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Analysis of proposed geosites in the Betong District, Yala Province, Southern Thailand

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Abstract

This study aims to analyse the geosite candidates of the Betong District (Yala Province) in Southern Thailand by means of several methods including inventory, characterisation, classification, assessment and SWOT analysis. Results of the present study are illustrated through seven proposed geosites that become resources for the development of the Betong District, namely Betong Hot Spring, Inthasorn Waterfall, Chaloem Phra Kiat Waterfall, Mount Silipat and Nakor Hot Spring, as well as Piyamit Tunnel and Aiyerweng Skywalk, two human-modified sites which can be used to observe geological and geomorphological features. The present study is expected to promote the conservation and development of these resources as geological heritage of the district.

Keywords: geodiversity, geoheritage, geoconservation, hot springs, waterfalls

1. Introduction

The term ‘geosite’ often refers to the *in-situ* occurrence of geodiversity features with high scientific, educational, aesthetic and cultural values. The existence of geosites is based on geodiversity including minerals, rocks, fossils, landforms and landscapes, soils, active geological and geomorphological processes, or other georesources. Meanwhile, the term ‘geomorphosite’ will be used if the element being valued is geomorphological in nature (Brilha, 2018). There are several other geological concepts that are closely related to geosite such as geodiversity, geoheritage, geoconservation and geotourism. Gray (2005, 2013) defined the term ‘geodiversity’ as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, physical processes), soil and hydrological features, inclusive of their assemblages, structures and systems. ‘Geoheritage’ describes *in-situ* and *ex-situ* occurrences of high value geodiversity elements and concentrates on distinctive, remarkable and representative geological features (Brilha, 2016). ‘Geoconservation’ is the study and practice of managing and protecting elements of geodiversity with extraordinary values (Henriques et al., 2011). Meanwhile, Newsome & Dowling (2010) defined ‘geotourism’ as a form of natural area tourism that specifically focuses on landscape and geology. It promotes tourism to geosites and the conservation of geodiversity and an understanding of Earth sciences through appreciation and learning.

In Thailand, the Department of Mineral Resources (DMR), a governmental agency which is responsible for study of and research into minerals and geological processes and phenomena, has produced a lot of media for introducing and promoting geosites all over the country. Guidebooks and DVDs of geosites in several provinces have been published and distributed through the website www.dmr.go.th. There are also publications on geosites in several provinces, such as Chiang Mai Province in Northern Thailand (Singtuen et al., 2019), Khon Kaen Province in Northeastern Thailand (Jantakham, 2018), Uthai Thani Province in Central Thailand (Singtuen & Won-in, 2018), as well as Songkhla Province and Samui Island in southern Thailand (Nazaruddin, 2019, 2020).

Betong District in Thailand's southern border province of Yala is rich in geological sites and features that may potentially be proposed as geosites. The present study aims to analyse proposed geosites of the Betong District in Yala Province, Southern Thailand as important resources for sustainable development in this area by producing an inventory, characterisation, classification, assessment and evaluation of these sites.

2. Study area

2.1. Geographical setting

"Betong" is a Malay word for bamboo. The Betong District is one of eight districts (*amphoe*) in Yala Province. This southernmost district of Thailand is located around 1,200 km from the capital Bangkok and about 140 km from Mueang Yala (capital of Yala Province). It connects with the Malaysian states of Perak and Kedah in the south and west, respectively, and with another Yala district, that of Than To, and the Narathiwat's district of Chanae in the north and east, respectively (Fig. 1). The Betong District is divided into five sub-districts (*tambon*): Betong in the southwest, Than Nam Thip in the central-south, Yarom in the south and southeast, Tana Maero in the west and Aiyerweng in the north. The town of Betong is the capital and the main town of the district. The Betong District is currently accessible from Bangkok, Kuala Lumpur and Singapore by airplanes that land at Betong International Air-

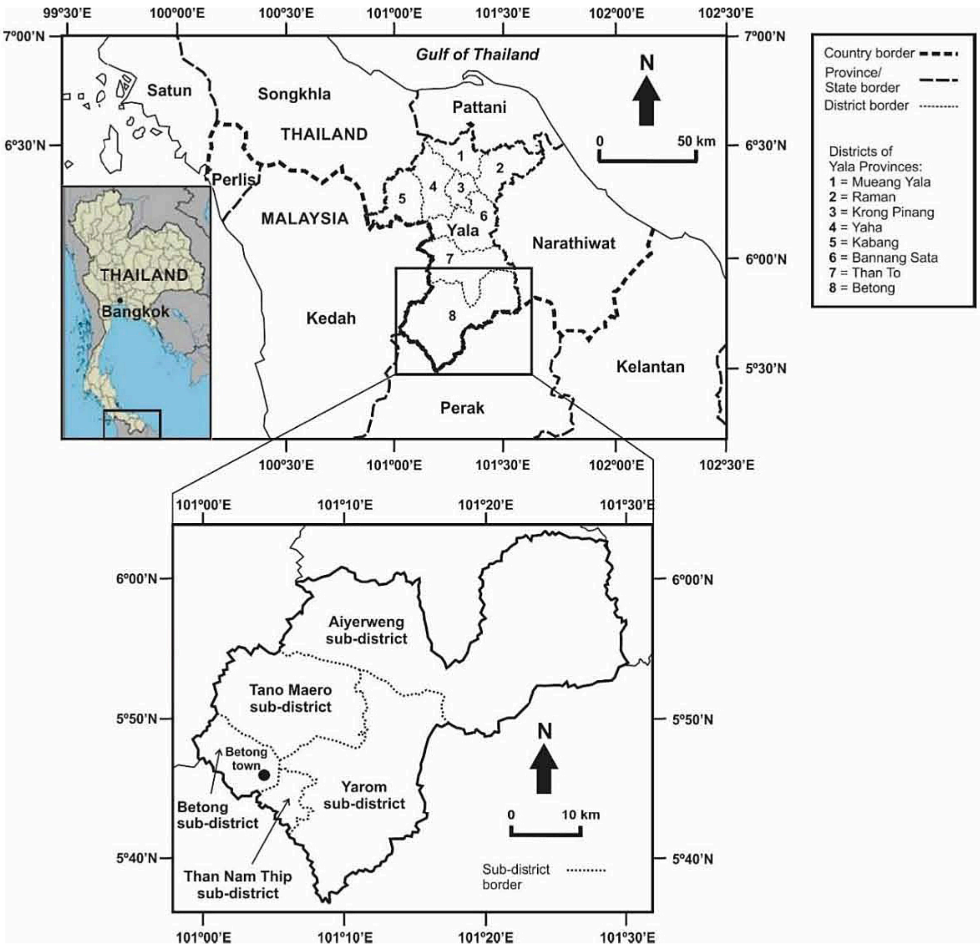

Fig. 1. Map showing the Betong District (Yala Province, Southern Thailand) and its administration areas.

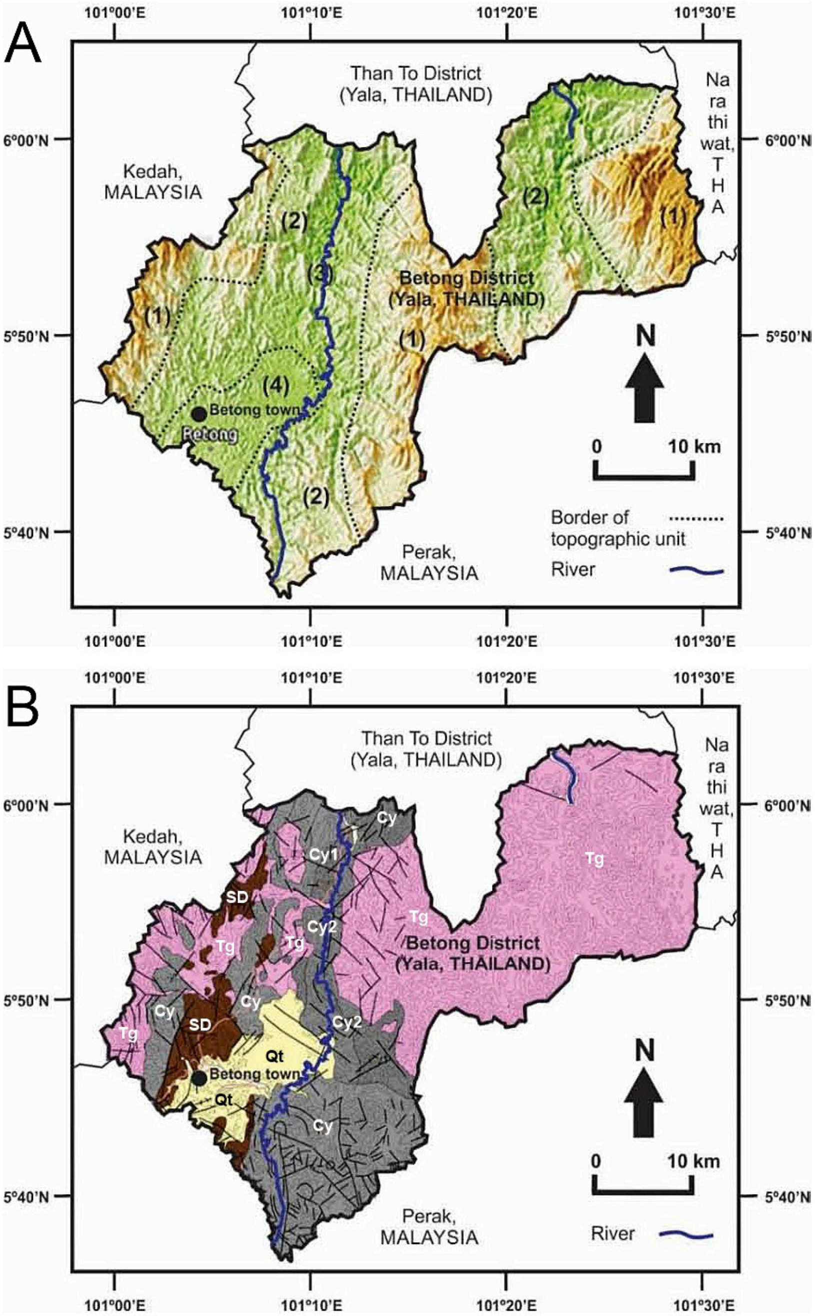

Fig. 2. A – Topographic map of the study area: 1 – mountainous area, 2 **–** hilly area, 3 – river valley, 4 – plain area; **B –** Geological map of the study area (DMR, 2007): SD – very thin- to thin-bedded shale, siltstone, lithic sandstone with subordinate chert and argillaceous limestone lenses (Silurian-Devonian), Cy – very thin- to medium-bedded sandstone, shale, siliceous shale, chert and conglomerate (Carboniferous), Cy1 – argillaceous facies of Cy, Cy2 – arenaceous facies of Cy, Qt – terrace deposits: gravel, sand, silt, clay and laterite (Quaternary), Tg – granite and granodiorite (Triassic).

port. The journey from the city of Yala to Betong passes via a lake, forest and rubber plantation. The district is surrounded by mountains and hills, causing a cool climate and high rainfall with early-day fog being common.

The Betong District is located in the Sankalakhiri Mountain Range, the northern section of the Titiwangsa Range, a mountain range along Peninsular Malaysia. The highest point in the Betong District is Mount Ulu Titi Basah (1,533 m a.s.l.), which is part of the Sankalakhiri Range on the Thailand-Malaysia border between the Betong District and Hulu Perak District of Perak. The topography of the Betong District consists mainly of mountainous and hilly terrains, river valleys and plain areas (Fig. 2a). Mountainous landscapes form the west, centre and east of the district, while hilly areas are distributed at the foot of mountains. The main river valley, that of the River Pattani, stretches from south to north where the river flows and forms the Ban Lang reservoir in the Than To District. Tributaries flow from surrounding mountains and hills, containing several interesting waterfalls. Plain landscape forms the southwest of the district where the town of Betong is located.

2.2. Geological setting

Since the Betong District is situated in the Sankalakhiri Mountain Range, it consists of granitic rocks with several enclaves of sedimentary/metasedimentary rocks that are overlain by Quaternary deposits. Based on the geological map of Yala Province (DMR, 2007; Fig. 2b), sedimentary/metasedimentary rocks in the Betong District stretch along the western part of the district forming the hills. Meanwhile, granitic rocks are distributed roughly in the west, centre and east of the district forming mountainous and hilly terrains. The granitic rocks in the area are a part of the eastern belt granitoid of Thailand that contains many plutons and batholiths (Ishihara et al., 1980; Charusiri et al., 1993). Quaternary deposits are found mainly in the south-west, in the plain areas and along the main river valley.

The Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC, 2009) has conducted a joint project to resolve the cross-border geological correlation problems in the Pengkalan Hulu (Malaysia)–Betong (Thailand) transect area. Based on their detailed study, Silurian-Devonian (SD) sedimentary rocks of the Betong Formation are the oldest rocks in the study area. This succession is distributed in a N-S trending stretch from the town of Betong to the village of Bo Nam Ron – Piyamit III. Local metamorphism to the west resulted in low-grade metamorphic rocks, such as hornfels and slates. Carboniferous clastic rocks (Cy) of the Yaha Formation conformably overlie the Silurian-Devonian Betong Formation and are largely exposed in the south-west and south and towards the north between the granitic belts. Fresh outcrops are well exposed along roadcuttings near the Malaysia-Thailand border. In the central part, this succession can be lithologically subdivided into two facies, the argillaceous facies (Cy1) in the lower part and the arenaceous facies (Cy2) in the upper. Cy1 is well exposed in low-relief areas in the central-eastern part of the district, near the eastern granite pluton. The rocks were metamorphosed to thin- to medium-banded phyllite and schist. Cy2 is well exposed in high-relief terrains also in the central-east of the district, near the eastern granite pluton.

Triassic granitic rocks (Tg) intruded the Palaeozoic sedimentary rocks. These plutonic rocks occur

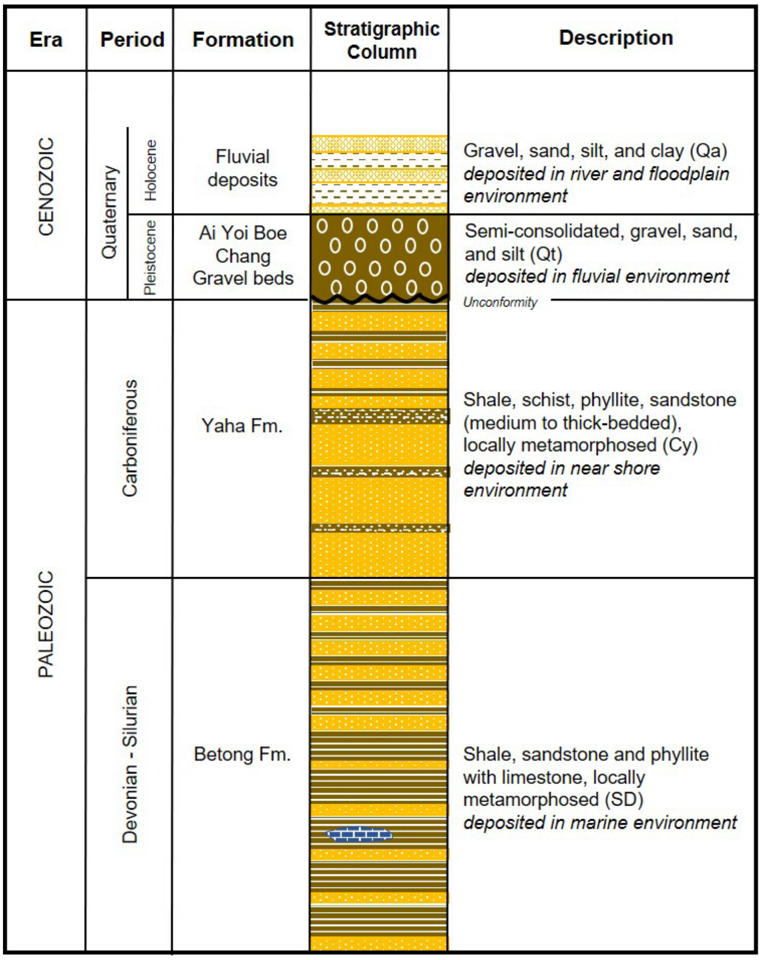

Fig. 3. General stratigraphical succession of the study area (modified from MT-JGSC, 2009).

as batholiths and small stocks and represent part of the Sankalakhiri Mountain the Main Range Granite Belt. There is a threefold subdivision of Triassic granitic rocks in the study area: Si Nakhon granite, Chantharat granite and Pa Ret Tu granite. The first-named is medium- to coarse-grained and light grey in colour, and is represented by N-S trending batholiths which extend across the border to the Malaysian side. These granite outcrops are well exposed along several roadcuttings such as those from Ban Nam Ron to the village of Piyamit 1. The Chantharat granite is characterised mostly by medium- to coarse-grained, sparsely megacrystic to well-megacrystic, unfoliated to weakly foliated, biotite granite. Outcrops of it can be observed in roadcuttings along the road near Ban Chantharat, a village to the east of Betong International Airport. Pa Ret Tu granite is characterised by a leucocratic, fine- to medium-grained, equigranular to inequigranular texture; it is a tourmaline-biotite granite. There are outcrops between the median portions of the Si Nakhon and Chantharat granites; the best exposure is at the village of Aiyerweng.

Geological structures of the Betong District correspond to the regional tectonic pattern of Southern Thailand. Local structures formed as a result of the collision between the Sibumasu (Shan Thai) in the west and the Indo-China blocks in the east (Metcalfe, 2006, 2011). During the Late Triassic, this collision was accompanied by a major tectonic event that caused rock deformation in the region; the continent-continent collision had resulted in uplifting and faulting in a N-S direction. The movement of the major fault may have given rise to younger NE-SW and NW-SE fractures which can be observed in both igneous and sedimentary rocks.

Unconsolidated sediments were deposited unconformably on top of the Betong Formation (SD) in the south-west; these can be subdivided into two formations: the Pleistocene Ai Yoi Boe Chang gravel beds (Qt) and the Holocene/Recent fluvial deposits (Qa). Qt is well exposed as small hills around the town of Betong towards the Malaysia-Thailand border, to the east of the town, and at the village of Ai Yor Boe Chang. Qa is well represented as fluvial deposits in the Pattani, Khlong Ka Pae and Ban Lang rivers. Figure 3 shows the general stratigraphical succession of the rock units in the study area.

3. Material and methods

For elaboration of the present study, we have conducted a literature review and used a set of materials, including maps and photographs related to the Betong District and its potential geosites. A methodology for the analysis of potential geosites, which comprises three phases of time, was established in the present study and is shown schematically in Figure 4. The **inventory** was carried out in the first phase by identifying and selecting geological sites for proposed geosites (both natural and human-modified sites) in the study area. The identification was conducted through an extensive literature review of the study area, including its geography and geology as well as touristic attractions, and the establishment of the proposed geosites was based on several criteria such as sites with representative geological features and processes, and importantly, those with scientific, educational, aesthetic, recreational as well as cultural or historical values (adopted from Predrag & Mirela, 2010; Brocx & Semeniuk, 2011, 2015). The list and map of the proposed geosites produced in this phase will be used for the second phase which encompasses the characterisation, classification and assessment, which were conducted through fieldwork. Following the fieldwork, the list and map were finalised. For the present study, the proposed geosites of this district were numbered, starting from the south which is closer to the town of Betong to the north of the district.

The **characterisation** of all geosite candidates was carried out based on our literature review and direct field observation to describe these and their features in detail for the purpose of the final list of geosites. All information collected from the literature review was then validated and integrated with data obtained during fieldwork. The fieldwork for this project was conducted on November 24 and 25, 2020. Proper attention was given to several geodiversity values including scientific, educational, aesthetic, recreational and additional values (if any), e.g., cultural/historical, economic, functional, etc. Other special natural features (animal and plant life, if any) were also briefly noted so as to support the description. Human-modified sites were also explained in terms of their background or history of development and function. This step provides substantial information on each site, among others (adopted from Brilha, 2016), the precise site name, geographical location, accessibility, geological description (most notably geological features, owner and legal status, if any), and others, wherever applicable.

In the present study, the **classification** of the proposed geosites is based on geodiversity types, scopes and scales of these. Geodiversity was divided into eight types (Gray, 2005): rock, mineral, fossil, landform, landscape, process, soil and other

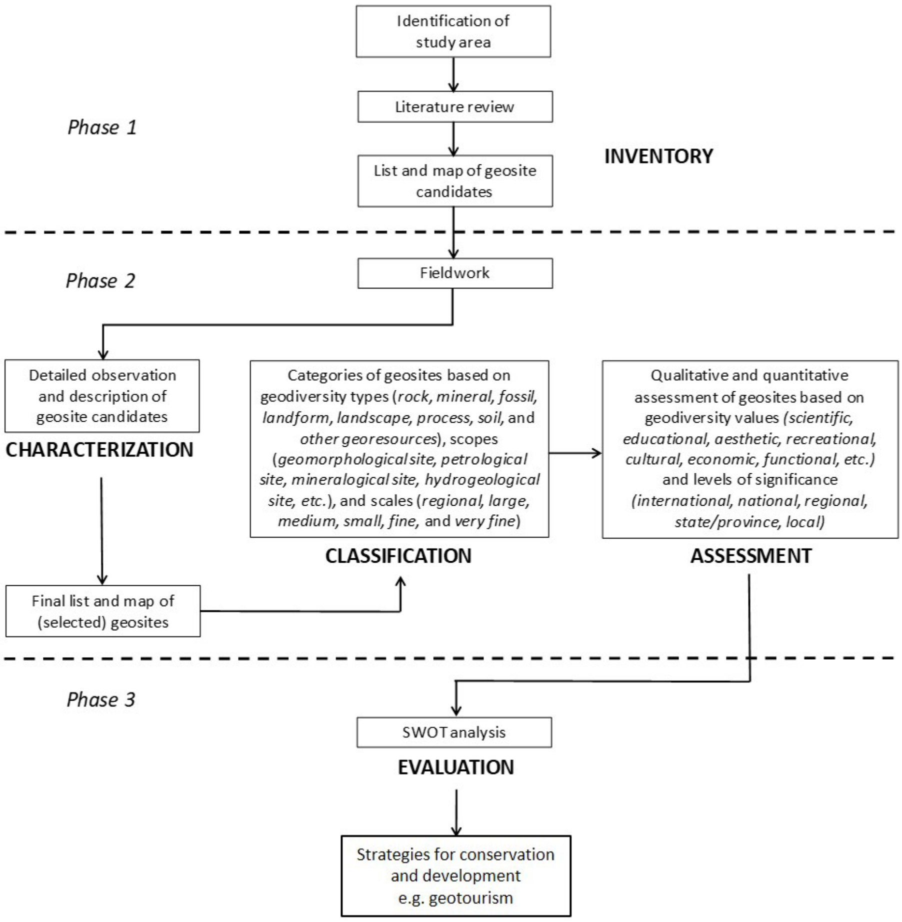

Fig. 4. Flowchart of the methodology established for the present study.

georesources. Potential geosites can also be categorised on the basis of their scopes, such as petrological site, mineralogical site, palaeontological site, geomorphological site, hydrogeological site and so on (Brocx & Semeniuk, 2007; Predrag & Mirela, 2010). The scales that make up the proposed geosites are *regional* (also known as megascale; coverage of about 100 x 100 km), *large* (also known as macroscale; coverage of about 10 x 10 km), *medium* (also known as mesoscale; coverage of about 1 x 1 km), *small* (also known as microscale; coverage of about 10–100 x 10–100 m) and *fine* (also known as leptoscale; coverage of about 1 x 1 m) (Brocx & Semeniuk, 2007).

The present study combines qualitative and quantitative methods for the **assessment** of the proposed geosites. The qualitative approach examines the geodiversity values, including scientific, educational, aesthetic, recreational, cultural/historical, economic, functional and other values wherever applicable (Gray, 2005, 2013). Levels of significance of every site should be determined as well, such as international, national, regional, state/province-wide and local (Brocx & Semeniuk, 2007). Meanwhile, the **quantitative approach** values or scores the sites numerically based on the above-mentioned geodiversity values and levels of significance. Each geodiversity value parameters were assigned and based on Brilha (2016) and Nazaruddin (2020). For each of these parameters, there are six levels of scoring: none (0), very poor (1), poor (2), fair (3), good (4) and very good (5). Five levels of significance (Brocx & Semeniuk, 2007) were scored as follows: local (1), state/province-wide (2), regional (3), national (4) and worldwide/international (5). For the purpose of ranking, the scores acquired for each geodiversity value have been averaged and added together, and the level of significance score has been taken into account as well.

Based on results of the second phase, the third phase was carried out through an **evaluation** of proposed geosites by using a SWOT (Strengths/Weaknesses/Opportunities/Threats) analysis for the establishment of a geotourism strategy.

4. Results and discussion

4.1. Inventory

Finally, on the basis of the literature review and fieldwork, there are seven proposed geosites of the Betong District which have been listed for geotourism development: two hot spring sites, two waterfall sites, and a mountain site. In addition, there are two human-modified sites, which contain man-made structures associated with nature that can be used for geological and geomorphological observation, such as a tunnel and a skywalk. All these sites are located in two subdistricts, Tano Maero and Aiyerweng. For the final list and location map of these proposed geosites, reference is made to Table 1 and Figure 5, respectively.

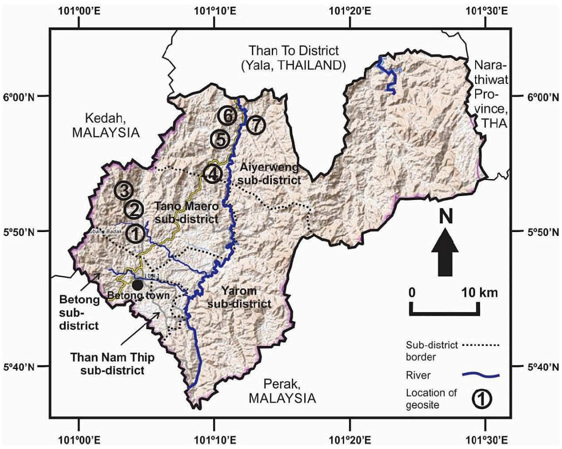

Fig. 5. Location map of proposed geosites in the Betong District (Yala Province, Southern Thailand): 1 – Betong Hot Spring, 2 – Inthasorn Waterfall, 3 – Piyamit Tunnel, 4 – Mount Silipat, 5 – Chaloemphrakiat Ro Kao (King Rama IX) Waterfall, 6 – Aiyerweng Skywalk, 7 – Nakor Hot Spring.

4.2. Characterisation

Characterisation of each potential geosite was conducted by compiling information through literature review and field observation. The following paragraphs contain a detailed description of each of the proposed geosites.

4.2.1. Betong Hot Spring

Betong hot spring (local/Thai name: Bo Nam Ron Betong) is one of the district's main attractions (Fig. 6). It is located in a low-lying area surrounded by the hilly terrain at the village of Ban Charo Parai (Ban Bo Nam Ron; Tano Maero Sub-district). This hot spring is very popular among Thai and Malaysian visitors and occurs along a N-S trending fault located at the contact between the Betong Formation (SD) and the Pa Ret Tu granite (Tg) (DMR, 2007; MT-JGSC, 2009). The surface exit temperatures of the springs here are above 80ºC; meanwhile reservoir temperature was measured by silica geothermometers showing a temperature of around 136°C at a depth of 1 km (Ngansom & Duerrast, 2019). Its flow rate is around 9 kg/s or 0.009 m^3/s (Raksaskulwong, 2004). In general, it may be assumed that the hot granitic rock (Pa Ret Tu granite) heats the groundwater in the Betong Formation (mainly in sandstone aquifers). The occurrence of this hot spring is also controlled by geological structure (fault). Subtavewung et al. (2005) classified hot springs in Thailand based on temperature, pH and usage, and categorised Betong Hot Spring as a hyperthermal spring (T ≥ 50ºC), weak alkaline spring

Table 1. List of proposed geosites in the Betong District (Yala Province, Southern Thailand).

No.	Geosite	Location	Main geological feature	Other features
1	Betong Hot Spring	Ban Charo Parai Village, Tano Maero Sub-district	Hot spring	Hot water pools
2	Inthasorn Waterfall	Ban Charo Parai Village, Tano Maero Sub-district	Waterfall	Stream and granitic rocks
3	Piyamit Tunnel	Ban Piyamit 1 Village, Tano Maero Sub-district	Quaternary deposits in a mountainous/ hilly area	Subsurface man-made tunnels
4	Mount Silipat	Ban Ko Mo 28, Tano Maero Sub-district	Granitic mountain	Viewpoint for surrounding topography
5	Chaloemphrakiat Ro Kao (King Rama IX) Waterfall	Ban Ko Mo 32, Aiyerweng Sub-district	Waterfalls	Stream and granitic rocks
6	Aiyerweng Skywalk	Aiyerweng Sub-district	Landforms of mountainous and hilly areas as well as river valleys	Skywalk tower (man-made structure atop a hill)
7	Nakor Hot Spring	Ban Nakor, Aiyerweng Sub-district	Hot spring and hot water pools	Cold stream

Fig. 6. Betong Hot Spring. **A –** Main entrance; **B –** Hot spring, main pool; **C –** Hot water swimming pool; **D –** One of hottest spots where visitors can cook eggs.

(7.5 ≤ pH < 9) and a hot spring for touristic purposes. The springs have been collected into a big pool structure to enable visitors to bathe and soak their feet. A walkway has been built to allow visitors to walk to the centre of the pool. Visitors can enjoy swimming in several other smaller hot water pools, and a hot spring shower is also available.

4.2.2. Inthasorn Waterfall

Inthasorn Waterfall (or "Namtok Inthasorn" in Thai) is located around 15 km from the town of Betong or about two kilometres from Betong Hot Spring, between that latter and the Piyamit Tunnel. This small cascading waterfall is part of a stream originating from a nearby mountainous area and flowing over the Si Nakhon granite (Tg) within the Hala Forest (as a part of the Hala-Bala Wildlife Sanctuary; TAT, 2003). This waterfall has three tiers, where the main (first) tier is a 6-7 m height vertical fall, the second tier is a shorter fall with around 3 m height, and the third tier is the stream where the water flows. There is a small pool at the base of the waterfall, which is suitable for swimming, bathing or just relaxing (Fig. 7). The waterfall is surrounded by beautiful scenery amidst various kinds of trees and flowers; all this results in a very shady atmosphere.

4.2.3. Piyamit Tunnel

Piyamit (Thai for "friendship") Tunnel (Fig. 8) is a man-made tunnel excavated by the Malayan Communist Party (MCP) and used for its stronghold and hideout during the Malayan emergency due to communist insurrection. The insurrection began in 1948 and ended in 1989 after the MCP signed a peace accord with the governments of Malaysia and Thailand (Yao, 2016). The tunnel is situated in a mountainous area in the middle of a tropical rainforest at the village of Ban Piyamit 1 (Tano Maero Sub-district). It is located approximately 18 km from the town of Betong. The tunnel is about five kilometres away from the hot spring and three kilometres from the waterfall. The tunnel was excavated inside the thick soil (laterite) which is the weathering product of the underlying Triassic granitic rocks (Tg). However, the tunnel has been enlarged and rendered into concrete in order to counter problems of collapse. Therefore, the laterite can be observed only in the entrance zones and outside the tunnels. The network of interconnected tunnels stretches for approximately 1 km and is currently part of a village belonging to the Thai National Development Front (TAT, 2003). On the wall of its gate, there is an explanation about the tunnel as follows: "The Piyamit Tunnel is the Malay com-

Fig. 7. Inthasorn Waterfall. **A –** Cascading waterfall; **B –** The stream below the waterfall.

munist's base built for bombshells and storing food supplies. The battlefield bases are located on the mountain top in the midst of the deep forests which separates the boundaries of Thailand and Malaysia covered the area of Yala Province. The Piyamit Tunnel was built in 1977 with the length of 1 km and 50–60 feet wide. It took three months for excavation of 50 hard manships and there are 9 entrance exit paths". There are several parts complemented to the tunnel such as a coal tunnel kiln, kitchen, seats, work rooms, sleeping area, storerooms and a well-like structure that was used to transport goods from the surface to the tunnel. It is interesting to note that the tunnel was dug by hand, without the use of modern technology. Before exploring the tunnel, a tour guide explains its history. In addition to Pi-

Fig. 8. Piyamit tunnel. **A –** Gate to the tunnel; **B –** Piyamit tunnel area map; **C –** Laterite excavation; **D –** Part of the tunnel.

yamit Tunnel, there is also a museum devoted to the history of the tunnel and displaying war equipment, weapons, communication tools and photographs of communist members, including how they lived in the forest. At the end of the tunnel journey, visitors should not miss seeing a giant millennium tree in the area. Descendants of the ex-communists now operate the tunnel and a nearby winter flower garden.

4.2.4. Mount Silipat

Mountains in the Betong District, including Mount Silipat (Fig. 9) in the Tano Maero Sub-district, are suitable locations to enjoy beautiful views, to study geomorphology and also provide nice, cool weather conditions in Southern Thailand. Local people call it *Gunung Silipat*, where "Gunung" means "a mountain" and "Silipat" stands for the midpoint or centre of a folded cloth because the mount resemble such. Geologically, this mountain is composed of Triassic granitic rock (Tg), estimated to be part of the Pa Ret Tu granite. Mount Silipat is one of the highest peaks in Southern Thailand and is popular among Thai and Malaysian hikers. It is also a suitable hiking place for beginners. There is a two-kilometre-long hiking trek from the starting point to the peak which is surrounded by the rubber plantation. The peak of this mount is a suitable place to study geomorphology as well as breathtaking vistas in 360° viewpoint. There is a package for hikers to reach the peak and stay overnight at the camp site.

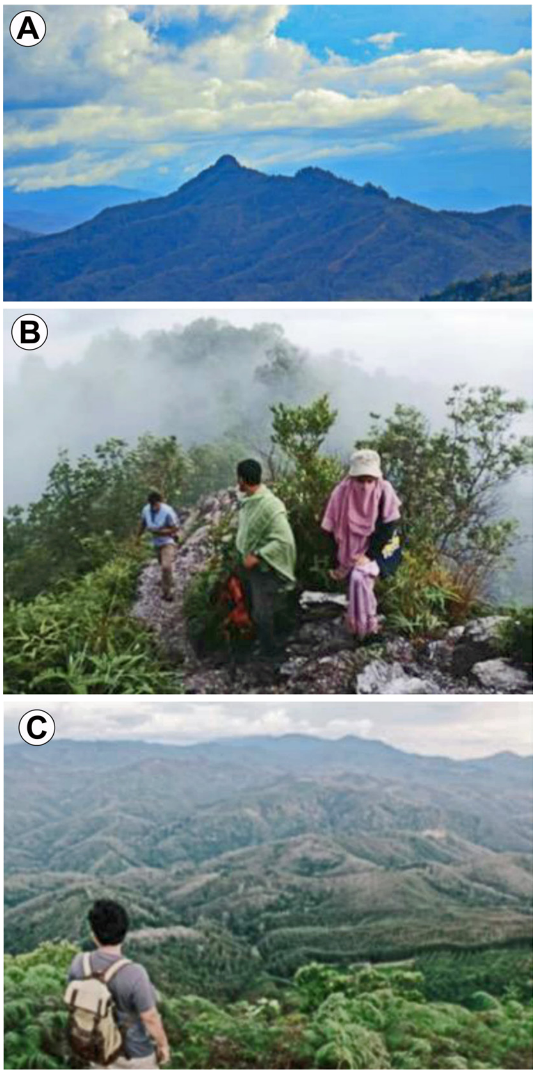

Fig. 9. Mount Silipat. **A –** View from afar; **B –** Hiking to the peak; **C –** Mountain view from the peak.

4.2.5. Chaloemphrakiat Ro Kao (King Rama IX) Waterfall

Chaloemphrakiat Ro Kao (Thai for "Long Live King Rama IX") Waterfall is another important geotourist attraction in the district (Fig. 10). This waterfall honours the late His Majesty the King Bhumibol Adulyadej (also called King Rama IX; the 9th king of the Chakri dynasty). It is located in Ban Km. 32, in the Aiyerweng Sub-district. It is a suitable place for nature lovers where they can enjoy the green scenery while trekking or swimming, or just for relaxing. The waterfall is part of a stream where the clean and cool water flows down from the cliff more than 30 m high, surrounded by tropical rain forest. This site is geologically composed of Triassic granitic rocks (Tg), the Pa Ret Tu granite. There are a lot of granitic boulders scattered along the stream. According to the waterfall classification in Thailand (Singtuen et al., 2021), this one can be classified as a fan-type waterfall, where the stream water fans out from a narrow width at the top to a larger base at the bottom with high slopes and continuously maintaining contact with the bedrock.

4.2.6. Aiyerweng Skywalk

The site is located about 36 km from the town of Betong. The skywalk is a man-made structure (made of steel and glass) built on top of a hill as a viewing area in the Aiyerweng Sub-district (Fig. 11A). This is the youngest modern structure built in Southern Thailand; it resembles a tower with a height of 45 m and a 63-metre-long suspension walkway at an altitude of more than 600 m a.s.l. (Ministry of Tourism and Sport, 2021). According to the Southern Border Province Administrative Centre (SBPAC, 2020), it is the longest skywalk in South East Asia. The skywalk is a six-storey building with the third floor as the main part which has a long balcony as the walkway extending from the tower building and is encircled with a fence made

Fig. 10. Chaloemphrakiat Ro Kao (King Rama IX) Waterfall. **A –** View of the waterfall; **B –** A natural pool in the waterfall area.

of glass for full experience of the view. At the end of the walkway is a semi-circular glass pane which is a viewpoint for the stunning "sea of mist", beautiful sunrise and sunset as well as the forest below when looking through the glass floor. Geologically, the skywalk was built on a mountainous area consisting of Carboniferous sedimentary rocks of the Yaha Formation which consist mainly of medium-bedded sandstones interbedded with shales (Cy1). A fresh outcrop of these rocks can be observed just behind the skywalk (Fig. 11B). This skywalk becomes more special because of its suitability to enjoy magnificent views of the surrounding geomorphology such as mountains, hills, and incised valleys as well as flood plains of the Pattani River. From these viewpoints, visitors can see the Hala-Bala Forest and Bang Lang Dam Lake as well. There is also another viewing point nearby the skywalk. The skywalk is accessible by shuttle pickup trucks and motorcycles or on foot by hiking trail. The development of this site has created job opportunities for local people, mainly the Sakai original people.

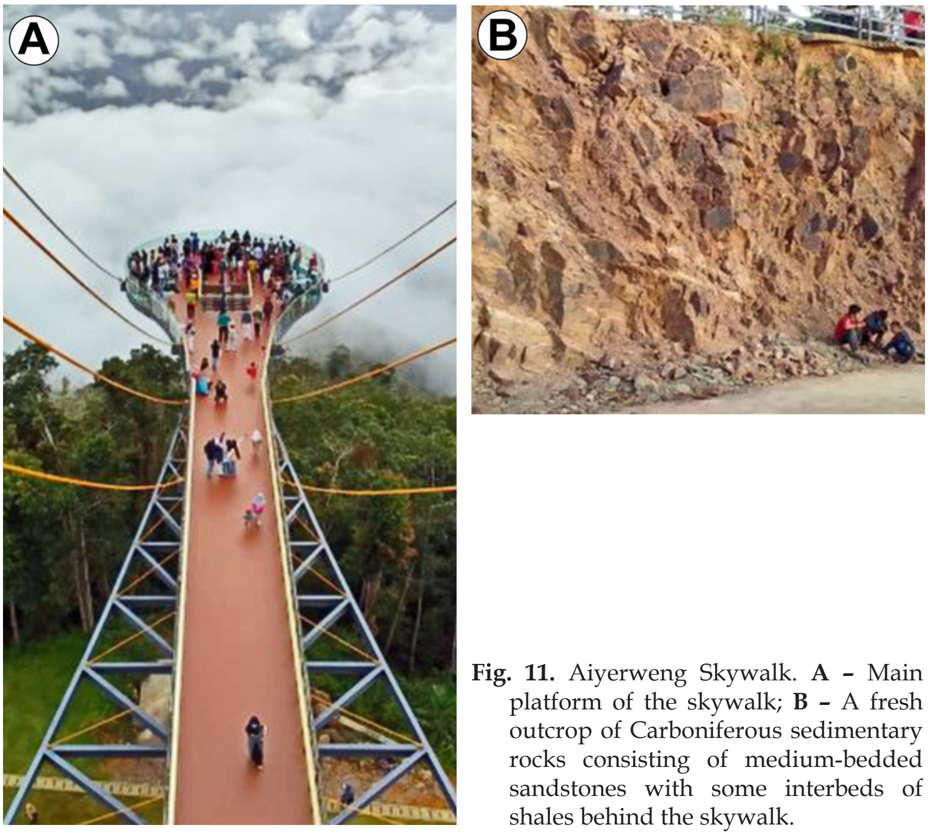

Fig. 11. Aiyerweng Skywalk. **A –** Main platform of the skywalk; **B –** A fresh outcrop of Carboniferous sedimentary rocks consisting of medium-bedded sandstones with some interbeds of shales behind the skywalk.

4.2.7. Nakor Hot Spring

Another hot spring within the Betong District is the Nakor Hot Spring which is located in the area of Moo 9, Ban Nakor, Aiyerweng Sub-district, around 38 km north-east of the town of Betong. This site is situated in the shady area of the forest with a cold stream flowing all year round nearby the hot spring (Fig. 12). Geologically, this hot spring originated from the NW-SE trending fault located at the contact between the Carboniferous sedimentary rocks of the Yaha Formation (Cy) and the Triassic Chantharat granite (Tg). The hot spring temperature is approximately 40–50ºC; however, the current surface exit temperatures of the hot spring can be below 40ºC (MT-JGSC, 2009; Ngansom & Duerrast, 2019). It is a good place for swimming, or just soaking your feet, as well as for family gatherings and camping.

4.3. Classification

As previously mentioned, all geosite candidates can be categorised based on geodiversity types (Gray, 2005), scopes (Brocx & Semeniuk, 2007; Predrag & Mirela, 2010) and scales of the sites (Brocx & Semeniuk, 2007). Table 2 provides a summary of the classification of these sites. This district has geodiversity mainly in terms of rocks, landforms and processes. The proposed geosites in the Betong District are dominated by geomorphological sites, followed by petrological sites and hydrological sites, as well as a single pedological site. The sites here range from small (around 10–100 x 10–100 m) to medium (around 1 x 1 km) scales.

Two hot springs (Betong and Nakor hot springs) which are classified as hydrogeological sites and two waterfalls (Inthasorn and Chaloemphrakiat Ro Kao waterfalls) as geomorphological and petrological sites which all cover small-scale areas are

Fig. 12. Nakor Hot Spring. **A –** Largest hot spring pool; **B –** Granitic rocks in the largest pool.

Table 2. Classification of proposed geosites in the Betong District (Yala Province, Southern Thailand).

No.	Geological site	Geodiversity	Scope	Scale
1	Betong Hot Spring	Rock: Silurian-Devonian sedimentary rocks of Betong Formation, Triassic Pa Ret Tu granite; Landform: Plain area; Other resources: hot spring	Hydrogeological (hot spring) site	Small scale
2	Inthasorn Waterfall	Rock: Triassic Si Nakhon granite; Landform: three-tier cascading waterfall	Geomorphological and petrological site	Small scale
3	Piyamit Tunnel	Rock/soil: Quaternary laterite; Landform: mountain	Pedological and geomorphological site	Medium scale
4	Mount Silipat	Rock: Triassic Pa Ret Tu granite; Landform: mountain	Geomorphological and petrological site	Medium scale
5	Chaloemphrakiat Ro Kao (King Rama IX) Waterfall	Rock: Triassic Pa Ret Tu granite; Landform: hill	Geomorphological and petrological site	Small scale
6	Aiyerweng Skywalk	Rock: Carboniferous sedimentary rocks of Yaha Formation (argillaceous facies); Landform: mountainous area	Geomorphological and petrological site	Medium scale
7	Nakor Hot Spring	Rock: Carboniferous sedimentary rocks (Yaha Formation) and Triassic Chantharat granite; Landform: Plain area; Other resources: hot spring	Hydrogeological (hot spring) site	Small scale

natural attractions of the district. Mount Silipat, another natural landmark of the district, can be also categorised as a geomorphological and petrological site covering medium-scale areas. Meanwhile, one of the human-modified sites in the district namely Piyamit Tunnel is categorised as a pedological and geomorphological site within a medium-scale area. Another latest artificial structure, Aiyerweng Skywalk, is associated with a geomorphological and petrological site within a medium-scale area.

4.4. Assessment

Both qualitative and quantitative approaches were carried out to assess geosite candidates of the Betong District. Table 3 contains a qualitative assessment on the basis of geodiversity values and levels of significance. This assessment shows that all proposed geosites in the study area cover all main (scientific, educational, aesthetic and recreational) values and a few different additional (e.g., cultural/historical, economic and functional) values. Of seven geosite candidates, only two (Piyamit Tunnel and Aiyerweng Skywalk) have more complete (main and additional) values. Levels of significance of these proposed geosites range from local to regional with the highest level (regional) for the Aiyerweng Skywalk.

The quantitative assessment was conducted by the authors scoring chosen parameters from a subjective point of view. Table 4 summarises this assessment, which results in an overall ranking of proposed geosites in the study area. The first ranking with the highest total of averaged scores is Aiyerweng Skywalk, followed by Piyamit Tunnel (2nd), Betong Hot Spring (3rd), Mount Silipat (4th), Nakor Hot Spring (5th), Chaloemprakiat Ro Kao Waterfall (6th), and Inthasorn Waterfall (7th).

4.5. Evaluation (SWOT)

Based on the above analysis of geosite candidates in the Betong District, the SWOT analysis can be formulated so as to evaluate the strengths, weaknesses, opportunities and threats of the area for a sustainable development of geotourism (Table 5).

4.6. Geotouristic activities and measures

The proposed geosites of the Betong District in Southern Thailand (Yala Province) can be utilised as important geotouristic resources which should be conserved and developed. Several geotouristic activities are possible to be conducted at these sites in order to attract visitors to enjoy them. However, several measures should be proposed to conserve the sites (Table 6). The most important measure is to enforce rules and regulations to protect them from disturbance or destruction.

5. Conclusions

The Betong District in Yala Province (Southern Thailand) has many remarkable potential geosites with their respective features. In the present study, the proposed geosites in the district are systematically analysed through several steps including inventory, characterisation, classification, assessment/ranking and SWOT analysis. Several geological sites have been identified as geosite candidates in the district: Betong Hot Spring, Inthasorn Waterfall, Chaloem Phra Kiat Waterfall, Mount Silipat and Nakor Hot Spring. Meanwhile, two human-modified sites which can be utilised to observe geological and geomorphological features have also been identified as proposed geosites, namely Piyamit Tunnel and Aiyerweng Skywalk. Characterisation and classification show that these potential geosites consist of several geodiversity elements such as rocks (such as Silurian-Devonian sedimentary rocks of the Betong Formation, Carboniferous sedimentary rocks of the Yaha Formation, Triassic granites and Quaternary laterites), landforms (such as plain areas, waterfalls, mountains and hills), and other geological resources (such as hot springs). These sites are dominated by landform/landscape features (geomorphological sites), followed by petrological or pedological sites, and hydrological sites with ranges of small to medium scales. Qualitative assessment of these sites shows that they have main geoheritage values, such as scientific, educational, aesthetic, recreational and cultural (and historical) values as well as other values, such as economic and functional values with local to regional levels of significance. Meanwhile, the quantitative assessment conducted to rank these sites reveals that Aiyerweng Skywalk takes first rank among all proposed geosites, indicating its highest geoheritage values and significance level, followed by Piyamit Tunnel (rank 2), Betong Hot Spring (rank 3), Mount Silipat (rank 4), Nakor Hot Spring (rank 5), Chaloemphrakiat Ro Kao Waterfall (rank 6), and Inthasorn Waterfall (rank 7). Their overall strengths, weaknesses, opportunities and threats were evaluated by using SWOT analysis.

These analyses can be used as a consideration for possible strategies for conservation and devel-

Table 3. Qualitative assessment of proposed geosites in the Betong District (Yala Province, Southern Thailand).

No.	Geosite	Scientific value	Educational value	Aesthetic value	Recreational value	Cultural and historical value	Economic value	Functional value	Level of significance
1	Betong Hot Spring	Formation processes of the hot spring; lithology of the area; structural control; geothermal system; water quality	Suitable place to educate people or students on hot spring	A plain area surrounded by hilly terrain	Enjoy the fresh hot water, swimming, bathing	-	Significant economic benefits of some stalls and resorts around the site	A place for therapy, fitness relaxation, and leisure	Province
2	Inthasorn Waterfall	Formation processes of waterfall; geomorphology and lithology of the area	Suitable to train people to swim in nature	An attractive landscape of waterfall and hilly surrounding	Enjoy the clean air and lush vegetation, swimming, bathing	-	-	Recreational place	Local
3	Piyamit Tunnel	Lithology of soil and geomorphology of the area	A place to study the history of ex-Malayan communists	A man-made tunnel network inside a mountain	Exploring the tunnel and studying the history	Shelter from the communist insurrection (1948-1989)	Income from the entrance fee and some stalls in the site	A favorite place for history lovers	Province
4	Mount Silipat	Geomorphology and geology of the area;	Suitable to train hikers of beginner level	An attractive landscape of granitic mountain surrounded by valleys	Hiking, camping, sightseeing	-	Income generation from services provided for hikers and visitors	A suitable place for hiking	Province
5	Chaloem-phrakiat Ro Kao (King Rama IX) Waterfall	Formation processes of waterfall; geomorphology and geology of the area	A place to train people for jungle trekking and swimming in nature	An attractive landscape of waterfall and mountainous area	Jungle trekking, swimming, bathing, sightseeing	History of a Chinese man who came here to engage in mining	-	Recreational place	Local
6	Aiyerweng Skywalk	Lithology and geomorphology of the mountain area	Suitable to education on morphological and geological processes	The tower atop a mountain and surrounded by mountainous landscape	Sightseeing	Located nearby the village of Sakai original people	Economic development for locals by providing services	Popular tourist destination to enjoy panoramic views and cool weather	Regional
7	Nakor Hot Spring	Formation of the hot spring; geology of the area; geothermal system; water quality	Suitable spot to education on geothermal system	The valley surrounded by mountainous area	Enjoy the hot water, swimming, bathing, camping	-	Income generation from some stalls and camp site	Relaxation, therapy, fitness and camping	Local

Table 4. Quantitative assessment of proposed geosites in the Betong District (Yala Province, Southern Thailand).

Geodiversity value & level of significance	Parameter (adopted from Brilha, 2016; Nazaruddin, 2020)	Geosite						
		Betong Hot Spring	Inthasorn Waterfall	Piyamit Tunnel	Mount Silipat	Chaloem-phrakiat Ro Kao Waterfall	Aiyer-weng Skywalk	Nakor Hot Spring
Scientific	1.1 Geodiversity	4	2	2	2	2	3	4
	1.2 Scientific knowledge	5	4	3	3	4	3	5
	1.3 Representa-tiveness	4	4	4	4	4	5	4
	1.4 Key locality	3	3	4	4	3	4	3
	1.5 Rarity	3	3	5	3	3	5	3
	1.6 Integrity	4	2	4	3	4	4	4
	Average	**3.8**	**3.0**	**3.7**	**3.2**	**3.3**	**4.0**	**3.8**
Educational	2.1 Geodiversity	4	2	2	2	2	3	4
	2.2 Didactic potential	5	4	4	4	4	3	5
	2.3 Accessibility	5	5	5	4	4	4	4
	2.4 Safety	5	4	5	4	4	4	5
	2.5 Logistics/educa-tional products	5	2	5	2	2	4	4
	2.6 Invulnerability	4	4	4	4	4	4	4
	2.7 Educational purposes	5	4	5	4	4	5	5
	2.8 Observation condition	5	4	5	5	4	5	4
	Average	**4.7**	**3.6**	**4.4**	**3.6**	**3.5**	**4.0**	**4.3**
Aesthetic	3.1 Scenery	4	3	4	5	4	5	4
	3.2 Viewpoint	3	2	3	5	3	5	3
	3.3 Surrounding landscape	4	3	4	5	4	5	4
	Average	**3.7**	**2.7**	**3.7**	**5**	**3.7**	**5**	**3.7**
Recreational/ tourism	4.1 Scenery	4	3	4	5	4	5	4
	4.2 Uniqueness	3	3	4	3	3	5	3
	4.3 Interpretative potential	4	4	4	4	4	5	4
	4.4 Accessibility	5	5	5	3	3	5	4
	4.5 Safety	5	4	5	4	4	5	5
	4.6 Tourism facili-ties and services	5	2	5	4	4	5	5
	4.7 Recreation-al/tourism activities	4	4	3	4	4	4	4
	4/8 Promotion	5	3	5	5	4	5	4
	4.9 Environment and vicinity	5	3	4	3	3	4	4
	Average	**4.4**	**3.4**	**4.3**	**3.9**	**3.7**	**4.8**	**4.1**
Cultural	5.1 History	0	0	5	0	3	0	0
	5.2 Religious	0	0	0	0	0	0	0
	5.3 Art and culture	0	0	4	0	0	4	0
	Average	**0**	**0**	**3**	**0**	**1**	**1.3**	**0**

Table 4. Cont.

Geodiversity value & level of significance	Parameter (adopted from Brilha, 2016; Nazaruddin, 2020)	Geosite						
		Betong Hot Spring	Inthasorn Waterfall	Piyamit Tunnel	Mount Silipat	Chaloem-phrakiat Ro Kao Waterfall	Aiyer-weng Skywalk	Nakor Hot Spring
Economic	6.1 Economic significance	5	3	5	5	3	5	5
	6.2 Visitors	5	3	5	4	3	5	4
	6.3 Attractions	5	4	5	5	4	5	4
	Average	**5**	**3.3**	**5**	**4.7**	**3.3**	**5**	**4.3**
Functional	7.1 Intensity of use	5	3	5	5	4	5	5
	7.2 Accessibility	5	5	5	3	3	5	4
	7.3 Invulnerability	4	4	4	4	4	4	4
	7.4 Viewpoint	3	2	3	5	3	5	3
	7.5 Safety	5	4	5	4	4	5	5
	7.6 Logistics	5	2	5	2	2	4	4
	7.7 Acceptable changes	4	3	4	3	4	5	4
	Average	**4.4**	**3.3**	**4.4**	**3.7**	**3.4**	**4.7**	**4.1**
Level of significance		2	1	2	2	1	3	1
Total		28	20.3	30.5	26.1	22.9	31.8	25.3
Ranking		3	7	2	4	6	1	5

Geodiversity value: 0 = none; 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good. Level of significance: 1 = local, 2 = province/state-wide, 3 = regional (within a country).

Table 5. SWOT analysis for evaluation of the proposed geosites in the Betong District (Yala Province, Southern Thailand).

SWOT	Remark
Strengths	– The study area has good accessibility – Suitable and potential for research and education – Several sites have high aesthetic, recreational, cultural/historical, economic, and functional values – All geosites are suitable for recreational purposes, including hot springs for therapy and a mountain for hiking – A few geosites have historical background – This district has a cultural asset of original people of Sakai ethnic – Advantage on local economic development due to income generation from tourism activities – Good support from local authorithy and local people – Favourable weather and environment
Weaknesses	– Several geosites are so famous that many people make them crowded – Low awareness of cleanlines and conservation at certain geosites – No contact with universities or other institutions to create scientific, educational, cultural, and other development plans
Opportunities	– More research and educational programs can be conducted in geosites – More panels of information should be provided to serve visitors – Improve existing facilities and ensure cleanliness – Good prospect for cooperation among stakeholders (e.g. authorities, private sectors, universities, local communities, etc.) – Development of this area will create employment opportunities mainly for local people – Potential for montain and water sports and cultural events – More promotion of less known geosites to attract more visitors
Threats	– Deterioration at some geosites due to overcrowding by visitors – Littering and rubbish deposition – Certain geosites are quite dangerous to visitors due to steep and slippery locations (mountain and waterfalls)

Table 6. Possible activities and measures in the proposed geosites of the Betong District for development of geotourism.

No.	Geosite	Possible geotourism activities	Suggested measures
1	Betong Hot Spring	Educational tour, swimming, bathing, therapy, taking photos	Improve facilities to support a lot of visitors; develop sports in water pools
2	Inthasorn Waterfall	Educational tour, swimming, bathing, taking photos	Renovate and improve facilities to serve visitors
3	Piyamit Tunnel	Educational tour, sightseeing, taking photos	Improve the facilities so that visitors can not only explore the tunnel, but also learn about other curiosities
4	Mount Silipat	Educational tour, hiking, camping, sightseeing, taking photos	Improve visitor safety as the terrain is quite steep; develop mountain sports
5	Chaloemphrakiat Ro Kao (King Rama IX) Waterfall	Educational tour, jungle trekking, swimming, bathing, sightseeing, taking photos	Improve accessibility and security as the site is in the deep jungle and remote area
6	Aiyerweng Skywalk	Educational tour, sightseeing, taking photos	Improve facilities to handle multiple guests; increase the involvement of the Sakai community in supporting tourism activities in the area
7	Nakor Hot Spring	Educational tour, swimming, bathing, therapy, camping, taking photos	More promotions to attract more visitors as it is less known

opment of the sites. One of these strategies is to produce and attach scientific information boards or panels at all sites in order to provide the necessary general and geological information to visitors. The scientific information can be collected from research works, such as the present study. Therefore, links between authorities and universities or other institutions are important. Another strategy is to improve the facilities at all sites so as to accommodate any overcapacity of visitors, mainly during holidays. However, these sites also need human resources to manage them and their conservation and development efforts have to contribute to local communities. Therefore, the participation of local communities (mainly the Sakai original people) is encouraged to improve their economic lives. Further studies are expected to contribute, for example, to the best management model for a sustainable development of geotourism.

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