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Magnetic spectrum of the San Kampaeng geothermal area, Northern Thailand

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Abstract: The energy spectrum of the San Kampaeng total magnetic field is cut off at the frequency higher than 0.0015 cycle/metre for each magnetic profile to remove a near surface magnetic noise. These filtered magnetic data are plotted as a contour magnetic map for magnetic interpretation. The contour map gives excellent results on which a geological interpretation can be based. The map shows magnetic bodies which are postulated to be a heat source of the San Kampaeng geothermal area. A major fault structure is also revealed by this magnetic contour map. This major fault is along the direction of magnetic bodies trending north-south. The results prove the existence of a fault, adjacent to the east of the massive limestone hills, which may have direct implication to the present position of the San Kampaeng Volcanics.

INTRODUCTION

San Kampaeng geothermal system is one of five geothermal systems in Northern Thailand and is the most promising one with temperatures higher than 180°C and heat-flow values ranging from 3.1–7.67 HFU or 129.52–320.45 mW/m^2 (Thienprasert and Raksaskulwong, 1983). Source of heat for this geothermal system is believed to be the result of igneous intrusion whose heat was transferred up under the tectonic extension in the western margin of the Indochina subcontinent (Ramingwong *et al.*, 1979). Using geophysical information and magnetic methods, the Japan International Cooperation Agency (1983) reported that magnetic anomalies at the San Kampaeng geothermal area may be derived from igneous activities that occurred along fault zones. They believed that a deep-seated granitic body or younger intrusive body along fault zones plays an important role as heat source at the San Kampaeng area. In a drilling project for geothermal exploration, the deepest borehole with the total depth of 500 metres was done at Ban Sahakorn 2(GTE 2), Amphoe San Kampaeng (Chuaviroj *et al.*, 1983a). Rocks collected from core samples were sandstone, siltstone, shale, chert and limestone with pyrite. Some parts of the core were highly fractured and altered. They found that hot water of at least 80°C migrated into the fractured zone. This meant that body of heat source must be deeper than 500 metres for this particular borehole.

This paper describes the magnetic anomalies, magnetic source depth determination, and finally its geological implications based on the magnetic anomalies at the San Kampaeng geothermal area.

Geological setting of the San Kampaeng area

The San Kampaeng geothermal area lies within a valley in a hilly area east of Chiang Mai, northern Thailand. Hot springs in the area occur in the Permian sequence of sedimentary rocks (Fig. 1), composed mainly of siltstone, shale, chert, bedded and

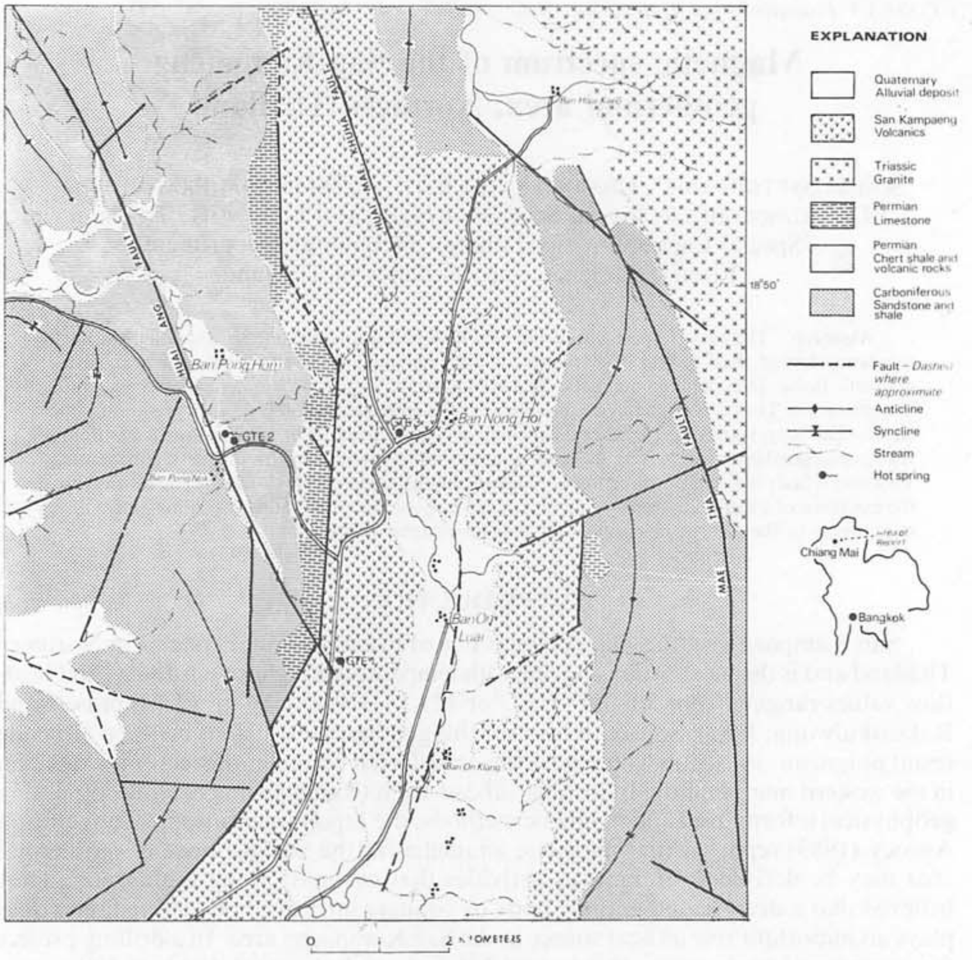

Fig. 1. Generalised geologic map of the San Kampaeng geothermal area (Compiled from Chuaviroj, Chaturongkawanich and Sukawattananan, 1980; Pothong, Sriprasert and Jaibun, 1982; and JICA, 1983).

massive limestone. In places, these rocks are intercalated by tuffaceous rocks. The sequence was formerly mapped as Kiu Lom Formation, Ratburi Group by Piyasin (1972). The rocks are bounded by elevated areas of Carboniferous clastic sequence of the Mae Tha Formation. Volcanic rocks are restricted to lowlands in the middle and higher elevations in the northern part of the area. They consist of basaltic rocks, breccia, agglomerate and tuff of Permo-Triassic age (Piyasin, 1972; Chuaviroj *et al.*, 1980). Macdonald and Barr (1978) pointed out that these rocks are remnants of a Late Carboniferous volcanic arc which extend through central northern Thailand. Recently, Chaturongkawanich and Chuaviroj (1983) reported a Jurassic age for these volcanics based on K-Ar age determination of 163 ± 8 million years by Sasada (1983, unpublished data). They suggested that the rocks, were formed by fissure eruption, intercalated and unconformably overlay the Permian sequence during Jurassic time.

The name 'San Kampaeng Volcanics' is used in this paper to denote these eruptive rocks of uncertain age. Its setting and possible implication to San Kampaeng geothermal field based on total field ground magnetic map will be discussed later.

Total field ground magnetic anomaly map

Figure 2 is a ground magnetic survey grid which has been installed at San Kampaeng area of known hot springs. Survey lines are oriented about N 60° E. Bottom line, in Figure 2, is set as line 1 and the top of the survey grid as line 11. Each parallel line is about 400 metres apart and about 3.2 kilometres long except the last five lines are

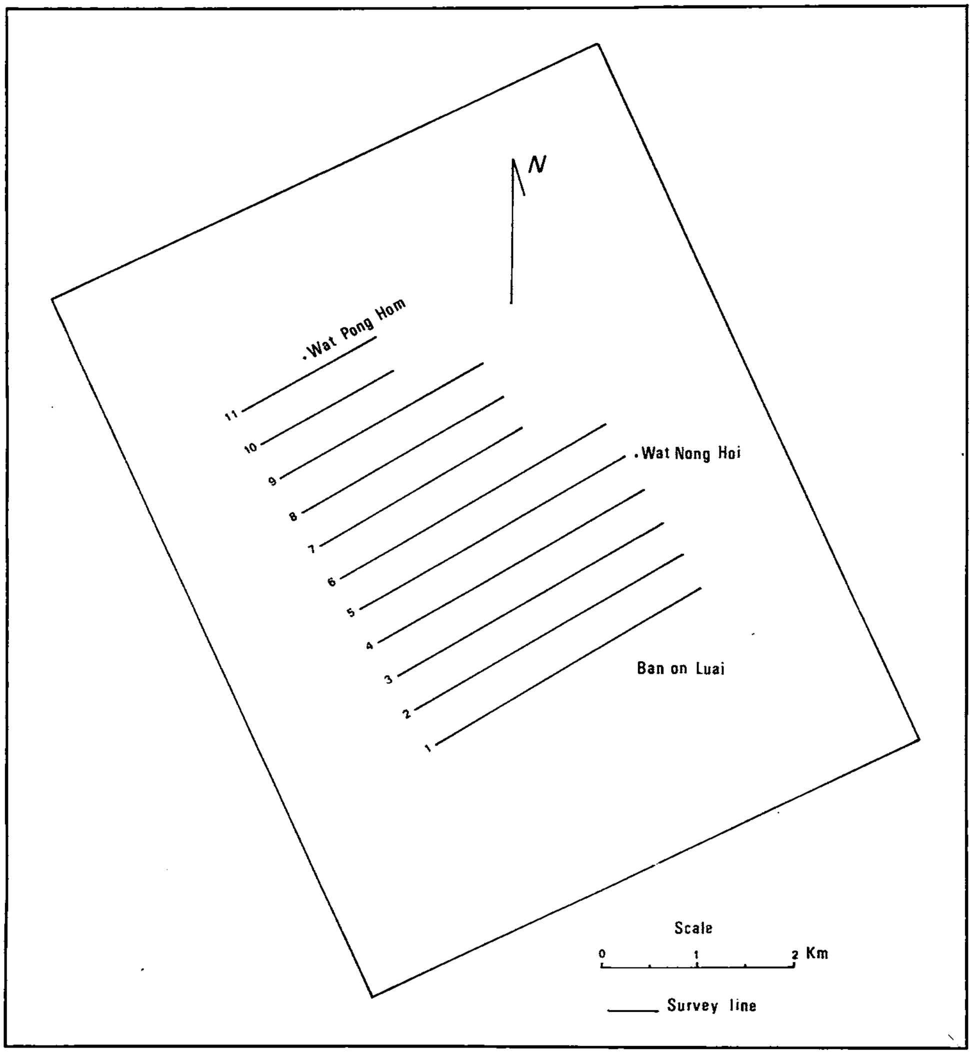

Fig. 2. Ground magnetic survey lines at San Kampaeng area.

shorter. These eleven lines cover this San Kampaeng geothermal area with an expected fault in the middle (N-S direction). Magnetic data were collected at 100 metre intervals along each survey line. Only 300 reading points from these survey lines are used for this paper. All these magnetic data have been corrected for diurnal variation before considering their magnetic anomalies.

Since drilling has already been done to a depth of 500 metres, only deep magnetic bodies will be considered for the magnetic anomaly map in this paper. That is, all magnetic anomalies near the surface will be removed by a digital filter. Since the magnetic spectrum for a deep magnetic body will be confined to the low frequency end, only the long wavelength magnetic spectrum will be shown on the contour magnetic anomaly map.

In processing these magnetic data, we will treat the data in profile form before stacking and contouring since McIntyre (1981) found that filter data on a single profile followed by stacking of all the profiles give a more accurate display of fine detail in the aeromagnetic data than processing data in the map form. In this paper, a digital Butterworth filter was chosen for processing these magnetic data because the Butterworth filter has the properties of providing a very sharp cutoff and a flat response in the pass range (Blair and Spathis, 1980). Before filtering the magnetic data, the cutoff frequency point must be known. To choose the range of frequency for these magnetic data, we used the technique set by Sertsrivanit (1983), that is, the energy

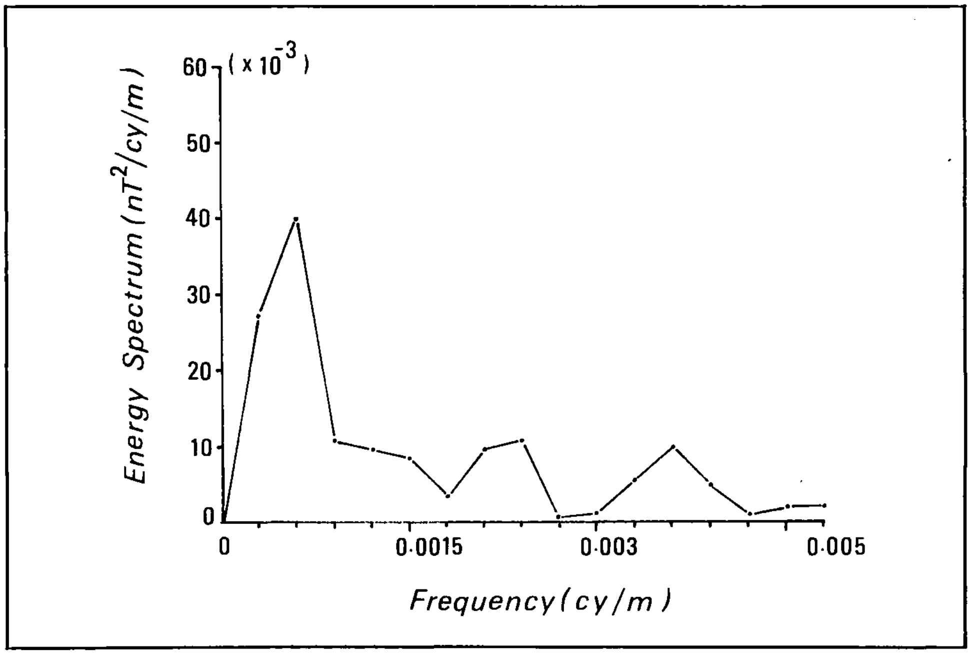

Fig. 3. Plot of energy spectrum of the raw data in the frequency range from 0 to 0.005 cycle/metre. Note the high energy spectrum is confined at the low frequency end less than 0.0015 cycle/metre.

spectrum was plotted against its frequency, hence the range of high amplitude energy spectrum was determined at the low frequency end. Therefore, a chosen magnetic profile line number 6 (see Figure 2) was computed for energy spectrum with a data point number of 2^5 via Fast Fourier Transform (FFT). We used the FFT computer program which was written by Sertsrivanit (1983) in FORTRAN IV in DECSYSTEM-20 computer for the University of New England. In using this computer program, we transferred the program into the VAXSYSTEM-11 computer of Chiang Mai University.

Figure 3 is a plot of energy spectrum from line number 6. The plot shows the energy spectrum in the range of frequency from 0 to the highest frequency or nyquist frequency at 0.005 cycle/metre. In Figure 3, the high amplitude energy spectrum is

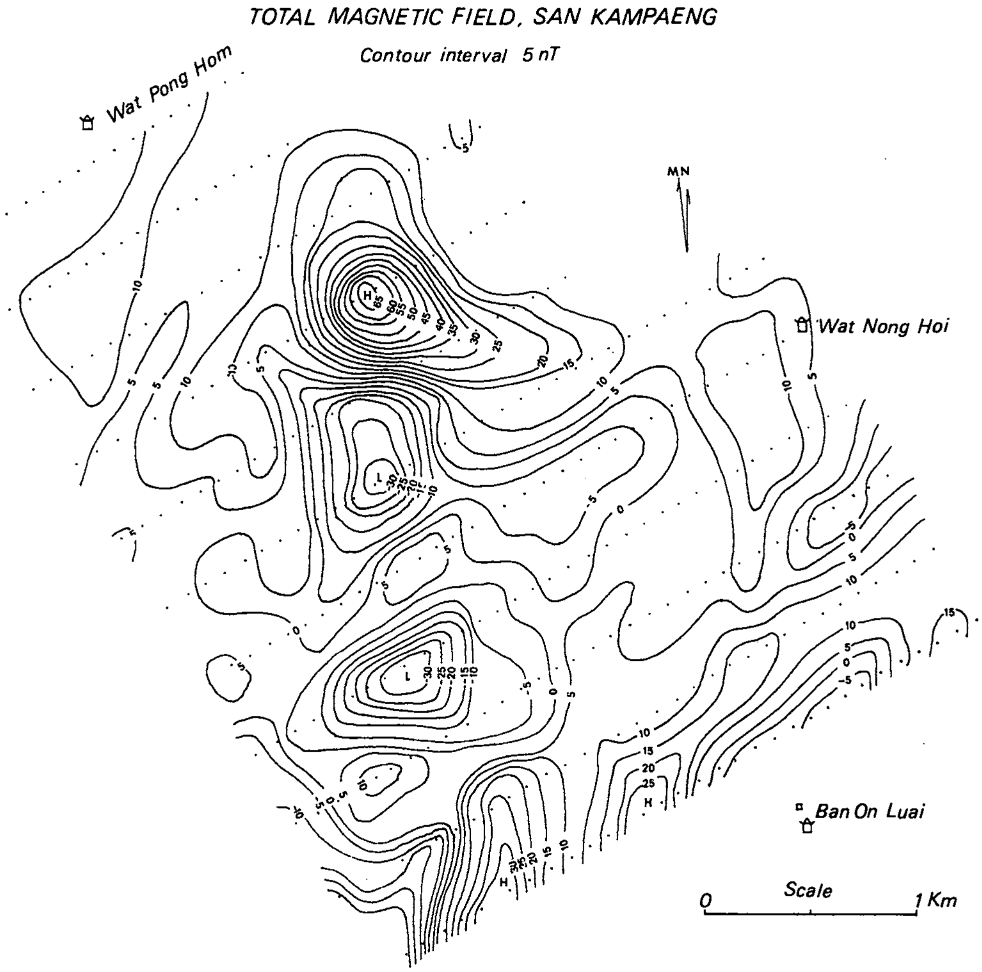

Fig. 4. Total field ground magnetic anomaly map at San Kampaeng geothermal area.

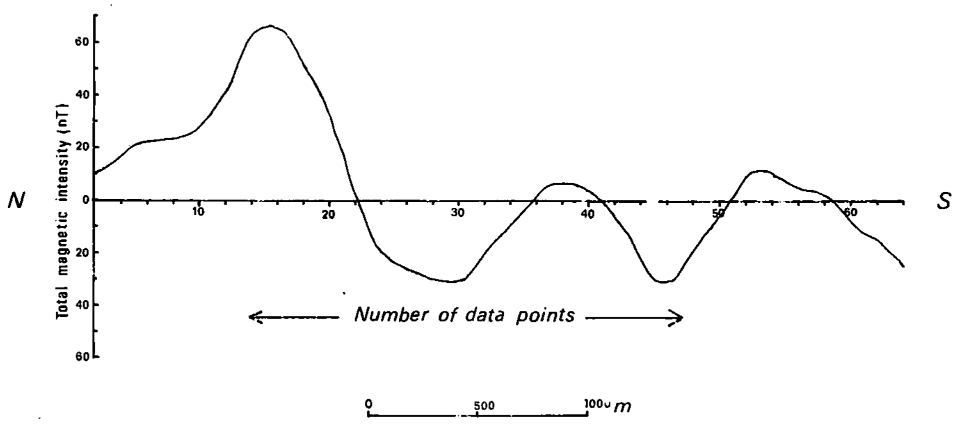

Fig. 5. Magnetic profile in N-S direction along the magnetic anomalies in Figure 4.

confined to the low frequency end of less than 0.0015 cycle/metre. Therefore, the frequencies which are higher than 0.0015 cycle/metre will be cut off by the digital Butterworth filter.

We plotted all these filtered magnetic data on a contour magnetic map form by hand with a contour interval of 5 nT as shown in Figure 4. The map shows a magnetic anomaly trend in N-S direction with the highest magnetic anomaly in the northern part. The maximum magnetic anomaly of this map is 65 nT and the minimum is – 30 nT, (see the magnetic profile along this magnetic anomaly trend in Figure 5). The maximum magnetic anomaly is approximately confined at the grid survey line of line number 8 (see Figure 2). The magnetic body strikes about N68°W and gently dips down approximately in the eastern direction. The magnetic anomaly trend (in the N-S direction) also gently dips down to the East with a steep side facing to the West, (see map in Figure 4). Magnetic bodies along the magnetic anomaly trend must be moved or dragged up through the fault which is gently dipping East and acts as a body of heat source at depth. Therefore, this linear feature (N-S direction) of these magnetic bodies shows the existence of fault adjacent to the massive limestone (see geologic map in Figure 1).

The shape of the magnetic bodies in terms of width and thickness is still in preparation by Sertsrivanit and Tantisukrit (1984) using curie-point depth determination of magnetic heat source at the San Kampaeng geothermal area. In this paper, we concentrate only on the depth of the magnetic body which will be computed in the next section.

Magnetic source depth determination

A mathematical expression for the power spectrum of the total magnetic field intensity anomaly over a single rectangular block was first derived by Bhattacharyya (1966). This expression was applied to describe two-dimensional (2-D) techniques for spectral analysis of aeromagnetic anomalies lacking linear features (Gudmundsson, 1967; Naidu, 1969; Spector and Grant, 1970; Mishra and Naidu, 1974; and Bhattachryya and Leu, 1975). But Green (1972) used the expression to describe magnetic profile data. That is, the expression for the energy spectrum of the magnitude of the magnitic field due to the block in one-direction is given by

$$E(v) = 4\pi^2.K^2.R_T.R_K.[\exp(-2hv)].\left[\frac{\sin(va)}{va}\right]^2.[1-\exp(-tv)]^2 \qquad (1)$$

where K = magnetic moment/unit depth,
R_T = factor for geomagnetic field direction,
R_K = factor for magnetization direction of the block,
h = depth to the top of the body,
v = the angular frequency,
$2a$ = width of the block, and
t = thickness of the body.

We used the magnetic profile data from Figure 5 to compute their energy spectrum via FFT. The magnetic profile was digitized by hand with reading interval of 62.5 metres and a data point number of 2^6 (64 points). Figure 6 is a plot of the

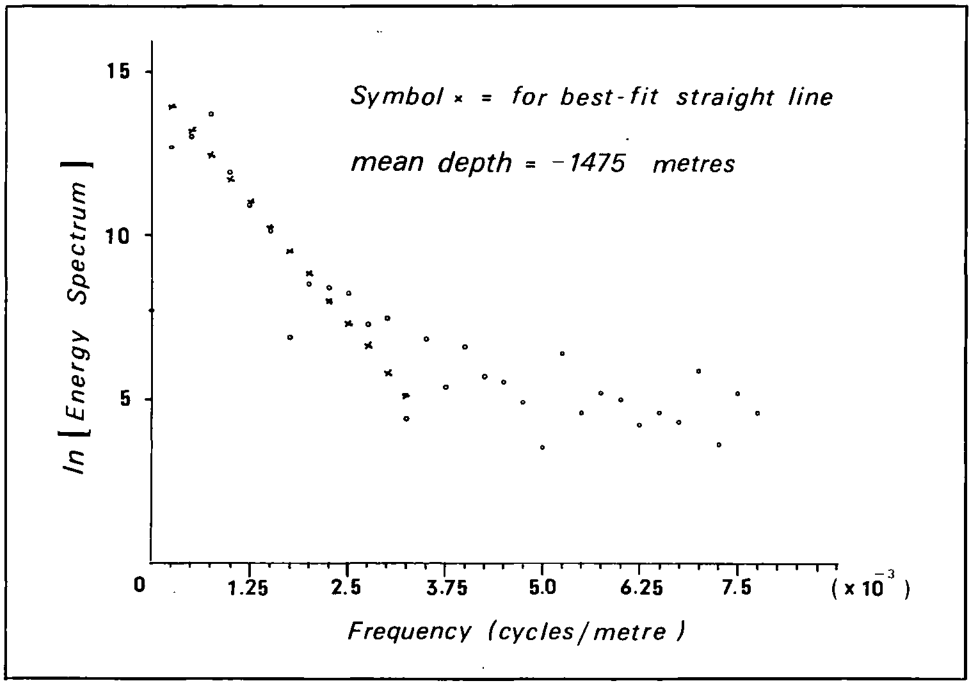

Fig. 6. Logarithm energy spectrum of San Kampaeng magnetic anomalies in N-S direction (see map in Figure 4) Depth estimate for an ensemble magnetic body was obtained by using the slope of best-fit straight line in the least-square sense of the logarithm energy spectrum.

logarithm of energy spectrum against its frequency, in the range from 0 to 8×10^{-3} cycles/metre. Depth estimation of magnetic body was obtained by best-fit straight line (in the least-square sense) at the low frequency end as shown in Figure 6. From Green (1972), the average depth is given by

$$\text{gradient} = -2 \times h \tag{2}$$

Then, the average depth of this magnetic body, computed by using equation 2, is 1475 metres.

Structural implications of ground magnetic anomalies

JICA (1983) believed that magnetic anomalies might be derived from igneous activities that occurred along the fault zones. In this study, magnetic anomalies are clearly seen in the area of Permian sequence approximately beneath the massive limestone hills. It is postulated that the cooling magnetic body inferred beneath the anomalies is the ultimate source of heat for the San Kampaeng geothermal system. The geothermal manifestations are distributed to the west of these anomalies and controlled by a fracture system in the Permian rocks. Geothermal potential within the volcanic field to the east of the anomalies is low because the lack of a fracture system.

The fault revealed by the alignment of magnetic anomalies is interpreted to locate the eastern rim of the massive limestone. It is dipping gently to the east and the sense of movement is likely to be a reverse one. The large volume of San Kampaeng Volcanics might be brought to the present location by this fault. A 500 m. depth hole (GTE 1) did not penetrate through the volcanics suggesting that the San Kampaeng Volcanics is large and complex and that multiple volcanic events are likely. The lower part of the sequence may be Carboniferous in age as suggested by Macdonald and Barr (1978).

The main structure of the area is characterised by horst and graben blocks formed by faults of north-northwest trend which is believed to occur during Tertiary–Quaternary. There is no Tertiary sequence in the depression within the area. But flat lying columnar basalt was reported by Pothong *et al.* (1982). It is proposed that the north-south trending fault might have been reactivated and that volcanic activity might have occurred as the last episode during Tertiary–Quaternary. The basaltic lava flow, in places, covered the depression instead of sedimentation as in the adjacent Chiang Mai Basin. The young igneous activity might have direct implication to the geothermal system. Further systematic geochemical and isotope analyses should be carried out to explain the geochronology and evolution of the San Kampaeng Volcanics.

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