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Spencer H. Wood
Boise State University

Fongsaward Suvagondha Singharajwarapan
Chiang Mai University

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Geothermal Systems of Northern Thailand and Their Association With Faults Active During the Quaternary

Spencer H. Wood[1] and Fongsaward Suvagondha Singharajwarapan[2]

[1]Department of Geosciences, Boise State University, Boise, Idaho USA
[2]Department of Geological Sciences, Chiang Mai University, Chiang Mai, Thailand
swood@boisestate.edu • fongsawardsingha@gmail.com

Keywords

Thailand, geothermal resources, active faults, fluoride, Chiang Mai basin, Mae Chan fault, Mae Tha fault

ABSTRACT

Many of northern Thailand hot springs systems are associated with regions of active faulting. An arcuate pattern of wells with high-fluoride water occurs in the Chiang Mai basin. The pattern is parallel to the Mae Tha fault which cuts Paleozoic and Mesozoic rocks 10 km east of the basin. The San Kamphaeng geothermal system is within parallel faults in Paleozoic rocks. The Mae Tha fault is believed to be active in the Quaternary. A conceptual diagram shows deep groundwater circulation driven by ~300 to 800 meters of relief in the hills east of the basin. The Mae Chan geothermal system lies along the active, left-lateral, strike-slip Mae Chan fault in northernmost Thailand. The Mae Chan hot springs emanate from Triassic granitic rocks in the fault zone. Several other hot springs emanate from the along the fault. It appears that late Cenozoic activity along faults creates permeability that allows upward flow of deep (> 2 km) percolating groundwater. These systems are currently being evaluated by geothermometry of water chemistry, geophysical exploration, and detailed geologic mapping. Aim is to establish drilling locations for wells that will provide 2-5 MWe of power generation.

Introduction

This paper focuses on geothermal systems associated with the Chiang Mai basin, and with those along the active Mae Chan fault in northernmost Thailand (Table 1; Fig.1). We emphasize the interesting association of high-fluoride wells in the center of the Chiang Mai basin and the hot springs systems that lie to the east (Fig. 2, Fig. 3, Fig. 4). Along the Mae Chan fault we report on a little known hot spring in the middle of a small basin that emanates into a large swampy depression. These and other prospective geothermal systems of northern Thailand are reviewed by Singharajwarapan et al. (2012), and this paper assembles more geological details on these specific systems. We show that many of the systems are related to faults active in the Quaternary.

The Chiang Mai Basin

Recent work on the structure of the Chiang Mai Basin (Morley et al., 2011; Rhodes, et al., 2000, 2002, 2005) leads to a better understanding of geothermal systems in the basin. A geologic

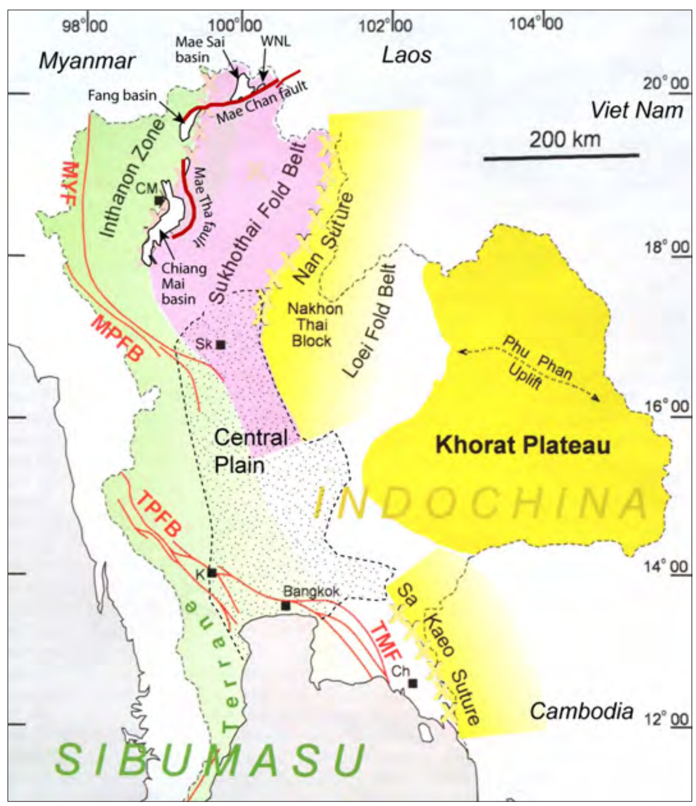


Figure 1. Location of the Chiang Mai basin and the Mae Chan fault in northern Thailand. Map shows the major tectonic terranes of the region: the Sibumasu block (green) thrust against the Indochina block (yellow) during the late Permian and Triassic (after Ridd et al., 2011).

Table 1. Location of hot springs.

Code	WGS84 UTM East	WGS84 UTM North	ddd mm s.ss Longitude	ddd mm s.ss Latitude	Surface temp (°C)	Flow rate (l/s)	Name
CR_01	576230	2205673	099 43 42.51 E	19 56 45.66 N			(Kok River)
CR_02	571176	2207545	099 40 48.65 E	19 56 46.35 N	85		(Yang Pa Kael, Kok River)
CR_03	572311	2206944	099 41 27.87 E	19 57 27.54 N	74.6	3.5	(Ban Pa Suert, Kok River)
CR_04	583900	2225400	099 48 9.62 E	20 07 26.22 N	99.1	1.1 and 5.5	(Mae Chan)
CR_05	560571	2180292	099 34 40.60 E	19 43 02.90 N	73.1	5.2	Pong Phu Fuang, Mae Suai
CR_06	548711	2113505	099 27 47.25 E	19 06 50.37 N	79.3	0.44	(Sop Pong, Wiang Pa Pao)
CR_08	587109	2209212	099 49 57.35 E	19 58 39.13 N			North of Mae Chan Hot Springs
CR_09	584225	2235289	099 48 22.46 E	20 12 47.84 N	49		(Na Pong, North of Mae Chan)
PR_07	577973	2171391	099 44 37.30 E	19 38 10.30 N	54.4	1.5	Huai Sai Khao, Phan
CM_01	524021	2080391	099 13 40.71 E	18 48 54.57 N	100.5	10	(San Kamphaeng)
CM_02	525934	2090905	099 14 46.57 E	18 54 36.57 N	96.3	0.26	(Ban Pong Kum, Doi Sacket)
CM_03	516113	2207650	099 09 14.40 E	19 57 55.11 N	98.1	1.56	(Fang)
CM_16	551755	2220975			68.1		Along the Mae Chan Fault
LPa_04	511283	2006176	099 06 24.00 E	18 08 40.20 N	78	-	(Ban Pong Nam Ron)
CR_WNL	602296	2232349	099 58 44.60 E	20 11 09.00 N	41	2.1	Wiang Nong Lom Swamp
PR_02	567485	1987932	099 38 14.70 E	17 58 42.80 N	71	3.8	Mae Jok, Phrae

map of the basin and adjacent area to the east is shown in Fig. 2, and a cross section in Fig. 3. Rocks of the "lower detachment" exposed on the west side of the basin are lower Paleozoic metasediments and metavolcanics (Morley et al., 2011) originally mapped by Baum et al.(1982). As interpreted by Morley et al., 2011) this detachment is underlain by the main low-angle normal fault, and paragneiss. The detachment slid off of the Doi Inthanon core complex in the early Miocene. These high-grade metamorphic rocks (paragneiss) are associated with the Inthanon zone comprising the east side of the Sibumasu Block (Barber et al., 2011).

Rocks on the east side of the basin are within the Sukhothai fold belt (Fig. 1), comprised of upper Paleozoic sediments and volcanics. These rocks are associated with the Sukothai arc, an east-dipping accretionary complex, thrust under the "Sukothai volcanic arc" during the late Triassic (Barber et al., 2011). Carboniferous and older rocks were presumably deposited along the (now western) edge of the Indochina block prior to the Permo-Triassic collision with the Sibumasu block. The

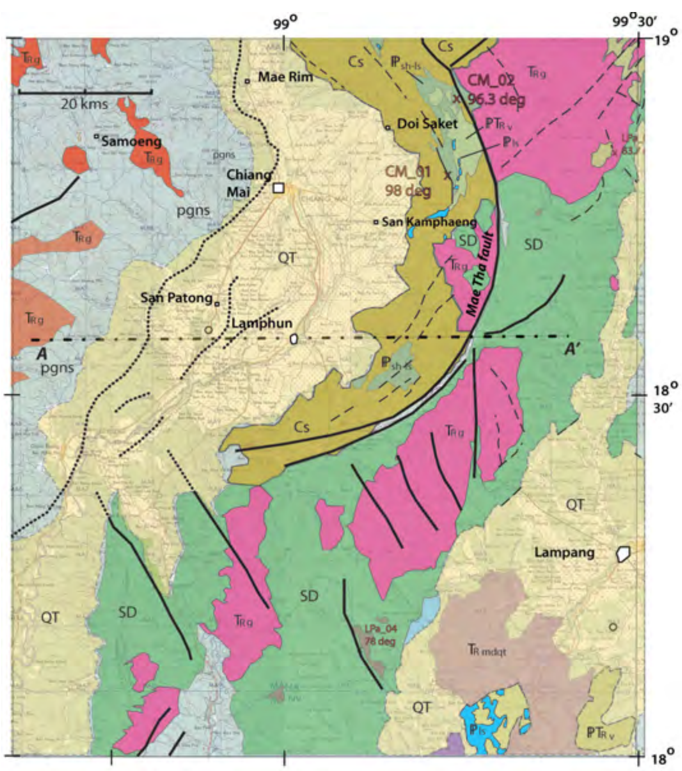


Figure 2. Geologic map of the Chiang Mai basin after Baum et al.(1981) and Piyasin (1972). Location of significant faults after Morley et al. (2011, p. 316). Mapping of faults is not of consistent reliability or well documented for much of this area, and should be considered conceptual on the cross section. Location of hot spring systems from Singharajwarapan et al. (2012). Line A-A′ is location of cross section of Figure 4.

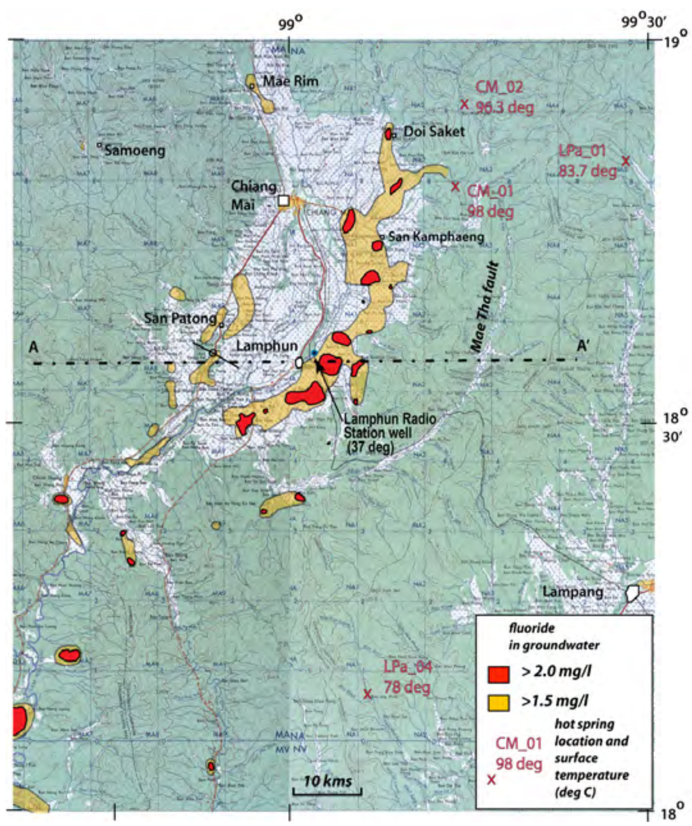


Figure 3. Map showing areas of anomalous fluoride in groundwater and locations of hot springs in the Chiang Mai basin (after Groundwater Division, 2000).

rocks are mainly quartzose sandstone of the Carboniferous Dan Lan Hoi Group (also called the Mae Tha Group) (Ueno and Charoentitirat, 2011; Barr and Charusiri, 2011). The sandstones rest unconformably on pre-Carboniferous low-grade metasedimentary rocks (Barr et al., 1990). The sandstones were originally mapped as the Mae Tha Formation by Piyasin (1971). The Dan Lan Hoi Group is associated locally with volcanics of the Chiang Mai belt and massive limestone overlying the sandstone and is believed to be Permian in age (Barr and Charusiri, 2011). Thickness of this late Paleozoic group is uncertain, but Bunopas (1981) estimated the quartzose sandstone rocks to be at least 2000-m thick. This group of rocks is strongly folded and faulted. The upper Paleozoic rocks of the east side are intruded by the Late Triassic/Earliest Jurassic granitic rocks of the “eastern marginal belt of plutons”, the best studied of which is the Khuntan Batholith (Yokart et al., 2003).

The tectonic history of the basin is important, particularly to understand the extent of fractured rock and fault zones. We defer to the work of Morley et al. (2011) for an understanding of the subsurface structure. They have proposed that the Cenozoic Chiang Mai basin is underlain by a low-angle normal fault, and that the basin and sedimentary rocks above the fault have been transported east, perhaps 5 to as much as 35 km along this fault. We have attempted to extend their cross section to the east to include the area of the Lamphun F-water anomaly, the hills to the east, and the Mae Tha fault (Fig. 4). . Gravity studies and proprietary seismic data indicate up to 2.5 km of Cenozoic sediment fills the Chiang Mai basin. Lithostratigraphy is briefly described by Rhodes et al. (2005) as sandstone and black shale that unconformably underlies c. 30 m of sandstone. A 180-210 m thick section of Mio-Pliocene organic rich brown claystone (Mae Sot Formation) overlies the sandstone. Above this is >760-m of sandstone, interbedded muddy sandstone, and minor conglomerate (Mae Fang Formation). The uppermost interval is > 150 m of Upper Pleistocene gravels. This adds up to about 1.2 km. Parts of the basin are clearly deeper and thicker. The deeper section is believed to be mostly lacustrine, but lithostratigaphy of the basin is poorly known.

Exposures east of the basin are limited to roadcuts and quarries, and where exposed, the quartzose sandstones of the Mae Tha Formation are everywhere extensively fractured. The extent of fracturing of the Khuntan Batholith is unknown.

Fluoride in Wells

Anomalous fluoride concentrations in well water (> 1.5 mg/l) defines an arcuate zone along the east side of the basin (Fig. 3). Ratanasthien and Ramingwong (1982) identified this zone and and suggested that deep thermal water is leaking upward through faults in the basin sediments. Subsequently, the Thailand Department of Groundwater Resources mapped many wells and defined the high fluoride zone (Fig. 3) to show the area of health concern for fluorosis (Groundwater Division, DMR, 2000). Most of the wells are shallow (<100 m), and the temperatures generally not measured. Ratanasthien and Ramingwong (1982) report a temperature of 37°C for the Lamphun Radio Broadcasting Station Well, and a fluoride concentration of 8.3 mg/l. In the same area, and perhaps in the same wells (locations reported only to the nearest one-minute) geothermal gradients exceeding 35°C/km and ranging up to 48.6°C/km are reported by Thienprasert and Rakaskulwong (1984).

Deep Groundwater Circulation

Models of groundwater flow (advective flow) in crystalline rocks show that groundwater is driven to several km depth by the surrounding hills of moderate topographic and water-table relief, even if rocks have moderate permeability (>10^{-16} m^2) (Toth, 2009). Permeability of rocks varies greatly from 10^{-23} m^2 for intact crystalline rock and shales to 10^{-7} m^2 for well-sorted gravels. Owing to the fractured nature of rock, a typical value for the upper 2.5 km of the continental crust is 10^{-15} m^2 , but varies from 10^{-16} to 10^{-13} (Ingebritsen and Manning, 1999). Lopez and Smith (1995) model a system (Fig. 5) with a water table sloping 300 m/5000m, and examine flow in a 2.6-km thick layer of country rocks with 10^{-16} m^2 permeability overlying an essentially impervious rock of 10^{-22} m^2. Heat flow from below the model is 0.090 Watts/m^2. The flow field in the country rock then encounters a vertical, 10-m-wide fault zone of permeability 10^{-13} m^2. The model shows fluid velocities as high as1.1 x 10^{-7} m/s (~3.5 m/year) in the fault plane, and fluid velocities as high as 4.9 x 10^{-10} m/s (0.015 m/year) in the country rock (See Fig.5). Fault-plane heat transport is ~20 Watt/m^2. If all water is captured in a well from a 2000 m distance along the 10-m-wide fault zone, one derives 0.4 MWatts of heat energy from the fault zone.

Wisian and Blackwell (2004) show a number of models typical of Basin and Range geothermal systems, with bedrock permeability 10^{-16} to 10^{-15} m^2, 200-m-wide fault zone of 10^{-14} m^2, and topographic relief of 800m. They make the point that convection occurs in the fault zone without topography, but that the flow and temperatures in the fault zone are greater with the topographic drive.

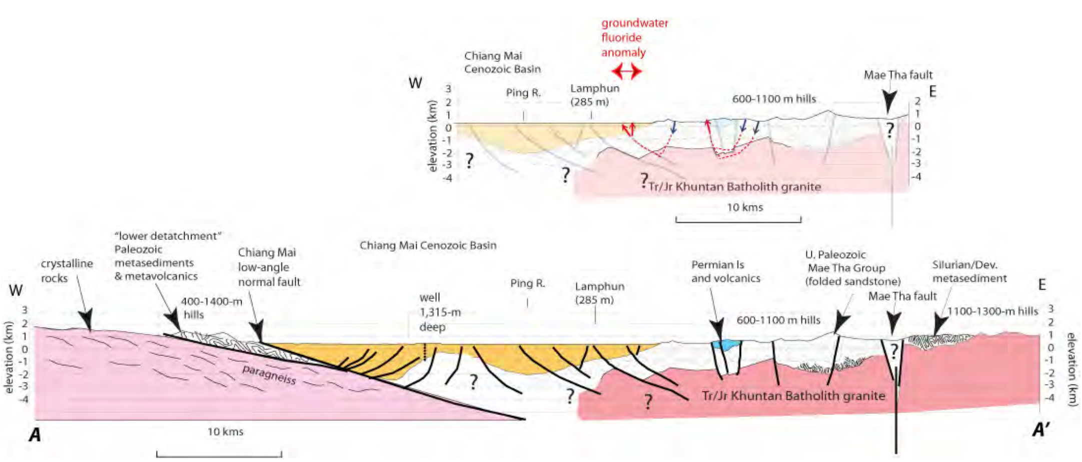


Figure 4. Structure cross section of the Chiang Mai basin modified after Morley et al. (2011). Fault locations are partly based on proprietory seismic and not exact. Upper picture shows a conceptual flow path (in red lines) of geothermal water and fluoride rich groundwater. Location of section in Figure 2.

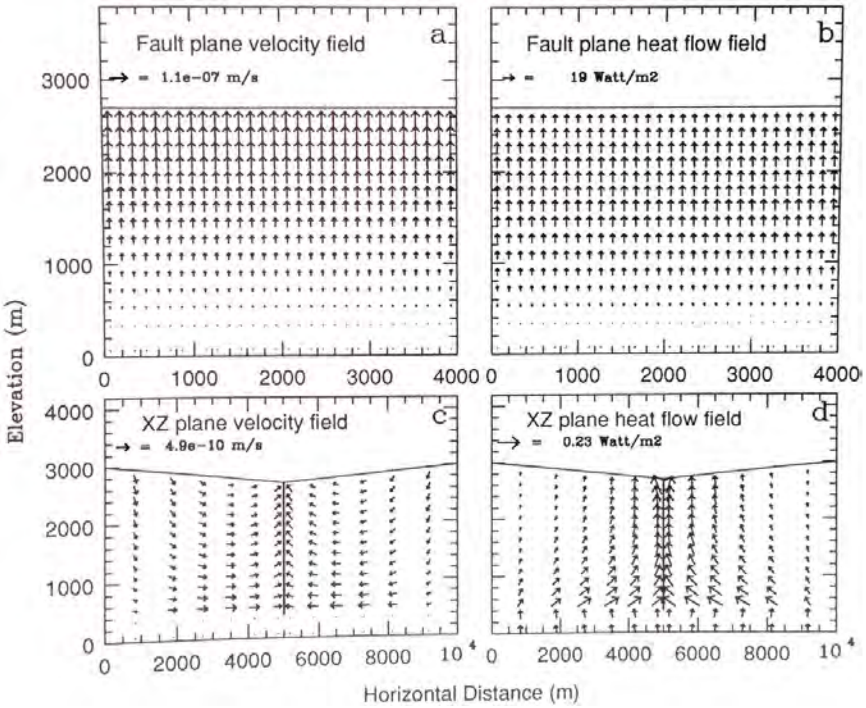


Figure 5. Diagram of flow in mountain block modeled by Lopez and Smith (1995). Mountain block has 300-m of relief above valley, and mountain block permeability is 10^{-16} m^2 permeability– a (upper panel) is water flow in the 10-m wide fault plane, and a (lower panel) is water flow in the mountain blocks. b is heat flow.

Conceptual Diagram for the Origin of High Fluoride Geothermal Water in the Chiang Mai Basin

Fig. 4 shows a conceptual flow paths for deep (2.5-km) circulation of recharge water from the surrounding hills with 300 to 800 m of relief above the basin. Deep groundwater flows through the folded sandstone, and the underlying fractured granite of the Khuntan Batholith. We also allow that some of the advective cells are confined to the permeable fault zones and do not necessarily require flow through the adjacent fault blocks.

High fluoride waters are common in geothermal water (Nordstrom and Jenne, 1977). Richardson and Holland (1979) show that the solubility product for the mineral fluorite (CaF_2) increases from 25°C to 100°C which partly explains geothermal water fluoride. Availability of Ca^{+2} from dissolution of mineral calcite ($CaCO_3$) and from breakdown of plagioclase feldspar also affects the concentration of F^{-1} . A ready source for the fluoride is the dissolution of biotite in granitic rocks (Chae et al., 2006), and the Kuntan Batholith is mostly biotite granite.

Mae Tha Fault

A conspicuous and poorly understood structural feature related to the Cenozoic Chiang Mai basin is the Mae Tha fault (Fig. 2). Geothermal resources of this area appear to be related to the tectonics associated with this fault. One of the hot-springs systems (CM_02) lies on the fault, and the larger system (CM_01,) lies just west of the fault (Fig. 2). The pattern of anomalous fluoride in water wells in the basin parallels the fault (Fig. 3). The fault does not lie in the basin, but cuts through older rocks 7-to-10 km east of the basin. The physiographic expression of the fault is an impressive 2-km-wide valley with an 80-km-long trace shaped like a semicircle, concave to the west. The southern end of the arc is shown splaying into two parallel faults resulting in a 2.5-km wide valley, but not extending into the Cenozoic sediments of the Chiang Mai basin (Department of Mineral Resources, 1995). The northern end of the arc truncates the SW end of the NE-SW-striking, 30-km long Mae Kuang fault, a fault with left-lateral Quaternary movement extending off to the NE (Rhodes, et al., 2004). Recent compilations of the fault have extended the Mae Tha arcuate trace northward another 30 km along N-S-trending faults to the east-facing escarpment of the west side of the Phrao basin (Rhodes, et al., 2004; Kosuwan et al., 1999). According to Charusiri et al. (1999) the Mae Tha fault has a moderate dip to the northwest, but details of the measurement are not provided. Shallow resistivity and refraction seismic profiles (Neawsuparp et al., 2010) across the fault zone near the north end indicate steeply dipping structure interpreted as faults dipping (65-90°), both to the NE and SW associated with the fault zone. The geophysics was not integrated into known geology of the site, so the interpretations are uncertain.

The geologic map compilation (Fig. 2) shows significant offsets of the intrusive contact of the late Triassic Khuntan granite with the older Paleozoic rocks, but the sense of movement on the fault is not obvious. Over most of the trace, the Carboniferous Mae Tha sandstone is faulted against pre-Carboniferous low-grade meta-sedimentary rocks or the Triassic granite. An area of Triassic granite outcrop (intruded into the Paleozoic rocks) also lies on the west block, southwest of San Kamphaeng (Fig. 2).

Earlier reports indicate the Mae Tha fault as active (meaning Quaternary movement), but recent compilations have shown it as a “pre-Quaternary fault” (Peterson, et al., 2007; Fenton et al., 2003). Rhodes et al. (2004) show that the course of the Mae Kuang River has an apparent right-lateral offset 4.5 km across the Mae Tha fault. Shift of the river course and truncation of the Quaternary Mae Kuang fault suggests that movement along the Mae Tha fault is younger than that of the Mae Kuang fault, and that it should be regarded as active in the Quaternary (Rhodes et al., 2004). Since the year 2000 at least 16 earthquakes greater than Mb = 3.5 and up to 4.6 have occurred in the Chiang Mai basin area (International Seismological Centre, 2014), and some have occurred near the Mae Tha fault, and also near the arc of fluoride-anomalous groundwater. Sense of movement is not clear, but some have regarded the Mae Tha fault as a strike slip feature with near vertical dip. The arc is convex toward the basin, and may be related to the detachment of rocks from the Doi Inthanon-Doi Suthep core complexes. If that be so, it is possible that the fault has a low angle dip to the west and is a thrust.

Ratanasthien and Ramingwong (1982) noted the association of the fluoride anomaly, local earthquakes and fault systems in the basin which may be active. This anomaly and the San Kamphaeng (CM_01) and Doi Sacket (CM_02) hot springs are all likely related to the enhanced permeability along faults with relatively recent movement.

Other Faults in the Chiang Mai Basin

Faults shown on the map are those indicated by Morely et al. (2011). Some are based on gravity mapping of the basin, and some on proprietary seismic data. Lacking that confidential data, the exact position, nor the numerous other subsurface faults can not be documented here, Subsurface faults shown on the cross section (Fig.4) and map (Fig. 2) are diagrammatic and not accurate locations. The central basin high (horst) exists west of Lamphun and has at least 2-km of subsurface relief as shown in Figure 4.

San Kamphaeng Geothermal System (Ban Pong Hom) (CM_01)

The San Kamphaeng system is the major surface emanation of thermal water near the Chiang Mai basin (Figure 5). Ramingwong et al. (2000) believed the system has the greatest

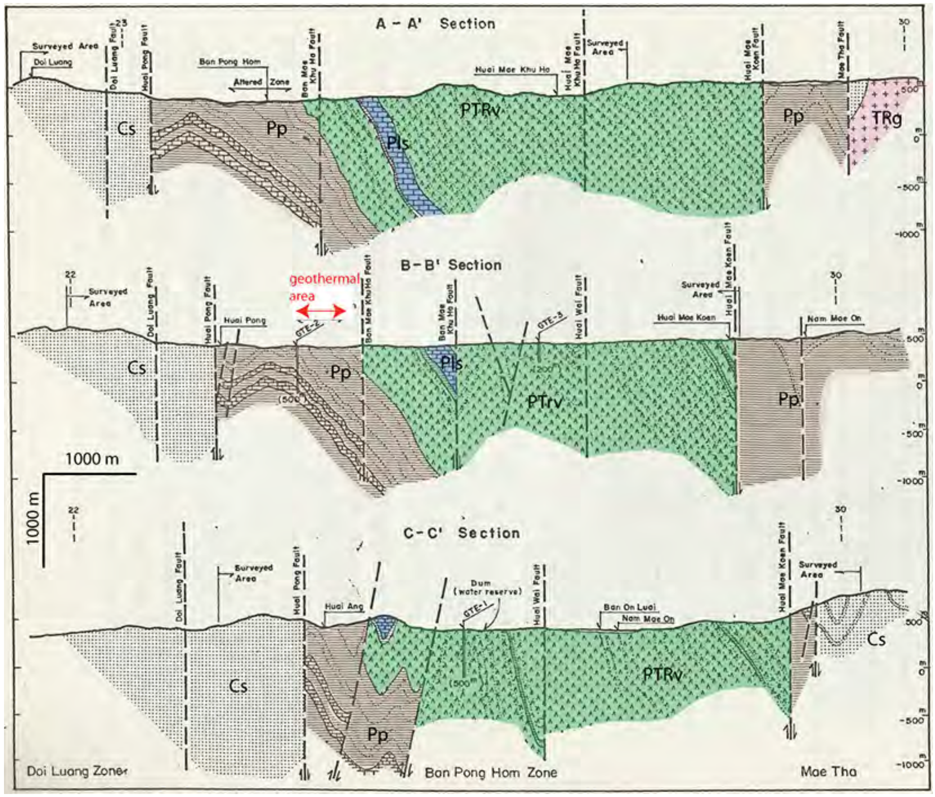


Figure 7. Structure cross sections of the San Kamphaeng geothermal area from Ratanasthien et al. (1985) after JICA (1984) and Coothongkul (1984). Location of sections shown on Fig. 6.

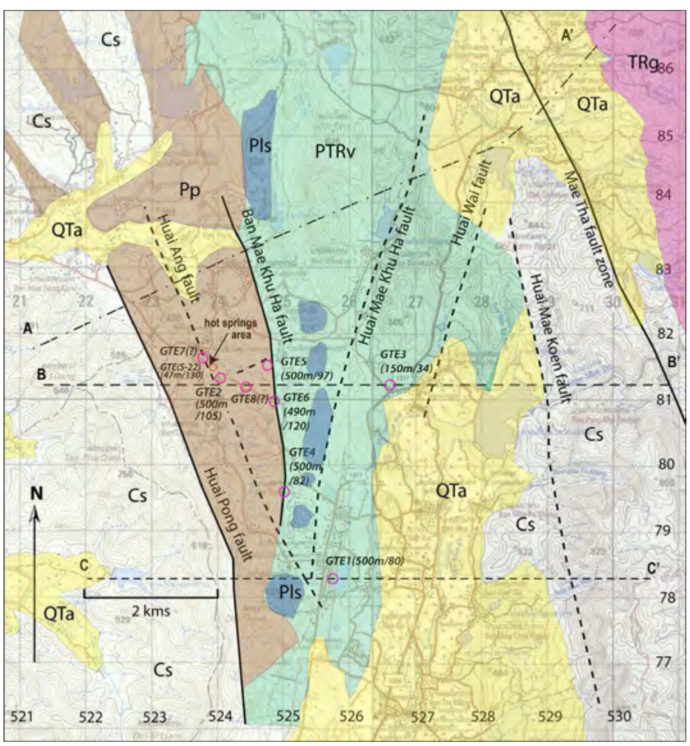


Figure 6. Geologic map of the San Kamphaeng geothermal area and location of exploratory wells. Compilation from maps by Piyasin (1972), Praserdvigai (1986), and Kita et al. (1990). Fault names are after Praserdvigai (1986). Existence of dashed-line faults is uncertain. Cs = Carboniferous sandstone of the Dan Lan Hoi (Mae Tha) Group, Pp = Permian sandstone, chert and shale of the Dan Lan Hoi Group, PTRv = basaltic volcanics of the Permian Dan Lan Hoi Group, TRg = Triassic biotite granites of the Khuntan batholith.

electrical power generation potential of the Thailand geothermal systems, possibly 5 MWe. The San Kamphaeng hot springs area has been developed as a recreational site, and new wells and piping make it difficult to observe the natural system. Ramingwong et al. (1978) indicated more than 20 hot springs emanated over a distance of 1 km along a small stream in a gravel-filled depression. The highest temperature they noted was 99.5°C. Nathan (1976) had visited the area earlier and noted that that two streams flow through the area and at the confluence he measured a flow of 72 l/s of 42°C. We measured the same flow point in May, 2014 at 10.1 l/s of 33.8°C water, with EC of 719µS/cm. A. Barr et al. (1979) noted the two streams and hot pools with small amounts of sinter and sulfur, and small crystals of FeS_2 in the muds. JICA (1984) indicate the hot springs are distributed over a 12-hectare area associated with branches of the Huai Pong fault, a high-angle, reverse fault.

A number of shallow wells (<50-m deep) were drilled at some time prior to 1986. Some of these wells produced hot bubbling and geysering water 100-130°C and flow rates greater than 10 l/s (Ramingwong et al., ~ 1982). In 1981-82 Several exploratory wells (GTE-2, GTE-4 through GTE-6) were drilled with a target depth of 500 m, but only GTE-6 had a significant flow, 4.1 l/s of 104°C water, and a temperature of 120°C measured at 489-m depth (Ramingwong and Praserdvigai, 1984).

The first deep exploration hole (GTE-7) was drilled to 1,227-m depth in 1985. The geologic results are reported in Praserdvigai (1986) and Barr et al. (1990). The upper 1000 m of strata in GTE-7 is carbonaceous shale, sandstone, siltstone, chert, limestone mudstone, and tuffaceous shale of the lower Permian Kiu Lom Formation. Barr et al. (1990) report that the well also contained a complex of basalt pillow lavas, dykes, porphyritic amygduloidal basalt and crystal lithic tuffs which they include in the Carboniferous-Permian (?) Dan Lan Hoi (or Mae Tha) Group (Barr and Charusiri, 2011). Praserdvigai (1986) reports dense and massive sandstone, 1000-1226-m depth, which we presume is the Mae Tha Formation sandstone. GTE-7 had a bottom hole temperature of 99°C, but no flow was reported. In 1989 GTE-8 were drilled to 1,300 meters depth. This well had only one producing fracture zone at a depth of 920 m which produced 40 tons/hr (11.1 liters/s) of 125°C water, the most promising well yet drilled (Raksaskulwong, 2011).

Structure of the geothermal system is interpreted as a complexly faulted graben structure bounded by high-angle faults (Figure 6 and 7); A number of shallow geophysics surveys were performed for the 1980-1989 drilling locations, but that data is not available to the authors in legible form at this time.

Fluoride content of the hot springs and wells is consistently 16-17 mg/l (Table 2). Water chemistry sampled from 5 flowing wells identifies a maximum geothermometry of 133°C (Lara Owens, written communication, 2012).

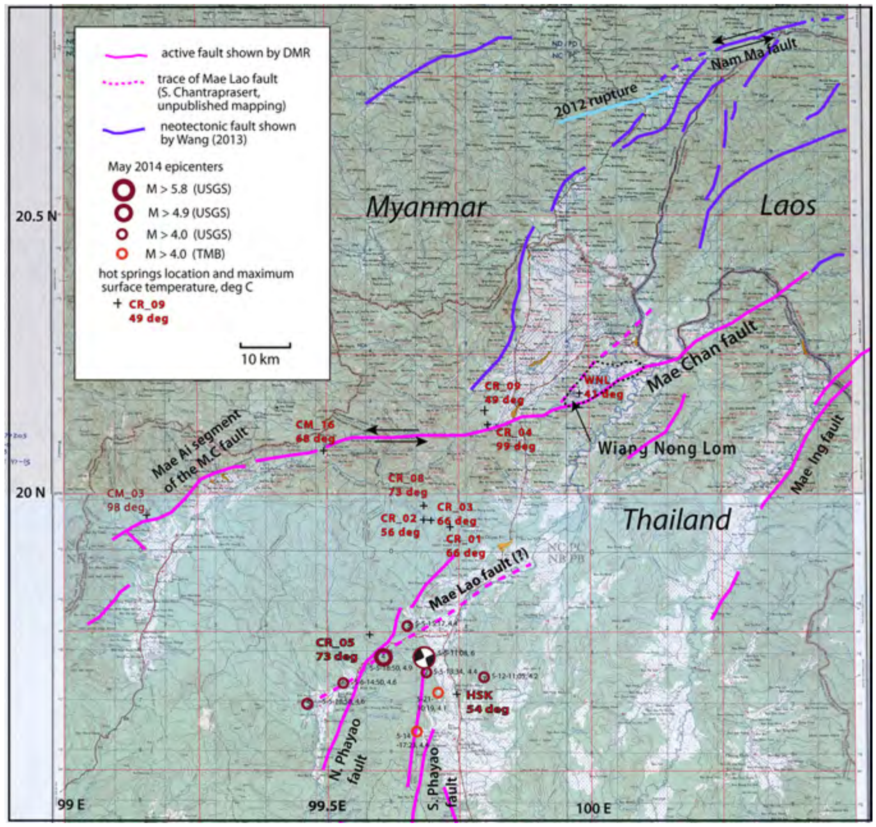


Figure 8. Map showing hot springs and active faults in northernmost Thailand. Spring locations from Singharajwarapan et al. (2012) and in Table 1. Active fault traces (pink) after DMR and Kosuwan et al. (1999) and (blue) from Wang (2013), and outline of the Wiang Nong Lom basin. Epicenters of the May 5, 2014 earthquake, USGS focal mechanism of main shock (M=6.0) and aftershocks M ≥ 4.

The Doi Saket Hot Springs (Ban Pong Kum) (CM_02)

Northwest of Doi Saket, and within the Mae Tha fault zone, are several hot springs distributed over about 150 m on a N-S trend. The highest temperature of 95.5°C was measured in 1984 by Geotermica Italiana (1984). They measured an aggregate flow of 8.1 l/s. Highest temperature measured in 2014 is 75°C. Fluoride content of that water is 9.6 mg/l.

The Mae Chan Fault, Active Fault Systems and Hot Springs in Northernmost Thailand

The left-lateral Mae Chan fault has been considered the most active fault in Thailand. The trace of the fault system can be seen on satellite imagery for 150 km in Thailand, and another 150 km northeast into Laos for a total of 310 km (Wang, 2013). Slip rate has been estimated between 0.075-0.3 mm/year (Wang, 2013) and 0.3-3.0 mm/year (Fenton et al., 2003). On May 16, 2007 an Mw = 6.3 earthquake occurred at about the middle of the 310-km trace, in the Bokeo Province of Laos.

During the writing of this paper, May 5, 2014, an Mw = 6.0 earthquake occurred on the system of faults 45 km south of the Mae Chan fault. The location, USGS focal mechanism, and the aftershock epicenters ($M \geq 4$) are shown on Figure 8. At the time of writing, the fault on which the earthquake occurred is unclear. Aftershock epicenters indicate the Mae Lao fault, but the main event locates on a northern extension of the Phayao fault.

Hot springs occur at several places along the active Mae Chan fault, as well as along the Kok River, 15 km south of the fault , and further south in the epicenter area of the 2014 earthquake (Figure 8). This report will focus on the hotter Mae Chan fault systems. The Kok River geothermal areas (CR_01, CR_02, CR_03, CR_08) have a maximum temperatures of 73°C. The Mae Chan geothermal area (CR_04), has a maximum measured surface temperature of 99.1°C, measured in the bed of the Mae Chan River.

Mae Chan Geothermal Area (CR_04)

Hot springs occur over an ~ 3 hectare area next to the Mae Chan River (Figs. 8, 9 and 10) along the active (Fenton et al., 2003) Mae Chan fault. When examined in 1976 flow was estimated at no more than 3 liters/s and maximum surface temperature of 99.5°C (Nathan, 1976). Two wells were drilled to 100 m in ~ 1996 (PR1 and PR2). Apparently PR1 did not flow and we have no temperature data from that well. Water spouted 15-m high, and flowed 5.94 l/s from PR2. Ramingwong et al. (2000) reports a temperature of 122°C, but the temperature log shows a maximum of 113°C, of water entering the hole from a fracture zone at 9-m depth (Manoonvorang and Virapun, 1996). In 2004, a 56-m borehole was drilled based on resistivity surveys and produced 5.6 liters/s of 94°C spouting 20 m into the air. All the springs emanate from fractures in outcrops of porphyritic granite or from the river bed alluvium. In 2014 a temperature of 99.1°C was measured in the river bed sand, but flow of that part of the system has never been evaluated because of dilution with river water. At present time

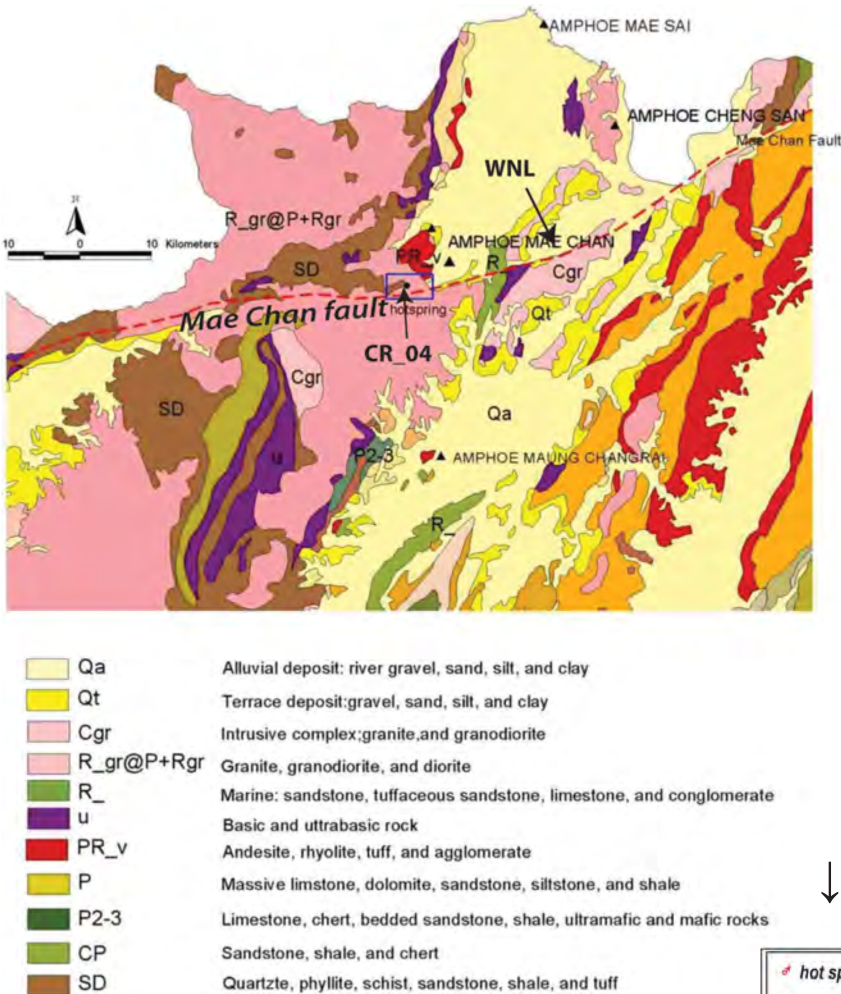


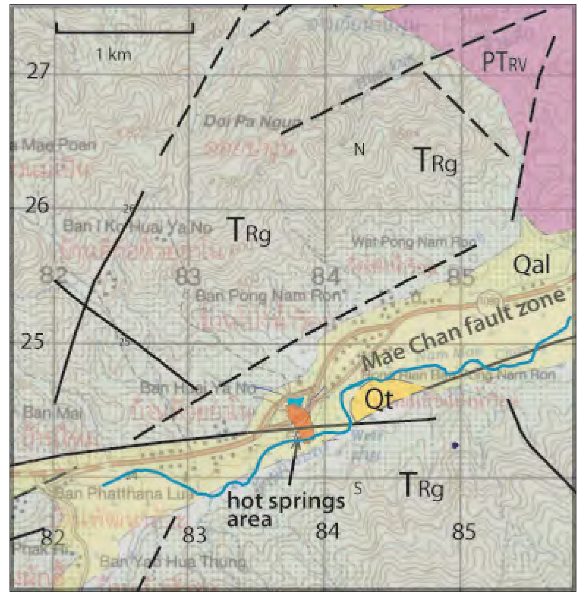
Figure 9. Geology of the Mae Chan region.

(2014), both wells spout hot water >12 m into the air. Chalcedony and fast K-Mg geothermometry indicate approximately 122-127°C for the potential deeper system (Singharajwarapan et al., 2012). Fluoride content of the water is 20 mg/l.

A 300-m long dipole-dipole resistivity profile across the area showed pronounced structures dipping 50-70° to the N or NE (Singharajwarapan, 2005) which we presume is the structure of the fault zone (Fig. 11). Interestingly, the successful wells and the many seeps of hot water are aligned along a 338° strike, nearly perpendicular to the 020° strike of the Mae Chan fault zone (Fig. 11) , suggesting pull-apart fractures within the strike-slip fault system. An MT survey is currently underway by Dr.Weerachai Siripunvarapon (Mahidol University) to better define low resistivity anomalies and structure of the geothermal area. More detailed survey and interpretation of these low resistivity features is a part of this ongoing project to identify a site for an exploratory well.

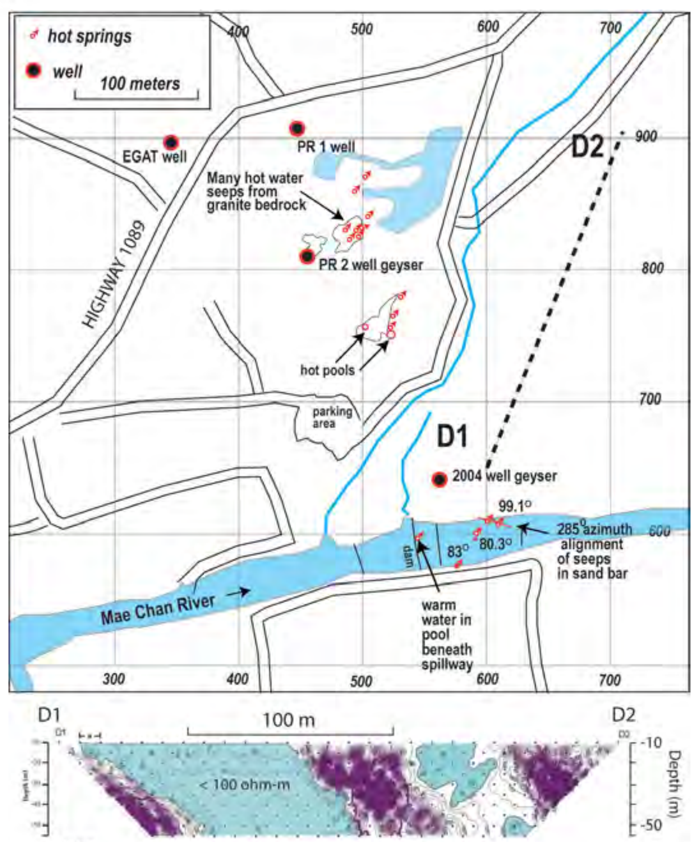
Warm Springs in the Wiang Nong Lom Swamp (WNL)

Villagers told us of a warm springs out in the middle of a floating-grass swamp known as Wiang Nong Lom (Fig. 8) In May, 2014 we measured a temperature of 41.1°C, an EC of 348 µS/



↑ **Figure 10.** Geologic Map of the Mae Chan hot springs area from Department of Mineral Resources (2012). TRg = Triassic biotite granite, PTRv = Permo-Triassic rhyolite, tuff and sediments. Qt = Quaternary terrace deposits, and Qal = Quaternary alluvium. Black lines are mapped faults, some of which are based on topographic lineaments in the granitic rocks. UTM coordinates of topographic map are India-Thailand Datum.

↓ **Figure 11.** Detailed map of Mae Chan hot springs area and dipole-dipole resistivity profile D1-D2 from Singharajwarapan et al., (2005). UTM coordinates are WGS84.



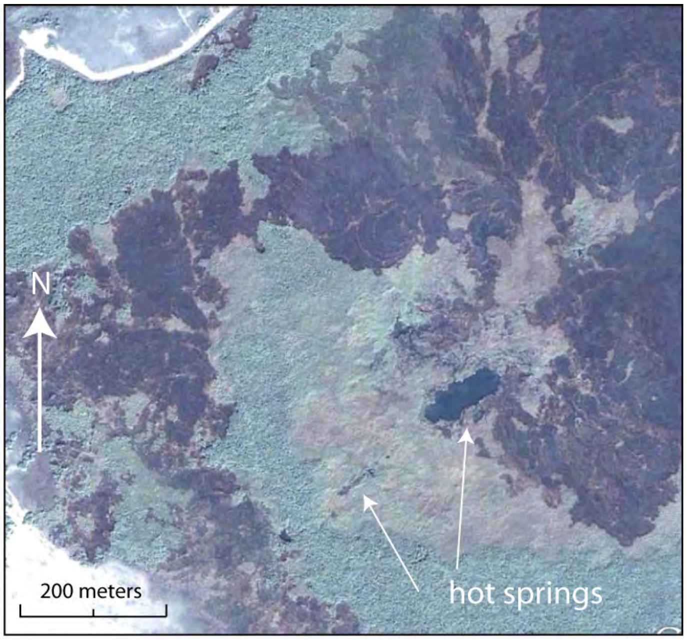


Figure 12. Satellite image (Google Earth, February 2, 2000) of the linear features and ponds marking the NE-SW alignment of warm springs that flow from beneath the floating grass swamp of the Wiang Nong Lom. In 2014, the flow was estimated by us to be 2 liters/s of 41°C water. Chemical analysis of water is in progress.

cm and an estimated a flow of 2.1 liters/s from the larger pond. Water was sampled for chemical analysis. On satellite images one can observe a clear NE-SW alignment of the spring system, as a break in the swamp-grass cover over a distance of 400 meters, the same alignment as the Mae Chan fault (Fig. 12). It is likely the water is diluted in temperature by the swamp sediments, but that the flow is large enough to be of interest for a geothermal resource. Seismic reflection lines indicate swamp sediment is at least 130 to 170-m deep (Singharajwarapan, et al., 2007; Wood et al., 2004). Here is another manifestation of geothermal water emanating from the active Mae Chan fault, but largely shielded from view by the overlying sediments.

Conclusions

This paper attempts to gather the scattered geologic information on major geothermal systems of northern Thailand. There is a clear association of the systems with faults believed to be active during the late Cenozoic. All hot springs have high fluoride (> 10 mg/l). The anomalous pattern of high fluoride wells (> 1.5 mg/l) in the Chiang Mai basin sediments suggests this is a "blind geothermal system" masked by Cenozoic sediments in which deep hot water mixes with basin waters as it flows upward through permeable fault zones. The Mae Chan geothermal system is clearly associated with the active Mae Chan strike-slip fault zone. That fault zone contains several hot springs distributed along its ~ 140-km-long trace. A project is currently underway by the Thailand Department of Groundwater Resources, Chiang Mai University, and Mahidol University to evaluate these systems for drilling locations in hopes of generating 2-5 MWe of electrical power.

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