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Affinity Study and Rock Types in the Beruang Kanan Area, Central Kalimantan

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Abstract:
The mineralizing bearing rocks on the Right Bear prospect are andesite. Geochemical data of rocks indicate that they are classified as intermediate igneous rocks rich in silica. The composition of andesite silica is approximately 60% with a total alkali (Na+K) of about 3.6%. Based on this data, it is known that the dacite affinity is calc-alkaline. The volcanic rocks of the Right Bear prospect are primarily andesite. This study aims to determine the affinity of magma and geochemical characteristics of volcanic rocks in the Beruang Kanan area, Central Kalimantan, as the basis for the interpretation of tectonic settings and mineralization potential. Geochemical analysis was carried out using the X-Ray Fluorescence (XRF) method for the main oxide element and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for trace elements. Samples that have an LOI value of less than about 2% by weight are assumed to be unaltered or fresh rocks and these rocks are generally characterized by the presence of relative euhedral phenocrites and mineral grains and the absence of secondary hydrothermal minerals. The results of the comparison of Co and Th (Hastie, et al., 2007) on samples of fresh/slightly altered rocks and completely altered rocks are included in the affinity of magma of the alkaline limestone type. The results of the comparison of Zr/Y and Th/Yb (Ross & Bedard, 2009) show that samples of fresh rocks and altered rocks are included in the affinity of magma of the alkaline calcage series. Based on the results of the plotting of some of the above methods, it can be concluded that the magma affinity of the Beruang Kanan area belongs to the type of alkaline limestone which can be interpreted as being related to the within plate (in the plate) in the form of a continental expansion zone. This finding has important significance for the exploration of Cu-Au epithermal-porphyry mineralization in the Central Kalimantan region, given that rocks with calc-alkaline affinity in the within plate setting are often associated with economical mineralization systems.

Keywords: igneous rocks; andesite, geology, affinity, alkaline limestone

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INTRODUCTION

The Beruang Kanan area in Central Kalimantan is part of the eastern Sunda Arc which has a complex geological history with significant magmatic and hydrothermal activity. The region is located in an active tectonic context that produces a highly economically viable epithermal-porphyry mineralization system for Cu-Au deposits (Anderson et al., 2023; Anthony et al., 2017; Li & Selby, 2019; Virmond et al., 2021; Zarasvandi et al., 2018). Beruang Kanan is located north of Palangkaraya, the capital of Central Kalimantan. It is about 190 kilometers long and geographically located at the following coordinates: 768.300-768.500 E and 9.931.500-9.932.850 LS. Physiographically, this area is a mountainous area located north of the Kahayan River. It takes an eight-hour drive (about 350 km) to Beruang Kanan or a 50-minute helicopter ride. The roads of logging companies provide access to this previously remote area (Anjarwati et al., 2018, 2019; Fathia et al., 2019; Sasa et al., 2023) (Figure 1).

The Beruang Kanan area in Central Kalimantan is an area with a complex geological history with significant magmatic and hydrothermal activity.

The classification of igneous rocks in this region is important to understand:

a. The origin of magma and magmatic differentiation.
b. The relationship between igneous rocks and mineralization (e.g. gold, copper).
c. Characteristics of hydrothermal alterations related to the epithermal-porphyry system.

The Total Alkali-Silica (TAS) diagram (Le Bas et al., 1986) is used because it provides a clear classification based on two main parameters:

1. SiO_2 (% by weight) – An indicator of magma acidity.
2. Total Alkaline (Na_2O + K_2O, % by weight) – Alkalinity indicator.

The purpose of this study was to classify igneous rocks in the Right Bear using a TAS diagram. Analyze geochemical variations and their implications for mineralization potential.

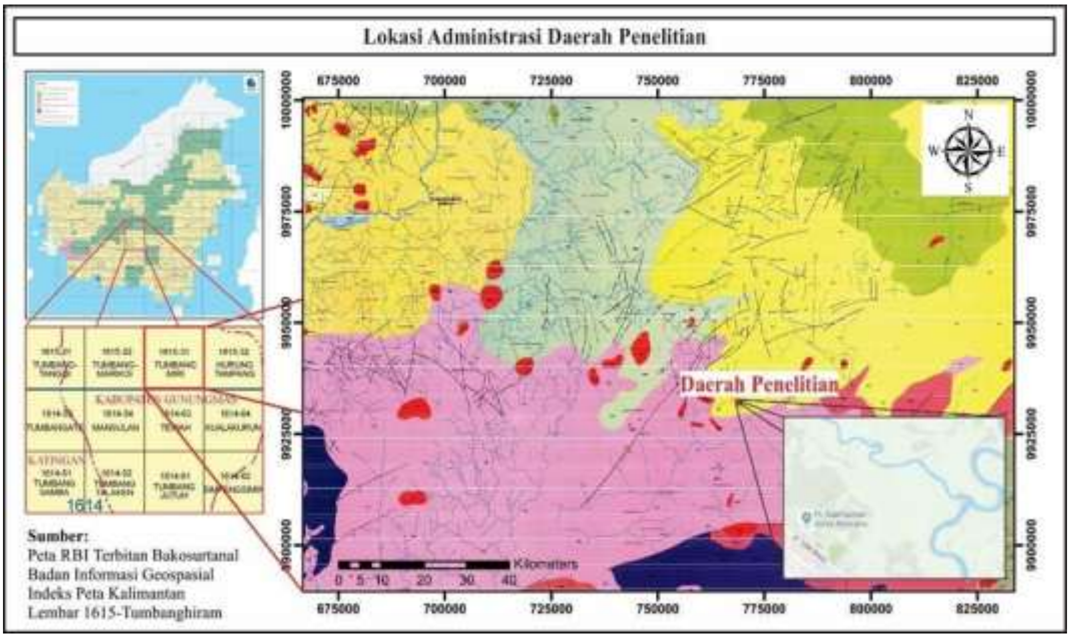

Figure 1. Location of the Research Area (Anjarwati, 2019)

The classification and characterization of igneous rocks in the Right Bear region is essential to understand several fundamental aspects, namely the origin of magma and the magmatic differentiation processes that occur, the genetic relationship between igneous rocks and economic mineralizations such as gold and copper, and the characteristics of hydrothermal alterations related to epithermal-porphyry systems. Previous research in the Borneo region has shown that volcanic rocks with calc-alkaline affinity are generally associated with Cu-Au mineralization in magmatic arc settings (Carlile & Mitchell, 1994; Leeuwen, 1994). However, detailed characterizations of magma affinity and the tectonic setting of volcanic rocks in Bear Kanan are still limited.

The Total Alkali-Silica (TAS) diagram developed by Le Bas et al. (1986) was used in this study as it provides a clear and systematic classification based on two main geochemical parameters. The first parameter is SiO_2 (% weight) which is an indicator of magma acidity and magmatic differentiation rate. The second parameter is the total alkaline expressed as Na_2O + K_2O (% by weight) which is an indicator of the alkalinity and geochemical characteristics of the magma. In addition to the TAS diagram, this study also used other discriminant diagrams such as Winchester & Floyd (1977), Pearce & Cann (1973), Hastie et al. (2007), and Ross & Bedard (2009) to confirm the classification and determination of magma affinity.

The novelty of this research lies in the provision of comprehensive geochemical data that integrates various rock classification methods and magma affinity determination to strengthen the interpretation of tectonic settings and their implications for the potential for Cu-Au mineralization in the Beruang Kanan area. This data is expected to be the basis for a more targeted mineral exploration strategy in the Central Kalimantan region.

RESEARCH METHODS

This research was conducted in the Beruang Kanan area, Gunung Mas Regency, Central Kalimantan. Rock samples were taken from five locations representing fresh rocks and rocks with varying degrees of hydrothermal alteration, namely hornblende, pyroxene, prophilic, sericitic, and argilic alterations. The sample codes used were RA 36 (fresh andesite hornblende), RA 27 (andesite pyroxene), RA 10 (prophylitic alteration), RA 21 (sericytic alteration), and RA 23 (argilic alteration).

Sample descriptions were performed megascopically and microscopically to identify textures, constituent minerals, and alteration rates. Samples that have a Loss on Ignition (LOI) value of less than 2% by weight are assumed to be fresh or slightly altered rocks, which are generally characterized by the presence of relative euhedral phenocris and primary mineral grains in the absence of significant secondary hydrothermal minerals.

The mineralizing carrying rock on the Right Bear prospect is andesite. Rock geochemical data indicates that rocks are classified as intermediate igneous rocks rich in silica. The composition of andesite silica is approximately 60% with a total alkali (Na+K) of about 3.6%. Based on these data, it is known that the affinity of the rock is calc-alkaline (based on the diagram of Le Maitre et al., 1989 in Rollinson, 1993). (Table 1). Analysis of major oxides was carried out using the X-Ray Fluorescence (XRF) method with an accuracy of ±0.01% for the main elements. Meanwhile, the analysis of trace elements was carried out using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method with an accuracy of up to ppb (parts per billion) for elements such as Zr, Y, Nb, Th, and Co. The volcanic rocks of the Right Bear prospect are mainly andesite.

The classification of rocks was carried out using a Total Alkali-Silica (TAS) diagram according to Le Bas et al. (1986) which plotted the content of SiO_2 to total alkali ($Na_2O + K_2O$). To confirm the type of rock, a Winchester & Floyd (1977) diagram was also used which plotted the ratio of Zr/TiO_2 to Nb/Y and SiO_2 to Zr/TiO_2, which is more reliable for altered rocks because it uses immobile elements.

The determination of magma affinity is carried out using several discriminant diagrams, namely: (1) K_2O vs SiO_2 diagram according to Peccerillo & Taylor (1976) to distinguish tholeiitic, calc-alkaline, high-K calc-alkaline, and shoshonitic series; (2) the Co vs Th diagram according to Hastie et al. (2007) to distinguish calc-alkaline and tholeiitic affinity; and (3) Zr/Y vs Th/Yb diagrams according to Ross & Bedard (2009) for the classification of calc-alkaline magma series.

The tectonic setting of volcanic rocks is determined using the Ti-Zr-Sr discriminant diagram and the Zr vs Ti diagram according to Pearce & Cann (1973), which can distinguish between volcanic basalt (island arc tholeiite), ocean floor basalt, calc-alkaline basalt, and within-plate basalt.

RESULTS AND DISCUSSION

Andesites have a concentration of trace elements and have SiO2 (55.74-59.91%), Al2O3 (15.65-17.87%), FeO* (tot) (4.06-5.38%), MnO (0.12-0.18%), MgO (2.11-3.85%), CaO (2.96-8.28%), Na2O (1.97-3.68%), and K2O (0.7-1.43%). (Table 1) (Figure 2).

This diagram provides a method of moving elements identifying lava arcs and their volcanic series. Triangle plot Ti, Zr and Sr diagrams (Pearce and Cann, 1973) (Figure 3) were used to confirm the tectonic environment of volcanic rocks. Based on the classification diagram, most of the parent rocks are shown in the calc-alkaline series and fall on the andesite plane.

Table 1. Geochemical Analysis Results of Fresh Rocks and Altered Rocks

Element Primary Oxide (%)	Hornblende Andesite RA 36	Pyroxene Andesite RA 27	Prophylitic Alteration RA 10	Serisitic Alteration RA 21	Argilic Alteration RA 23
Si2	59,39	56,44	51,12	52,12	**51,78**
Uncle2	2,24	1,12	0,9	1,2	**0,78**
Al_2O_3	11,18	8,45	9,86	14,52	**9,2**
Ugly*	18,11	20,71	22,04	19,38	**20,54**
MnO	0,22	0,24	0,28	0,18	**0,13**
MgO	3,66	4,76	4,12	1,92	**3,89**
Tall	3,20	5,68	6,36	1,44	**6,88**
Na_2O	1,38	0,85	1,22	0,08	**0,73**
K_2O	0,88	0,68	0,66	3,78	**2,42**
Fe_2O_3	0,10	0,24	0,2	0,08	**0,13**
LAW	1,75	2,3	3,72	7,1	**5,19**
Sum	**102,11**	**101,47**	**100,48**	**101,80**	**101,67**

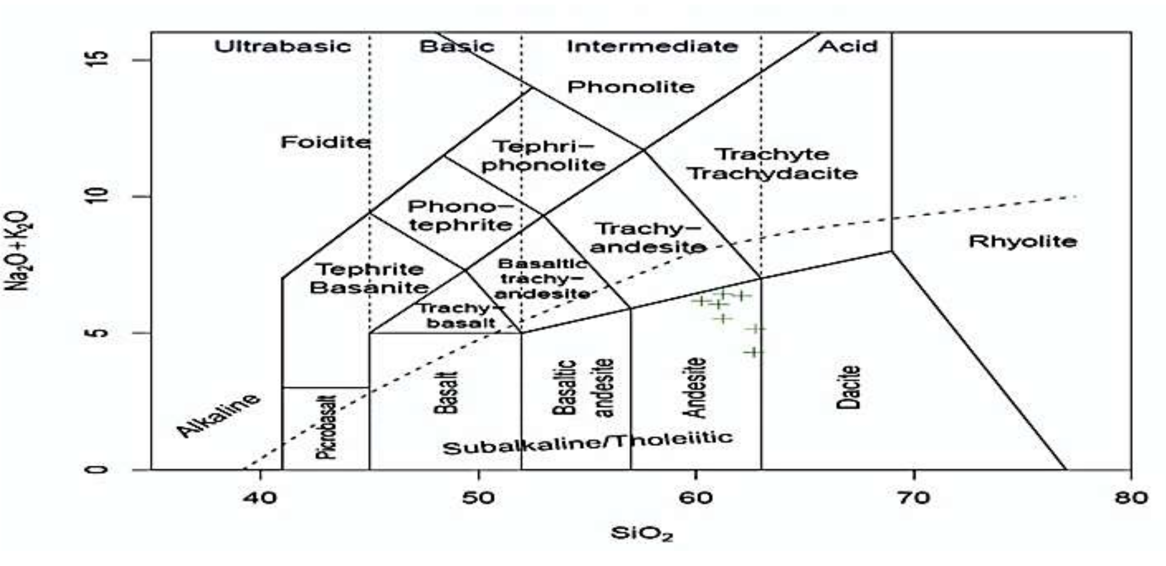

Figure 2. Plot diagram of the classification of volcanic rocks (Na2O + K2O vs SiO2) (after Le Bas et. Al., 1986). The dividing line between alkali and sub-alkaline rocks is from Irvine and Baragar (1971)

Based on the diagram of Total Alkaline Silica (Le Bas et al., 1986) which is based on the comparison of the main oxide element SiO2 with K2O +K2O shows that the fresh rocks in the study area include in basaltic andesite to andesite for fresh rocks, altered rocks show a decrease in SiO2 including in basalt to basaltic andesite with subalkaline/tholeiitic magma affinity

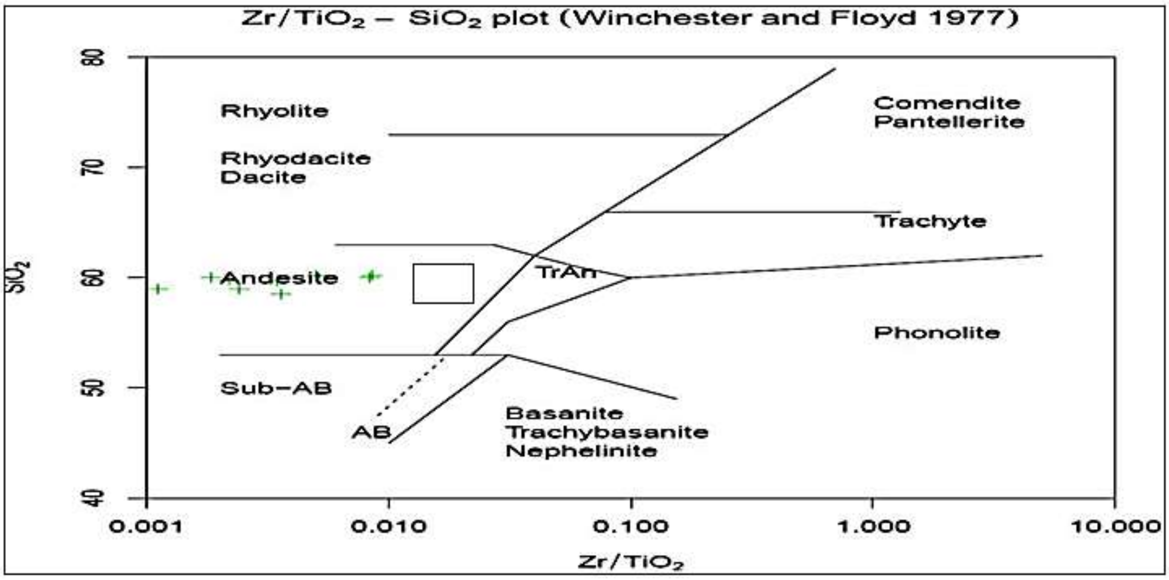

Figure 3. Identification of arc lava and its volcanic series (SiO2 vs Zr/TiO2b plot ratio Winchester and Floyd, 1977)

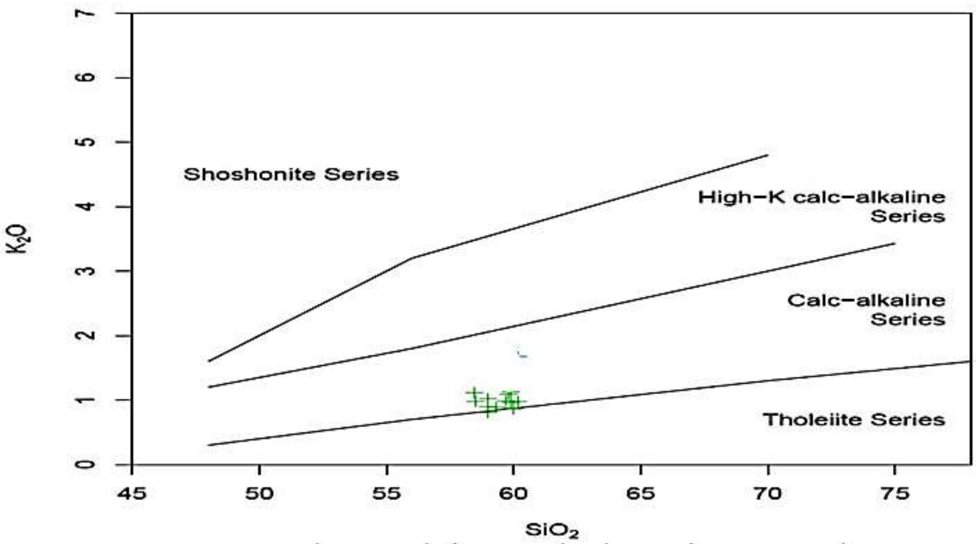

Figure 4. Diagram of K2O vs SiO2 variation (Pearce and Cann, 1973)

The rock types in the Right Bear Sample based on the comparison of Nb/Y with Zr/TiO2 (Winchester & Floyd, 1977) were found to be fresh/slightly altered rocks including andesite/basalt, while altered rocks included in basalt to basalt andesite. Based on the comparison of Zr/TiO2 and SiO2 (Winchester & Floyd, 1977), it was found that fresh/slightly altered rocks were included in andesite, while altered rocks were included in basalt which showed a reduction in SiO2 in altered rocks.

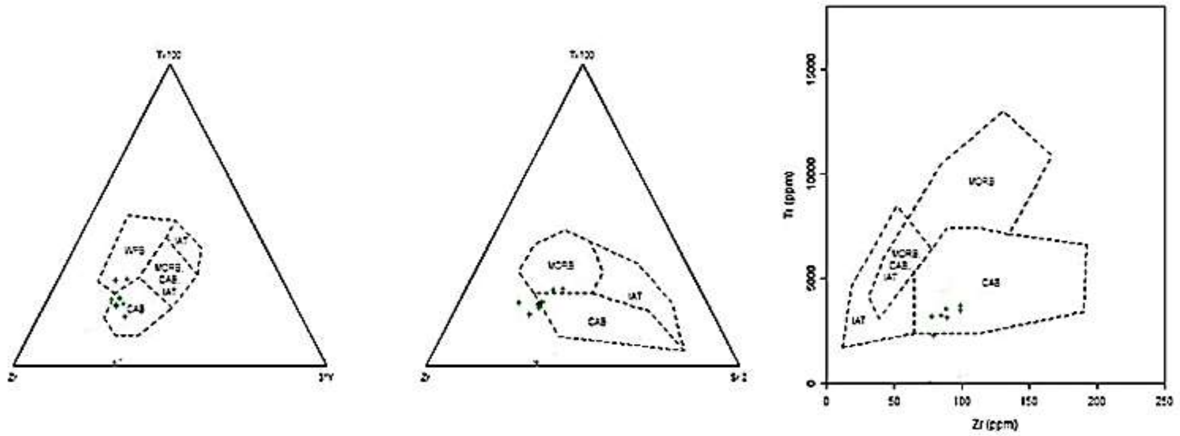

Figure 5. The Ti-Zr-Sr diagram (Pearce and Cann, 1973) and the Zr-Ti discrimination diagram (after Pearce and Cann, 1973) for the Right Bear prospect volcanic rocks.

X-Ray Fluorence (XRF) and ICP-MS analysis of the Right Bear area consisted of 5 samples with sample codes RA 36, RA 27, RA 10, RA 21 and RA 23 which are representatives of fresh rocks and altered rocks according to the type of alteration that developed in the Right Bear area (Table 2).

Table 2. Geochemical Analysis Results of Fresh Rocks and Altered Rocks

Element Primary Oxide (%)	Hornblende Andesite	Pyroxene Andesite	Prophylitic Alteration	Serisitic Alteration	Argilic Alteration
	RA 36	**RA 27**	**RA 10**	**RA 21**	**RA 23**
Si2	59,39	56,44	51,12	52,12	51,78
Uncle2	2,24	1,12	0,9	1,2	0,78
Al_2O_3	11,18	8,45	9,86	14,52	9,2
Ugly*	18,11	20,71	22,04	19,38	20,54
MnO	0,22	0,24	0,28	0,18	0,13
MgO	3,66	4,76	4,12	1,92	3,89
Tall	3,20	5,68	6,36	1,44	6,88
Na_2O	1,38	0,85	1,22	0,08	0,73
K_2O	0,88	0,68	0,66	3,78	2,42
Fe_2O_3	0,10	0,24	0,2	0,08	0,13
LAW	1,75	2,3	3,72	7,1	5,19
Sum	**102,11**	**101,47**	**100,48**	**101,80**	**101,67**

The determination of magma affinity in the study area is based on several parameters, including the comparison of SiO2 and K2O (Pecerillo and Taylor, 1976), Co and Th (Hastie, et al., 2007), Zr/Y and Th/Yb (Ross & Bedard, 2009).

Based on the comparison of SiO2 and K2O (Pecerillo and Taylor, 1976) the Right Bear samples in fresh/slightly altered rock samples were included in the affinity with the calc-alkaline – tholeitic type, while the altered rock samples showed a significant increase in K2O resulting in the affinity of tholeitic – shonsonite. The results of the comparison of Co and Th (Hastie, et al., 2007) on samples of fresh/slightly altered rocks and completely altered rocks are included in the affinity of magma of the alkaline limestone type. The results of the comparison of Zr/Y and Th/Yb (Ross & Bedard, 2009) show that samples of fresh rocks and altered rocks are included in the affinity of magma of the alkaline calcage series.

Based on the results of the plotting of some of the above methods, it can be concluded that the magma affinity of the Beruang Kanan area belongs to the type of alkaline limestone which can be interpreted as being related to the within plate in the form of a continental expansion zone (Wilson, 1989) (Table 3).

Table 3. The characteristics of the magma series are associated with special tectonic orders (Wilson 1989)

TECTONIC SETTING	Plate Margin		Within Plate	
	Convergent (destructive)	Divergent (constructive)	Intra-oceanic	Intra continental
volcanic feature	island arcs, active continental margins	mid-oceanic ridges, back-arc spreading centres	Oceanic island	Continental rift zone continental flood basalt provinces
characteristic magma series	tholeiitic, calc-alkaline, alkaline	tholeiitic, - -	Tholeiitic - Alkaline	Tholeiitic Calc-alkaline Alkaline
SiO}_2$ range	basalts and differentiates	basalts	Basalts and differentiates	Basalts and differentiates

Discussion

Implications for Mineralization

The andesite to dacite rocks with calc-alkaline affinity identified in the Right Bear area have important implications for the potential for Cu-Au epithermal-porphyry mineralization. Rocks with this intermediate composition are often central to epithermal mineralization systems due to their ability to supply metal-rich hydrothermal fluids and form fracture structures that serve as channels for the circulation of mineralized fluids (Hedenquist, 1995; Sillitoe, 2010). The calc-alkaline affinity indicates that the magma formed has a high volatile content (H_2O, CO_2, S), which is a key factor in the formation of epithermal and porphyry deposits (Corbett & Leach, 1998).

The developing hydrothermal alteration zones in the Right Bear, including prophilic, sericitic, and argilic alterations, confirm the existence of an active hydrothermal system associated with calc-alkaline volcanic rocks. The identified sericytic alterations are proximal indicators of the Cu-Au porphyry system, while argilic alterations indicate a high sulfidity epithermal system (Pirajno, 2009; Idrus & Prihatmoko, 2021). Combinations of these two types of mineralization (porphyry and epithermal) are often found in calc-alkaline magmatic settings in the Indonesian volcanic arc region (Carlile & Mitchell, 1994; Leach & Corbett, 1994).

Tectonic Implications

The intra-plate tectonic setting in the form of continental expansion zones interpreted for the Beruang Kanan area has relevance to the tectonic history of Central Kalimantan. This region is part of the Schwaner complex that underwent tectonic reactivation in the Tertiary period that produced calc-alkaline magmatism (Van Bemmelen, 1970; Van Leeuwen, 1994).

The continental expansion that occurred allowed magma to rise from the mantle which then underwent contamination of the continental crust, producing calc-alkaline volcanic rocks with distinctive geochemical characteristics as identified in the Right Bear.

Significance for Exploration

The calc-alkaline magma affinity data confirmed through various geochemical methods in this study provide a strong scientific basis for mineral exploration strategies in the Right Bear area and beyond. The identification of calc-alkaline volcanic rocks as mineralized bedrocks can be used as a prospect mapping criterion on a regional scale. In addition, an understanding of tectonic settings and characteristics of hydrothermal alterations can be helpful in the determination of more specific exploration targets for epithermal-porphyri-type Cu-Au deposits (John et al., 2018).

CONCLUSION

Based on comprehensive geochemical analysis using various methods of classification and determination of magma affinity, it can be concluded that several important things about the volcanic rocks of the Beruang Kanan area, Central Kalimantan can be concluded.

First, based on the K_2O vs SiO_2 diagram according to Peccerillo & Taylor (1976), samples of fresh/slightly altered rocks of the Right Bear were classified as having calc-alkaline to tholeiitic affinities. The andesite to dacite rocks identified are often central to epithermal mineralization systems due to their ability to supply hydrothermal fluids and form fission structures that become channels of mineralized fluids. Meanwhile, basalt and andesite rocks show involvement in hydrothermal alteration zones such as sericytic, which is a proximal indicator of the Cu-Au porphyry system.

Second, the results of the comparison of Co and Th according to Hastie et al. (2007) on fresh/slightly altered rock samples and completely altered rocks are consistently plotted in the calc-alkaline magma affinity zone. The results of the comparison of Zr/Y and Th/Yb according to Ross & Bedard (2009) also show that fresh rock samples and altered rocks are included in the calc-alkaline series magma affinity. The consistency of the results of these various methods confirms the reliability of the magma affinity interpretation for the study area.

Third, based on the plotting results of some of the above methods, it can be concluded that the magma affinity of the Right Bear area is included in the calc-alkaline type that can be interpreted to be related to the setting within the plate (in the plate) in the form of a continental expansion zone. This tectonic setting, combined with the volatile calc-alkaline geochemical character, creates favorable conditions for the formation of the Cu-Au epithermal-porphyry mineralization system. These findings provide significant implications for mineral exploration strategies in the Central Kalimantan region, particularly in the identification of prospect targets with similar geological and geochemical characteristics.

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