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+APPLICATION OF GEOTHERMAL RESOURCES OF THAILAND, VIETNAM, AND MYANMAR TO TECTONIC SETTINGS

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ABSTRACT

Data on 94 hot springs in Thailand indicate that they are mostly dominated by Na-HCO_3 (-SO_4) type water with minor Cl and occur mostly in granitic terrains. Variation in geochemical composition is relatively nonsignificant, although in the south the thermal springs contain less abundant TDS and other alkaline values. In general, hot springs in the north have strongest mineral constituents with the amounts of TDS varying from 315 to 700 , Na 80-176 mg/l, S04 16-65 mg/l. and Cl 1.7-31.O mg/l. In the south, although data are rather scarce, chemistry of springs in general is similar to the north. Heatflow data of Thailand indicate that northern Thailand can be divided into 2 regions - western region with heatflow over 1.5 HF and the eastern region with heatflow less than 1.5 HF. The occurrence of geothermal resources suggests that geothermal fields are controlled by tensional and strike-slip tectonics in association with seismically active faults and shallow to deep igneous bodies.

In Vietnam, most of the reported thermal springs (up to 60 locations) are of Na-CO_3 (-Cl)- type water. Geochemical characteristics of hot springs in northern Vietnam are HCO_3-dominated, in the central they are Cl-dominated, and in the south they are Cl-and HCO_3-dominated. More significant is that in the deltaic plain of the Red River, the thermal springs are characterized by the presence of CH_4. It is notably important that the marked geochemical contrast of thermal springs may indicate the difference in geotectonic units occurring as a result of heterogeneous mantle melting with mixing crustal materials in central and southern Vietnam and of extensional and strike-slip tectonics in the south.

In Myanmar, thermal springs are quite abundant and widespread. Up to a total of 92 thermal springs are reported. They are much more concentrated in granite region in eastern Myanmar in the N-S trend. Most of the hot springs occur in magmatic regions, particularly along the N-trending fault and fracture zones. In the northeastern part near China border, the hot springs are distributed in the northeast trend following major fault zones, immediately close to the metamorphic /igneous terrains. Exploratory drilling from reports on petroleum activities in central region advocates the existence of high geothermal gradients in proximity to shallow-depth magma bodies and active fault zones.

1. INTRODUCTION

Geothermal activity in mainland SE Asia, though localized, is quite high in several areas. In this region, the activity is denoted by the presence of hot springs and heat flow, both of which are spatially related to some extent to present-day tectonics.

SE Asia is located in the southeastern part of the Eurasian plate, with the east-dipping subduction of Indo-Australian plate to the east and the south, and the west-dipping Philippine Sea plate and West Pacific plate to the west. It is currently accepted that the present-day tectonic activity of SE Asia has been governed by the interaction of Indo-Australian plate with Eurasian plate since the time that the India continent collided drastically with Asia during approximately 55 Ma (Packham, 1993). This have caused anti-clockwise rotation of South China plate and a commence of extrusion of continental SE Asia southeastward. Such a mega-change in tectonic style may have initiated the major, rift-generating, tensional, pull-apart basins of SE Asia, e.g. Andaman Sea, Gulf of Thailand, and South China Sea. The present-day tectonics in continental SE Asia is manifested by the involvement of geothermal resources and neotectonically moderate to strong earthquake activities (Phuong, 1991, Charusiri et al., 1996).

This paper focuses mainly upon our remote sensing data and compilation of the very recent and most available data on geothermal resources of Thailand, Vietnam, and Myanmar, and to relate them to unravel the tectonic activities of these countries.

2. HOT SPRING AND HEAT FLOW DATA

In Thailand the first detailed investigation on geothermal resources is that of Takashima et al. (1979). At present, at least 65 thermal springs in northern and western parts of the country have been studied. In the south, a recent investigation has been made by Chaturongkawanich and his coworkers (this volume), and up to 30 locations have been recorded. However, the thermal springs in southern Thailand always contain similar values of total dissolved solids (TDS) and some other alkaline values. Comparison between chemical compositions of thermal springs in northern and southern Thailand reveals relatively nonsignificant geochemical variation. Thermal springs in Thailand, based upon our compilation and investigations, indicate that they are located largely within the granite terrain and chiefly characterized by Na and CO_3 with some SO_4. Chlorine is also detected in some locations. In addition, Charusiri et al. (1996) observe that many hot springs, particularly those in northern Thailand, are located in the vicinity of lineament features. These lineaments are interpreted to represent active faults.

In northern Thailand, hot springs have generally stronger mineral constituents. The TDS of water vary in a large degree from 315 to 700. The Na content ranges from 80 to 176 mg/l. The anion contents seem not changed very much, ranging from 16 to 65 mg/l for SO_4 and from 1.7 to 31.0 mg/l for Cl. In the south, investigation on thermal springs have been carried out very recently, so far data on physio-chemical characteristics of thermal springs are much more scarce. Less than 10 locations have been observed for their geochemical concentrations, and the contrast among them in this region is not much. Quite commonly, ranges of the TDS and Na contents for thermal springs become higher in some areas of southern Thailand due to sea water invasion. Surface temperatures vary from 60 to 99 °C in the north and from 55 to 85 °C in the south. Based upon exploration drilling, subsurface temperatures averagely range from 120 to 130 °C in the north and approximately 110 to 120 °C in the south. Although with some high - temperature hot spring areas in northern Thailand where main reservoir temperatures are up to 200 °C (see Raksaskulwong and Thienprasert, 1995), further detailed studies are required to carry out in areas with highest temperatures in order to enhance more confidence prior to development of geothermal energy for power plants being launched.

In the light of heat flow information, it was reported that heat flows in northern Thailand (Takashima et al., 1989) vary from 1 to 2 HFU (microcalories/cm^2-sec, 1 HFU = 41.87 mW/m^2) which is not high. However, the more recent data on heat flow of Thailand by Thienprasert and Rasaskulwong (1984) and Raksasakuwong and Thienprasert (1995), depict variable values from < 1 HFU up to > 2.5 HFU. In their maps, there are three regions where heat flows were observed to be quite high. These are 1) Tak (along the Mae Ping Fault) in the westernmost part of Thailand, 2) Lopburi - Phetchabun (along the Phetchabun Fault) in the eastcentral part, and 3) Lampang-Phrae (within the Thoen Fault) in the north, the latter being much smaller inside than the other two regions.

In Vietnam, the situation is rather similar to Thailand in that only few researches concerning geothermal resources were carried out. However, there are few unpublished data to indicate thermal springs (see Tram Du Lounge and Nguyen Xuan Boa, 1982). Presently, about 60 locations of hot springs have been observed. Geochemical monitoring and results on thermal springs reveals that most of the springs are dominated by the Na- and CO_3 - rich water. However, the occurrence of some Cl contents in several locations leads us to consider some difference in the water type. In addition, the disappearance of the SO_4 content of the springs make more contrast in geochemical thermal - spring characteristics between Vietnam and Thailand. Additionally, it was also observed that thermal springs in northern Vietnam are much more HCO_3 - dominated. However, hot springs in central Vietnam show the enrichment of Cl, apart from the Na and CO_3 contents, whereas in the south it is characterized by high concentrations of both Cl and HCO_3 values. It is important to note herein, that the thermal springs and some surface water, particularly in deltaic environment such as Mekhong and Red River flood plain areas, are characteristically manifested by the appearance of CH_4.

In Myanmar, there are more than 92 hot springs have been located (ESCAP,1997). The first identification of thermal springs was traced back to 1883, however, a systematic hydrochemical investigation has been carried out very recently. Distribution of hot springs in Myanmar (Fig. 1) appears to align within five major zones. The most abundant zone is in the Tenasserim region (Mon state) of southern Myanmar, which commences in Mergui and extends southwards to Thailand following several complex fault systems. These thermal springs are mostly located within granitic belts of Myanmar. The second zone includes the Sino-Burman ranges between Inle lake and the area around Lashio in the northeastern trend following the Takuang Fault (Fig. 1) through Myitikyina and Mandalay districts and swings southwards. The third zone occurs along the edge of Shan Plateau following Sagiang and Pan Luang Faults. The hot springs are located also in the igneous terrains of Mokok belt (Mitchell, 1992), which stretches southwestward from southern Yunan of China. Less common geothermal areas are those extending from Assam in the north-south direction to delta area of the Bay of Bengal and the eastern edge of Arakan Yoma. The fifth zone is located remotely in northern Myanmar and may be related to the Myithina (Galigong) Fault.

Geothermal resources of Myanmar have been reviewed by Htay Htay et al. (1986), Tin Tin Aung (1988) and Maung Nyunt (1996). Not until 1990, a joint programme by the Myanmar Oil and Gas Enterprises and UNOCAL was granted to conduct a geothermal investigations of hot springs in Myanmar. As quoted from ESCAP (1997), the hot springs are chiefly low-surface temperature in the range 40 to 60 °C with the subsurface temperature averagely less than 100 °C. It is surprisingly stated that mostly the hotsprings of Myanmar posses their average temperatures (<100 °C) slightly less than those of Thailand. At this point, it is likely to conclude that high - temperature geothermal energy for power development seem unlikely established in their investigated areas.

3. APPLICATION TO TECTONIC SETTINGS

Information gathered by the first heat-flow map of northern Thailand (Takashima and Kawada, 1981) leads us to subdivide northern Thailand into 2 parts with the averagely higher heatflow (>1.5 HFU) in the west than that of the lower (<1.5 HFU) in the east. Geothermal waters in Thailand are considered to be non-volcanic origin, since neither active nor recent volcanoes are encountered in Thailand. The youngest volcanic eruption event, as indicated by the ^{40}Ar - ^{39}Ar age data by Sutthirat et al. (1995), is about 0.5 Ma. However, when taken into account, the works by Chuaviroj and Chaturongkawanich (1984), Thienprasert and Raksasakulwong (1984), and Raksasakulwong and Thienprasert (1995) on heat flow data in Thailand, it is obvious that several geothermal fields in Thailand are aligned in the N-S direction, most of which (at Fang, Chiang Rai, Chiang Mai, Lampang, and Phrae, see Ramingwong et al., 1985, Ratanasathien et al., 1988) correspond fairly well with Cenozoic basins, whose sedimentary covers are not thick (less than 2,000 m). The heat source may have come from active granitic magma bodies by disintegration of their radioactive elements- K, Th, U. The ultimate source may have linkage to the active faults, providing heat circulation through these fracture systems.

The medium values of heat flows in the Khorat Plateau, although without any hot spring relationship, probably advocate the NW-trending elongate and narrow zone of the uplifted region compatible with the Phuphan Fault. The NS

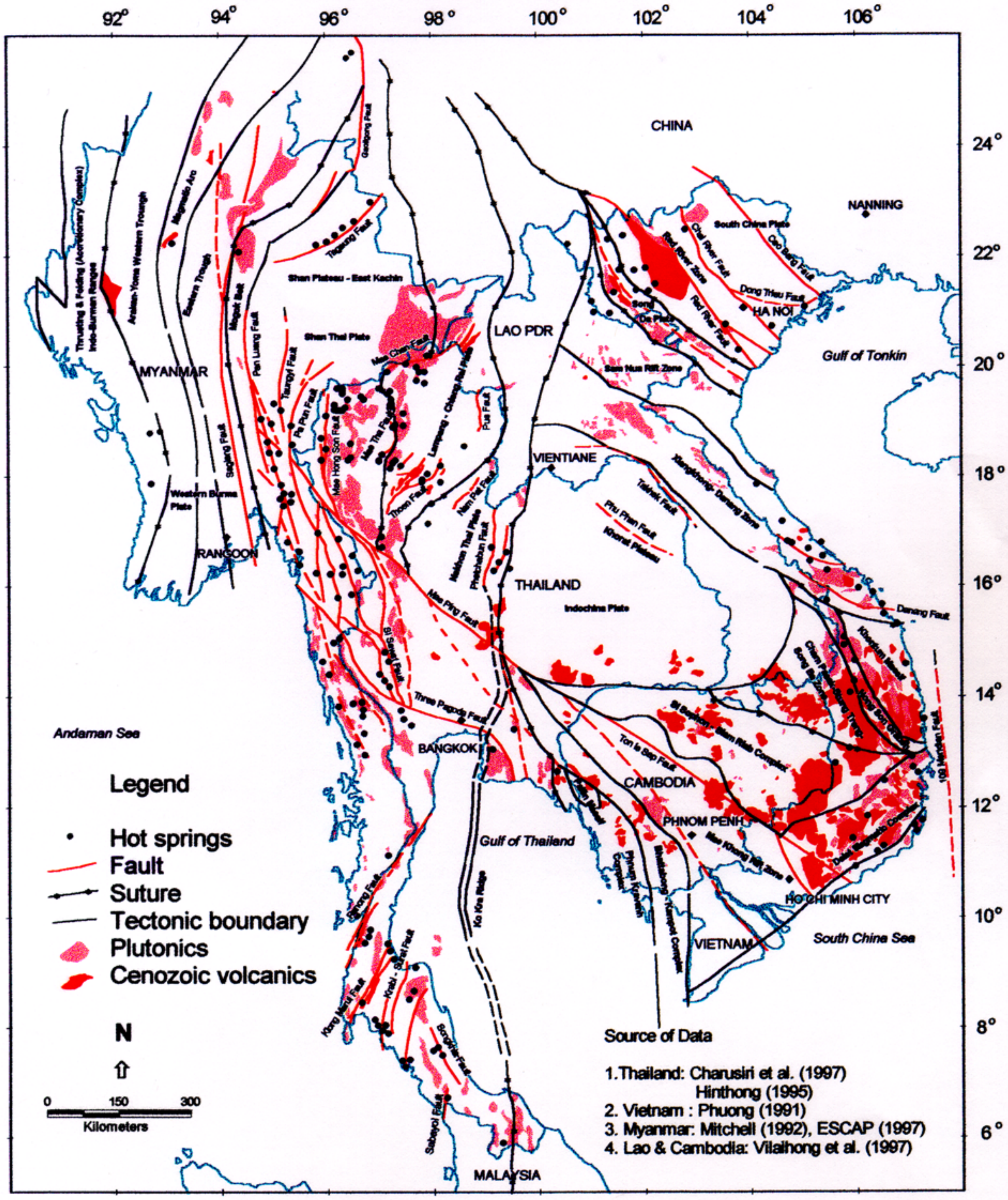

Figure 1. Simplified tectonic map of SE Asia showing some major active faults and distribution of plutonics, Cenozoic volcanics, and hot springs.

alignment of hot springs, associated high heat flows and Cenozoic volcanic activities in the Phetchabun basin along the Khorat Plateau which extends to eastern Thailand (Chonburi) and to the Gulf of Thailand along the Ko Kra Ridge, probably indicate the edge of the fault-bounded pull apart basins. In areas of southern margin of Khorat Plateau, young basalt volcanism, though reported by Hoke and Cambell (1995) not to be related to any tectonic features, are considered by us to be controlled by the occurrence of E-trending lineament associated with Cenozoic tectonic thrusting. This tectonothermal lineament corresponds very well with the suture between Cham Pasak - Stung Treng - Song Ba and Sisophon - Siam Rieb tectonic units (Fig. 1). Moreover, Hoke and Cambell (1995) and Hoke (1997) depicts, using C and He isotope systematic signatures, that Cenozoic basalt volcanism in Lampang, northern Thailand, may indicate an active intraplate mantle degassing. We infer that the Lampang region and nearby (Lampang - Chiang Rai plate in Fig. 1) may be occupied by thin layers of sedimentary materials overlying the thicker paleo-oceanic crust. Since based upon their works, no isotopic contamination are encountered. Therefore, in Thailand lithospheric extension seems to be more essential than hot mantle plume process.

In Vietnam, tectonic subdivision of Vietnam (see Tran Van Tri, 1994, Le Van De, 1997), as simplified and illustrated in Fig. 1, can be well explained by the geochemical contrast of thermal springs. In the north particularly Song Da plate between Red River and Song Ma (Ma River) Fault Zones (Fig. 1) where active thermal springs are mostly predominated. The spring waters are also characterized by the presence of CH_4. The difference in geochemistry of thermal springs between this region and the others in Vietnam, i.e., HCO_3 type-dominated in the north, Cl-type in the central, and CH_4 -type in the south, suggest the difference in tectonic units. In addition, isotope geochemistry of helium and carbon in areas predominated by Cenozoic basalts, as reported by Hoke (1997), are also interesting. The isotopic results, particularly those in the central and the south, may indicate the mixing between active magmatic and thick crustal sedimentary-organic rich components. The latter corresponds to the Precambrian Kontum massif and Paleozoic strata of the Indochina continent (Xieng Khong- Danang Zone, in Fig. 1), particularly those close to Dong Ho Fault and a suture zone encompassing Khontum massif. Based upon these sensitive geochemical tracers, such the tectonic scenario of Vietnam is different from that of Thailand in that active mantle melting, as a consequence of mantle plume or upwelling underneath the Cenozoic basalt volcanism in the failed rifting regions, may be the principal mechanism for the occurrence of geothermal fields in Vietnam rather than the extension tectonics.

In Myanmar, information deduced from our LANDSAT and NOAA image interpretation, petroleum exploration drilling data and our field survey, indicate that high geothermal gradients are concentrated in areas closely related to Cenozoic volcanics, Mesozoic to Cenozoic granites, and active faults. The latter are quite more cryptic, since the geothermal springs are likely to follow the N-trending left-lateral Sagaing and Papun active faults in Myanmar along which Cenozoic-Mesozoic intrusions have taken place. In addition, several hot spring locations in southern Myanmar aligned following the northward extension of Three Pagoda Fault of western Thailand. Although some thermal springs in Myanmar are also associated with volcanism, the more common features are those within the granite regions where faulting are still active. Therefore, it is likely that the hot springs are predominantly triggered by the active tectonic faults where underlying shallow-depth magma bodies are currently cooling down. We therefore consider that the geothermal resources of Myanmar have been triggered by extension tectonics in seismically active areas.

4. CONCLUSIONS

Several lines of evidences lead us to consider that tensional and strike-slip tectonic regimes which may have been developed as a result of the interaction of India to Asia and extrusion tectonics of Southeast Asia mega-block, play essential roles in the development of heat-flow and earthquake activities in this region.

In Myanmar, the hot springs seem to be associated with the on-going left-lateral fault movement in regions underlying on-cooling shallow-depth magmas. In Thailand, mostly thermal springs are associated with both actively cooling down, shallow magmatic bodies in the west, northwest and south (of Shan Thai plate), as well as the hot mantle plumes beneath volcanic terrains (Lampang - Chiang Rai and Nakhon Thai plate boundaries), all of which are, to some extent, controlled by the lithospheric extentional tectonics. However, the hot springs of Vietnam may occur within the regions essentially dominated by extensive mantle-melting hot spots underlying Cenozoic volcanic terrains and thick continental crust without significant tensional and strike - slip tectonic regimes.

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