Bulletin of the Geological survey of Japan, vol. 38(1), p. 1-6, 1987 550.836 : 778.3 : 551.23 : 550.361(593-17)

Structural control of the hot springs of northern Thailand based on the analysis of Landsat imagery

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SASADA, M., CHATURONGKAWANICHI, S., SOPONPONGPIPAT, P., OBARA, K. and OCHI, M. (1987) Structural control of the hot springs of northern Thailand based on the analysis of Landsat imagery. *Bull. Geol. Surv. Japan*, vol. 38(1), p. 1-6.

Abstract: Landsat imagery was photogeologically interpreted to elucidate a structural control of the hot springs of northern Thailand. As the result of the photogeologic interpretation, the geology of northern Thailand was classified into Quaternary sediments, Tertiary sediments, granitic rocks, dike rocks and others consisting mainly of Precambrian to Mesozoic metamorphic and sedimentary rocks. Folds, lineaments and semi-annular structures were also interpreted.

There are 42 hot springs in the study area. Most of them occur in pre-Tertiary basement rocks. They appear to be correlative with major lateral faults, Cenozoic basins, semi-annular structures and fracture systems in the granitic region.

1. Introduction

Hot springs principally occur in pre-Tertiary basement rocks in northern Thailand. It has been noted that the hot springs are closely related to the fracture system developed in the basement rocks (BARR et al., 1979; RAMINGWONG et al., 1980). In order to clarify a structural control of the hot springs, Landsat imagery was photogeologically interpreted. This paper presents the results of the analysis of Landsat imagery and the considerations on relationship between the hot springs and geologic structure of northern Thailand.

The authors would like to express their appreciation to Dr. K. KAWADA, formerly Geological Survey of Japan, Dr. I. TAKASHIMA, Akita University, and Messrs. M. RAKSASKULWONG, A. SURINKUM and K. TURALTAMKUL, Department of Mineral Resources, Thailand for suggestions, discussions and encouragement during the course of the work. They are also much indebted to Dr. S. J. GAWARECKI, U. S. Geological Survey and Mr. S. CHUAVIROJ, Department of Mineral Resources, Thailand for critical reading of the manuscript. They take full responsibility for the ideas presented in this paper.

2. Analytical Procedure

Six Landsat scenes were prepared to analyze morphological features and macroscopic geologic structures (Fig. 1 and Table 1). They are clear images of high quality with minor cloud development. False color composite images on a scale of 1 : 500,000 were obtained of the scenes by using a red filter on band 5 and a blue filter on band 7. The resulting red and reddish brown areas on the imagery represent dense vegetation. Other areas are characterized by sparse or no vegetation, that is, grayish blue represents either cultivated or marshy area. In addition, medium to dark blue symbolizes river or sea water and light gray to cream shows flat flood plains. White, seen on some images

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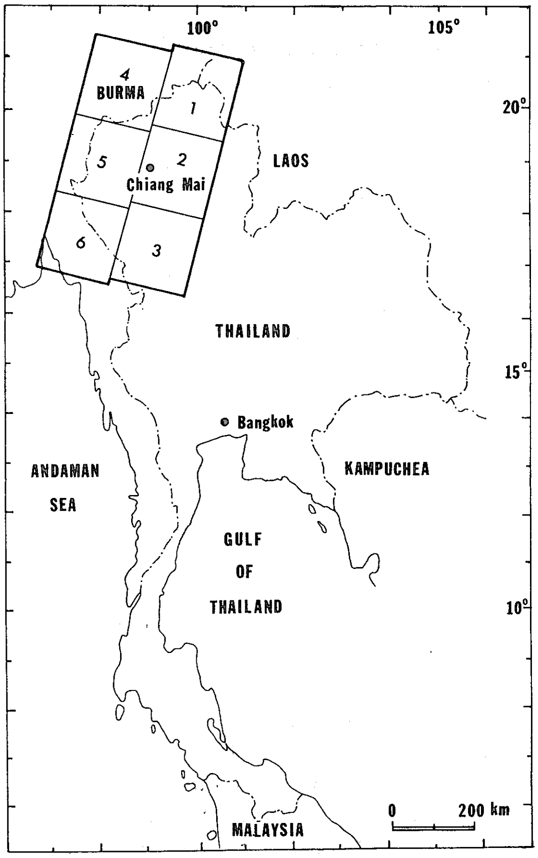

Fig. 1 Location of the study area.
Numbers of the Landsat scene correspond to those in Table 1.

is clouds and / or ground fog.

The surface drainage system was interpreted and transferred to an overlay. A classification of geologic units as well as an interpretation of geologic structures were then carried out. The geologic structures were analyzed photogeologically with attention to the following interpretation factors: photocharacteristics (tone and texture) and morphological expressions (drainage pattern and its density, resistance, cross section of valley, relief energy, lineaments, ridge forms, bedding attitude etc.). Annotation symbols such as bedding, fold, lineament and other geologic structures obtained by the interpretation were transferred to another overlay.

The results of analyses are shown in the following two maps; a drainage map by interpretation on Landsat imagery with hot spring location (Fig. 2) and a geologic structure map by interpretation on Landsat imagery with hot spring location (Fig. 3).

3. Results of Analyses

3.1 Classification of Geologic Units

As the results of the analyses of the Landsat false color composite imagery, the study area was classified into the following geologic units; Quaternary sediments (Q), Tertiary sediments (T), granitic rocks (Gr), dike rocks (D) and others (O) (Fig. 3). This classification of the geologic units is consistent with the geological map of northern Thailand compiled by Geological Survey Division, Department of Mineral Resources (1982). The area classified into others (O) corresponds mainly to Precambrian to Mesozoic metamorphic and sedimentary rocks on the geological map.

Quaternary sediments (Q) are mainly distributed in the eastern and central parts of the study area, including Chiang Mai, Fang, Chiang Rai, Lampang and Phrae (Fig. 3). They are also found in the southern part of the study area, which belongs to Burma. Their tones on the false color composites are light gray, cream, pale brown and grayish blue. The Quaternary sediments generally

Table 1 Landsat Scene Data

Nos	Date	Scene ID	Format center coordinate Latitude	Longitude	Sun elevation angle	Sun azimuth angle
1	1976.2.25	E 2399−03013	N 20° 09′	E 99° 51′	42°	124°
2	1976.2.25	E 2399−03015	N 18° 43′	E 99° 30′	42°	123°
3	1976.2.25	E 2399−03022	N 17° 19′	E 99° 08′	43°	122°
4	1976.2.26	E 2400−03071	N 20° 12′	E 98° 25′	42°	124°
5	1976.2.26	E 2400−03074	N 18° 46′	E 98° 04′	43°	123°
6	1973.1.27	E 1188−03231	N 17° 26′	E 97′ 46′	40°	134°

Fig. 3 Geologic structure map by interpretation on Landsat imagery with hot spring location.

Fig. 2 Drainage map by interpretation on Landsat imagery with hot spring location.

show a fine-grained and smooth texture. Meander and parallel drainage patterns with low density of development are observed on plains. This unit can be easily discriminated from other geologic units, based on the geomorphological features mentioned above and extremely sparse vegetation.

Tertiary sediments (T) are mainly found adjoining the Quaternary sediments, especially developed in the central and eastern parts of the study area (Fig. 3). Their tones on the false color composites are light grayish orange, light bluish gray and reddish brown. This unit generally shows a fine-grained and smooth texture with a parallel drainage pattern having low density of development. This unit is found on plains and hilly districts with slightly higher erosion resistance than the Quaternary sediments. The boundary between this unit and others is generally sharp.

Granitic rocks (Gr) are found mainly in the central part of the study area (Fig. 3). The tones on the false color composites for these rocks are vermillion and grayish orange red. This unit shows a medium-grained texture. The drainage pattern is parallel or rectangular with low density of development. This unit forms the mountainous areas showing moderate to high resistance. Lineaments of low intensity are well developed with prominent directions in this unit. Lengths of those lineaments are short compared with those of medium and high intensity on other units and generally have intermittent mode of a short interval. The boundary between this unit and others is generally vague. Field evidence shows that highly metamorphosed rocks associated with the granitic rocks are involved in this unit.

Dike rocks (D) are found only in the southern part of the study area (Fig. 3). They are characterized by a linearly independent terrain with a high resistance. The tone on the false color composites for these rocks is light orange gray. This unit shows fine-grained texture. It makes linear structure on the plain of Tertiary and Quaternary sediments. Though there are less geological and petrographical data available on this unit, the mode of occurrence suggests that the dike rocks may have formed during or after the Tertiary period.

Other rocks (O), mainly Precambrian to Mesozoic metamorphic and sedimentary rocks are widely distributed outside of the above units (Fig. 3). Their tones on the false color composites are vermillion, grayish orange red and reddish brown in mountainous districts, bluish gray and dark bluish gray in cultivated hilly districts, light grayish orange in plains and dark grayish blue along rivers. This unit shows medium- to coarse-grained texture and moderate to high resistance to erosion. Some linear structures are attributable to relict bedding planes. Drainage patterns can be either sub-dendritic, sub-parallel or rectangular. The boundary between this unit and others is generally vague.

3.2 Geologic Structures

The western half of the study area is underlain mainly by pre-Tertiary sedimentary and metamorphic rocks and granitic rocks (Fig. 3). North-south trending faults are well developed and are often associated with elongate Cenozoic basins. One of the largest fault, the Yuam fault system (BAUM et al., 1970), runs through Mae Sariang and Mae Hong Son.

The Cenozoic basins, which are developed in the mountains, are underlain by the intensively folded pre-Tertiary system in the eastern half (Fig. 3). They are generally elongated in the north to south direction. The folded pre-Tertiary system has many faults parallel to the fold axes. Both of the structures in the western and eastern halves turn and converge each other toward the south (Fig. 3).

Folding occurs mainly in the Precambrian to Mesozoic metamorphic and sedimentary rocks (Fig. 3). In the western part fold axes generally run north-south. Anticlinal and synclinal structures with short wavelengths (3 to 5 kilometers) occur repeatedly in the southwestern part. In the eastern part the fold belt swings in broad curving trends, form northeastward in the south through northward to northeastward in the north (Fig. 3).

Lineaments are classified into three groups in the study area, that is, of high, medium and low intensity. A lineament of high intensity would be a fault, because it is long, continuous and characterized by an anomalously straight drainage. A lineament of low intensity would be a fracture such as a major joint or a fault without obvious dislocation, because it is generally restricted to one geologic unit and usually is discontinuous with a preferred orientation. A lineament of medium intensity has intermediate characteristics between those of high and low intensity.

The Yuam fault system is one of the lineaments of high intensity (Fig. 3). The associated drainage pattern suggests that it would be a right-lateral fault. The lateral movement of this fault system shows the same sense of direction as the Sittang fault in Burma (e. g. HAMILTON, 1979). An east-west trending high intensity lineament runs on the north of Fang basin through Mae Chan hot spring (Fig. 3). The drainage pattern suggests that it would be a left-lateral fault.

The NNW- and NE-trending lineaments are developed in the granitic region (Fig. 3). The former trend is observable widely while the latter is remarkable to the northeast of Chiang Mai.

Semi-annular structures, with their annular drainage patterns, occur in the vicinities of Chiang Mai, Fang and Chiang Rai, mainly in sediments of the Tertiary and Quaternary systems (Fig. 3). There are three semi-annular structures around Chiang Mai, the largest of which is 40 kilometers in radius. The other two are obscure as are the semi-annular structures in the vicinities of Fang and Chiang Rai.

Some of the interpreted Cenozoic dikes in the southern part of the study area trend northeastward (Fig. 3).

4. Structural Control of Hot Springs

There are 42 hot springs in the study area (CHUAVIROJ and CHATURONGKAWANICH, 1984). They seem to be scattered in the wide area, but it has been pointed out that some hot springs are distributed around Cenozoic basins and some are around granitic batholiths (BARR et al., 1979). As the result of the comparison of the hot springs with the photogeologic map made from the Landsat imagery, the hot springs seem to correlate with major lateral faults, Cenozoic basins, semi-annular structures and lineaments in the granitic region and most of them occur in the pre-Tertiary basement rocks (Table 2).

Some hot springs are distributed along major lateral faults. Hot springs MH 1, MH 2, MH 11, MH 12 and MH 13 are situated along the Yuam fault system (Fig. 3). They all are distributed within several kilometers of the major fault. Some of them are located near the lineaments of medium intensity close to the faults system. On the other hand the Mae Chan hot spring (CR 4) and CM 12 are very close to the east-west trending left-lateral fault which runs through the north of Fang basin (Fig. 3). Hot water seeps through the joint of the local granitic rocks, whose alignment is about N 20°E. This direction is almost parallel to one of the predominant joint sets in this area (RAMINGWONG et al., 1980). This evidence suggest that minor faults and joint systems associated with the major faults would play an important role in the circulation of hot water. They are assumed to have rejuvenated by recent lateral movement of the major faults.

Many hot springs are located around Cenozoic basins. Especially, there are 8 hot springs in and around Pai basin underlain by the Tertiary and Quaternary systems (Fig. 3).

San Kamphaeng hot spring (CM 1) is situated about 5 kilometers inside the large and clear semi-annular structure previously mentioned. Another three hot springs (CM 2, LN 1, LN 2) are also located along the semi-annular structure. NNW- and NE-trending lineaments occur in the pre-Tertiary basement rocks near the semi-annular structure. The hot springs align along the NNW-trending Huai Ang fault at San Kamphaeng (CM 1) (CHUAVIROJ et al., 1980). Although it is a minor fault as is not presented on the geologic structure map (Fig. 3), it is parallel to the lineament prominent in this area. These hot springs could be related to the fracture systems rejuvenated by a recent movement of the semi-annular structure.

Some of the hot springs appear to be cor-

Table 2 Hot springs and related geologic structures

Hot Spring	Geologic Unit	Surface Temp. (℃)	Related geologic structures
CM 1	O	99	Semi–annular structure and lineaments of medium intensity
CM 2	O	81	Semi–annular structure
CM 3	G	96	Cenozoic basin
CM 4	O	99	
CM 5	O	…	Lineament of medium intensity
CM 6	O	< 60	Lineament of medium intensity
CM 7	G	90	Intermittent lineament of high intensity in granitic region
CM 8	O	70	Intermittent lineament of high intensity
CM 9	T	68	Cenozoic basin
CM 10	T	75	Cenozoic basin
CM 11	O	74	Lineament of high intensity
CM 12	G	60 - 90	EW–trending major lateral fault (lineament of high intensity)
CR 1	G	65	Lineament of medium intensity in granitic region
CR 2	G	85	Lineament of high intensity in granitic region
CR 3	G	80	Lineament of medium intensity in granitic region
CR 4	G	99	EW–trending major lateral fault (lineament of high intensity)
CR 5	O	80	
CR 6	O	93	Cenozoic basin
CR 7	O	60	Cenozoic basin
LN 1	O	< 60	Semi–annular structure
LN 2	T	< 60	Semi–annular structure
LP 1	T	78	Cenozoic basin
LP 2	Q	60	Cenozoic basin
LP 3	Q	60	Cenozoic basin
LP 4	O	74	Lineament of high intensity
MH 1	O	60 - 90	Yuam lateral fault (lineament of high intensity)
MH 2	O	…	Yuam lateral fault (lineament of high intensity) and associated lineaments
MH 3	O	92	Pai basin (Cenozoic basin)
MH 4	G	78	Pai basin (Cenozoic basin)
MH 5	O	93	Pai basin (Cenozoic basin)
MH 6	G	75	Pai basin (Cenozoic basin)
MH 7	O	40	Pai basin (Cenozoic basin)
MH 8	G	82	Pai basin (Cenozoic basin)
MH 9	G	…	Pai basin (Cenozoic basin) and lineament of medium intensity
MH 10	T	…	Pai basin (Cenozoic basin) and lineament of medium intensity
MH 11	O	78	Yuam lateral fault (lineament of high intensity)
MH 12	G	60 - 90	Yuam lateral fault (lineament of high intensity)
MH 13	O	81	Yuam lateral fault (lineament of high intensity)
PR 1	O	< 60	
PR 2	O	78	
PR 3		< 60	(Outside the study area)
PR 4	O	…	Lineament of high intensity
SK	O	< 60	Lineament of medium intensity

relative with lineaments developed in the granitic region. Hot spring CM 7 is located along the NNW-trending intermittent lineaments of high intensity (Fig. 3). The hot spring could be controlled by this fracture system. CR 2 and CR 3 are also located near the NNW-trending lineaments in the granitic region to the west of Chiang Rai.

5. Summary and Conclusions

Geology of northern Thailand was classified into the following five geologic units, based on the photogeologic interpretation of Landsat imagery; Quaternary sediments, Tertiary sediments, granitic rocks, dike rocks and others consisting mainly of Precambrian to Mesozoic metamorphic and sedimentary rocks. Folds, lineaments, some recognizable as faults; and semi-annular structures are also interpreted by the photogeologic study.

The hot springs appear to correlate with the following young geologic structures; major lateral faults, Cenozoic basins, semi-annular structures and fracture systems in the granitic region.

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ランドサット画像解析にもとづくタイ北部の温泉の構造規制

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要　旨

タイ北部の温泉の構造規制を明らかにするために，ランドサット画像の解析を行った．調査地域は写真地質学的にみて，第四紀堆積岩類・第三紀堆積岩類・花崗岩類・岩脈・その他（先カンブリア紀から中生代の堆積岩類・変成岩類等）に区分できる．本地域の西半分は先第三系の堆積岩類・変成岩類・花崗岩類から主として構成され，その中に右横ずれのユアム断層，新生代の堆積盆等の南北性の新しい構造が認められる．一方東半分では褶曲した中生代以前の堆積岩類の間に，新生代の堆積盆が繰返し細長く伸びている．またサンカンペン付近には大きな半環状構造が認められる．本地域には 42 の温泉があり，それらのほとんどは先第三系中に胚胎している．これらの温泉は，大きな横ずれ断層，新生代の堆積盆，半環状構造及び花崗岩地域に発達する断裂系に関連しているようにみえる．

（受付：1986 年 7 月 2 日；受理：1986 年 10 月 27 日）