern, North-Central, Southern Coast and Central Highlands, Southeastern and Southwestern (Fig.1).

Some data from this resource is used by Vietnamese and foreign scientists to analyze characteristics of the nature, origin, reservoir temperature in a place or in a narrow area by simple methods and approaches. Since 1992 based on the chemical data and temperature of hot water samples from archives, Hoang Huu Quy used geochemical thermometers to evaluate the temperature of geothermal reservoirs at 100 sites throughout the territory, at most of the sources temperature are high enough, exceed > 150˚C. In results 10 sites revealed very hot water in the Central and South Central Coastal areas are proposed to exploit for electricity generation (Flynn and Quy, 1998). Some of resources in Central region are recalculated by Mathew (2008) using geochemical thermometers such as Chalcedony, Silica-quartz, Na/K, Na-K-Ca identified the lower values varying from 90˚C to 177˚C, using Mixing model giving extreme high values from 132˚C to 263˚C.

Cao Duy Giang and Tran Trong Thang (2008) reported the information of the origin of geothermal water in the Northwestern region and Red River Delta. Diagram HCO_3-Cl - SO_4 of 119 hot geothermal water samples shows that, the origin of most hot water here is the mixed meteorological water or water of the sea, only a few sources in Northwestern area indicate magmatic origin, but other factors such as chemical pH, total mineralization, chemical composition of them no identified this origin. The report informs the estimated reservoirs temperature based on using different formulas of geochemical thermometers, results values are very unstable: the thermometer Na - K - Ca valuates between 160-200˚C for resources in northern-western area, 110-228˚C for resources in the Delta; the silica thermometer: 50-150˚C; the thermometer K - Na: 120-250˚C in all regions.

Thus the results of evaluation of geothermal potential in Vietnam are sparse and unreliable. This can be explained by several reasons: most of the samples are mixing water, hot water no rised from the magmatic origin and not in thermal equilibrium yet. In this case the use of the chemical thermometer is not satisfied, results are not reliable (Chandrasekharam and Bundschuh, 2008).

Currently, in geothermal research, there are many methods to establish the correlation between group of chemical composition and the structure distribution, physical parameters and characteristics of the geothermal fluid (Giggenbach, 1988, Chandrasekharam, 2008). The diagrams for groups of main ions are widely used: the chart Cl-SO_4-HCO_3 allow identifying the water quality sampling:

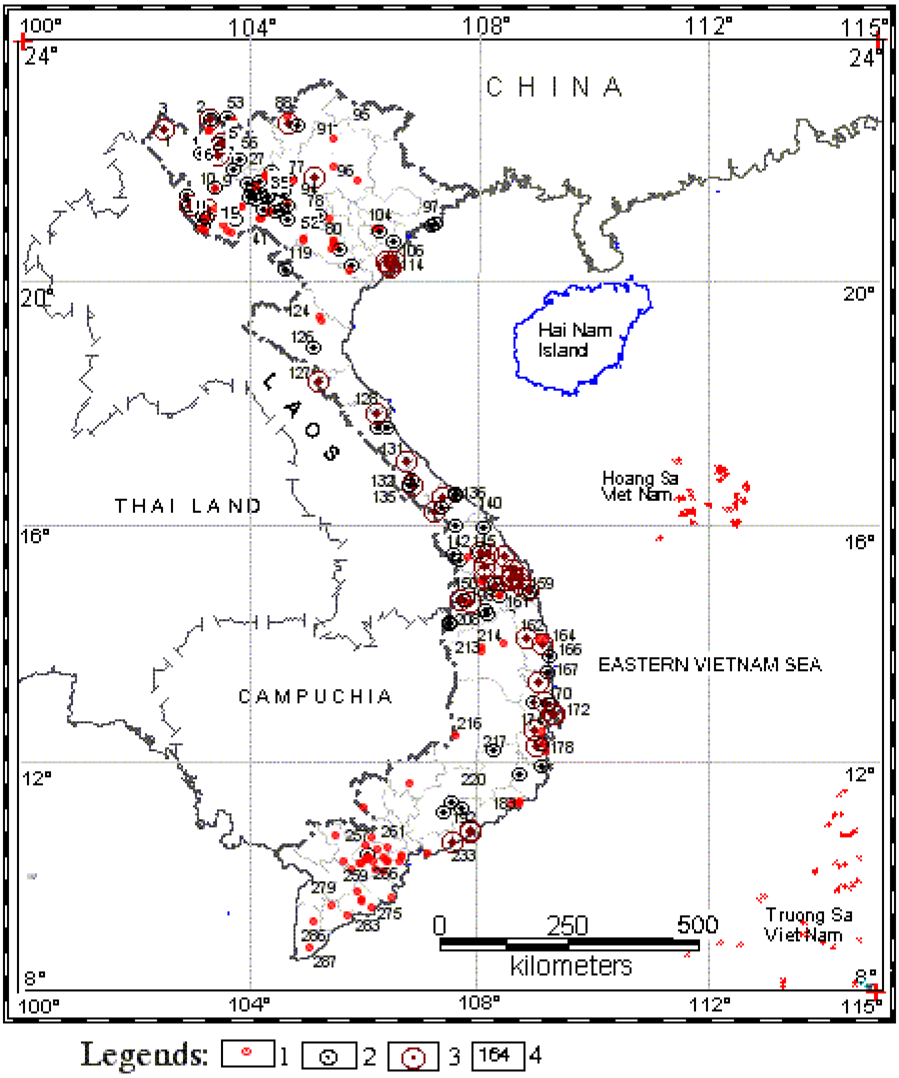

Fig 1. Manifestation of hot water sources on the territory of Vietnam

Legends: Temperature of hot water samples: 1: 30 - 40◦C; 2: 41- 60◦C; 3: 61 - 100◦C; 4: Index number of hot water source

native or sea water for the best information about geothermal resources, volcanic water, water from the peripheries of heat sources or steam heated water; diagram Na-K-Mg allows identify classification of status of water sampling at locations, indication of fast or slow equilibrium conditions of the geothermal fluid and forecasts temperature of geothermal resources in terms of water has reached full equilibrium or partial/mixed equilibrium. The dependency of soluble silica concentration - temperature and water sample analysis results allow interpret conditions and changes the nature of geothermal water in the process leading to the surface from deep heat sources (Fournier, 1985, Chandrasekharam, 2008). Several graphs of relationships as between pH and silica-temperature, between the concentration of dissolved silica with other elements in ground water, such as the ratio of K/Mg, with the temperature-enthalpy, ... also be used for getting additional information about the nature, classification of geothermal water and temperature of underground geothermal resources/reservoirs (Powell, 2010). The relationship between the concentrations of soluble silica and temperature can used to evaluate the enthalpy of heat source/reservoir instead temperature will be more reliable than the measured temperature of the mixed water (Fournier, 1981, Henley et al. 1984).

The evaluation of reservoir temperature by the geochemical thermometers is used widely, but the reliability of the application of the methods to determine the geothermal reservoir temperature depends on many factors (Chandrasekharam, 2008, Fournier, 1983, Armorsson, 1983, Giggenbach, 1983,…). As a rule, for increasing the reliability of results, the use several methods or group of methods is needed.

Using this Liquid_Analysis_v1_Powell-2010-StanfordGW.xls with all available data of chemical composition of hot water samples entire territory of Vietnam, the authors received more new information to interpret the nature and origin of the hot water, reservoir temperature of the geothermal resources having differences between the Northern, Central and Southern regions. The obtained results allow suggest preliminary interpretation of the relationship between the geothermal resources and tectonic- geological and heat flow features on the territory and surrounding region, also identify the prospective area for next investigation.

2. Overview of geography and geology

2.1 Geography

Vietnam's territory consists of a land and sea parts. The land square of approximately 333,000 km^2 located on Indochinese peninsula, bordered by China to the north, with Laos and Cambodia to the west, the Eastern Vietnam sea to east and south with adjacent coast contour with a length of over 3,000 km. The sea part of territory includes an area of vast continental shelf of millions square kilometers. The land distribution extends in the meridian direction should be divided into 3 main regions: North, Central and South. In each region is divided into smaller areas depending on the natural conditions and characteristics such as topography, hydrology and climate.

The topography and geomorphology of land divided into 3 categories: 1) Low topographic area spends only a quarter of the land territory is the type of delta distributing along the sea coasts, and 2) The terrain of transition from lowlands to high land 3) high land is mountain ranges and plateaus occupied a large area of territory. Largest lowland area is Northern Delta and Southern Delta, along the central coast is the narrow strip of plain. Transitional terrain characterized by low hills with high as tens of meters to 100-200m over sea level. High terrain with dipping slopes of mountain ranges with elevations over 1000 m at sea level and deep valleys cleaved. It widely distributed in the North-Eastern, North-Western and Central regions, the high land with the topography relatively flat distributing in west southern central highlands known as Southern Central plateau.

2.2 Geology

According to the tectonic map of Indochina established by Nguyen Trong Yem and Van Duc Chuong (1996) earth crust of Vietnam's territory and a part of the mainland continental crust of the Indochina peninsula and the Eastern Vietnam sea, including the continental crust, transitional crust and the oceanic crust. Geological context of the territory of Vietnam and Indochina is an integral part of the geological history of formation of the continental crust in Southeastern Asia.

2.2.1 Earth crustal structure

The crust of mainland territory of Vietnam is divided into geological blocks of age formation and distribution in the geographic regions, including: 1) Series of oldest Precambrian and early Proterozoic structures distributed in limited square of the several regions surrounding the older blocks; 2) Series of Fanerozoic structure (Kaledonian, Hecxinian and Indosinian ages) are widely distributed in the regions; 3) The overburden and continental rift structures appeared by the strong tectonic activity in Mezozoic and Cenozoic eras are largely distributed on the hidden space between the older crustal structures.

Although geophysical data the thickness of earth crust on Vietnam territory ranging from 10-14 km (in deep water basin of Eastern Vietnam sea) to 38-40 km, tends to increase toward the center of the ancient structures in the northern –western region, northern eastern, South Central highlands (Cao Dinh Trieu et al., 2010).

2.2.2 Magmatism

On the geological map scale of 1: 1,000,000 published by the Vietnam Department of Geology (1996) on the territory presence of igneous formations are main groups: 1) Precambrian acid igneous rocks, 2) basic igneous and Paleozoic acid rocks; 3) Cenozoic acid igneous and acid-alkaline rocks; 4) Neogene-Quaternary basalt; 5) Quaternary basalt.

The reveal of all groups and igneous rocks, especially the Neogene-Quaternary and Quaternary basalts are widely distributed in the southern central coast and highland regions, while they are small outcrop scale and more dispersed in the northern central region and northern regions of territory.

2.2.3 Neotectonic

In the Cenozoic, about 32 Ma to recent there are two events from activity of the Earth's crust affected to geological – tectonic faces on the Indochina peninsula, including Vietnam territory (Phung Van Phach, Nguyen Trong Yem, 1996, Taponnier, 1986): 1) the collision between two India and Asia lithosphere's plates; 2) the seafloor spreading of Eastern Vietnam sea.

The consequences of the collision between India and Asia lithosphere plates occurred in the period 32-5 Ma (Oligocene-Miocene) caused slip movement along northwestern - south eastern faults (Red River fault, Hau River fault) pushed Indochina peninsula shifted southeastern award with the amplitude reaches 500-700 km (Taponnier, 1986). At the same time, during the period 32-16 Ma to create the subsidence of ocean basins appeared in Eastern Vietnam sea. It affects differences of the tectonic regimes between the northern and southern parts of Vietnam territory.

In the northern part, in the Cenozoic era tectonic activity has two stages: Oligocene and Pliocene - Quaternary. In the first phase, in the Oligocene period rift processes occurred, subsidence and sedimentary process results to fill a series of basins along the faults of north western - south-eastern direction. A number of these sedimentary formations have conditions for water accumulation and heat storage, the available temperature values observed in some oil and gas drilling holes in sedimentary basins on the territory and adjacent shelf no exceed 179°C (Tran Huyen, et al.. 1999, Duchkov et al., 1992). At a later stage, during the Pliocene - Quaternary and recent, due to changes in tectonic stress field caused the lifting motion of earth crust, it creates differentiated topography: the high mountain ranges on the western territory and the middle mountain valleys and coastal plains.

In the southern part of the territory, due to the affects of both events, the collision between lithosphere plates India and Eurasia, either Eastern sea floor spreading causes the eruption magmatic activity in Pliocene - Quaternary happen strong, they are taken up mainly by the sub-meridian and northeastern - southwestern faults. Signs of active tectonic and appearance of young's magmatic N-Q volcanoes in Central regions, and South Central Highlands have been observed lightly on the recent geomorphology, volcanic activity continued in the most recent, the latest even occurred in 1923 in the Tro Island of Southern Central shelf, where there is a wide distribution of the Quaternary basalts and the high heat flow anomaly in the continental shelf (Nguyen Hoang, et al., 1996, He Lijuan, 1999).

3. Geochemical characteristics of hot water samples on the territory of Vietnam

3.1 Data sources

To carry out the geochemical analysis the data of chemical composition and temperature of water samples of 253 hot sources on the whole territory of Vietnam are used, is stored in the overwritten archive "List of mineral and hot water source in Vietnam". Thus index number of water samples in this paper is retained same as in the archive.

Note that the archived data of water samples is collected in the different conditions (revealing or recovered in the shallow boreholes), during long time (from 1954 to 1990, mainly from 1975). Results of chemical analysis has carried out in many laboratories, mainly in Vietnam for the hydro-geological and mineral water's studies, often have low precision and does not allay satisfy for all requirements of geothermal research. To apply the geochemical methods only these samples have enough data: temperature, pH, the compositions - geoindicator Na, K, Mg, Ca, Cl, HCO_3 and SiO_2 are available.

3.2 Methods

Only limited numerous of water samples in every region from archive can have conditions to use following methods of geochemical analysis:

- The data can used to get Cl-SO_4-HCO_3, and Na-K-Mg ternary diagrams for groups of the hot water samples in every region for using Excel spreadsheet Liquid_Analysis_v1_Powell-2010-StanfordGW.xls.
- The data of pH, temperature and concentration of dissolved silica (SiO_2) is used for establishing diagrams of relationship between the pH and dissolved silica –temperature, diagrams of correlation log (SiO2) with log (K^2/Mg), correlation SiO_2 – enthalpy.
- Following geochemical thermometers had used to evaluate the geothermal reservoir temperature: Quartz no steam loss (Fournier, 1977), Quartz maximal steam loss (Fournier, 1977), Chalcedony (Fournier 1977, Armorsson, 1983), Na-K (Fournier, 1977, Armorsson, 1983, Giggenbach, 1988), Na-K-Ca (Fournier, Truesdell, 1973).
- Mixing model SiO_2 – enthalpy (Henley et al., 1984, Truesdell and Fournier, 1977).

3.3 Results

3.3.1 Chart Cl-SO_4-HCO_3:

In all regions there is some number of water sources with high chlorine characterizing native or sea origin of water are all water samples from the deltas and coastal plains (fig. 2).

There are three sources with high together SO_4 and Cl characterizing magmatic origin distributing only in the adjacent boundary between North-Western and North-Eastern areas of Northern region (fig. 2A).

There is light tendency of increasing HCO_3 –Cl compositions (peripheral water) and decreasing SO_4 (steam heated water) of water samples from northern to central and southern regions (fig. 2), is a main difference of geochemical characteristic of regions on the territory.

3.3.2 Chart Na-K-Mg:

Because of limited number of water samples in Northern and Southern regions for calculation the correlation Na-K-Mg, therefore not enough information to discuss about the full characteristics, but available result shows most of the geothermal water in all regions has the Mg composition rich, lying in zone no equilibrium (fig. 3). The water source distributing at full equilibrium is only one sample collected from drilling hole at depth 290 m in north-eastern area of Northern region (fig. 3A), some of these sources is lying at partial or mixed equilibrium, often they are water from revealed sources of high temperature, distribution nearly magmatic massive in Central regions or samples collected in relatively deep boreholes. Almost water samples characterizing partial or mixed equilibrium are distributed or concentrated in tendency of temperature lines from top $Mg^{1/2}$ to axis K/100 - Na/100 balance have values in the range of 100-160◦C.

3.3.3 Diagrams on correlation between SiO_2 and temperature with pH of geothermal water samples in all regions on the territory with large fluctuations, but can identify relatively linear distribution of them lying between the two experimental curves pH = 9 and pH = 10, so in which the water samples in the southern regions going out the linear dependence, because of the values of dissolved SiO_2 here no changed correspondingly with temperature (fig. 4 left).

The correlation between log (SiO_2) and log (K**/Mg) can identify relatively a linear distribution, but may be dividing into two groups with the different levels of concentration of dissolved silica in the dependence (fig. 4 right): Group 1 has higher levels of dissolved silica concentration including mainly water sources in the southern central coastal region. In other rest regions it seems distribute on both groups. Group 2 indicates relatively lower levels of dissolved silica in the dependence with presence mainly of the water sources in the southern region.

Note that, available compositions SiO_2 and Cl of several number of water samples allow to establish diagrams of the correlation between SiO_2 and Cl for each region and as all territory, but obtained results show large fluctuation, linear correlation between SiO_2 and Cl is not observed (it is not presented).

3.3.4 Diagram of correlation between dissolved silica and temperature (like fig. 6) is expressed weakly linear correlation with high dispersion and concentrated in very low values: SiO_2 <150 mg/l, temperature <100˚C causing difficulty to distinguish between regimes of water cooling: soluble quartz no steam loss or soluble quartz with maximal water vapor loss for each geothermal water sample. But some of the samples of hot water in the southern central coast (symbol rhombic) and highland (symbol circle) lying over the top boundary of dependency of quartz no steam loss may be indicate soluble quartz maximal water vapor loss.

3.3.5 Calculated reservoir temperature by methods of geochemical thermometers quartz does not lose steam, quartz maximal steam

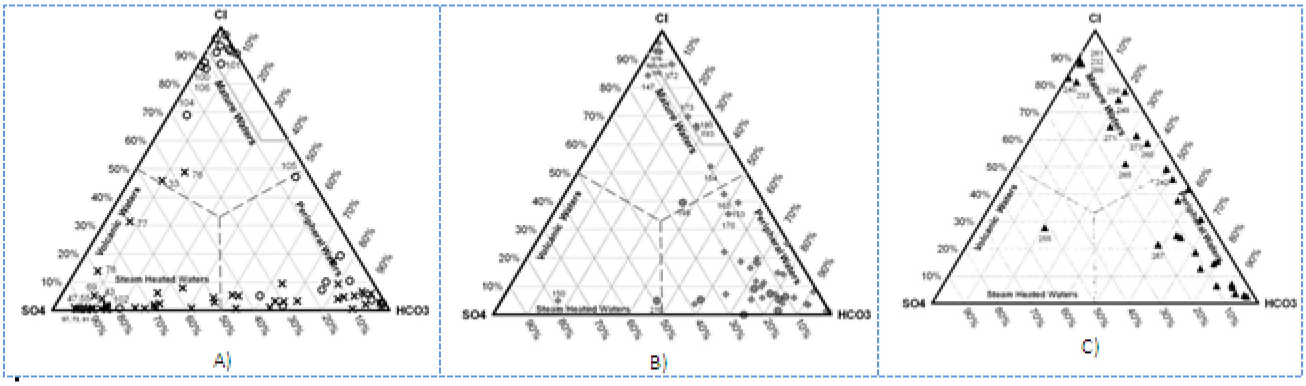

Figure 2. Chart SO_4-HCO_3-Cl for geothermal water samples in Northern (A), Central (B) and Southern (C) regions

Legends of symbols: in 2A): x- Northwestern area; o- North-Eastern area and Northern plain; in 2B): 9 - Northern Central area; ∀ - Southern central area.

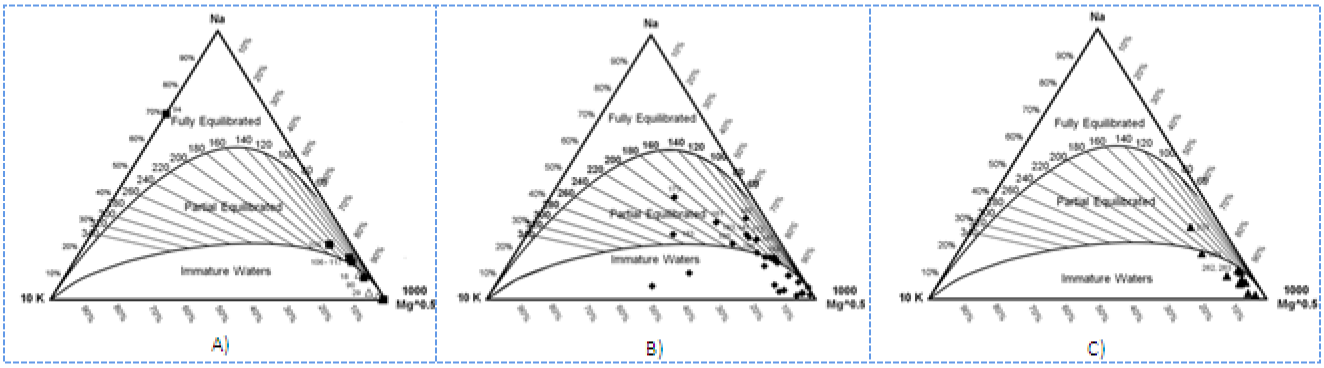

Figure 3. Chart Na-K-Mg for geothermal water samples in Northern (A), Central (B) and Southern (C) regions

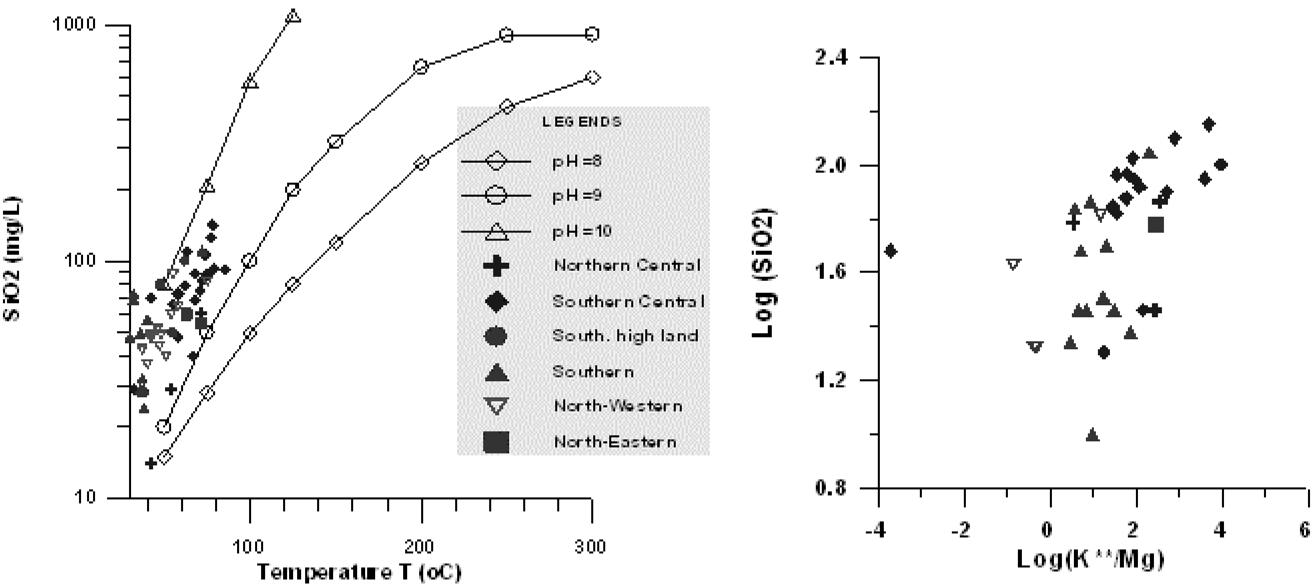

Figure 4. Diagrams of correlation between SiO_2 and temperature with pH and between log (SiO_2) and log (K/Mg) for geothermal water samples on territory of Vietnam**

loss at 100◦C (Fournier, 1977), silica-chalcedony (Fournier, 1977, Arnorsson et al., 1983), Na-K (Fournier, 1977, Arnorsson et al., 1983, Giggenbach, 1988), Na-K-Ca (Fournier and Truesdell, 1973) for available hot water resources in all areas of territory is shown by graphical form in figure 5.

The reservoir temperature of the most hot water in all sites concentrated in range from 80°C to 180°C. The variations of the reservoir temperature received by the group of thermometers as silica - quartz, silica - Chalcedony and Na-K-Ca ranging at least in all areas. So in a few sources reservoir temperature determined by Na-K thermometers has abnormally high values: more 200°C to 400°C. In comparison of all the temperature values by chalcedony - silica thermometer is lowest, in the range of 80-100°C, then values increasing steeply by the thermometer silica – quartz maximum steam loss in the range 100-120°C, by the quartz thermometer no steam loss, Na-K-Ca, Na-K thermometer mainly in the range 130-170°C, by the thermometer Na-K for a few

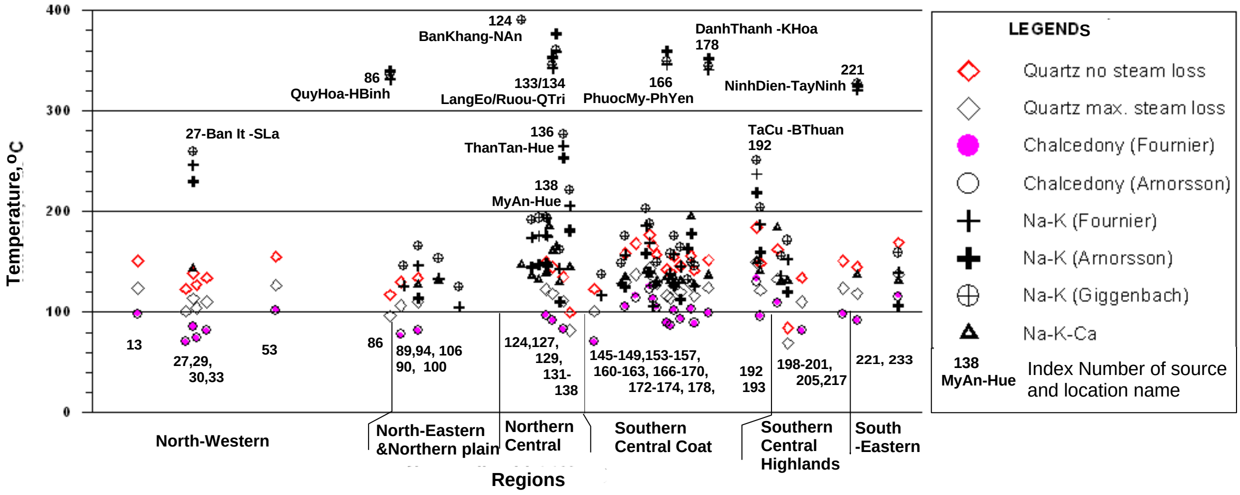

Figure 5. Statistical diagram of reservoir temperature obtained by geochemical thermometers for geothermal water samples in different regions on territory of Vietnam

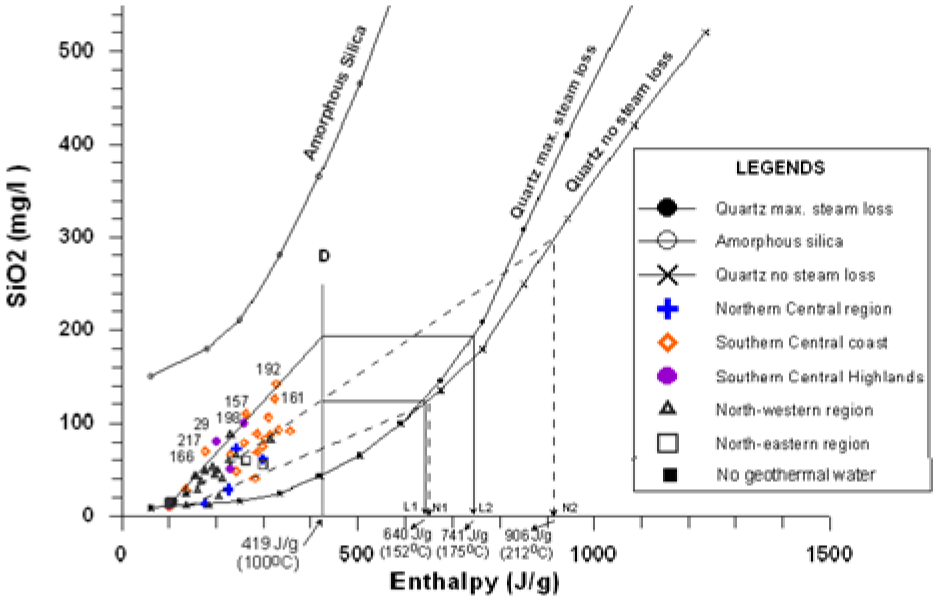

Figure 6. Mixed model SiO_2 – Enthalpy for geothermal water samples in regions on territory of Vietnam

Legends: the number with symbol on the picture is index of water sites from archived data

sources in the northern central region and southern central coast having the values in range 180 -200°C. The temperature by thermometer of quartz no steam loss and Na-K-Ca is 120 - 200°C, equally the average values of all the applied methods.

In comparison between regions on the territory, the temperature of most sources in regions in Central Vietnam (including northern region, southern central coast and highlands) has enough higher value than rest regions.

3.3.6 Mixing model silica – enthalpy

The diagram of relationships between the soluble silica and enthalpy of available water samples in different regions of whole territory is presented in figure 6. Most data of the water sources located in the area of low enthalpy, no divided regimes of quartz no steam loss and maximal steam loss at boiling temperatures 100°C. To estimate the reservoir temperature the mixed model SiO_2 - enthalpy (Truesdell, and Fournier, 1977, Henley et al., 1984) rationally used for 3 cases: highest, immediate and lowest lines of the correlation (fig. 6).

In the case of highest line of correlation the water characterizing only cooling condition of geothermal water by maximal steam loss. Enthalpy and reservoir temperature can be exceeding 741 J/g and 175◦C respectively (point L2 at the enthalpy axis).

In the immediate line of correlation the geothermal water may be cooling by both conditions: maximal steam loss and no steam loss. In the case, enthalpy and reservoir temperature are estimated about 640 J/g (152◦C on the point L1 at the enthalpy axis) and 906 J/g (212◦C on the point N2 at the enthalpy axis) respectively.

In the lowest line the geothermal water cooling by condition no steam loss having enthalpy (point N2) nearby the enthalpy of the water cooling by maximal steam loss of immediate line (point L1). In this case enthalpy and reservoir temperature by maximal steam loss no less than 500 J/g and 120◦C (no presented).

In general the estimated reservoir temperature of available geothermal water sources on territory Vietnam by mixing model silica – enthalpy is ranging from 120◦C to 212◦C. It is nearly values of reservoir temperature obtained by almost geochemical thermometers.

4. Discussions about the geochemical characteristics of geothermal water on the territory of Vietnam

4.1 Although the series of chart SO_4-HCO_3-Cl, SiO_2-temperature and log (SiO_2)-log (K^2/Mg) can be classifying geothermal water on the territory with chemical features between the regions as bellow:

- Hot water is rich Cl occupied most of the resources in coastal areas, where topography is low, as northern and southern deltas, in general all sea coastal plains. The water with high chlorine here seems affected by the geothermal water mixed with sea water, is not native water. They are not suited for estimating reservoir temperature.

- There is light tendency of high HCO_3 –Cl with low SO_4 of water is increasing in geographical direction from northern region to central and southern one indicating the water rising from peripheries of the magmatic heat source relating to the recent tectonic and N-Q magmatic activities resulting by the event of sea floor spreading of Eastern Vietnam sea.

- The nearly linear correlations SiO_2-temperature, SiO_2-temperature on the experimental curves pH of geothermal water, log (SiO_2)-log (K^2/Mg) show the several factors as mixing process or cooling regimes of geothermal water rising to the near surface (Ellis and Mahon, 1977, Chandrasekharam, 2008) causing change of the concentration of dissolved silica, may be affect strongly on the reliability and uniqueness of results applying some geochemical methods such as Na/K and Na-K-Ca thermometers in justly one region (Chandrasekharam, 2008, Fournier, 1985).

4.2 Series of chart Na-K-Mg indicates the conditions and living time of geothermal water on the territory have difference between the regions. Most of the geothermal water in all regions has the Mg composition rich, lying in zone not equilibrium. The water lying at full equilibrium is rare or no revealed. Most water in partial or mixed equilibrium distributed or concentrated in tendency of temperature lines have values in the range of 100-160◦C from top $Mg^{1/2}$ to axis K/100 - Na/100 balance indicates slow equilibrium of geothermal fluid. A few water in the southern central coast dispersed from above trend may be relate to the contours connecting the top Na/100 to axis K/100 – $Mg^{1/2}$, it indicates that rapid equilibrium of solution (Chandrasekharam, 2008, Giggenbach, 1988).

All the above characteristics of hot water are reasons and affects of the reliability of results in estimation of the reservoirs temperature in previous works in Vietnam.

4.3 The instability and high dispersion of reservoir temperature in several hot water sites obtained by different geochemical thermometers can be explained by the following reasons (Chandrasekharam, 2008, Fournier, 1983):

- There is systematical difference of data, in particular case the values of most reservoir temperature determined by the silica – chalcedony thermometer are always lower than a compared with other one because these formulas are summarized from the geothermal sources with temperature as well as high levels of dissolved silica, while the geothermal water in Vietnam is very low one, so received temperature by the thermometer silica - chalcedony often is also lower than the real reservoir temperature.

- There are abnormal high temperatures (>200°C to 400°C) in some water sources obtained by the cation thermometer Na-K can also caused by water in Vietnam is low temperature, ratio Na/K is dominated by percolation, the concentration of Calcium is high, so reservoir temperature should be determined with the abnormally high compared to the actual temperature of the reservoir, especially when the reservoir temperature <180°C (Chandrasekharam, 2008).

In the obtained result observed the trend of higher reservoir temperatures in the central regions compared with both the northern and southern one is explained by the more active tectonic and geological conditions: it contributing in regions of large distribution of young magmatic rocks, the volcanic and N-Q basalt eruption, activity of recent volcano on Tro island in 1923. Also it is adjacent to a large high heat flow anomaly (> 80 mW/m^2) of earth crust relating to seafloor spreading of the Eastern Vietnam sea (He Lijuan, 1999).

4.4 From mixing model SiO_2 - enthalpy in cases of soluble quartz no lose steam of water at 100°C, when the enthalpy of the water in immediate correlation giving abnormally high reservoir temperatures (>200°C) may caused by thermal conductivity during cooling of the geothermal water leads to make the determined value higher than the actual temperature of the geothermal reservoir. The figure on mixing model SiO_2 – enthalpy showed reservoir temperatures of all available hot water samples on territory varying only in range of 120 - 212°C, nearly average values of all geochemical thermometers, should be useful information of the method to estimate reservoir temperatures of hot water resources on this territory.

4.5 The received reservoir temperature in different regions on territory of Vietnam from the chemical thermometers mainly concentrated in the range of values 100°C - 180°C is acceptable. This data is relatively satisfied with the normal geothermal regime of Earth's continental crust and compared with the available temperature values observed in some oil and gas drilling holes in sedimentary basins on the territory and adjacent shelf no exceed 179°C (Tran Huyen, et al.. 1999, Duchkov et al., 1992).

5. Conclusions

Main results in geothermal study in entire territory of Vietnam today is the archived data of chemical compositions and temperature of the water samples in over 200 outcrop hot water sites. The previous works showed the available studied results on the geothermal water on the territory are sparse and adequate for understanding reservoir temperature and assessing geothermal potential.

The obtained results by geochemical analysis of the available data allowed interpret specifically difference of geochemical characteristics of hot water resources in different region on the territory: almost hot water sources with high chlorine are affected by the geothermal water mixed with sea water, is not native water. Water in northern region having property of HCO_3-SO_4 (steam heated water), while water from central and southern regions is HCO_3 –Cl (peripheral water). Water in all regions indicates mainly slow equilibrium of geothermal fluid; nearly linear correlations SiO_2-temperature, SiO_2-temperature on the experimental curves pH of geothermal water, log (SiO_2)-log (K^2/Mg) indicate the presence of mixing process and different cooling regimes of geothermal water rising to the near surface causing change of the concentration of dissolved silica. All the above factors may be are reasons and affects of the reliability of results in estimation of the reservoirs temperature in previous works in Vietnam.

Calculated by geochemical thermometers and mixed model SiO2 - enthalpy for all available hot water samples giving reservoir temperature concentrated around 100-180°C, a few values >200°C to 400°C at a some sources received from the Na-K thermometers may not ensure reliability. In comparison between regions, the reservoir temperature in Central part of territory (including the Northern Central region, Southern Central Coast and Plateau) has higher in the Northern and the Southern one.

The geochemical analysis based on limited archived data, but the obtained results showed main geochemical characteristics and reservoir temperature of hot water sources in the different regions on the territory are useful information in primary reconnaissance stage of geothermal research. The indication on peripheral origin and relatively high reservoir temperature of geothermal hot water sources in central regions in comparison with the northern and southern one are suited with tectonic – geological and heat flow manifestations. It allows conclude that, the geothermal hot water sources in central regions are perspective object for more detail and extensive investigation in future.

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