Petrochemistry of volcanic rocks in Suwan-N Prospect of Chatree gold deposit, Phichit Province, Central Thailand

Kobkul Khiaosanuan[1], Thitiphan Assawincharoenkij[1,2*], Sirawit Kaewpaluk[1,2]
Abhisit Salam[1], and Chakkaphan Sutthirat[1,2]

[1]Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
[2]Applied Mineral and Petrology Research Unit, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
[*]Corresponding author e-mail: thitiphan.a@chula.ac.th

ABSTRACT

Suwan-N prospect is in Phichit Province, Central Thailand, within the Loei Fold Belt, a region known for its significant mineral deposits, including the nearby Chatree gold deposit. This study focused on the lithology and geochemistry of volcanic host rocks and an associated andesitic dyke collected from the Suwan-N prospect. Main volcanic hosts were identified as plagioclase-hornblende-phyric andesite, plagioclase-phyric dacite, and andesitic breccia. In addition, an andesitic dyke was described as a later state that intruded into the earlier host volcanics. Petrographic features and geochemical compositions indicated that these host volcanic share similarities with other epithermal deposits in the Loei-Phetchabun-Nakhon Nayok volcanic belt. The host rock displays calc-alkaline magmatism and pervasive hydrothermal alteration. In contrast, the later andesitic dyke exhibited a distinct tholeiitic magma series and presented differences in chemical composition from host rock with high TiO_2, Na_2O, P_2O_5, FeO_t, Co, Ni, and As, suggesting it originated from a different magmatic process. Geochemical data suggested that this andesitic dyke intruded after the main mineralization phase, pointing to the continuation of tectonic activity in the region.

Keywords: Epithermal deposit, Loei Fold Belt, Geochemistry, Petrochemistry

1. Introduction

Thailand, located in Southeast Asia, is characterized by two major tectonic terranes: the Indochina terrane in the east and the Sibumasu terrane in the west (Bunopas, 1981). These terranes collided during the Late Triassic, resulting in the formation of the Sukhothai and Loei fold belts, which mark the boundary between them and signify the closure of the Paleo-Tethys Ocean (Shi et al., 2021). The Loei Fold Belt is particularly notable for its tectonic significance and metallogenic potential, being associated with subduction and magmatic events that have given rise to numerous mineral deposits (Kamvong & Zaw, 2009; Salam et al., 2014; Shi et al., 2021; Zaw et al., 2014).

This region hosts several economically important mineral deposits, including the Phu Thap Fah (Au skarn deposit), Khao Phanom Pha (Au skarn deposit), and Chatree deposit (epithermal Ag-Au deposit) (Zaw et al., 2014). Extensive research has been conducted on these deposits, focusing on volcanic stratigraphy, petrochemistry, mineralization, geochronology, and geochemistry (Andrianarimanana et al., 2016; Cumming et al., 2008; Kaewpaluk et al., 2024; Kaewpaluk et al., 2022a; Kaewpaluk et al., 2022b; Kamvong, 2004; Kamvong & Zaw, 2009; Kamvong et al., 2006; Nualkhao et al., 2018; Salam, 2013; Salam et al., 2014; Zaw et al., 2007).

The Suwan-N prospect, located around 10 km north of the Chatree deposit—the largest epithermal Ag-Au deposit in Thailand (Zaw et al., 2014) is situated in Phichit Province, Central Thailand (Figure 1). Although this area is identified as an epithermal deposit hosting gold according to an unpublished Akara mining report, it currently has no mining activity, and no comprehensive study has been undertaken on the Suwan-N prospect. Therefore, the primary objectives of this study are to identify the mineral and geochemical composition of the volcanic hosts and dyke within the Suwan-N prospect.

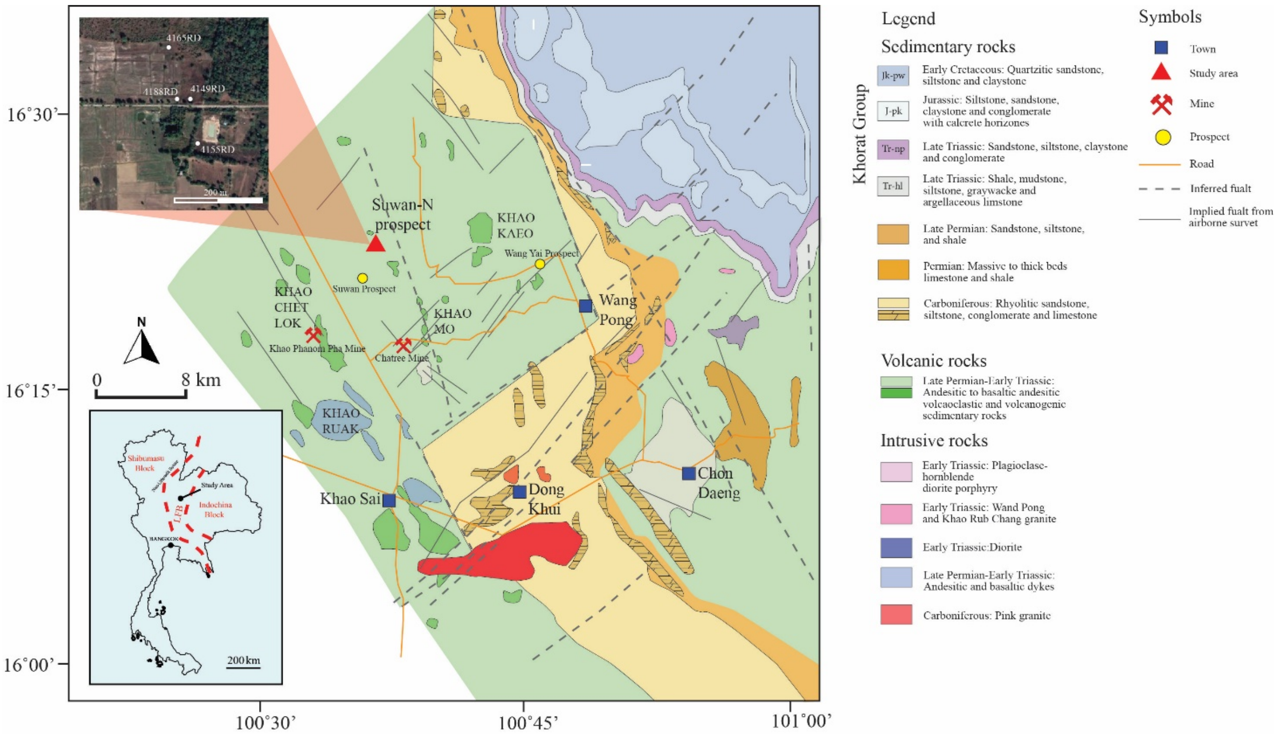

Figure 1. Geologic map of the study area and surrounding area in Phichit, Phetchabun, and Phitsanulok Provinces, Central Thailand modified after Salam et al. (2014).

2. Material and methods

This study involved the collection and analysis of core samples from four drill holes (4149RD, 4188RD, 4155RD, and 4165RD) within the Suwan-N prospect, provided by Akara Resources Public Company. A total of thirty-five representative samples were systematically selected for laboratory analyses, including petrographic investigations and whole-rock geochemical analysis. The samples included five plagioclase-hornblende-phyric andesite, three plagioclase-phyric dacite, fourteen andesitic breccia (including twelve polymictic and two monomictic samples), and six andesitic dyke samples.

For petrographic analysis, thirteen samples were prepared as thin sections to identify rock types and mineral assemblages using transmitted-light microscopy. Based on the petrographic observations, representative samples were selected for further geochemical analysis.

Whole-rock geochemical analysis was performed on nine host volcanic samples and three dyke samples. Major and minor oxides were quantified using X-ray fluorescence (XRF) BRUKER model S4 Pioneer (WDXRF) spectrometer. The analysis was calibrated using standard reference materials, including AGV-2, BHVO-2, JG-2, JG-1a, JB-1b, and SGR-1, to ensure quantitative accuracy.

Moreover, trace element analysis was conducted using an inductively coupled plasma mass spectrometer (ICP-MS), Analytik Jena PlasmaQuant MS Elite model. Samples were prepared through microwave digestion following a general rock digestion method (Digestion Application Note: DG-GE-06).

All research facilities reported above are based at the Department of Geology, Faculty of Science, Chulalongkorn University.

3. Results

3.1 Lithology

A stratigraphic description of the drill holes, collected from depths between 200 and 280 meters (from the surface), is illustrated in Figure *2*. At the top of the core sample, a greyish-green plagioclase-phyric dacite layer, approximately 50 to 70 meters thick, is observed. This layer gradually transitions into volcanic breccia, indicated by thin interbedded breccia deposits within the plagioclase-hornblende-phyric andesite.

The middle section of the core is dominated by volcanic breccia, consisting of both polymictic and monomictic andesitic breccia. This breccia contains volcanic and sedimentary rock fragments, with an increase in pumice fragments and a decrease in clast size observed at greater depths.

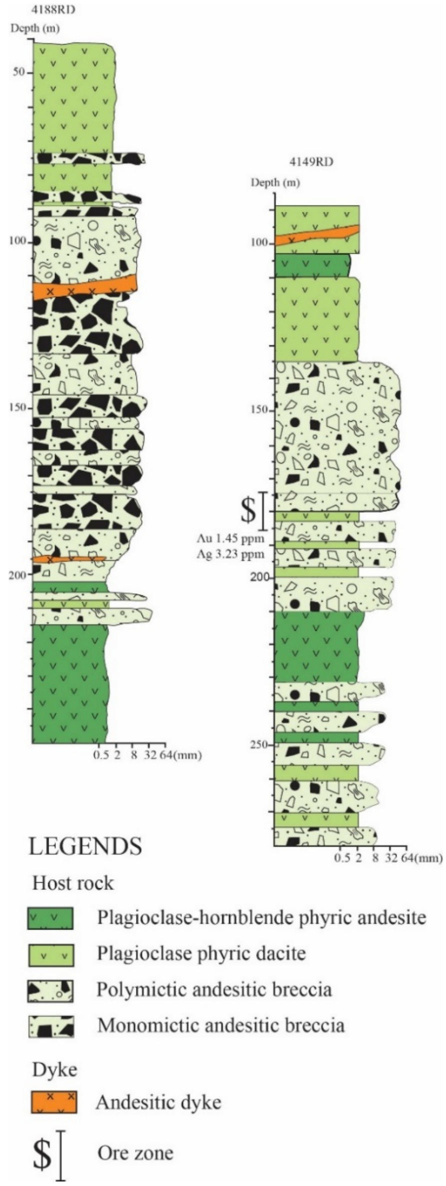

Figure 2. West-east stratigraphic logs correlation of 4188RD and 4149RD of the Suwan-N prospect

At the base of the core, plagioclase-hornblende-phyric andesite is predominant, accompanied by occurrences of plagioclase-phyric dacite. An andesitic dyke crosscuts the host volcanics. Certain intervals of the drill cores show alteration of country rocks by sulfide minerals, with alteration zones ranging from 1 to 3 meters in thickness. The detailed lithological descriptions are as follows:

Plagioclase-hornblende-phyric andesite

Plagioclase-hornblende-phyric andesite exhibits significant alteration, with colors ranging from dark green to grayish green (Figure 3a). Phenocrysts consist of euhedral and subhedral plagioclase and hornblende crystals, typically 1 to 2 mm in size, comprising approximately 40% of the rock's volume. These phenocrysts have altered into secondary minerals, with hornblende converting to chlorite and plagioclase to sericite (Figure 4a). Groundmass is mainly quartz, with a grain size of approximately 0.8 mm, and between grains are filled with fine-grained chlorite. Mineral assemblage includes approximately 10% quartz, 50% plagioclase, and 40% hornblende, with fine-grained sulfide minerals, such as pyrite, disseminated throughout.

Plagioclase-phyric dacite

Plagioclase-phyric dacite shares similarities with the plagioclase-hornblende-phyric andesite but is distinguished by fewer and smaller phenocrysts and a lighter, grayish-green color (Figure 3b). Phenocrysts, constituting about 20% of the rock, are primarily altered plagioclase to sericite, appearing as anhedral to subhedral crystals (Figure 4b). Groundmass mainly comprises quartz and feldspar, with chlorite filling between crystals, and typically has a grain size of around 0.1 mm. Mineral assemblage includes approximately 40% quartz, 35% feldspar, 20% plagioclase, and 5% mafic minerals. Pyrite and other fine-grained sulfide minerals are disseminated throughout the sample.

Andesitic Breccia

Polymictic andesitic breccia is matrix-supported and poorly sorted, with common clasts including pumice, andesite, and dacite fragments (Figure 3c and d). All mafic minerals have been altered to chlorite. Most clasts are subangular to subrounded with high sphericity. Although coarse sandstone fragments are rare, when present, they are rounded and exhibit high sphericity (Figure 4c). Clasts range from 0.2 to 6 cm in size, within a mud to sand-sized matrix. The polymictic andesitic breccia contains 75% clasts, with 70% rock fragments and 5% crystal clasts, while the matrix, which makes up 25%, consists of quartz and alkali-feldspar altered to sericite, with some clasts replaced by calcite.

At certain depths, monomictic andesitic breccia is interbedded with polymictic breccia. The monomictic breccia displays a jigsaw-fit texture with andesite clasts (Figure 3e), similar in composition to plagioclase-hornblende-phyric andesite, with angular clasts of high sphericity (Figure 4d). This rock type consists of 80% clasts and 20% matrix. Clasts range from 0.6 to 5 cm, with a euhedral quartz matrix indicative of crystallization from hydrothermal fluid. At some depths, significant alteration has imparted a grayish-green color, with numerous sulfide minerals disseminated throughout.

Andesitic dyke

Andesitic dyke features dark green and light green crystals, identified as orthopyroxene and plagioclase (Figure 3f). The mineral assemblage includes 65% plagioclase, 30% orthopyroxene, and 5% quartz. Plagioclase crystals are euhedral with multiple twins, while orthopyroxene appears as small, rounded crystals. Quartz is present as small, irregular grains. Mafic minerals such as orthopyroxene show alteration to chlorite around crystal rims (Figure 4e and f). Blade-shaped and cubic sulfide minerals, such as pyrite are also disseminated throughout the sample.

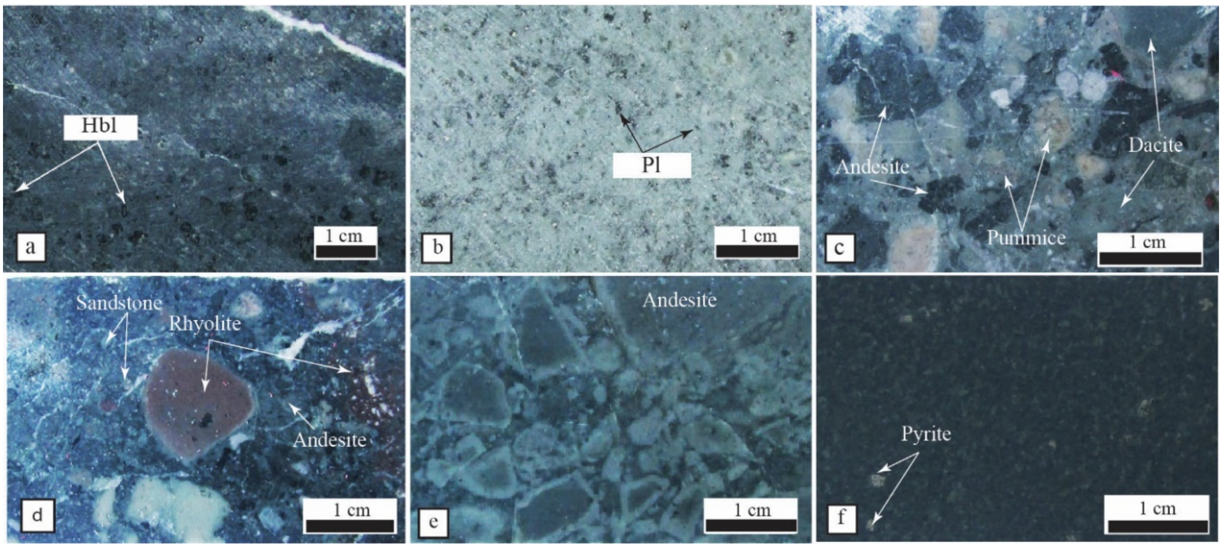

Figure 3. Photographs of volcanic host rocks in Suwan-N prospect. (a) Plagioclase-hornblende-phyric andesite. (b) Plagioclase-phyric dacite. (c) and (d) Polymictic andesitic breccia. (e) Monomictic andesitic breccia. (f) Late-stage andesitic dyke.

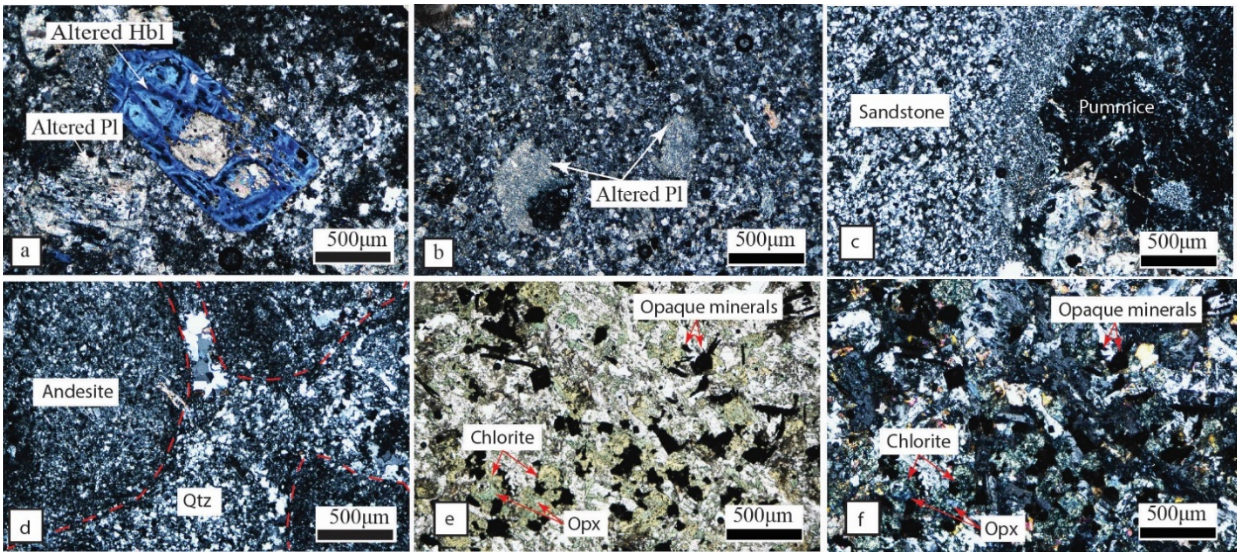

Figure 4. Photomicrographs of volcanic host rocks in Suwan-N prospect. (a) Plagioclase-hornblende-phyric andesite shows hornblende phenocryst altered to chlorite. (b) Plagioclase-phyric dacite shows plagioclase phenocryst changed to sericite. (c) Polymictic andesitic breccia shows sandstone and pumice fragments. (d) Monomictic andesitic breccia shows andesite clasts and quartz groundmass. (e, PPL) and (f, XPL) Andesitic dyke show plagioclase and orthopyroxene (opx) crystals which some are altered to chlorite at the rim of orthopyroxene crystal and present opaque minerals that spread across the sample.

Table 1 Whole-rock chemistry of volcanic rocks in Suwan-N prospect. All major and minor oxides are reported in wt.% and trace elements are present in ppm.

Rock	Plagioclase-hornblende-phyric andesite			Plagioclase-phyric dacite			Andesitic breccia			Andesitic dyke		
Sample	CT1	CT4	CT5	FT2	FT3	FT4	BX6	BX7	BX8	AD4	BD3	BD4
SiO_2	52.97	53.57	51.45	70.52	68.49	69.44	40.74	50.87	37.50	48.39	48.74	48.58
Al_2O_3	17.40	17.50	18.00	13.90	15.10	14.00	15.60	16.16	13.95	13.70	14.10	13.70
TiO_2	0.44	0.45	0.44	0.33	0.35	0.34	0.58	0.60	0.50	2.94	3.02	2.94
Fe_2O_3	8.04	8.57	8.78	3.84	3.93	3.61	9.92	9.57	7.75	13.24	13.52	13.39
MnO	0.19	0.22	0.17	0.11	0.07	0.08	0.34	0.37	0.21	0.17	0.24	0.22
MgO	6.81	5.91	4.74	2.98	2.62	2.30	3.83	4.93	4.07	4.05	4.28	4.66
CaO	4.29	4.68	7.94	1.21	1.88	1.77	15.12	6.94	19.49	8.22	7.92	6.91
Na_2O	1.72	2.18	3.25	2.00	3.33	3.34	1.79	2.70	1.47	3.43	3.75	4.13
K_2O	2.05	1.53	0.88	2.41	1.48	1.86	2.31	1.69	2.52	0.00	0.08	0.06
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.18	0.14	0.60	0.54	0.54
LOI	6.10	5.36	4.33	2.68	2.75	3.26	9.62	5.99	12.40	5.28	3.83	4.86
Total	100.01	99.96	99.98	99.97	100.00	100.00	100.00	100.00	100.00	100.01	100.01	99.98
Mg#	45.86	40.83	35.07	43.71	39.98	38.92	27.84	33.99	34.43	23.42	24.04	25.82
Co	87.53	87.83	85.84	28.85	25.92	25.39	58.53	52.94	51.14	123.71	108.25	112.77
Ni	38.53	25.57	32.48	17.05	9.58	12.32	16.08	13.00	16.65	73.32	35.12	38.54
Cr	167.69	198.49	228.63	224.02	251.84	233.77	104.58	142.26	150.32	118.41	92.72	82.29
Pb	28.40	121.16	27.62	51.99	11.49	12.74	44.85	10.64	20.59	15.69	19.03	12.86
Ag	1.77	2.08	1.74	2.02	1.91	1.59	2.01	1.78	1.76	1.61	1.89	1.84
As	14.57	33.51	19.38	59.61	13.77	24.48	32.18	18.41	31.33	50.82	61.10	44.75
Cd	3.09	3.64	3.86	3.28	3.17	3.25	3.61	3.09	3.11	3.77	3.08	3.39
Cu	493.28	485.69	532.92	164.94	151.39	115.89	186.33	122.23	41.31	116.92	107.31	102.64
Zn	779.52	1076.17	682.39	705.32	398.39	677.64	449.06	613.20	543.82	523.29	770.88	631.76

3.2 Whole-rock geochemistry

Geochemical data of all volcanic types (plagioclase-hornblende-phyric andesite, plagioclase-phyric dacite, andesitic breccia, and andesitic dyke) in this study are summarized in

Table ***1***. Three polymictic andesitic breccia samples were selected to represent both groups (monomictic and polymictic) of andesitic breccia.

Petrographic analysis reveals that both the host rock and dyke have undergone alteration, primarily through the development of sericite and chlorite. The Chemical Index of Alteration (CIA) values indicate that the rock samples exhibit low to moderate degrees of weathering (Figure 5). Andesitic breccia and andesitic dykes show signs of weak weathering, whereas plagioclase-hornblende-phyric andesite and plagioclase-phyric dacite display moderate weathering

Chemical composition data can be categorized by the TAS diagram (Le Bas, 1989) (Figure 6) the plagioclase- phyric dacite was categorized close to the felsic rhyolite-dacite field, while the other samples, including the andesitic dyke, fall within the intermediate to the mafic fields. The andesitic breccia displayed a high distribution of data points, likely due to the heterogeneous nature of its clasts which found several kinds of fragments due to the represented samples. Overall, the chemical data align well with the findings from the petrographic study.

Magnesium number was considered the chemical composition of igneous rock, which is ratio of magnesium to iron ($Mg/ (Mg + Fe_{total}) \times 100$). Magnesium number (Mg#) is consistent among host rocks, ranging from 28 to 46, whereas the andesitic dyke presents a lower magnesium number, ranging from 23 to 25.

Variation plots of magnesium number versus major oxides and trace elements (Figure 7 and 8) show distinct trends among these rock types. There is a positive correlation between magnesium number and MgO, K_2O, and Ni, while a negative correlation is observed between magnesium number and CaO, Na_2O, P_2O_5, FeO_t, and As. No clear trend is observed between magnesium number and TiO_2, Al_2O_3, Zn, Pb, and Co, which vary significantly across rock types. Additionally, the chemical composition of the andesitic dyke deviates from the trends observed in the host rocks, particularly in the plots of magnesium number against TiO_2, Na_2O, K_2O, P_2O_5, FeO_t, Co, Ni, and As.

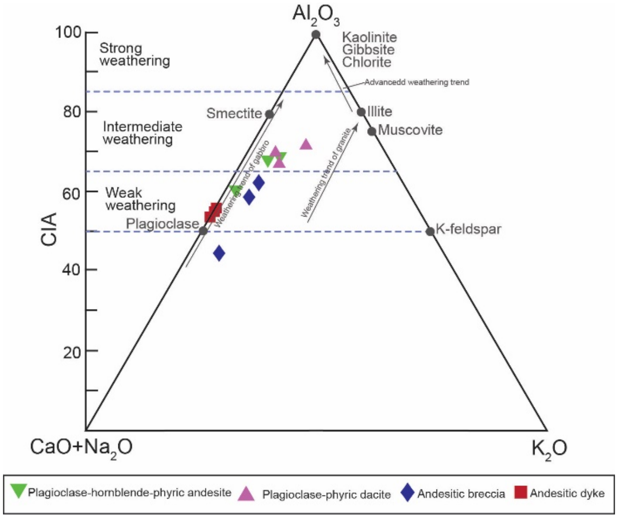

Figure 5. Chemical Index of Alteration (CIA) with ternary diagram (after Nesbitt and Young (1982, 1984, 1989) of the samples from Suwan-N prospect.

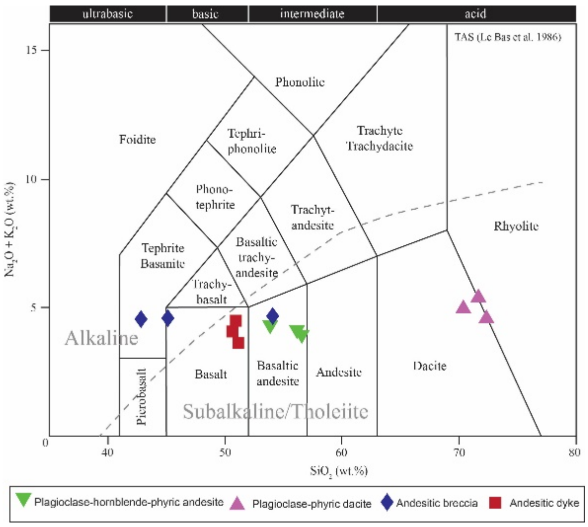

Figure 6. Volcanic discrimination diagram, total alkaline vs. silica (TAS) plot with subdivision of the alkaline and sub-alkaline/tholeiitic magma series (Le Bas, 1989).

4. Discussion

The volcanic rocks in the Suwan-N prospect have been classified into four types: plagioclase-hornblende-phyric andesite, plagioclase-phyric dacite, andesitic breccia, and andesitic dyke. The later andesitic dyke appeared to crosscut into the other types. The lithological characteristics of these volcanic rocks are consistent with other deposits in the Loei-Phetchabun-Nakhon Nayok volcanic belt, such as the Chatree deposit, Wang Yai prospect, and Suwan prospect (Cumming et al., 2008; Kaewpaluk et al., 2022b; Salam, 2013; Salam et al., 2014; Soisa et al., 2020; Tangwattananukul et al., 2014; Vivatpinyo et al., 2014). The rock accumulation in the Suwan-N prospect is consistent with those commonly found in the Loei-Phetchabun-Nakon Nayok volcanic belt in the Phichit-Phitsanulok province, including polymictic and monomictic andesitic breccias, fiamme breccia, phyric andesite, phyric dacite, and phyric rhyolite. The lithological characteristics of the Suwan-N prospect align with those observed in other nearby areas, such as the Chatree deposit, Suwan prospect, and Wang Yai prospect (Cumming et al., 2008; Little, 2005; Salam, 2013; Soisa, 2019; Soisa et al., 2020).

Furthermore, distinct differences in chemical composition are observed between the host rocks and the andesitic dyke. In the Chatree deposit and Suwan prospect, the andesitic dyke exhibits elevated levels of TiO_2, Fe_2O_3, and P_2O_5, as reported by Salam et al. (2014), Cumming et al. (2008), and Soisa et al. (2020), which presents a similar composition as a andesitic dyke in this study area. In contrast, the intermediate volcanic host rocks—such as plagioclase-hornblende-phyric andesite and andesitic breccia—are characterized by high concentrations of Fe_2O_3, MgO, and CaO, similar to those found in the Chatree deposit, Wang Yai prospect, and Suwan prospect (Cumming et al., 2008; Little, 2005; Salam et al., 2014; Soisa et al., 2020). Felsic volcanic rocks are comparatively rare in the Suwan-N prospect. The only felsic rock identified, plagioclase-phyric dacite, shares a composition with rocks from the Chatree deposit and Suwan prospect, such as plagioclase-phyric dacite, fiamme breccia, and monomictic feldspar-phyric rhyolite, which all show lower concentrations of Fe_2O_3, MgO, and CaO (Cumming et al., 2008; Salam et al., 2014; Soisa et al., 2020).

In addition, the pervasive sericite alteration observed in the host rocks of the Suwan-N prospect further suggests a strong association with hydrothermal systems, indicative of a mineralization process (Gifkins et al., 2005; Kaewpaluk et al., 2022a; Little, 2005; Misra, 2012; Ridley, 2013; Salam, 2013; Soisa, 2019).

The TAS diagram (Figure 6) also categorized all volcanic host rocks and andesitic dyke into the subalkaline/ tholeiitic magma series. However, the AFM diagram (Figure 9) highlights a significant distinction between the dyke and the host volcanic. The andesitic dyke falls within the tholeiitic magma series, contrasting with the calc-alkaline magma of the host rocks. This suggests that the dyke originated from a different magmatic source or represents a separate magmatic process.

The distinct chemical signature of the andesitic dyke, particularly when compared to the volcanic hosts, supports the hypothesis of a later magmatic event. This is corroborated by evidence from other deposits in the Phichit-Phitsanulok province, where similar andesitic dykes are noted to postdate the main mineralization events. For instance, in the main Chatree deposit, the ages of andesitic dykes range from 244 ± 7 Ma to 238 ± 6 Ma based on U-Pb zircon dating, whereas the mineralization age is slightly older at 250.9 ± 0.8 Ma, as determined by $^{40}Ar/^{39}Ar$ dating of adularia (Salam et al., 2014). This temporal relationship suggests that the andesitic dykes, including those in the Suwan-N prospect, likely intruded after the primary mineralization phase, potentially during a tectonic or magmatic reactivation phase.

Differences in lithology, alteration, and geochemistry between the host volcanic rocks and the andesitic dyke imply a complex magmatism in the tectonic history of the Suwan-N prospect. The host volcanic rocks, with their calc- alkaline affinity and extensive hydrothermal alteration, are likely closely associated with the main mineralization processes in the area. In contrast, the andesitic dyke's tholeiitic nature and distinct geochemical profile suggest that it has been emplaced during a later magmatic event, potentially unrelated to the primary mineralization but possibly indicative of continued tectonic activity in the region.

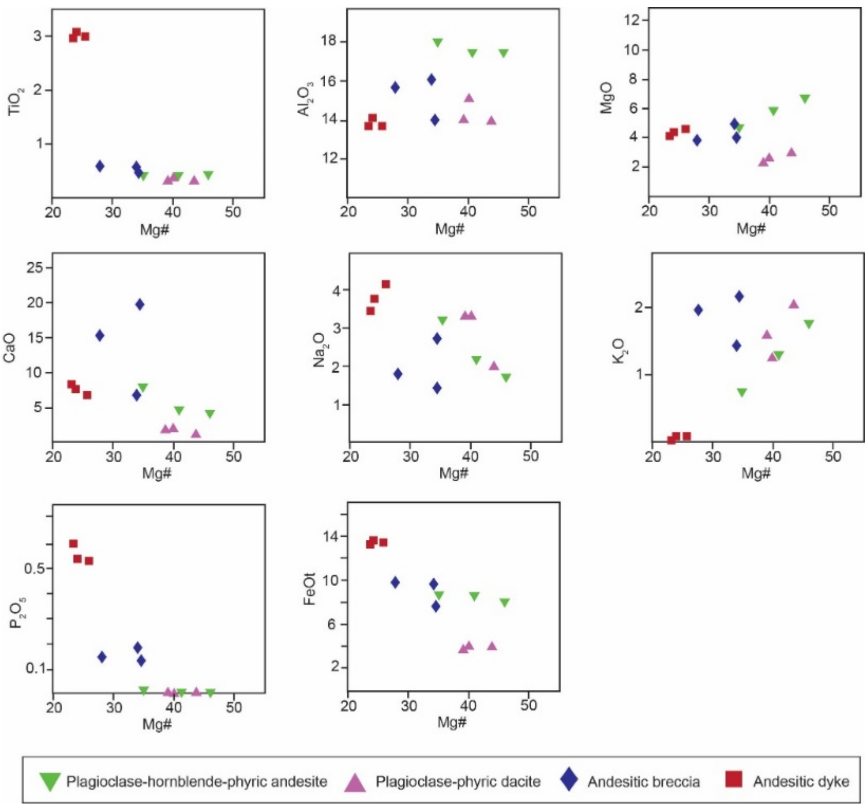

Figure 7. Variation plots between magnesium number (Mg#) against major oxides (wt.%) of volcanic rocks collected from the Suwan-N prospect.

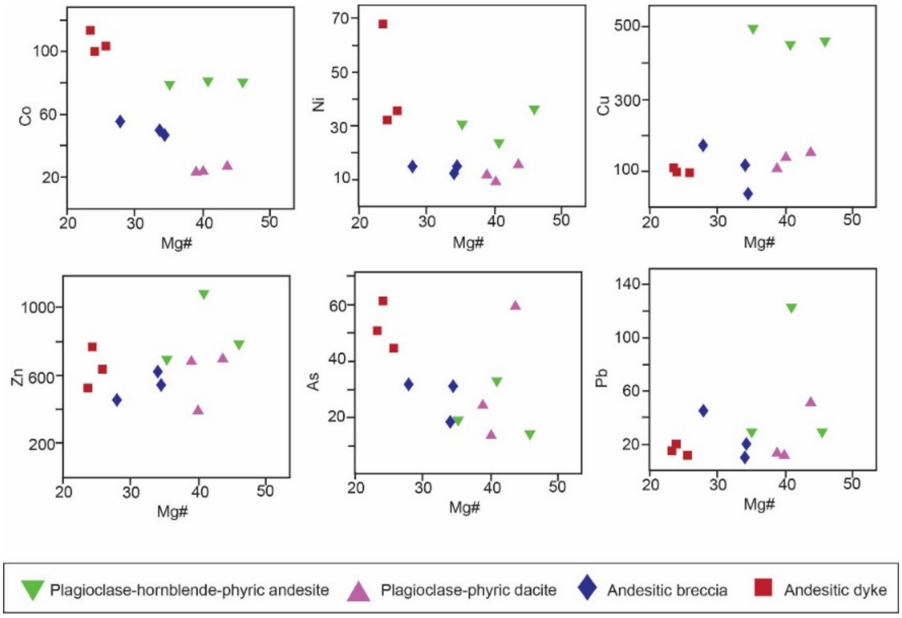

Figure 8. Variation plots between magnesium number (Mg#) against trace elements (ppm) of volcanic rocks taken from the Suwan-N prospect

5. Conclusions

1) Volcanic rocks in the Suwan-N prospect are classified into plagioclase-hornblende-phyric andesite, plagioclase-phyric dacite, polymictic/monomictic andesitic breccia, and later andesitic dyke. They vary from felsic to mafic compositions
2) The host volcanics share similar characteristics with other deposits in the Loei-Phetchabun-Nakhon Nayok volcanic belt, suggesting a regional geological consistency, particularly in terms of rock types and alteration patterns. The intermediate volcanic rocks present the same chemical characteristic as other areas (Chatree deposit, Suwan prospect, and Wang Yai prospect), with high FeO_{total} and CaO, while felsic volcanic rocks are opposite.
3) Andesitic dyke clearly differs from other host rocks which have high TiO_2, Fe_2O_3, and P_2O_5, this contrast is also present in the Chatree deposit and Suwan prospect study. Andesitic dyke exhibits a tholeiitic magma series, distinct from the calc-alkaline series of the volcanic hosts, indicating a different magnetism.

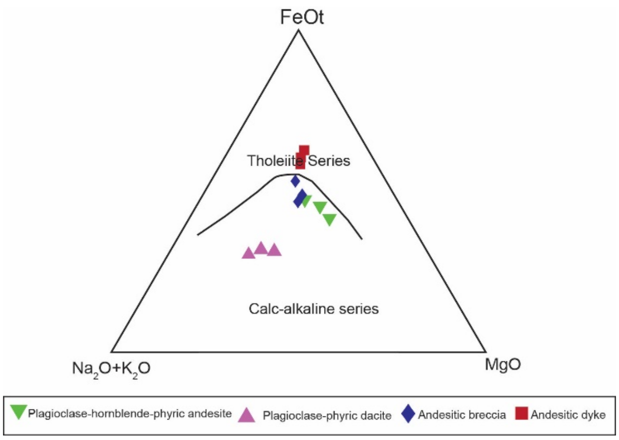

Figure 9. AFM diagram (Irvine & Baragar, 1971), showing the calc-alkaline and tholeiite series of volcanic hosts and andesitic dyke from the Suwan-N prospect.

6. Acknowledgments

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