Characteristics of The Chantaburi Thermal Spring, Eastern Thailand

Punya Charusiri,[1,2] Prakarn Buenkhuntod,[3] Krit Won-In,[4] Malatee Thayakupt[1] and Jiraprapa Niampan[1]

Three small hot springs of easternmost Thailand have been recently discovered since 1995. The hot springs are located very close to the Thailand - Kampuchea border at Ban Pong Nam Ron District, Chantaburi Province, covering an area of about 500 m^2. In 2001 we conducted a detailed investigation to cover the thermal springs in order to gain basic knowledge of the hot springs and to preliminarily identify their applications.

Geologically, Quaternary unconsolidated alluvial deposits extensively cover the hot spring area. Several small outcrops are exposed sporadically in and nearby the thermal springs. Our field mapping shows the occurrence of Cenozoic basalts in the southern part of the studied springs. These basalts extruded thick sequences of clastic and chert strata of Triassic age. Quartz veins are quite abundant and cut the chert beds. At the hot springs the outcrops, which are mostly clastic rocks, are intensively hydrothermally altered by pervasive silicification. Silica materials later fill up abundant vugs. Enhanced Landsat information reveals that the springs are related to and controlled by faulting and that the basalts are located immediately at the fault. The fault zone in the study area is regarded as a southeastward extension of the so-called major "Three-Pagoda Fault" which passes through the large central plain of Thailand.

Geochemically, the basalts are mostly alkaline olivine basalts, so they are regarded to have been deposited in a rifting tectonic environment. These basalts extend southeastward to the Gulf of Thailand and become gem-bearing. Our new $^{40}Ar/^{39}Ar$ dating information reveals that the average age of these basalts is about 1 Ma. Our current field and air-borne magnetic results, together with previous studies, indicate the close genetic relationship of hot spring and basalt. We also consider that the most probable heat source of the springs is near-surface active rift-related magmatism, which could have given rise to the existence of basalts in the past and may be responsible for the hot spring development by an active intraplate mantle melting through the major fault. It is inferred also, though not well-defined, that water in the thermal springs is a mixture of meteoric water and connate water.

Our geochemical analyses of spring waters reveal that they belong to the $Na\text{-}HCO_3^-$ type with quite high contents of Mn (>0.3mg/l) and high pH values (>9), over recommended standards. Therefore, they are not appropriate for domestic uses. Subsurface temperatures as calculated by quartz and Na-K (-Ca) geothermometers are mostly within the range of 77 to 98 ^{0}C. This temperature range is not high enough for a small geothermal power plant. However, it is recommended that the studied hot springs can be used for space heating and material drying, or they can be developed as tourist attractions.

Key words: Thermal springs, hot springs, Chantaburi, eastern Thailand, geothermometers, faults.

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ลักษณะเฉพาะของแหล่งน้ำพุร้อนจันทบุรีภาคตะวันออกของประเทศไทย

ปัญญา จารุศิริ, ปราการ เบือนขุนทด, กฤษณ์ วันอินทร์, มาละตี ทัยคุปต์, จิระประภา เนียมปาน (2546)

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เมื่อปี พ.ศ2538 .ได้มีการค้นพบน้ำพุร้อนขนาดเล็ก 3จุด ในภาคตะวันออกของประเทศไทย ใกล้ชายแดนไทย-กัมพูชา ในเขตอำเภอโป่งน้ำสอย จังหวัดจันทบุรี ซึ่งปกคลุมพื้นที่ประมาณ 500ตารางเมตร ในปี พ.ศ 2545 .เราได้สำรวจรายละเอียดน้ำพุร้อนเหล่านี้ เพื่อทราบถึงสภาพพื้นฐานและการนำน้ำพุร้อนเหล่านี้ไปใช้

ในทางธรณีวิทยา เราพบแหล่งตะกอนสะสมที่ยังไม่แข็งตัวโดยทางน้ำแผ่ปกคลุมไปทั่วพื้นที่และมีหินโผล่ให้เห็นเป็นแห่งๆ บ้างในพื้นที่ จากการทำแผนที่พบว่ามีหินบะซอลต์มหายุคซีโนโซอิค และชั้นหินเชิร์ตยุคไตรแอสซิกปรากฏ โดยมีสายแร่ควอร์ตมากมาย แทรกตัดหินเชิร์ต บริเวณน้ำพุร้อน เราพบหินโผล่ชนิดหินเนื้อผสมซึ่งถูกแปลงเปลี่ยนโดยน้ำร้อนด้วยกระบวนการเติมซิลิกาเข้าไปทั่วหิน สารจำพวกซิลิกาเหล่านี้บรรจุอยู่ตามช่องว่างในหิน ข้อมูลภาพจากดาวเทียมแลนด์แซทแสดงให้เห็นว่าน้ำพุร้อนเหล่านี้อาจถูกควบคุมด้วยรอยเลื่อนซึ่งมีแนวต่อเนื่องมาจากแนวรอยเลื่อนหลัก “แม่ปิง” ซึ่งผ่านเข้ามาทางภาคกลางของประเทศ

ในทางธรณีเคมี หินบะซอลต์ที่พบเป็นจำพวกที่เป็นแอลคาไลต์และมีแร่โอลิวีนปรากฏอยู่ จึงเชื่อว่าเกิดขึ้นมาในสภาพแวดล้อมการแปรสัณฐานแบบแยกออก และแผ่กระจายตัวไปทางใต้สู่อ่าวไทย และเป็นหินบะซอลต์ที่ให้พลอยด้วย ข้อมูลการหาอายุหินโดยวิธี $^{40}Ar/^{39}Ar$ ของหินแสดงว่าหินบะซอลต์นี้มีอายุประมาณ 1 ล้านปี ผลจากการศึกษาในสนามและการแปลความหมาย สนามแม่เหล็กโลกทางอากาศควบคู่กับการศึกษาโดยผู้อื่น แสดงถึงความสัมพันธ์ระหว่างน้ำพุร้อนกับหินบะซอลต์ โดยที่เรา

เชื่อว่าน้ำพุร้อนเหล่านี้ได้ความร้อนมาจากการที่หินหนืดสัมผัสกับการแยกตัวในปัจจุบัน ซึ่งทำให้เกิดหินบะซอลต์ในอดีต และทำให้เกิดการพัฒนาเป็นน้ำพุร้อนโดยการหลอมละลายเนื้อโลก ข้างใต้แผ่นเปลือกโลกตามแนวรอยเลื่อน โดยที่เราเชื่อว่าน้ำพุร้อนอาจเป็นการผสมผสานระหว่างน้ำจากหินหนืดและน้ำฝน ผลการวิเคราะห์ธรณีเคมีของน้ำพุร้อนเหล่านี้แสดงว่าน้ำพุเป็นจำพวก Na-HCO_3^- โดยมีปริมาณธาตุแมงกานีสค่อนข้างสูง)> 0.3 mg/L) และมี pH สูง)> (9ซึ่งเกินกว่าระดับมาตรฐาน ดังนั้นจึงไม่เหมาะสำหรับกิจกรรมครัวเรือน เราได้คำนวณอุณหภูมิใต้ผิวโลกของน้ำพุร้อนโดยใช้วิธี ควอร์ซและ Na-K (-Ca) และพบว่าอยู่ในช่วงประมาณ 77ถึง 98 ° ซ ซึ่งช่วงอุณหภูมินี้ไม่สูงมากในการผลิตกระแสไฟฟ้า อย่างไรก็ตามเราขอเสนอว่าน้ำพุร้อนในแหล่งดังกล่าวอาจนำมาพัฒนาใช้กับการให้ความร้อนในครัวเรือน การอบแห้งผลิตภัณฑ์เกษตรและเพื่ออุตสาหกรรมการท่องเที่ยวได้

ดัชนี น้ำพุร้อน จันทบุรี ภาคตะวันออกของประเทศไทย รอยเลื่อน

INTRODUCTION

Nowadays energy consumption in Thailand, either in the forms of petroleum, natural gas, coal, wood, or nuclear substances, has become high in price and quantity, and surprisingly some of them are nearly exhausted. Intensive exploration for other energy resources for replacement or compensation is therefore necessary. Energy from geothermal resources is one significant form of renewable energy. Geothermal resources can be applied for recreational, heating, agricultural, industrial, and electricity purposes, etc. The geothermal energy is clean and cheap, so it can considerably replace or compensate the present-day widely used and unclean energy. Geothermal energy is a naturally occurring heat in the Earth's crust that has been used since the earliest times of human beings for a variety of purposes.(1) Geothermal resources often occur near island arcs, transformed crustal regions, and subduction zones, and several of them often occur with natural hot springs.(2)

In the world three main types of natural hot springs are recognized, viz. thermal springs, fumaroles, and geysers. The first type includes the water that outflows from the subsurface with a temperature that is generally higher than the temperature of the human body. However, the out-flowing water may be warm up to the temperature of boiling water. The minerals or dissolved gases in water cause different tastes and odors. The flow rate can be varied in individual sources. The second spring type is characterized by hot gas and steam water erupting from the subsurface. The main gases are carbon dioxide (CO_2) and hydrogen sulfide (H_2S). A geyser always has such a high water pressure that water can be intermittently ejected quite high from the Earth's surface.

Generally three important factors control the generation of hot springs, including heat sources, ground water and reservoir rocks. The main heat source is from magmas within the crust that intrude to shallower levels from unstable areas such as active volcanic belts, fault zones, and subduction zones, or from radioactive elements such as uranium (U), thorium (Th), and potassium (K). Groundwater is the main source of water, which is principally derived from rain and cool water on the surface that percolates to the subsurface along voids, fractures, joints, or faults of rocks. Some portions may be derived from steam of magmas in a cooling stage (magmatic water) and water-bearing pore spaces of sediments (connate water). Good properties of reservoir rocks are high porosity and good permeability produced from both primary and secondary fractured or faulted rocks. When cool water from the surface percolates to reservoir rocks and receives heat transfer from the heat sources, The water will be heated and flow up along fractures or faults of rocks to the surface and become a hot spring.

The history of the hot springs distribution in Thailand was first recorded by Brown and Buravas.(3) However, not many studies have been performed so far on the hot springs in Thailand, and mostly they are only preliminary work or unpublished reports.(4) Approximately 100 hot springs have been discovered.(5) appearing in all parts of the country except in the northeastern part. At present there are 50 known hot springs in northern Thailand, mainly in Mae Hongson, Chiang Rai, Chiang Mai, Lamphun, Lampang, Tak and Phrae provinces.[6, 7] In central and eastern Thailand there are about 20 hot springs in Sukhothai, Phetchabun, Kamphangphet, Uthaitani, Kanchanaburi, Lopburi, Ratburi, Phetburi, Chonburi provinces.[8] Southern Thailand has approximately 30 hot springs in Chumporn, Ranong, Suratthani, Phunga, Krabi, Puttalung, Satul, Yala, Trung and Nakron Sithammarat provinces.[9]

Hot springs in Thailand have been used for a long time.[3] for direct bathing, boiling and cooling agricultural products, a curing and drying crops and foods. Exploration and development activities for small-scale power plants have been performed at Fang, San Kampaeng, Mae Chan, Mae Chaem, and Pa Pae, all in northern Thailand.[6, 10, 11, 12] At the Fang area, geothermal wells at depths of 150 m and 300 m of the Electricity Generation Authority of Thailand (EGAT) were conducted under the auspices of the Japan International Cooperation Agency (JICA)[13] and a French Agency (ADEME),[14] respectively The wells produce water at an average of 130^0c at the rate of about 60 t/h.[15, 16] At the San Kampaeng area, two deep wells were completed and produce water at an average of 125 ^{0}c at the rate of 40 t/h from a fracture zone at the average depth of 900 m.[8, 10]

A hot spring field in easternmost Thailand was discovered a long time ago. However, due to its long-term inaccessibility, a preliminary investigation was only launched by Department of Mineral Resources and by the authors in 2001.

The area under current investigation is in the Pong Namron area of Chantaburi province. It appears in the 1:50,000 scale topographic map of the Royal Thai Survey Department, sheet 5434 I (series L7017). The hot springs site is situated at grid reference 153293 or latitude 12^o55’ N and longitude 102^o 22’ E, based on our GPS survey. The hot spring area was discovered a long time ago by local villagers living here. The study area could be accessed only very recently due to the demand for gem exploitation. The area under study is about 250 km from Bangkok via Highway no. 3 (Bangkok-Chantaburi). Then along the Route 317 (Chantaburi - Sra Keaw) about 40 km to the north, turn right (to the East). Very recently, local and immigrant villagers contaminated the area and probably caused sporadic wastes and landfills.

The purposes of this study are of two-fold. One is to analyze the physical and chemical properties of water in the studied hot spring area, and the other is to compare them with those of the developed hot springs in northern Thailand.

MATERIALS AND METHODS

In this study, we mapped both the regional and local geology of the hot spring area and nearby using both satellite image data provided by National Research Council of Thailand and our current field investigation. Regional geology was investigated at the first stage and originally compiled at a scale of 1:250,000. Then local geology was investigated and compiled at scale of 1:50,000.

Water sampling was performed along with geologic mapping during the two summer periods of 2000 and 2001. Spring water was sampled at the hottest part of the spring, usually directly above the inlet whereas stream water was sampled in the middle of the stream. Buenkhuntod(17) described methods of water treatment and analysis in detail.

Subsequently, we analyzed the physical and chemical properties of thermal spring and stream water both in the field and in the laboratory. The temperature, conductivity and salinity of spring water were measured directly in the field by a standard thermometer conductivity and salinity meter, respectively. Acidity, alkalinity, chloride, and hardness were also analyzed in the field by portable digital titration. In addition, fluoride, sulfide, nitrate, sulfate, iron, and manganese were analyzed by a portable spectrophotometer. For laboratory work we analyzed calcium, magnesium, potassium, and sodium using an atomic absorption spectrometer at the Department of Geology, Chulalongkorn University. Interpretation on occurrences in the studied thermal springs was made after acquiring all important physical and chemical results. Comparisons were made with the well-documented hot springs in Thailand in order to visualize the ultimate uses of the springs.

RESULTS

Regional Structure and Setting

Results from previous work as well as Landsat images and airborne geophysical interpretations (Figures 1 and 2) together with our field survey in the hot springs and nearby areas (Figure 3) indicate that the regional structure is mainly controlled by the northwest-trending fault. This fault is considered to be a branch of the major strike-slip fault that extends from the Thailand-Myanmar border through the central plain of Thailand and southeastward to the hot springs area. Therefore the study area is located within the zone of weakness of the crust.

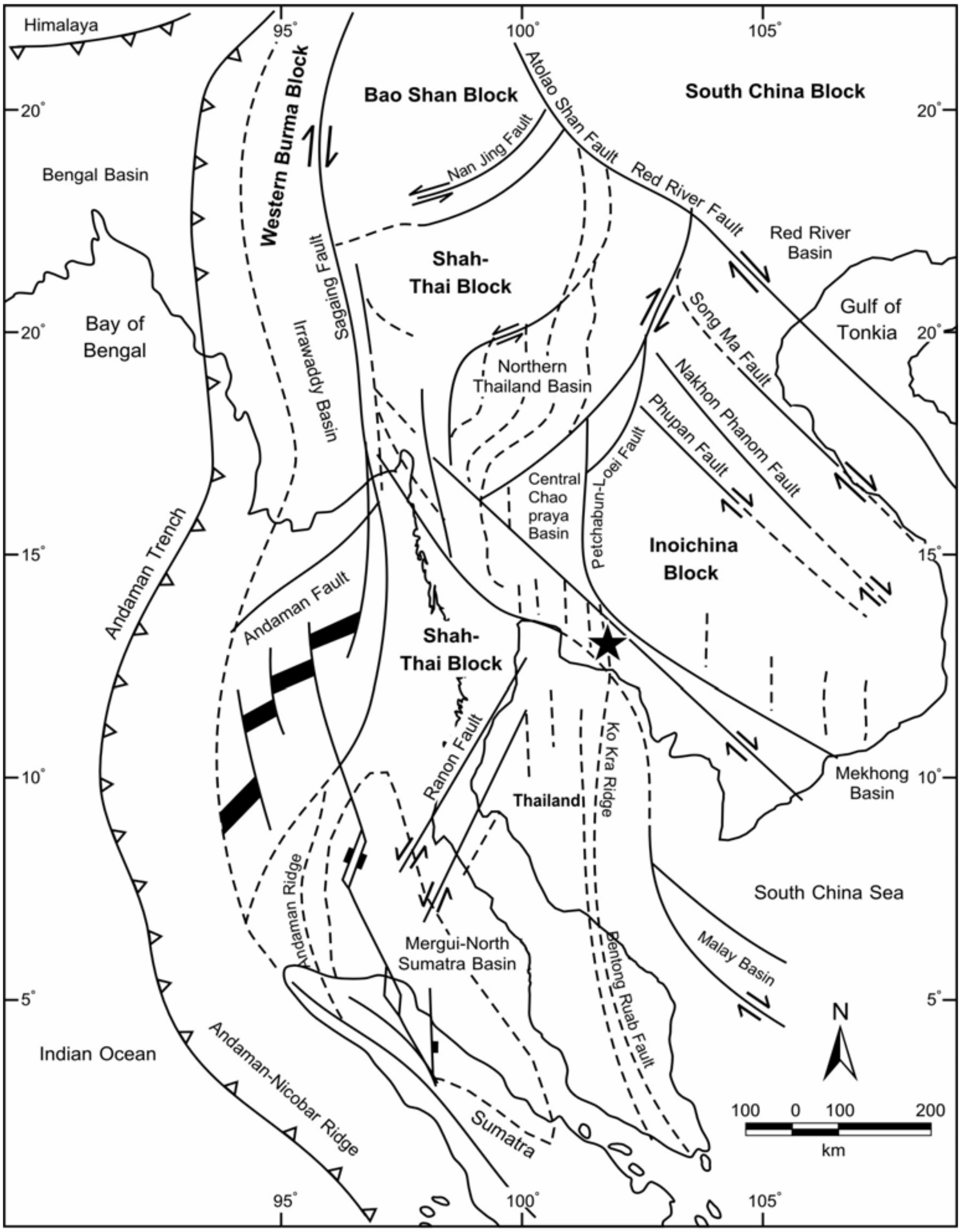

Figure 1. Map of Thailand showing hot spring locations, major fault zones and the location of the study area (black star) (modified after Charusiri et al.[(4)]).

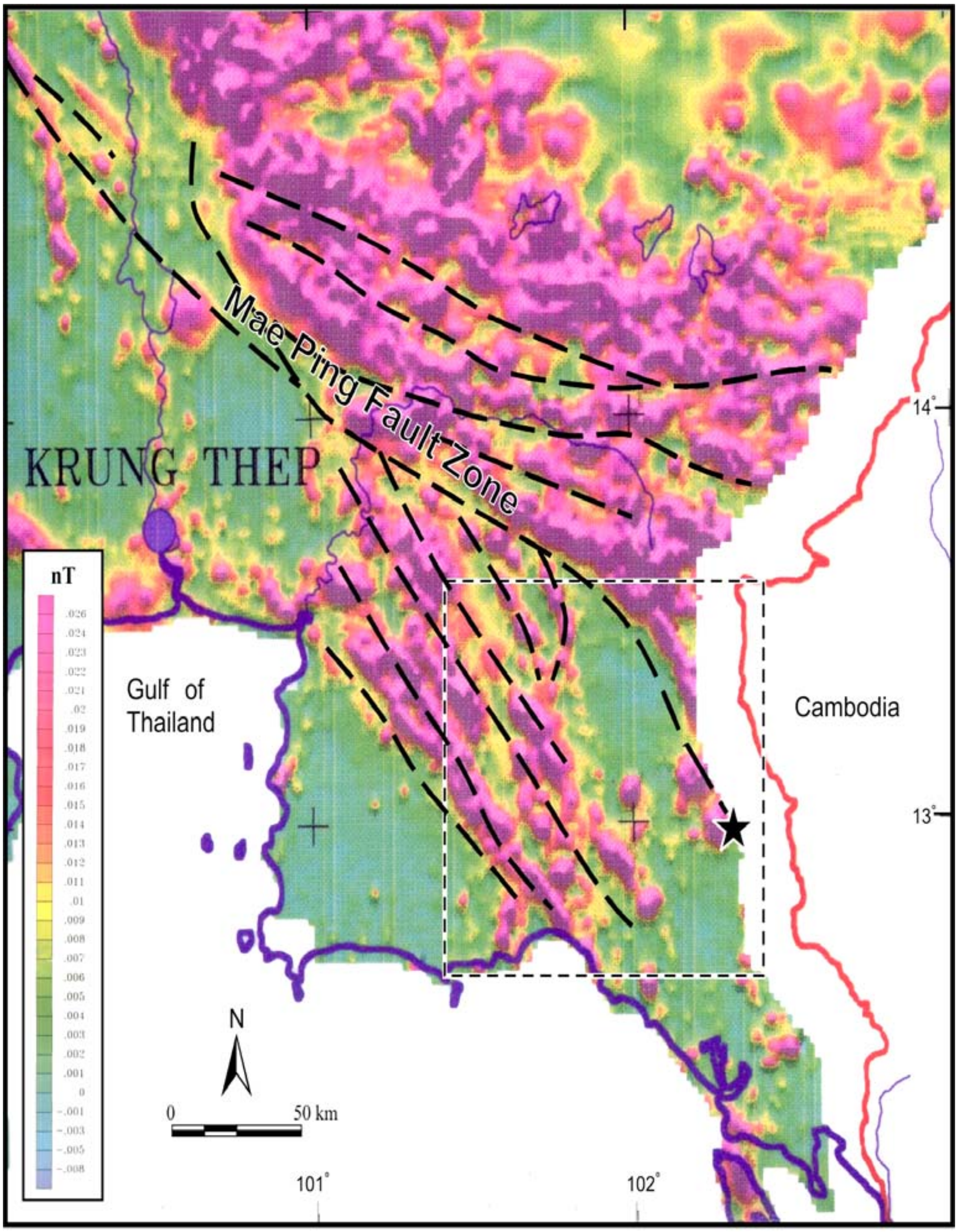

Figure 2A. Air-borne magnetic map Thailand showing major lineaments (dashed line). Note that the box area is for figure 2B, star = studied area, and MPZ = Mae Ping Fault Zone.

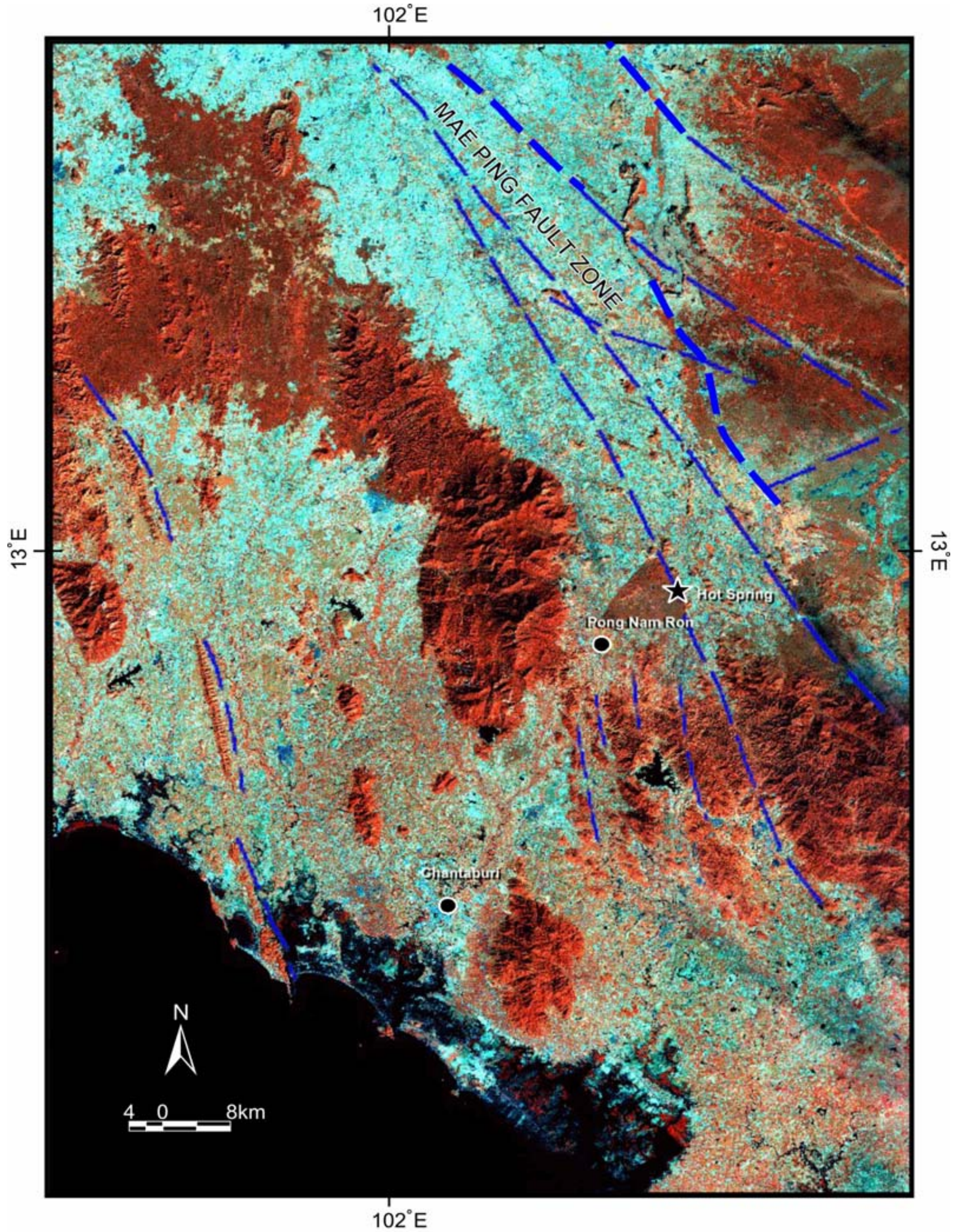

Figure 2B. Air-borne magnetic map of Thailand showing major lineaments (dashed lines).

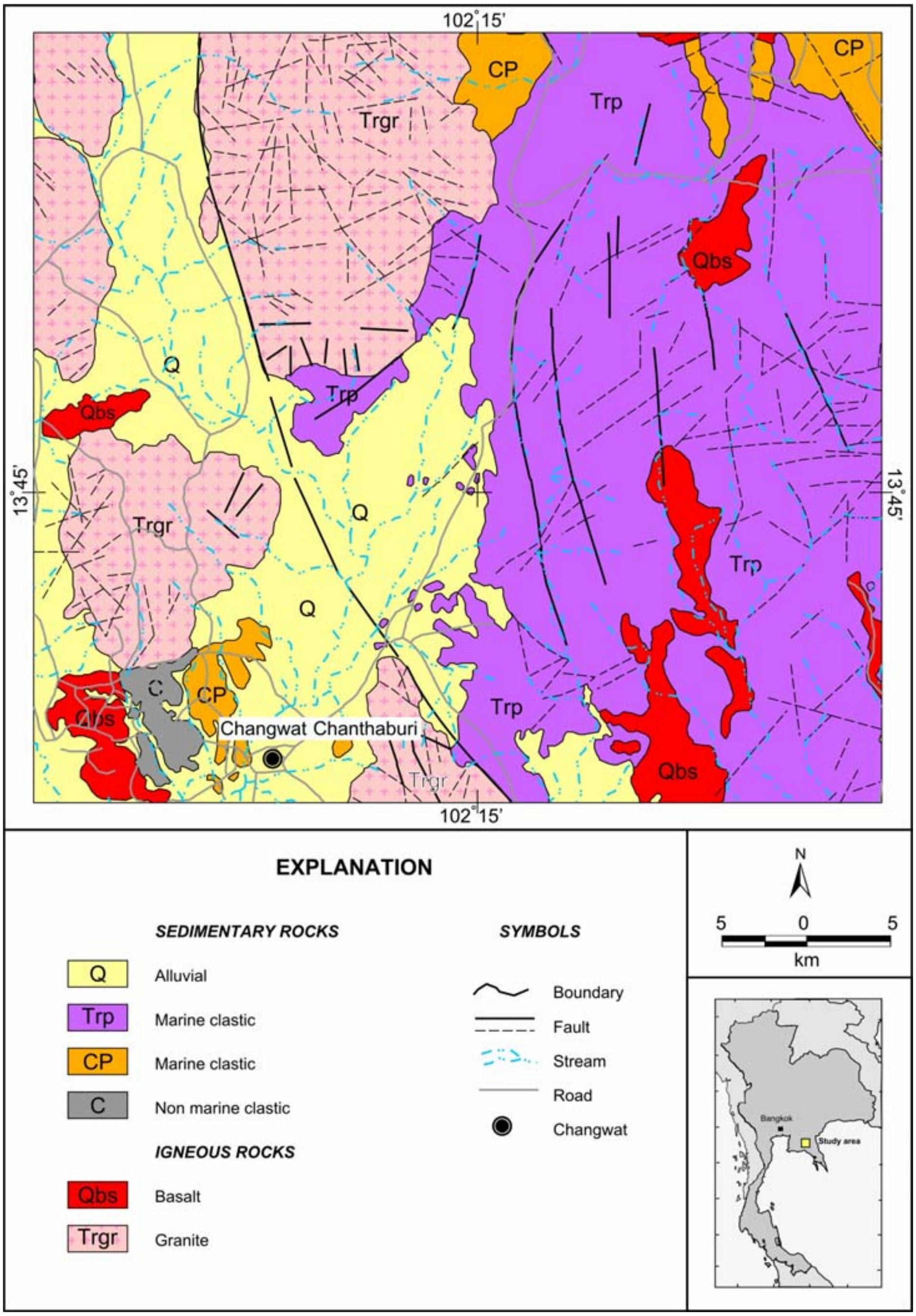

Figure 3. Regional geology of easternmost Thailand showing distribution of rocks and major faults (cmodified after Buenkehuntood tood[17]).

The rocks found in the study area are different in lithology, structure, and age. However, based upon our multi-disciplinary surveys mentioned earlier, they can be grouped into 4 units as described below:

Cherts, Volcanic Ashes and Limestones in Clastic Unit

This unit of rock assemblages is the oldest unit in the study area. Its age is assigned to be younger than Permian based on abundant fusulinids, algae, and corals in limestone blocks in fine-grained clastic rocks. This rock unit is chiefly present in the north of the hot spring study area, particularly at Khao Khwai Pla and Khao Chao Sut. Chert beds are observed as large chunks (up to 3 m) in association and sometimes as fault contacts with small limestone strata. The cherts are well-bedded, compact and hard, invariably having dark to reddish brown colors. Folds and faults with their dipping planes to the northeast can be observed in the areas where bedded cherts are intervened by thinly bedded, dark-colored shales. Volcanic ashes, such as tuffs, are found in association with cherts hosted by shales(?), suggesting a close genetic relation between cherts and volcanic rocks or volcanic eruptions possibly occurring during chert precipitation. Volcanic ashes are usually greenish white, pale brown and purple and posses porphyritic texture with coarse-grained feldspar phenocrysts in groundmass of very fine-grained quartz and glass. The clastic rocks are mostly fine-grained sandstones and shales. These two types of rocks always contain large chunks of cherts, volcanics, and limestones. Very recently, Chutakositanont et al.(18) interpreted this rock unit as a melange rock unit occurring in the subduction-related tectonic setting.

Sandstone and Shale Unit

This group of sedimentary rocks is present dominantly along the road in Amphoe Pong Namron from Ban Tap Sai to Ban Pong Namron between km 2 and km 5. The rocks are well exposed as small hills and in rolling areas in the northwest-southeast trend. The rocks cover much of the western part of the hot spring area, such as Ban Phaya Kam Phut, Ban Khlong Ta Khong and Ban Khrua Wai and nearby villages.

Sandstone is mainly pale green to greenish gray, partly micaceous, fine-grained (meta-)graywacke sometimes with siliceous and calcareous cementing materials. The rock is widely distributed in Amphoe Pong Namron area. In general the rock shows concoidal fractures and very poor sorting with various sizes of angular quartz, chert, and sandstone fragments. The graywacke is thick bedded to massive and frequently intercalated with shale. At some places the rocks show hydrothermal alteration as shown by very dense features with abundant quartz veins and felsic veinlets by late stage fluids of nearby Soi Dao Granite of Juro-Triassic age.(19)

Shale is mainly brown, greenish gray and black. Well-bedded strata are common, and sometimes they are overturned and display deformation structures. In some places, such as at Ban Khrua Wai, the shale is intercalated with reddish gray polymictic paraconglomerates. Both shale and sandstone strata mainly strike in the northwest direction with moderate to steep dipping to the northeast. This rock unit is interpreted by Chutakositkanon et al.[18] to represent a thick sequence of submarine fan deposits occurring in the Triassic period.

Quaternary Deposit Unit.

Two kinds of Quaternary units are recognized in the study area, including terrace and stream deposits. The alluvial terrace deposit comprises unconsolidated layers of gravels, sands, silts, and muds with grains derived from nearby source rocks. These sediments are transported over short distances in valleys by water and deposited at bases of hills. The unit can be found at the eastern and southern parts of Khao Khwai Pla. The presence of the terrace deposits implies young tectonic uplift of the old flood plains occurring during the Quaternary period. Recent alluvial stream deposits consist of unconsolidated beds of gravels, sands, silts, and clays deposited as flood plains along the active Pong Namron permanent stream.

Igneous Rock Unit

Two types of igneous rocks are found in the study area. One is Cenozoic basalt and the other is Juro-Triassic Soi Dao granitic rocks. Most basaltic rocks are distributed in a narrow belt from Chantaburi to Sra Kaew provinces, almost in a north-south trend, particularly from Ban Pong Namron to Ban Sam Sib. It covers an area of approximately 40 km^2. Some of the Cenozoic basalt areas have been exploited for gemstones for more than 60 years. The exposed basalts are also considered as gem-bearing basalts. Our panning indicates that few grains of small gems were observed in the basalt area. Geochronologically, the basalts in this area were dated, using the whole-rock $^{40}Ar/^{35}Ar$ dating method, at 1.0 Ma. Geochemical results indicate that the basalts took place in a rift-related tectonic environment.[20]

The Soi Dao granites, though not widely exposed, occur as very small, isolated stocks in the study area. A larger exposed area (more than 5 km^2) is observed to the west of the study area. This I-type granite was dated by the $^{40}Ar/^{39}Ar$ method to be about 230 Ma.[21] This granite subsequently intruded several clastic rocks and limestone.

Geology of the hot-spring site

Geographically the site area is characterized by rolling topography with relief of about 20m. The area is situated nearby the Khlong Pong Namron (or Klong Klang) stream channel. To the east of the studied hot-spring area, the Pong Namron stream is characterized by exposed active point bars $(6x2m)^2$ with bed loads comprising well-sorted and well-rounded Cenozoic basalts. Sedimentary rocks that appear in the site area are well-bedded, light to grayish green and black, fine-grained graywacke with thinly bedded shale. The Cenozoic basalt appears in the southern part of the hot springs and the solidified shale interbedded with limestone cut by 2-cm thick quartz veins are observed in the north. The northwest trend is very diagnostic in the field. Fault breccias and deformation structures are common in the study area (Figure 4).

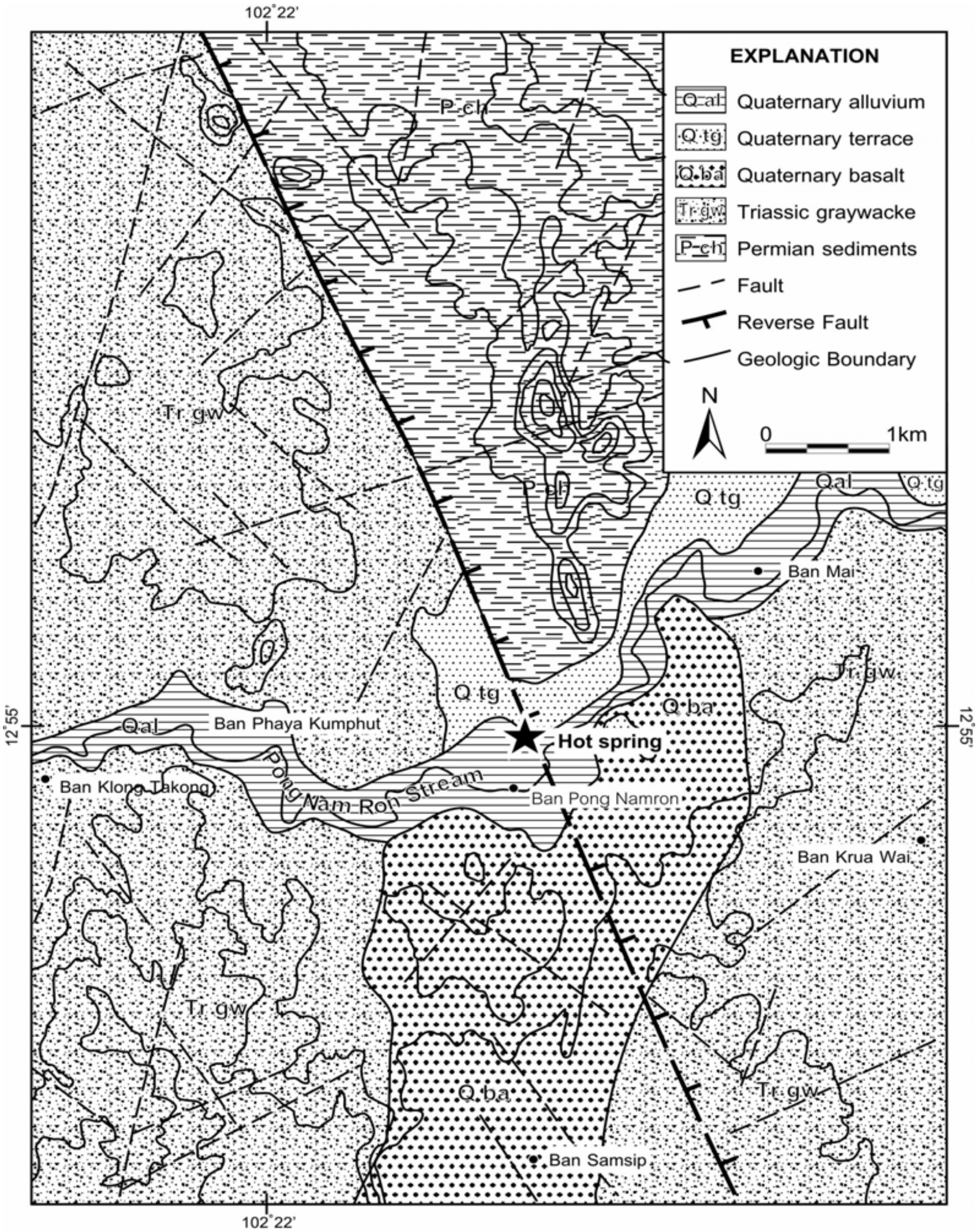

Figure 4. Local geology of the hot spring area, Pong Namron, Chantaburi (modified after Buenkhuntod[17]).

Hot springs in the study area are located at 3 sites-D1, D2, and D3. The sketch map and picture of the hot spring area are shown in Figure 5A and B. The diameter of the D1 site is approximately 180 cm whereas that of the D2 site is about 130 cm and that of D3 is about 80 cm. Only the D1 site has small bubbles that arise every 27 sec. The diameter of bubbles ranges from 1 to 7 cm. Light to grayish brown slush is present around all surveyed sites with H_2S odors. Nearby the study site, the rocks are clastic and most of them are very altered and brecciated. This suggests that the rocks nearby were subject to geothermal alteration. Our preliminary X-ray diffraction investigation on clay mineralogy reveals the presence of kaolinitic and montmorillonitic clays. Petrographic analysis indicates that the rocks (particularly at the studied hot spring sites) were subject to pervasive silicification.

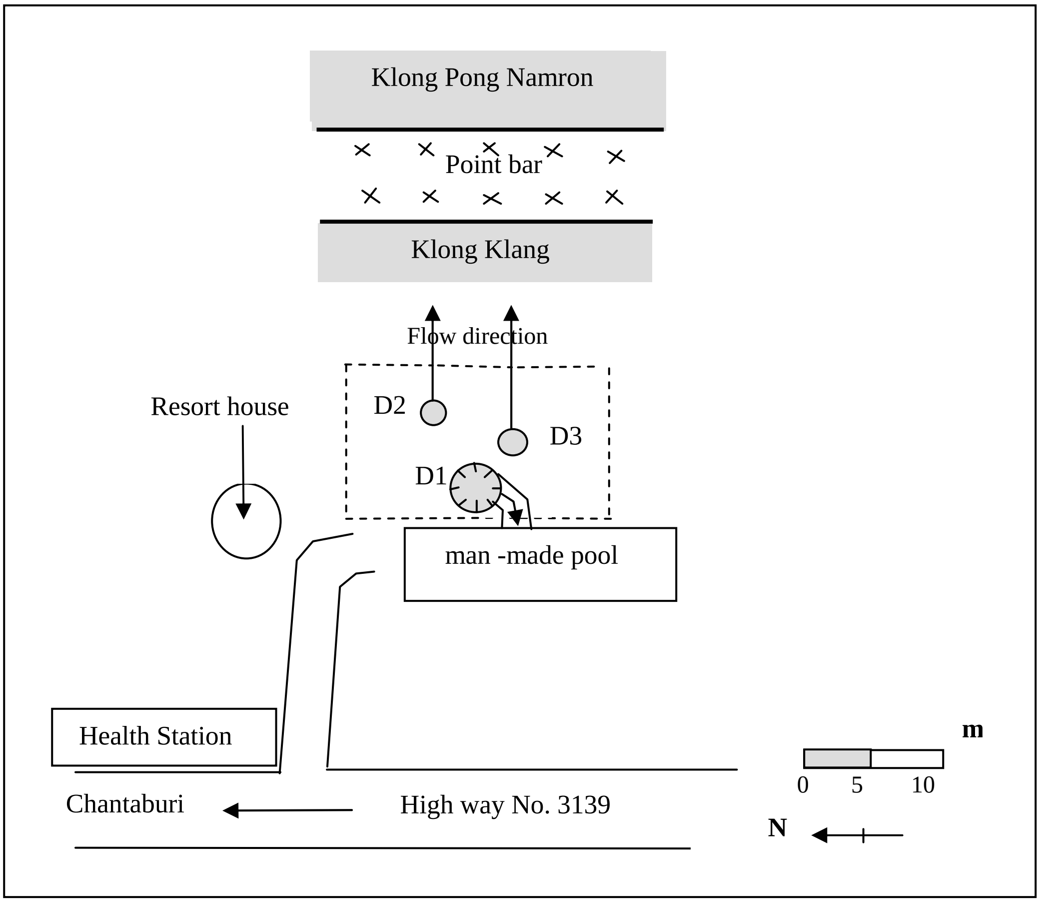

Figure 5A. Sketched map of the studied hot spring sites at fong Namron district.

Figure 5B. Hot spring site D1 occurring in the Quaternary alluvial deposit, Pong Nomron area, Chantaburi.

Results of hot spring analyses.

The results of the physical and chemical analyses of water from 3 hot spring sites (well nos. D1, D2, and D3) are shown in Table1.

The surface temperatures of the spring water range from 34 ºC to 36 ºC, all of which can be classified as warm springs. The spring water is classified as weakly basic as indicated by the invariable pH from 9.18 to 9.26. Conductivity of the hot springs at 25 ºC shows insignificant variation ranging from 659 to 672 μS/cm and total dissolved solids (TDS) vary from 318 to 325 mg/L. Salinity of hot springs are quite low and constant at 0.3 %. Acidity of hot springs at individual study sites is not present (measured as $CaCO_3$) whereas alkalinity ranges from 320 to 350 mg/L as $CaCO_3$ at D1. Hardness of the water ranges from 8 to 16 mg/L as $CaCO_3$. Chloride contents in hot springs vary from 7.2 to 10.4 mg/L whereas fluoride values range from 1.29 to 2.64 mg/L at D3. Sulfide contents in hot springs are from 0.167 to 0.672 mg/L. Nitrates and sulfates vary from 0.8 to 3.7 mg/L and from 19 to 22 mg/L, respectively. The spring water has iron and magnesium varying from 0.03 to 0.24 mg/L and from 0.2 to 0.4 mg/L, respectively, whereas values of calcium (av. 1.65 mg/L) and potassium (av. 0.97 mg/L) are almost the same for all study sites. Silica contents of the hot spring sites vary from 32 to 43.5 Mg/L.

Table 1. Composition of hot springs and running water in study area.

Composition	Sample number				Unit (mg/l)	Spring water		Remark
	NW	D1	D2	D3		Range	Average	
Surface Temp.	25	36	34	35	°C	34-36	35	-
pH	7.75	9.26	9.24	9.18	-	9.26-9.18	9.23	-
Conductivity	61.9	665.3	672	659	μS	672-659	665.43	-
TDS	28.8	321.3	325	318	L/Mg	325-318	321.43	-
Salinity	0	0.3	0.3	0.3	%	0.3	0.3	-
Acidity	6	0	0	0	Mg/L	0	0	-
Alkalinity	115	322	350	320	Mg/L	350-320	330	as HCO_3^- ,pH4.5
Hardness	148	16	8	16	Mg/L	16.0-8	13.33	Total hardness
Cl^-	5.6	10.4	7.2	7.2	Mg/L	10.4-7.2	10.4	-
F^-	0.32	2.10	1.29	2.64	Mg/L	2.64-1.29	2.01	-
S^{-2}	0.005	0.672	0.167	0.259	Mg/L	-0.167 0.672	0.366	-
NO_3^{-2}	1.1	3.7	1.8	2.5	Mg/L	3.7-1.8	2.67	-
SO_4^{-2}	1	19	22	19	Mg/L	22-19	20	-
Fe	0.52	0.21	0.03	0.24	Mg/L	0.24-0.03	0.16	-
Mn^{+2}	0.0	0.4	0.2	0.2	Mg/L	0.4-0.2	0.27	-
Mg^{+2}	3.2	0.34	0.10	0.27	Mg/L	0.34-0.1	0.24	-
Ca^{+2}	4.5	1.7	1.6	1.6	Mg/L	1.7-1.6	1.63	-
Na^+	60	90	60	170	Mg/L	170-60	106.67	-
K^+	0.439	0.882	0.892	0.948	Mg/L	-0.882 0.948	0.907	-
SiO_2	24.5	43.5	37	36	Mg/L	43.5-36	38.83	-
(a)T Qtz	-	95.43	88.27	87.09	°C	-	-	.Fournier et al(27)
(b)T Qtz	-	97.03	90.81	89.78	°C	-	-	.Fournier et al(27)
K-T Na	-	75.38	94.44	52.54	°C	-	-	Aemorsson et al. (27)
Ca-K-T Na	-	88.63	77.21	98.99	°C	-	-	.Fournier et al(28)

N.B. NW=surface water; D, D_2, and D_3 = hot-spring water

Result of running water analyses

Apart from the analyses of thermal spring water, we also measured properties of running water located very close to the thermal spring site. Results from the analysis of the stream water are shown in Table 1. The surface water has an average surface temperature of about 25 ºC, which is classified as cool water. The water is slightly basic as indicated by the pH of 7.75. The conductivity of running water at 25 ºC is 61.9 μS/cm. TDS is 28.8 mg/L. The salinity of the hot spring is 0 %. The acidity of running water is 6 mg/L. The alkalinity of running water is 115 mg/L. The hardness of running water is 148 mg/L. The chloride, fluoride, and sulfide in running water is 5.6 mg/L, 0.32 mg/L, and 0.005 mg/L, respectively. The nitrate in running water is 1.1 mg/L, and the sulfate is about 1 mg/L. Contents of iron, manganese, calcium, and magnesium in running water are 0.52 mg/L, 3.2 mg/L, 4.5 mg/L, and 3.2 mg/L, respectively. The sodium content is about 60 mg/L, the potassium content is 0.439 mg/L, and the silica content in running water is 24.5 mg/L.

DISCUSSION

Comparison with other hot springs in Thailand

As shown in Table 2, we compare the results on physical and chemical analyses of the Pong Namron hot spring with those of the other hot springs in northern and southern Thailand as reported by Thienprasert and Raksasakkulwong(11), Thienprasert et al.(12),and Chaturongkawanich and Leewongcharoen,(9) respectively.

Table 2. Subsurface temperature based on quartz and Na-K(-Ca) geothermometers for the Chantaburi hot spring.

Area	Surface temp. (^{0}C)		Subsurface temp. (^{0}C)							
			Qtz_A		Qtz_B		K-Na		Ca-K-Na	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
Pong Nanron	36-34	35.33	- 88.27 95.43	90.26	- 89.78 97.03	92.54	- 52.54 94.44	74.12	- 77.21 98.99	88.28

Physical Characteristics

The surface temperature of the hot spring water in the study area averages to 35^{0}C whereas those of northern and southern Thailand range from 65 to 81 ^{0}C (Table 2). Subsurface temperature of the hot spring (based on quartz - no steam loss geothermometry) in the study area is in the range of 88 to 95 ^{0}C. This range is much lower than lower than those of the hot springs in northern and southern Thailand, viz. 120 to 150 ^{0}C.

Chemical characteristics

The hot spring water in the study area is more alkaline (average pH of 9.2) than most of the hot springs in northern and southern Thailand (with average pH of 8.4). The conductivity and TDS of the studied hot spring are similar to those of the hot springs in northern and southern Thailand. The average alkalinity and Cl^- content of the determined hot spring are higher than those of the hot springs elsewhere in Thailand. Interestingly, the F^- content of the studied hot spring is lower than those of the hot springs in northern southern Thailand. The S^{2-} content of the hot spring in the study area lies within the range of the northern Thai hot springs.

It is quite interesting that the average NO^-_3 content (2.2 mg/L) of the hot springs in the study area is much higher than those of the northern Thailand hot springs. The SO_4^{2-} values of the studied hot spring fall within the range of northern Thailand hot springs and is lower than those of the southern Thailand hot springs.

The Fe^{2+}, Ca^{2+} and Mn^{2+} contents of the studied hot spring are higher than those of the northern and southern Thailand hot springs. The Mg^{2+} contents of the studied hot spring are similar to those of the other hot springs. The Na^+ content of the Pong Namron hot spring is within the range of hot springs in northern Thailand but higher than those of the southern Thailand hot springs. The average K^+ content of the studied hot spring is much lower than those of the springs in northern and southern Thailand. The average SiO_2 content of the studied hot spring is generally lower than those of the springs in northern and southern Thailand.

It is therefore considered that the type of the studied hot spring is Na-HCO_3 type, which is similar to most hot springs in Thailand.

Types of Spring Water and Geothermometry

Plotting Na, Mg, Ca, SO_4, HCO_3 and Cl in the standard trilinear Piper diagram for the spring and stream water (Figure 6). Shows that the points of Na-Mg-Ca in the cation diagram are near the end-member of Na and the points of anions in the anion diagram are near the HCO_3 end-member. In the upper part of the Piper diagram, the plots are near the Na+K and CO_3+HCO_3 end-members. The water type of the hot spring is, therefore, classified as the Na-HCO_3 type.

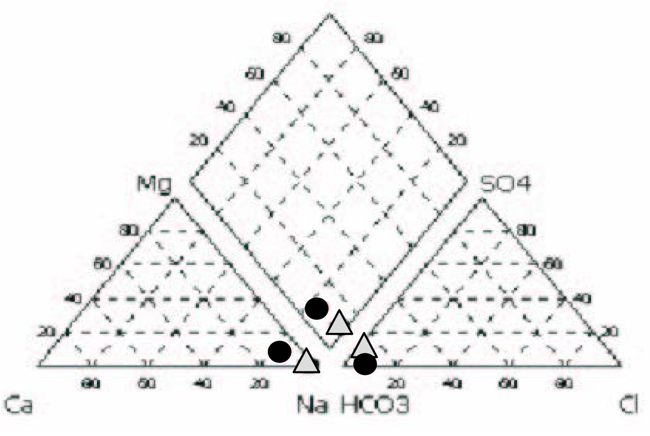

Figure 6. Piper diagram showing composition of the Chantaburi hot spring (circle = hot spring, triangle = running water).

Chemical geothermometry has been extensively used in geochemical exploration to evaluate subsurface temperature conditions of hot springs

Chemical geothermomety has been extensively used in geochemical exploration to evaluate subsurface temperature conditions of hot springs and fumaroles discharges.[22-24] The basic assumption involved in the applying chemical geothermometers is that temperature-dependant water-mineral equilibria prevail in the reservoir at depth. Numerous studies demonstrated that fluid-mineral equilibria are closely approached in geothermal reservoirs with respect to major aqueous components to temperatures as low as 50-100 ^{0}C. By contrast the composition of surface and non-thermal groundwater mainly governs the composition of surface and non–thermal groundwater.[25] The major problem in applying chemical geothermometry to geothermal systems of relatively lower temperatures lies, therefore, in assessing whether or not chemical equilibration is closely approached between water and minerals for those aqueous components used as chemical geothermometers.[26]

Geothermometry results for the quartz, NaK, and NaKCa geothermometers for the Pong Namron hot spring sites are given in Table 3. The respective geothermometry equations were obtained from Armorsson et al.,[23] Fournier et al.[27] and Fournier et al.[28] It is concluded that:

1. the average subsurface temperature based on the quartz (no steam loss) geothermometry method is 90.26 º C;
2. the average subsurface temperature based on the quartz (maximum steam loss) geothermometry method is 92.54 º C;
3. the average subsurface temperature based on the Na-K geothermometry method is 74.14 º C; and
4. the average subsurface temperature based on the Na-K-Ca geothermometry method is 88.27 º C.

Table 3. Main compositions of the hot springs in Thailand.(6, 7, 9, 10, 12)

	Range	Average	Unit	pleof sam .No
.Surface temp	99.0-34.0	68.286	°C	28
pH	9.5-6.78	8.365	-	28
Conductivity	765.0-225.0	574.9	µS	7
TDS	700.0-130.0	387.511	L/mg	28
Alkalinity	438.0-107.0	254.321	L/mg	28
Hardness	-	-	L/mg	-
Cl	31.0-0.0	8.862	L/mg	28
F	21.5-0.0	8.413	L/mg	25
S	106-0.167	3.671	L/mg	15
NO_3	3.7-0.0	0.767	L/mg	15
SO_4	104.0-0.0	30.789	L/mg	28
Fe	0.5-0.0	0.125	L/mg	28
Mn	0.5-0.0	0.068	L/mg	24
Mg	29.1-0.0	2.109	L/mg	27
Ca	139.0-1.3	17.388	L/mg	28
Na	176.0-4.0	92.886	L/mg	28
K	19.9-0.8	6.476	L/mg	28
SiO_2	273.0-26.7	92	L/mg	28
Br	1.5-0.0	0.386	L/mg	7
I	0.3-0.0	0.075	L/mg	4

Origin of the hot spring

In order to specify the most probable origin of hot springs, an isotope study would be definitive. However, in this research, an isotopic study of hot springs in the study area was not carried out due to a limited budget. Therefore, in an attempt to explain the origin of the hot springs, all available and existing information are applied. Several geologic features of the study area reveal that the studied hot springs cover the Quaternary alluvial sediments immediately at the major northwest-trending fault and not too far from Quaternary basalt extrusion in the south of the study area. To the north of the studied hot spring site, several north-to-northwestern trending quartz veins and veinlets intruded into chert and limestone at Khao Khwai Pla.

Since the Soi Dao granite to the west of the study area is Late Triassic[29] this granite pluton is therefore too old to be a heat source of the hot spring.

Chuaviroj and Chaturongkavanich [30] classified geothermal resources in northern Thailand into two patterns, namely granite and non-granite related. Both patterns are always associated with fracturing and faulting. We consider that faults and fractures can provide good channel ways for ascending geothermal fluids. Cenozoic gem-bearing basalt in the southern part of the study area is believed to have been derived from mantle.[20] Additionally, Hoke and Campbell[31] studied ^{3}He isotopes of fluid inclusions from olivine and pyroxene phenocrysts in basalts of Indochina and Thailand. They concluded that the source of basalts was the mantle originating from a deep level and that the intraplate mantle melting of Indochina and Thailand is active till the present day.

From the interpretation above, it is suggested that the heat source of the studied hot spring is an underling active magmatic source related to the intraplate Quaternary basalt derived from a mantle plume from a deep level. The spring water is considered to derive from mixtures between the paleo-pore (or connate) water of Triassic thick clastic sediments and the meteoric water, percolating through recent sediments. Heat is definitely provided by a shallow seated magmatic body containg a high concentration of He gas originating from the deep mantle.

Utilization

Drinking water

The pH of the hot spring which is in the range of 9.18 to 9.26 (weakly alkaline) is higher than that of the standard drinking water.[32] Additionally, the manganese and fluorine contents are higher than those of the standard drinking water (i.e., 0.05 mg/L and 1.5 mg/L, respectively). Thus the studied hot spring is not suitable for drinking water. However, these characteristic results are always the same for hot springs elsewhere in Thailand.

Subsurface - temperature uses

The average subsurface temperature of the chantaburi hot spring in the study area is about 91 ^{o}C. Therefore the studied hot spring can be used for space-heating for buildings and greenhouses, drying of stocked foods, and intense de-icing operations.

CONCLUSIONS

Three small thermal springs in the Pong Namron site of Chantaburi province, easternmost Thailand are present in the area dominated by Quaternary basalts and alluviums. The northwest-trending fault, which serves as a conduit for hot-spring water, mainly controls the hot springs. Physical results indicate that the analyzed spring water has lower surface and subsurface temperatures than the other thermal springs in Thailand. The Pong Namron spring water is weakly alkalic and belongs to the Na-HCO_3 type. The spring water contains high contents of manganese and is therefore unsuitable for drinking. The low subsurface temperature leads us to suggest that the Pong Namron spring water can be only applied for space heating and resort bathing.

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