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Tin mineralization indicator in Sungai Bahoi-Charok Jawa area, Ulu Muda Forest Reserve, Kedah

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Abstract: A study on tin (Sn) mineralization indicator in Sungai Bahoi-Charok Jawa area was conducted through detailed field geological mapping and stream sediment geochemistry analysis. The study area consists mainly of Late Triassic igneous intrusion and sedimentary rocks of Carboniferous Kubang Pasu Formation. The conducted field mapping has successfully discovered a band of brecciated phyllites along parts of granite – phyllite contact zone and a limestone hill with caves in the study area. Based on the geochemical results and interpretations, 6 multielement anomaly areas were delineated, where Sn exists as the main constituent.

Keywords: Geochemistry, geoheritage, Labua Cave, tin, Ulu Muda

Abstrak: Kajian petunjuk pemineralan timah (Sn) di kawasan Sungai Bahoi-Charok Jawa telah dilaksanakan berdasarkan pemetaan geologi lapangan terperinci dan analisis geokimia sedimen sungai. Sebahagian besar kawasan kajian terdiri daripada rejahan granit berusia Trias Akhir dan batuan sedimen Formasi Kubang Pasu berusia Karbon. Hasil pemetaan lapangan berjaya menemukan jalur filit terbreksi di sepanjang sebahagian zon sentuhan granit – filit dan bukit batu kapur yang mengandungi gua di kawasan kajian. Berdasarkan keputusan dan pentafsiran keputusan analisis geokimia, sebanyak 6 kawasan beranomali pelbagai unsur dapat disempadankan, di mana sebahagian besarnya terdiri daripada Sn sebagai unsur utama.

Kata kunci: Geokimia, geowarisan, Gua Labua, timah, Ulu Muda

INTRODUCTION

Background

Malaysia was once the largest tin producer in the world, back in 1883. During that period, tin was mined extensively in Kinta Valley in Perak, Klang Valley in Selangor and Sungai Lembing in Pahang.

However, the tin mining activities in Kedah were dated earlier back in the 9th century by Arabic voyagers including Abu Zaid (Winstedt, 1920), Abu Dulaf (Suarez, 1999) and Al-Mas’udi (1861). Yip (1969) reported that tin trading agreement between Kedah and the Dutch was signed in the 17th century while Thow (1995) recorded that tin mining activities in Kulim were monopolized by the Chinese immigrants who had immigrated through Penang since 1880. Semeling area of near the Gunung Jerai foothills was probably the source of 4,470 piculs of tin ores exported from Kuala Muda district between 1906 and 1908 (Hart, 1990). The ore, together with associated wolframite had been mined in the Sintok-Bukit Kachi area later in 1922 (Willbourn, 1926).

In the Sik district, there is one placer tin prospecting activity that commenced in 1958 (Ismail, 1986; JMG, 2019). Casual to small scale tin sluicing and panning activities had also taken place at several main tributaries of upper Muda River, currently known as Ulu Muda, particularly near Kg. Teliang, Kg. Siam and Kg. Berhala prior to the construction of Muda Dam in 1969. Several tin mines were operated on the Thailand side, in proximity to the Ulu Muda area (MT-JGSC, 2009).

Nowadays, tin is still regarded as one of the metals that has high worldwide demands in many industries. In recent years, it is needed for manufacturing lead-acid batteries and lithium-ion batteries for start-stop and microhybrid vehicles, as well as alloys for high technology equipment (ITRI, 2017).

Previous study

The distribution of tin in Peninsular Malaysia was divided into Western, Central and Eastern tin belts (Scrivenor, 1931). According to Ishihara *et al*. (1979), the more-mineralized Western and Eastern tin belts are categorized as ilmenite series where divalent tin was enriched towards ore during late magmatic fractionation, while the less-mineralized Central Tin Belt is categorized as magnetite

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series as the trivalent tin was settled as trace composition in the earlier formed minerals.

The origin of tin is related to granite intrusion events in the Western Belt which occurred between 230 and 210 million years ago, while in the Eastern Belt, the events occurred between 290 and 270 million years ago (Yang *et al.*, 2020). The tin granites were derived from polycyclic events including metamorphism, anatexis and magmatic-tectonic related process (Hutchison & Chakraborty, 1979; Hutchison, 1988). Hosking (1973) divided the main tin deposits in both tin belts into 4 types, which are pegmatite, aplite, pyrometasomatic and hydrothermal. Chu *et al*. (1988) later reclassified the primary tin occurrences into 4 main types: pneumatolytic-hydrothermal, pyrometasomatic, stanniferous pegmatites and aplites, and stanniferous polymetallic sulfide bodies.

The earliest study on tin in Kedah was conducted as part of a Regional Mapping Program by the Geological Survey Department back in 1970, and later by the Department of Mineral and Geoscience Malaysia (JMG) starting from 2001. Willbourn (1926) conducted a preliminary field observation at Ulu Muda, including the Sungai Bahoi-Charok Jawa area in 1922. This was followed by scouting from an airplane by Bradford and a reconnaissance field mapping by Bradford and Flinters in 1954 (Bradford, 1955), and a regional field mapping by Mat Niza Abdul Rahman in years 1994 to 1995 (Abdul Rahman, 1995).

Photogeological interpretations by Lai (1980) has divided the study area into units of igneous intrusions, argillaceous, arenaceous-argillaceous and metamorphic contact. Structural interpretations of Ulu Muda area were also completed by Mat Akhir & Abdullah (1997) using LANDSAT thematic imageries. MT-JGSC (2009) later conducted a detailed photogeological interpretation to correlate geological information of Malaysia-Thailand border for the Pengkalan Hulu-Betong transect area.

Regional studies on geochemistry and mineral occurrences were also completed by Bradford (1955) and Abdul Rahman *et al*. (2008) simultaneously with field mappings.

Hence, this study aims to gather detailed geological information of the Sungai Bahoi-Charok Jawa area, and to obtain geochemical anomalies of Sn including other heavy elements based on close stream sediment samplings.

Topography of the study area

The Sungai Bahoi-Charok Jawa area is situated in the vicinity of Ulu Muda Forest Reserve in Sik district, Kedah. Its topography is moderately to hilly with elevations increasing to nearly 1,000 meters above sea level eastward. The study area comprises of about 142 km^2 virgin jungles and is only accessible by boat from the Muda Jetty at Gubir, and by foot to reach the upstream. The area is currently strictly prohibited for logging and hunting activities due to its proximity to Muda Lake (Figure 1).

Both Sungai Bahoi and Charok Jawa are among the main tributaries of Muda River and are regarded as the catchment rivers for Muda Lake. They are dominated by subparallel to parallel drainage systems except near the downstream tributary of Sungai Bahoi which shows notable dendritic and centralized drainage systems, based on Howard (1967).

GEOLOGICAL SETTING

The study area lies within the tin-bearing Main Range Granite of Peninsular Malaysia. The granites are part of the Southeast Asian Magmatic Arc that was triggered during the Early Permian to Triassic subduction-collision event due to the closure of Paleo-Tethyan Ocean beneath the Southeast Asia crust (Robb, 2019).

The tin granites of western Peninsular Malaysia are considered as a result of partial melting of the metamorphic basement during the collision of Sibumasu and East Malaya blocks (Ng *et al*., 2015; Liu *et al*., 2020), based on their ilmenite-series, peraluminous character (Ishihara *et al*., 1979), and characteristic of S-type granites (Chappell & White, 2001).

The granite body in the study area, namely Rimba Telui granite is porphyritic and leucocratic, with feldspar phenocrysts and biotite spots (Abdul Rahman *et al*., 2008). The granite intruded Carboniferous areno-argillaceous bedrocks of Kubang Pasu Formation.

The Gunung Labuah limestone hill is mentioned in Willbourn (1926) to exist within the study area from which native people collected saltpeter from the cave floor to make gunpowder.

Apart from the lithological information, at least ten saltlicks including hot springs have been recorded in the Ulu Muda area where two of them are located within the study area (Bashir Ali, 2014; Hor, n.d.).

MATERIALS AND METHODOLOGY

Geological mapping and stream sampling

Two series of field mappings and stream sediment geochemical samplings were commenced simultaneously throughout the study area for 35 cumulative days in 2013 and 2015 via flying camp due to limited accessibility.

Field mapping included observation of lithologies, prominent geological structures and possible mineralization and rock alteration occurrences.

Stream sediment geochemical samplings were focused on streams under class 1 to 3 based on Strahler (1978). The silt samples were scooped within 50 meters range of one sampling location. Excluding 10 grams of wet samples for Hg analysis, the samples were dried and sieved to remove any sand-sized grains to get a total weight of 60 grams each. Heavy mineral concentrates were also obtained via panning technique using 1 litre sized wooden pan at combined low and high stream flow energy points per sampling location according to Fletcher *et al*. (1984) and Che Harun *et al*. (2009). Samples were dried and those for other element analysis were thoroughly cleaned to remove quartz grains before weighted

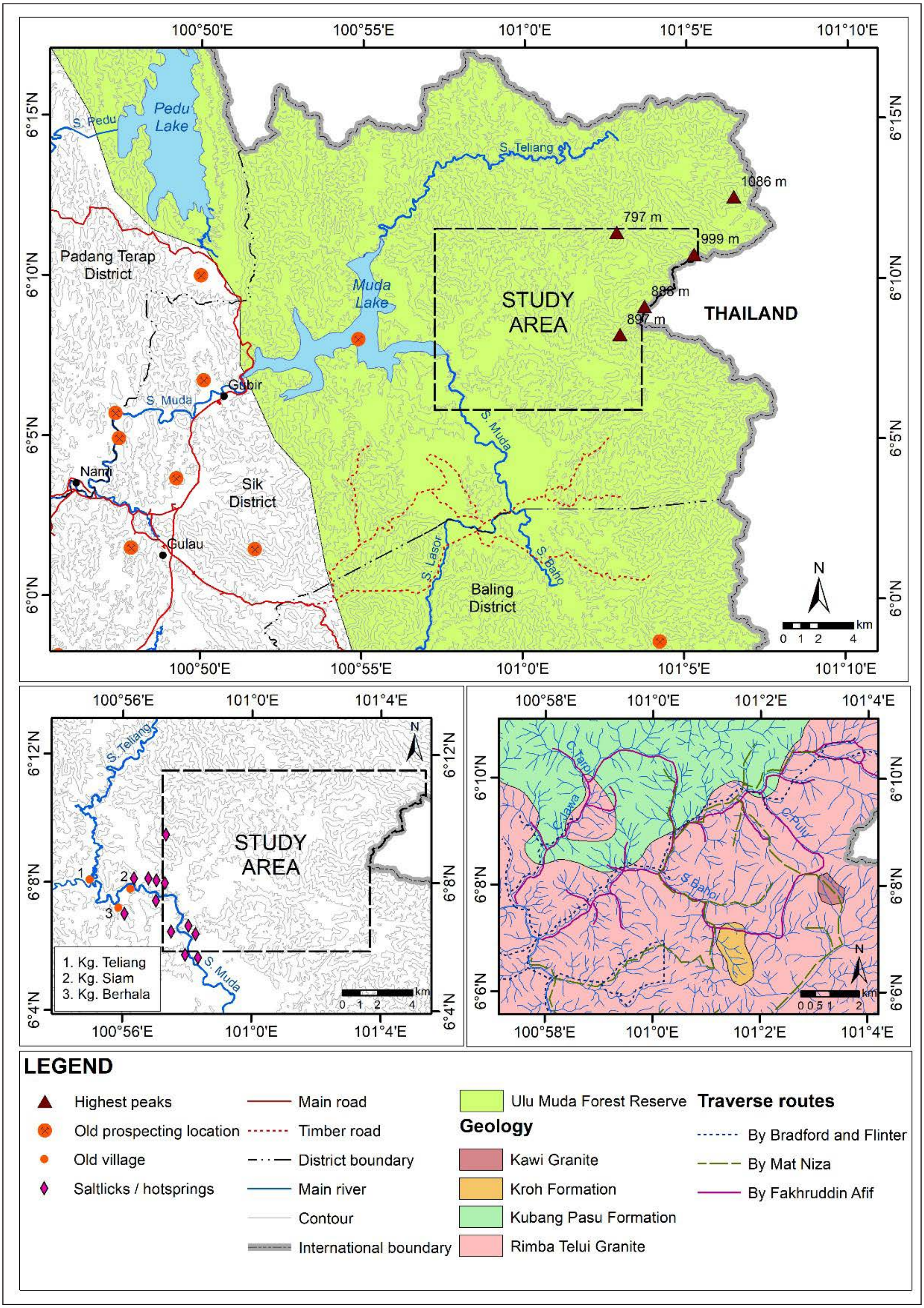

Figure 1: Location of the study area within the Ulu Muda Forest Reserve (top), old prospecting and saltlick or hot spring locations within the study area (bottom left) and general geology and traverse routes by previous geologists and author in the study area (bottom right).

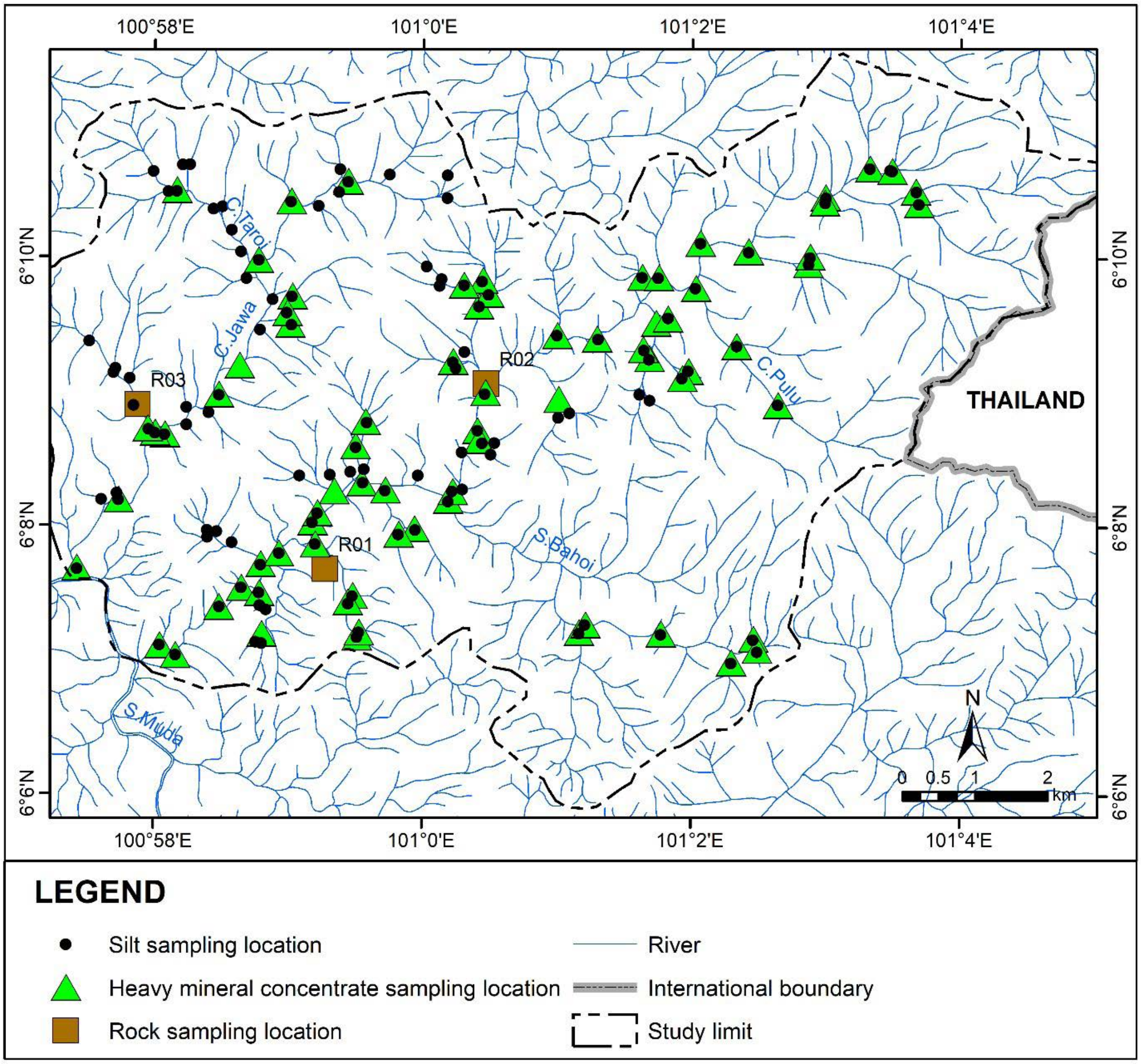

Figure 2: Geochemical sampling locations in the study area.

and packed. Suitable rock samples showing mineralization patterns were also taken for geochemical analysis in order to get heavy elements background values (Figure 2).

Geochemical and statistical analysis

All samples were sent to the JMG Geochemistry Lab in Kuantan for 17 heavy element analysis through Inductively Coupled Plasma – Mass Spectrometry (for Ag, As, Ba, Bi, Co, Cu, Fe, Mn, Mo, Ni, Pb, Sb, W and Zn), Fire Assay (Au), FIMS (Hg) and Atomic Absorption Spectrometry (Sn).

The geochemical results for silt and heavy mineral concentrate samples were then statistically analyzed in order to get the elemental distribution histogram patterns and basic parameter values including 50th, 85th and 95th percentiles through Microsoft Excel. In this study, the ranges between the percentiles were regarded as low and moderate anomaly value respectively while values which fall below the 50th percentile and greater than the 95th percentile were respectively treated as background and high anomaly values. The distributions of high anomaly areas based on elements were mapped using ArcGIS 10.4.

Lastly, cluster analysis was conducted by which areas consisting of two or more high anomaly of different elements were delineated according to sample types. The analysis aimed to provide a possible elemental association that could lead to particular mineralization patterns.

RESULTS AND DISCUSSIONS

Lithology

The field mappings have successfully recognized 5 main different bedrocks which are granites, phyllites, hornfels, breccias and limestones (Figure 3).

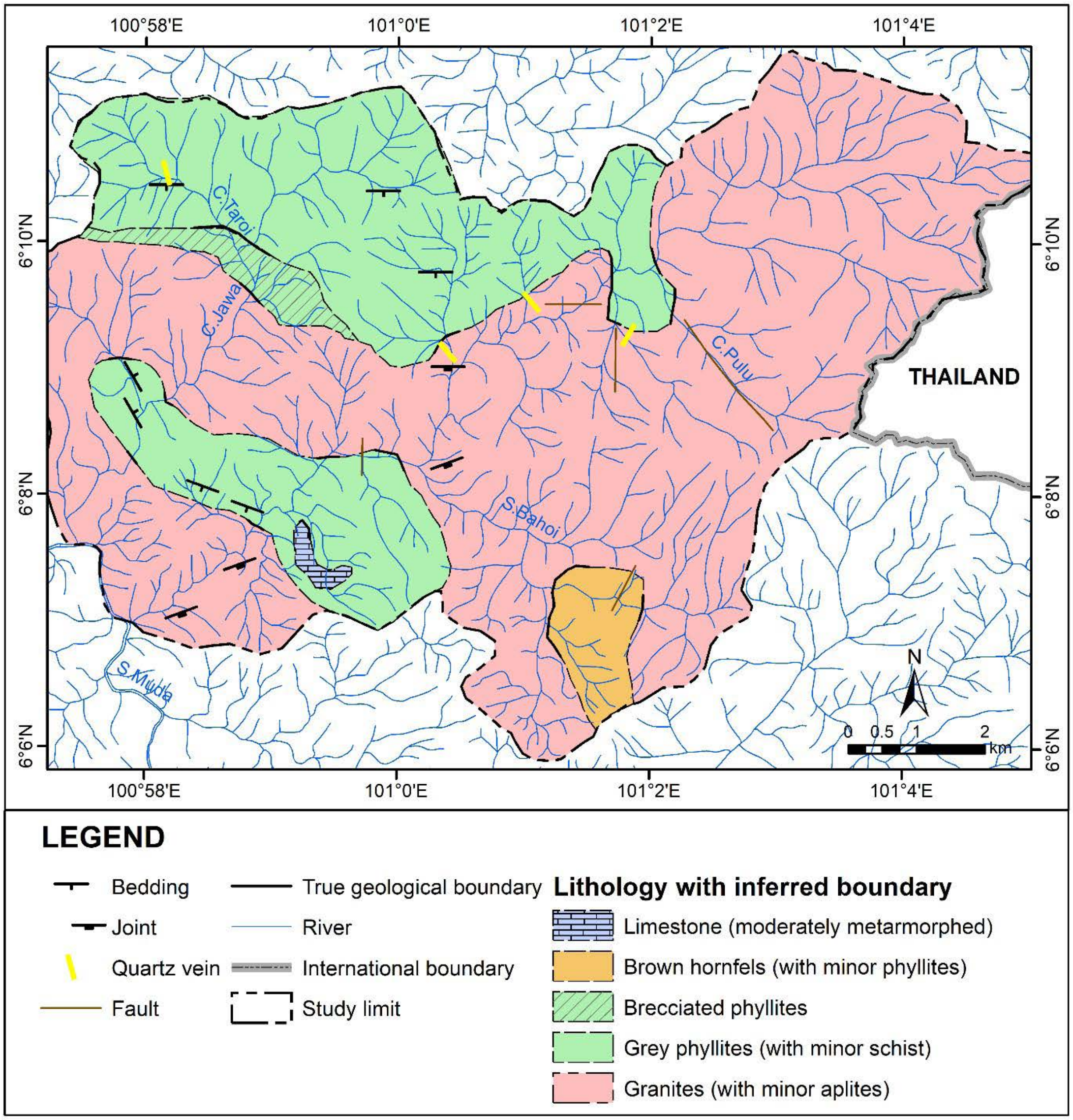

Figure 3: Field mapping results.

The granites are porphyritic, consisting chiefly of biotite, muscovite, plagioclase feldspar and quartz minerals underlaying the lower parts of the Sungai Bahoi-Charok Jawa area and the upper part of Charok Pulu area (Figure 4A). Joint readings of the bedrocks showed dominantly west to southwest directions. Aplites cut the bedrocks particularly at the south part of Sungai Bahoi area, consisting chiefly of fine-grained plagioclase and quartz minerals with biotite as chief accessory minerals (Figure 4B).

Phyllites found are greyish, blackish or brownish mostly within the middle part of Sungai Bahoi, at the middle part of Charok Jawa, and at the upper part of Charok Jawa (Figure 4C, 4D). There are 3 different dipping plane directions observed; which is towards the southwest and northeast at the middle of Sungai Bahoi area, and towards the south at the middle of Charok Jawa area. Hornfels, mainly brownish in colour are found enveloping the granitic bedrocks at the southeastern part of the study area. Breccias are exposed along parts of the boundaries between granites and phyllites within the upper part of Charok Jawa. The bedrocks consist of poorly sorted and randomly oriented blackish to greyish clasts of angular to subangular phyllite clasts up to 5 cm in size with matrix of similar lithological origins but finer grain size (Figure 4E).

Limestones are found as a small hill with its diameter less than 50 meters and height up to 20 meters from ground level. The outcrop has massive beddings but poorly distinguished due to high metamorphism into marble with major appearance of quartz veinlet swarms (Figure 4F). Speleothems inside the 2 cave chambers found at the upper part of the hill consist of stalactites, stalagmites, pillars and flowstones (Figure 4G). The limestone area also sits

Figure 4: (A) Porphyritic biotite granites with phenocrysts of plagioclase feldspars cut by quartz veins at Sungai Bahoi downstream. (B) Porphyritic biotite granite (left) borders or cut by aplites (right) found near Charok Pulu upstream. (C) Blackish to greyish phyllite bedrocks at Charok Jawa upstream. (D) Moderately weathered phyllites with intercalations of calcareous facies found near the limestone hill area within Sungai Bahoi area. (E) Breccias consisting clasts and matrix of blackish phyllites found within the central part of Charok Jawa. (F) Limestone showing highly metamorphed to marble with fracture filling veinlets found as hill within Sungai Bahoi area. (G) Karstic features including flowstones, speleotherms and stalagtites in the limestone hill cave. (H) Vertical granitic bedrock bank (arrow) found at Charok Pulu indicating displacement due to fault.

on a negative circular feature, observed from aerial photo interpretation. Development of faults were also observed at 4 locations where stream banks composed of granitic bedrocks show displacement with slickensides featured on the surfaces (Figure 4H).

The general descriptions of granites, phyllites and hornfels during the field mapping are similar but is more detailed in Abdul Rahman *et al*. (2008). The phyllite roof pendant is notably a part of the Kubang Pasu Formation as the outcrop has similar lithological features with the exposed bedrock at upper Charok Jawa, and the descriptions in Abdul Rahman *et al*. (2008). Based on its argillaceous characteristic, the roof pendant is regarded as part of the lowest facies of Kubang Pasu Formation (Yap, 1991). The moderate to steeply dipping of beddings measured at the roof pendant suggest that its near anticlinal feature is caused by granitic intrusion. Similar steeply dipping of the Semanggol Formation bedrock near Karangan, Kulim is also reported to be triggered by the intrusion of Kulim Granite (Courtier, 1974; Fauzi, 2020).

The deposition of brecciated phyllite could possibly be due to factors including accumulation of debris or sedimentation from mechanical weathering in ancient fluvial environment during post-Triassic or Quaternary period, or epizonic intrusion towards brittle phyllite bedrocks, which eventually created tectonic fracture zones along the margins of granite – metasedimentary bedrocks in the area, or a combination of both factors (Twiss & Moores, 2000). The existence of large angular clasts in the breccia indicates short distance and fast sedimentation (Surjono *et al*., 2004). In relation to local tectonism, occurrence of the fracture zones is within the timeline of deposition of Saiong Bed (Khoo, 1983) and faulting of Bok Bak (Burton, 1965), which was during Cretaceous period (Salmanfarsi *et al*., 2018) as both geological features are due to major tectonic events and closer to the study area.

The limestone hill is confirmed as the Gunung Labuah mentioned in Willbourn (1926). The hill contains 2 main cave chambers at its upper part, complete with stalactites, stalagmites and flowstones which indicate that there were enough humidity, atmospheric precipitation and temperature to develop the karstic features (Sun *et al*., 2018). The karstic features are believed to be wider than

Table 1: Statistical values of geochemical result for silt samples in ppm, except Fe (%) and Hg (ppb).

Element	Min	Median	Standard Deviation	Minimum	50^{th} Percentile	90^{th} Percentile	95^{th} Percentile	Maximum
Ag	0.05	0.05	0.05	0.01	0.05	0.11	0.14	0.25
As	9.57	5.00	8.53	1.60	5.00	21.97	29.30	42.00
Au	0.005	0.003	0.010	0.003	0	0.003	0	0.103
Ba	66.70	58.50	31.29	17.00	58.50	106.70	124.00	159.10
Bi	1.18	1.00	0.810	0.01	1.00	1.00	1.80	7.00
Co	7.51	5.15	6.25	0.84	5.15	16.00	20.00	30.00
Cu	24.30	16.00	25.19	1.00	16.00	66.99	79.80	104.00
Fe	1.84	1.62	0.95	0.19	1.62	3.17	3.88	5.03
Hg	19	16	14	3	16	37	43	79
Mn	601	366	566	85	366	1258	1672	4000
Mo	1.13	0.70	1.03	0.08	0.70	2.76	2.90	4.40
Ni	16.30	11.26	16.08	1.00	11.30	34.20	41.20	101.00
Pb	42.40	29.00	41.25	2.00	29.00	87.26	135.00	260.00
Sb	0.83	1.00	0.38	0.01	1.00	1.00	1.18	2.42
Sn	69	46	101	1	46	144	242	680
W	6.75	2.00	11.13	0.01	2.00	16.00	32.00	60.00
Zn	57.90	45.00	36.06	11.34	45.00	104.20	124.00	184.30

Table 2: Statistical values of geochemical result for heavy mineral concentrate samples in ppm, except Fe (%) and Hg (ppb).

Element	Min	Median	Standard Deviation	Minimum	50th Percentile	90th Percentile	95th Percentile	Maximum
Ag	0.19	0.01	0.37	0.01	0.01	0.71	1.04	1.69
As	17.45	10.8	16.53	0.50	10.80	38.67	47.91	77.20
Au	0.003	0.003	0	0.003	0.003	0.003	0.003	0.003
Ba	35.29	26.42	27.34	8.07	26.42	77.20	91.39	144.10
Bi	11.60	0.01	26.80	0.01	0.01	19.94	84.25	124.00
Co	4.55	2.00	5.45	0.84	2.00	10.00	13.34	29.00
Cu	18.52	6.60	24.55	0.68	6.60	53.10	72.20	103.00
Fe	3.18	2.80	2.03	0.47	2.80	5.51	7.68	10.20
Hg	9	7	8	3	7	19	28	33
Mn	2573	2524	1178	404	2524	4231	4377	5783
Mo	1.50	0.01	2.36	0.01	0.01	5.12	7.37	8.40
Ni	9.27	2.52	13.89	0.13	2.51	26.57	43.06	58.99
Pb	241.33	111.00	296.32	14.00	111.00	575.40	794.00	1419.00
Sb	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01
Sn	61598	28000	82200	1000	28000	187780	236800	424500
W	36.59	3.52	79.99	0.01	3.52	120	222.22	400.00
Zn	93.16	82.16	50.36	18.47	82.16	154.90	191.82	250.00

the hill area as there are very poor vegetations around the hill ground and missing stream flow within its proximity, suggesting the occurrence of underground streams due to either cavities or voids underneath the ground level. This is also supported by the negative circular feature where the limestone hill sits, by which the negative type is commonly interpreted as depressions due to existence of karstic voids beneath ground level (Gutiérrez & Cooper, 2013) (Figure 6).

Stream sediment geochemistry

A total of 125 silt and 76 heavy mineral concentrate from stream sediments including 3 fresh rock samples were successfully obtained and analyzed. The basic statistical parameter values and percentiles of elemental geochemical results for silts and heavy mineral concentrates are shown in Table 1 and Table 2.

The concentrations of Sn in heavy mineral concentrate samples is significantly high, from 1,000 up to 424,500 ppm. Although the Sn values range from 1 to 680 ppm in the silt samples, the Mn values show higher results which range from 85 to 4,000 ppm. The Cu, Pb and Zn elements also show high concentrations while Ag, Au, Hg and Sb elements do not show significant values in both sample types.

The elemental distributions according to sample types which falls between moderate and high anomaly values are plotted accordingly (Figure 5).

The distributions of moderate (85th to 95th percentile) and high anomaly (> 95th percentile) values for all elemental concentration in the silt samples appear within the sedimentary bedrocks at Charok Jawa- Charok Taroi area, around hornfels bedrock at Sungai Bahoi and granitic bedrock at the upstream of Charok Pulu while those in concentrate samples appear within the limestone bedrock and Charok Taroi area (Figure 6). The geochemical results of rock samples show that the limestone contains a high concentration of Au while quartz veins contain prominently high concentrations of As, Ba, Bi, Co, Cu, Hg, Mn, Pb, Sn, W and Zn, in either one or both samples (Table 3).

The field geological mapping conducted has successfully updated the geological information of the study area with aids from different traverse routes. The geological mappings has also discovered the occurrence of brecciated phyllite at the contacts between Kubang Pasu Formation and Rimba Telui

Table 3: Geochemical results of rock samples in ppm, except Hg (ppb).

Sample No.	R01	R02	R03
Rock type	**Limestone (with veinlets)**	**Quartz vein**	**Quartz vein**
Ag	0.04	7.48	0.07
As	5.40	36.50	110.50
Au	0.010	0.003	0.003
Ba	10.38	8.82	22.90
Bi	0.01	805.80	0.42
Co	5.05	52.63	59.10
Cu	1.45	57.73	28.93
Fe	0.01	7,800	7,200
Hg	7.00	42.00	20.00
Mn	48.33	183.10	52.70
Mo	0.01	3.17	2.45
Ni	0.40	2.43	6.51
Pb	0.04	361.20	12.86
Sb	0.22	0.18	0.01
Sn	0.01	17.13	0.01
W	6.63	249.80	194.40
Zn	26.94	74.84	58.69

Granites; while confirming the existence of the limestone hill mentioned previously by Willbourn (1926).

Cluster analysis of moderate and high elemental concentration values have successfully delineated 2 multielement anomalies from concentrate samples (C01 and C02) and 5 multielement anomalies from silt samples (S01, S02, S03, S04 and S05). All anomaly areas lie on the contact zone between granites and sedimentary bedrocks, except S03 and S04 which dominantly sit on granites, while only S01 and S04 do not contain Sn as a constituent element (Figure 7).

The stream sediment samples act as secondary sources in order to determine ridges and spurs where primary mineral deposit exists. Anomalies from fine-sized silt sample could indicate either the main mineralized zone or ore lodes located further upstream or deeper beneath the ground while anomalies from coarser-sized concentrate samples indicate closer primary source of mineralization (Fauzi, 2018).

Geochemical results of rock samples also generally confirmed that most elemental anomaly come from quartz vein which contains gold and tin. High anomaly within the circular features could be due to either greisen related deposit type as reported in Bongsu Granite in Kulim, or skarn-related deposit type, due to its proximity to limestone, similar to Bujang Melaka area near Kampar in Perak (Schwartz & Abdul Kadir, 1989; Fauzi *et al*., 2019). Multielement combinations also suggest the possible mineralization could be either greisen Sn-W, skarn, sulfides Pb-Sn or porphyry-Au (Rose *et al*., 1979; Ridley, 2013). The occurrence of gold mineralization in the study area does not appear in any gold belts in Peninsular Malaysia mentioned in Yeap (1993). Nonetheless, gold was reported to occur in Weng area, 20 km southeast from the study area (Abdul Rahman *et al*., 2008).

CONCLUSION AND RECOMMENDATIONS

The conducted study on the geology of the Sungai Bahoi-Charok Jawa area has successfully completed the geological information with aids from different traverse routes by previous geologists. The brecciated phyllites along the contact zone between granites and Kubang Pasu Formations and limestone hills near the Sungai Bahoi downstream were newly discovered.

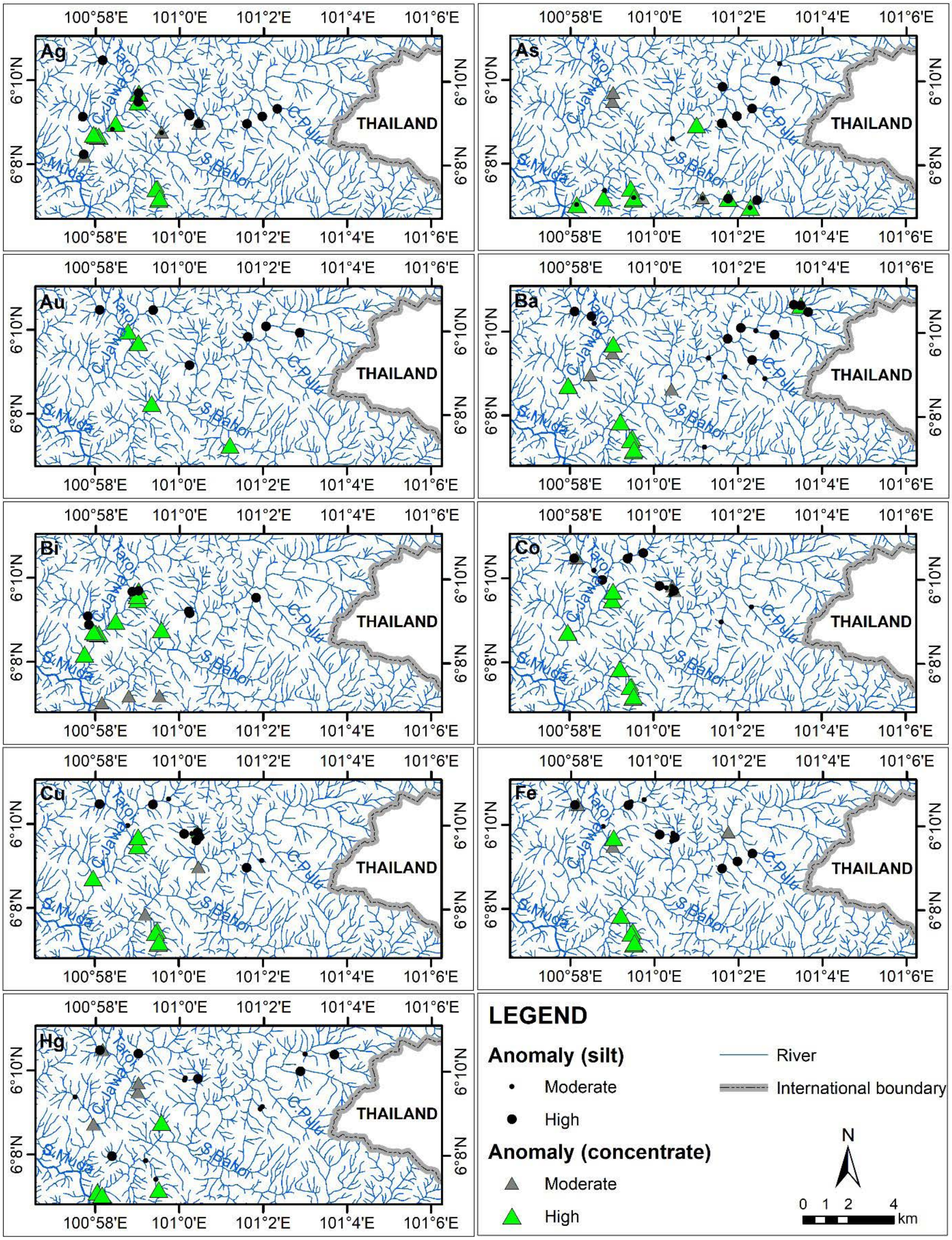

Figure 5: Distributions of moderate and high anomaly values from silt and concentrate samples according to element type.

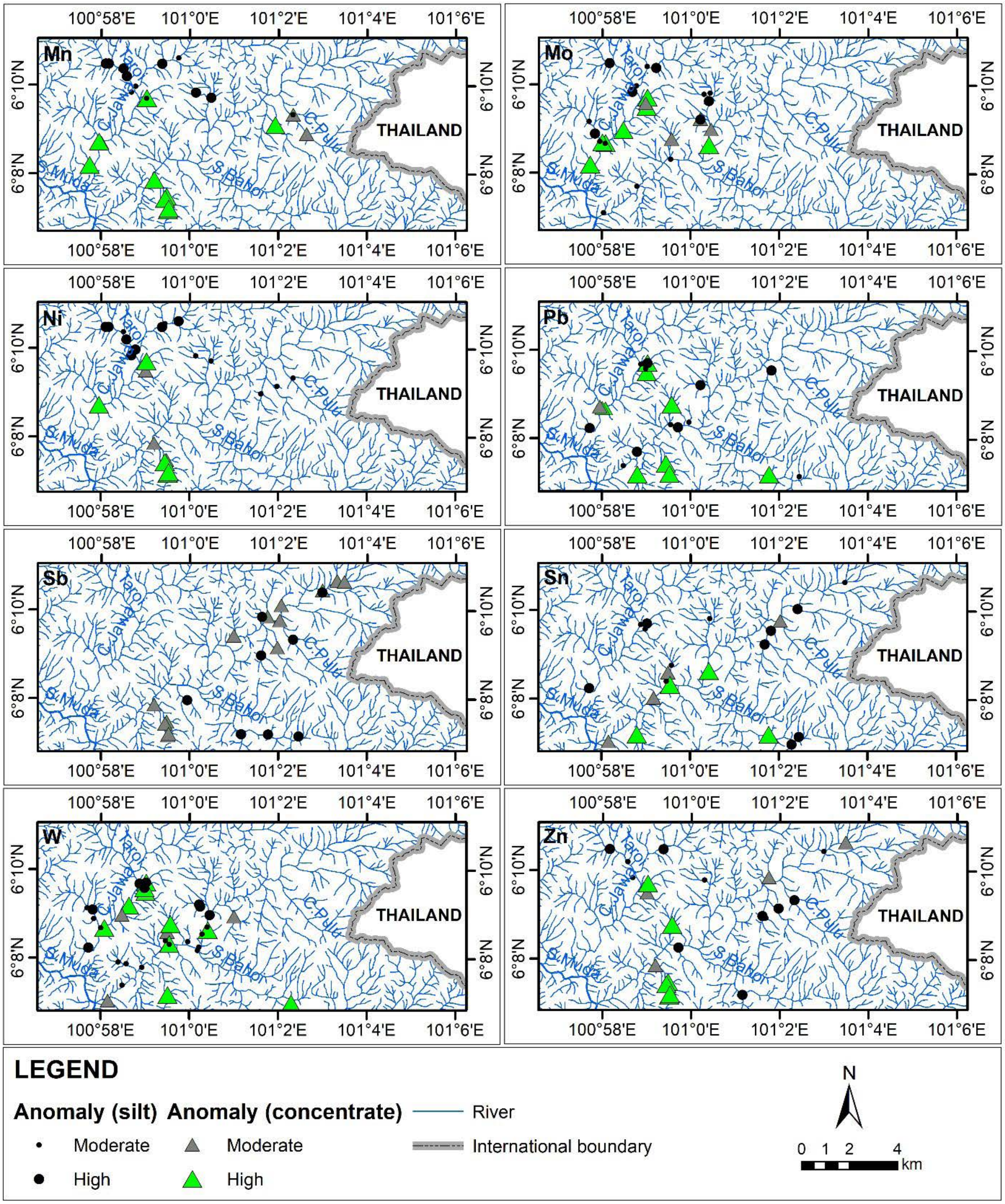

Figure 5: Distributions of moderate and high anomaly values from silt and concentrate samples according to element type (continued).

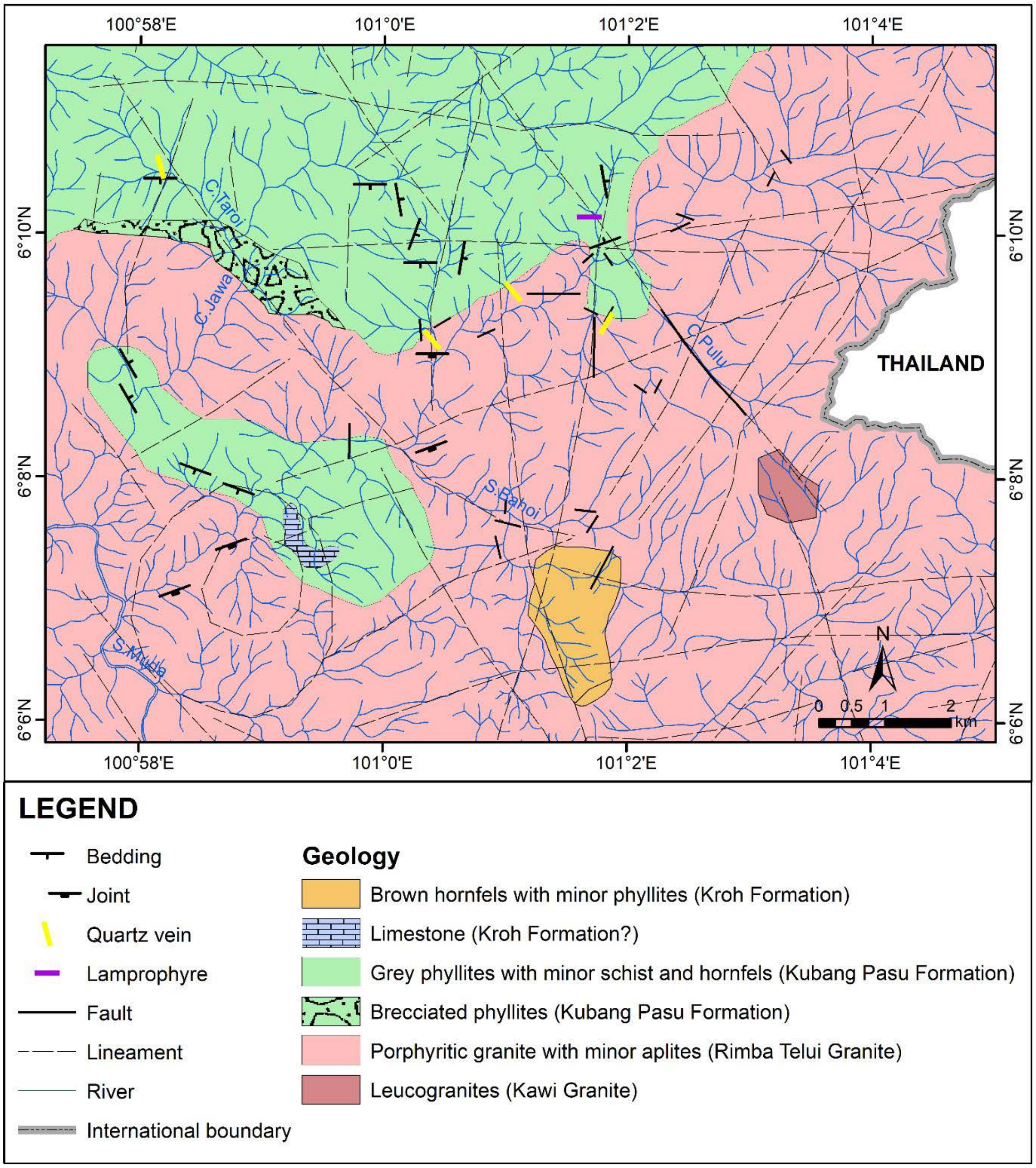

Figure 6: Geology of the study area, combined with results of field mappings and lineaments from aerial photo interpretations.

The geochemical result of Sn based on heavy mineral concentrate samples ranges from 1,000 to 424,500 ppm, by which high anomaly value starts at 236,800 ppm. Cluster analysis based on the results has also successfully determined multielement anomaly areas within the granite – sedimentary contact zone, by which Sn appears as the main element in 5 out of 7 anomaly areas. The high concentration of Sn and its anomaly areas which mostly sit on granitic – sedimentary contact zone indicates that tin mineralization exist in the Sungai Bahoi-Charok Jawa area.

Further study on tin metallic mineral potential is also suggested to be carried out to define its primary resource. Recommended study includes detailed mapping, ridge and spur sampling and geophysical survey particularly on high anomaly areas, especially within the circular features and within the proximity of already discovered mineralized quartz vein. Besides tin, the occurrence of gold within the study area is also interesting and should be further studied. Additional study on the age and geoheritage values of the limestone hill and its caves is also suggested to be carried out.

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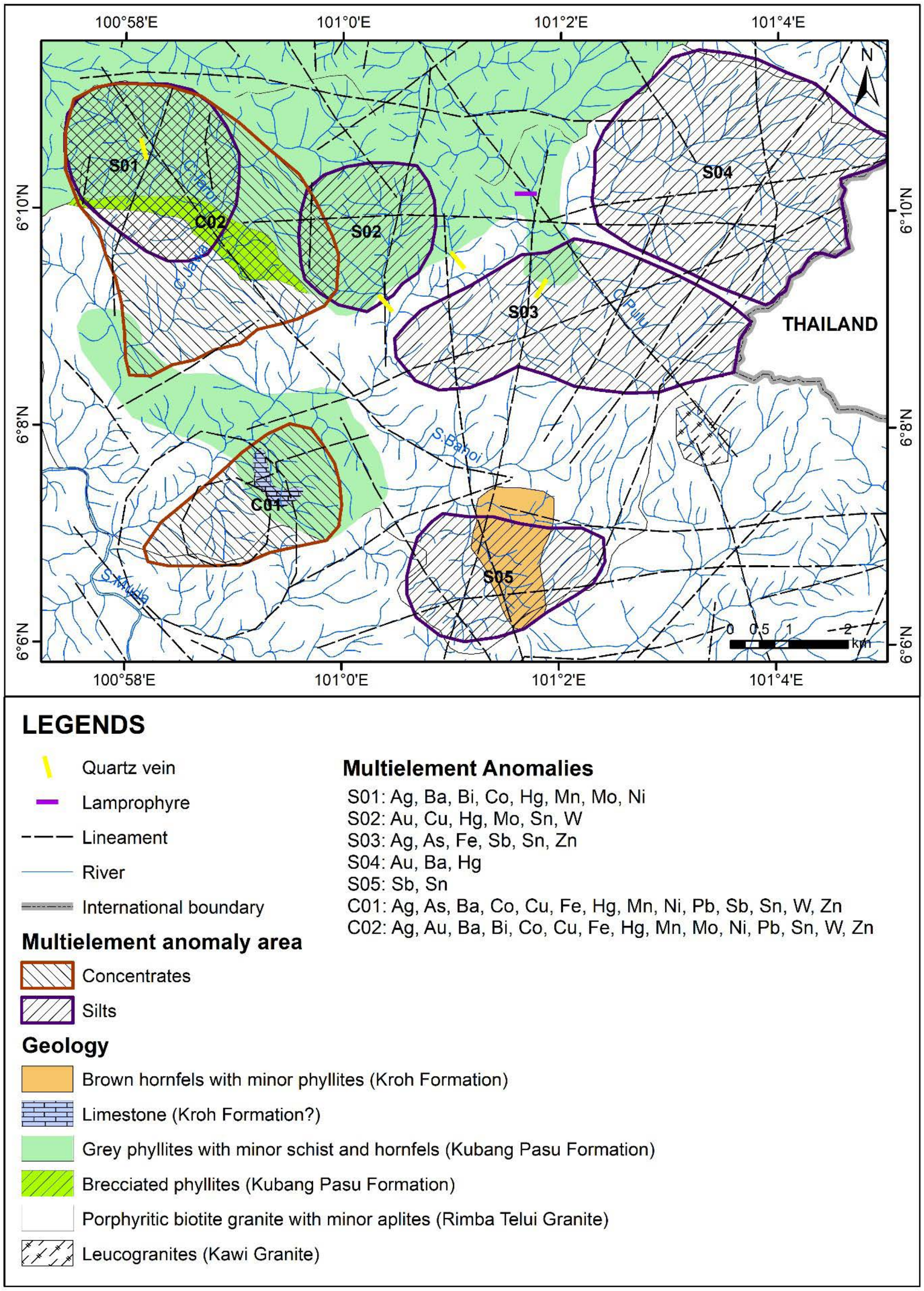

Figure 7: Distributions of multielement anomalies in the study area.

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AUTHOR CONTRIBUTIONS

FAF performed field mapping, sampling, geochemical result interpretation and wrote the whole manuscript. HA contributed to critically reviewing the manuscript and contributing ideas to improve the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

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