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On the Paleomagnetism of the Intrusives from the Panguna Porphyry Copper Deposit, Bougainville, Papua New Guinea

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Abstract

The temporal relation between intrusives and mineralization of the Panguna porphyry copper deposit, Bougainville Island, Papua New Guinea, was reexamined using paleomagnetic method.

The Kaverong Quartz Diorite intruded at the reversed geomagnetic period of 4.0 to 5.0 Ma. After the geomagnetic polarity changed, the Biotite Granodiorite intruded, and the surrouding rocks were mineralized. These rocks have remanent magnetizations of normal polarity . At the next geomagnetic period of reversed polarity, the second mineralization expanded in and around the Leucocratic Quartz Diorite. The Feldspar Porphyry and the Biuro Granodiorite might also intruded at this period.

The K_2O contents of the Kaverong Quartz Diorite is higher than those of the other intrusives (MASON and MCDONALD, 1978). Hence, it is confirmed that the high K_2O intrusive predated the low K_2O intrusive, with which porphyry copper mineralization was closely associated.

Introduction

Porphyry copper deposits and some other hydrothermal ore deposit are closely related to felsic magma. The physical and chemical roles of felsic magma for mineralization have been discussed by many investigators. Especially, the discussion on the behaviour of volatile components from magma has developed in this decade (e. g. BURNHAM, 1979). URABE (1984) showed through laboratory work that the partitioning of base metals between the melt and aqueous phases was dependent on the composition of magma ; alkaline or aluminous. However, as determined from field evidences, the relationship between the chemistry of major elements of the felsic magma and associated mineralization has remained unsolved.

TITLEY and BEANE (1981) summarized the data of the major elements of the

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intrusives genetically related to porphyry copper deposits, and pointed out that almost of all intrusives were of calc-alkaline nature. JAQUES and WEBB (1975), and CHIVAS (1975) have suggested that there were two suites of K_2O content in some of the limmited porphyry copper mining areas in the island arc of the southwestern Pacific. In this case. MASON and MCDONALD (1978) pointed out that the earlier intrusive rocks showed higher K_2O nature compared to the later intrusion, which was closely related with mineralization.

Unfortunatly, however, the temporal relationship between intrusion and mineralization in a limmited mining area have yet to be correlated in detail with each other. For instance, on the Panguna porphyry copper deposit, PAGE and MCDOUGALL (1972) suggested that the relatively high K_2O intrusive postdated the low K_2O intrusives and the mineralization. On the other hand, EASTOE (1978, 1982) has recognized that the first mineralization followed the higher K_2O intrusive and the second and third mineralization followed the lower K_2O intrusives.

In this study, the temporal relationship between intrusions and mineralization of the Panguna porphyry copper deposit is reexamined using the paleomagnetic method. The geochronological data by PAGE and MCDOUGALL (1972) and the paleomagnetic polarities summarized by MANKINEN and DALRYMPLE (1979) are shown in Fig. 1.

Outline of Geology

The Panguna ore deposit is one of the well known typical porphyry copper deposits in the world. The general geology has already been described by many workers (e. g. MACNAMARA, 1968 ; FOUTAIN 1972 ; BAUMER and FRASER, 1975 ; BALDWIN et al., 1978).

The southern part of Bougainville Island is essentially composed of : volcanic and sedimentary rocks of the upper Oligocene to the lower Miocene, intrusive complexes of Pliocene, and materials from recent volcanic eruptions. The Panguna porphyry copper deposit is situated at the southern end of an intusive complex.

The earliest intrusive body, named the Kaverong Quartz Diorite, intrudes the

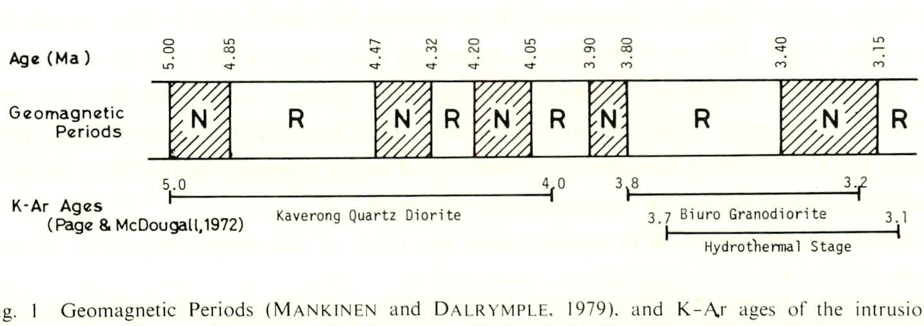

Fig. 1 Geomagnetic Periods (MANKINEN and DALRYMPLE, 1979), and K–Ar ages of the intrusions and hydrothermal stage (PAGE and MCDOUGALL, 1972) of the Panguna porphyry copper deposit. (N : Normal polarity, R : Reserved polarity)

Panguna Andesite from the upper Oligocene to the lower Miocene age. The southern margin of the Kaverong Quartz Diorite consists of biotite-bearing assembleges called the Biotite Diorite. Some small porphyritic stocks, named the Biotite Granodiorite, the Leucocratic Quartz Diorite, the Feldspar Porphyry and the Biuro Granodiorite are emplaced in the order of formation at or near the southern margin of the Kaverong Quartz Diorite.

Kaverong Quartz Diorite : The Kaverong Quartz Diorite is Pinkish grey in color, and has an equigranular texture. It consists mainly of hornblende, plagioclase, quartz and potassium-feldspar. Euhedral crystals of hornblende are slightly altered to biotite or chlorite. Plagioclase is partly altered to sericite. Compared to plagioclase, quartz and potassium-feldspar occur as small grains. Accessary minerals are magnetite, ilmenite, apatite, sphene and others. Magnetite occurs as a euhedral grain of 0.2 to 0.5 mm in size, and contains TiO_2 up to 1.5 wt. %

Biotite Diorite : The Biotite Diorite is a marginal facies of the Kaverong Quartz Diorite, and the boundary with the Kaverong Quartz Diorite is unclear. This rock is light grey in color, and has an equigranular to slightly porphyritic texture. It is characterized by an abundance of biotite psudomorph derived after hornblende. Plagioclase is altered to sericite. Epidote is commonly observed. Magnetite occurs as euhedral to anhedral crystals containing 0.2 to 1.0 wt. %TiO_2. A small amount of hematite occurs in the marginal part of magnetite. Magnetite coexists with disseminated sulfide minerals such as chalcopyrite and bornite.

Biotite Granodiorite : The Biotite Granodiorite intruded after the Kaverong Quartz Diorite. Many places within the body are strongly altered. The unaltered rock shows a typical porphyritic texture with phenocrysts of corroded quartz and plagioclase. Groundmass is composed of plagioclase, quartz, potassium-feldspar, biotite, magnetite, ilmenite, apatite and epidote. Magnetite is euhedral to subhedral in shape, and coexists with a small amount of subhedral ilmenite in the the unaltered rock. Magnetite coexists with titanian-hematite in the altered zone, and disappears in the strongly altered zone. In hydrothermally altered areas, the clots of sericites, kaolinites and chlorites are predominant. Pyrite, chalcopyrite, rutile, anhydrite and hematite are also observed in the body.

Leucocratic Quartz Diorite : This is a micro-quartz diorite to quartz diorite porphyry, and intrudes into the Panguna Andesite and the Biotite Granodiorite. The rock consists mainly of plagioclase, quartz, potassium-feldspar and biotite pseudomorph drived from hornblende. Intense mineralization of quartz-bornite-chalcopyrite-molybdenite veins extend in this intrusive and the surrounding Panguna andesite. The mineralizatiton is associated with the wall rock alteration bearing biotite, pinkish potassium-feldspar and magnetite. Secondary magnetites compose the film of 1 to 5 mm in thickness along the quartz vein.

Feldspar Porphyry : Small stocks and dykes of the Feldspar Porphyry are found in the Biotite Granodiorite and the Panguna Andesite near the Leucocratic Quartz Diorite. They are dark grey in color. Plagioclase is the major phenocryst. Quartz, biotite and hornblende are occasionally found as phenocrysts. Groundmass is composed of plagioclase, quartz, biotite, potassium-feldspar and magnetite, with a small amount of pseudobrookite and rutile. Plagioclase is slightly altered to sericite. A small amount of sulfide minerals such as bornite and chalcopyrite occur occasionally. Copper-iron sulfide bearing quartz veins in the Panguna Andesite are cut by the Feldspar Porphyry. This means that the intrusion of the Feldsper Porphyry alternated with the quartz veining.

Biuro Granodiorite: This body intrudes both the Panguna Andesite and the Biotite Diorite. The rock is light grey in color, and shows porphyritic texture. Phenocrysts are composed of well grown euhedral crystals of plagioclase, quartz, hornblende and biotite. Groundmass is composed of plagioclase, quartz, potassium-feldspar, biotite, magnetite, ilmenite, apatite and hydrothermal epidote. Magnetite is euhedral to subhedral in shape, and contains lamellae of ilmenite.

Breccia Zone: There are many breccia zones in the mining area. They occur in a cluster especially around the margin of the Biotite Granodiorite, where the breccia consists of angular fragments of granodiorite, diorite and andesite. Copper-iron mineralization occurs intensely in some parts of the matrix. Ore minerals are chalcopyrite, bornite, magnetite, hematite and molybdenite.

Measurements

Oriented samples were collected from the open-pit shown in Fig. 7. Two or three cubes of $2\times2\times2$ to $4\times4\times4$ cm^3 were taken from each specimen. Remanent magnetization was measured by an astatic magnetometer having sensibilities of 15×10^{-6} Oe/mm. The data were computed by MERCOM 800 of Kagoshima University, using the furier function. The stability of each natural remanent magnetization was inquired by step-wide alternating field (AF) demagnetization method with the magnetic field up to 800 Oe.

Results

The results of the measurements are listed in Table 1 and magnetic polarity sequences are shown in Figs. 2 to 6. AF demagnetization curves are also shown in the figures.

Kaverong Quartz Diorite: Although the measured samples contain a small amount of secondary minerals by alteration, magmatic magnetite has evently remained. AF curves (Fig. 2b) show that this rock has a stable magnetization. Thus it is thought that the rock obtained the thermal remanent magnetization at the same time as the intrusive emplaced and cooled.

Those rocks clearly have reversed polarities (Fig. 2a). PAGE and MCDOUGALL

Table 1. Natural remanent magnetization of the intrusives of the Panguna porphyry copper deposit.

Sample No.	Decl.	Incl.	Intensity ($\times 10^{-4}$ emu/g)	Stability	Polarity
KAVERONG QUARTZ DIORITE					
PG76-1	144 E	2 U	9.9		R
PG76-2	153 E	24 D	1.7	o	R → R
PG76-3	151 E	8 D	3.5		R
BIOTITE DIORITE					
PG58	28 W	10 U	5.6	o	N → N
PG61-1	154 W	11 U	6.5	o	N?→ N
PG61-2	40 W	41 U	4.3		N
PG66-1	32 W	30 U	14		N
PG66-2	30 W	32 U	4.1		N
PG66-3	23 W	26 U	3.5	o	N → N
PG72-1	9 W	21 U	6.9		N
PG72-2	17 W	13 U	4.8		N
PG87	15 W	41 U	0.49	o	N → N
PG127-1	146 E	23 D	1.0		R
PG127-2	129 E	45 D	1.1		R
BIOTITE GRANODIORITE					
PG41-1	9 W	19 U	3.6		N
PG41-2	11 W	17 U	0.59		N
PG41-3	14 W	18 U	0.67	o	N → N
PG48-1	-	-	0.05	x	?
PG48-2	21 W	28 U	0.12		N
PG84	23 W	23 U	3.0	o	N → N
PG101-1	22 W	52 U	6.4		N
PG101-2	22 W	47 U	6.1		N
PG101-3	28 W	27 U	6.2	o?	N → N
PG116-1	30 W	53 U	3.0		N
PG116-2	41 W	41 U	1.4	o	N → N
PG114-1	28 W	32 U	0.82		N
PG114-2	15 W	17 U	0.71		N
PG123	23 W	19 D	0.43		N
PG124	130 W	63 U	0.64		N?

Table 1. (Continued)

Sample No.	Decl.	Incl.	Intensity ($x10^{-4}$ emu/g)	Stability	Polarity
LEUCOCRATIC QUARTZ DIORITE					
PG45-1	52 E	56 D	6.0	x	? ⇀ R
PG45-2	26 E	58 D	1.7		R?
PG45-3	178 W	62 D	2.0		R?
PG79-1	125 E	7 D	1.8		R
PG79-2	120 W	11 D	0.6	o	? ⇀ R
FELDSPAR PORPHYRY					
PG54-1	139 E	24 D	3.2		R
PG54-2	132 E	35 D	3.7		R
PG54-3	136 E	50 D	9.7	o	R?⇀ R
PG109-1	174 E	58 D	1.0	o	R?⇀ R
PG109-2	161 E	20 D	1.3		R
BIURO GRANODIORITE					
PG30-1	135 E	16 U	1.6	o	R ⇀ R
PG30-2	180 E	14 U	0.3		R
PANGUNA ANDESITE					
PG44	21 W	13 U	0.5		N
PG74-1	20 E	22 D	1.8	o	N?⇀ R
PG74-2	61 W	7 U	1.7	o	N ⇀ R
PG108	7 W	11 U	4.3	o?	N ⇀ N
PG133-1	171 E	58 D	18		R
PG133-2	145 E	72 D	4.3	x	R

(o; stable, x; unstable, N; normal R; reversed)

(1972) estimated the K-Ar age of this intrusive to be 4 to 5 Ma. MANKINEN and DALRYMPLE (1979) showed that the ages of reversed geomagnetic periods during 4 to 5 Ma are from 3.90 to 4.05, 4.20 to 4.32, and 4.47 to 4.85 Ma (Fig. 1). The Kaverong Quartz Diorite can be thought to intrude at one of the three periods.

Biotite Diorite : Almost of all the samples have the remanent magnetization of normal polalities (Fig. 2a). The remanent magnetization does not change its direction during AF demagnetization, and the intensity does not decrease sharply with advancing the AF demagnetization step (Fig. 2b).

All the samples contain hydrothermal biotites disseminated in the rock. Measuring with a biotite geothermometer, the biotitization temperatures are thought to be about 450 to 550°C (FORD, 1978). The filling temperatures of fluid inclusions in the quartz vein in this rock body are from 400 to 750°C (EASTOE, 1978). Thus it seems that the original thermal remanent magnetization, acquired at the magmatic stage, disappeared at the alteration and mineralization stage. The rock obtained the renewed remanent magnetization when the intrusive was hydrothermally altered. The geomagnetic polarity of the alteration has been normal.

The Biotite Diorite intruded at almost the same time as that of the Kaverong

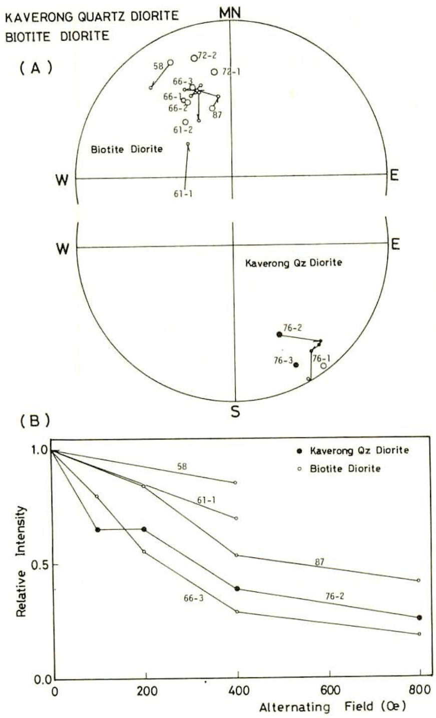

Fig. 2 Magnetism of the Kaverong Quartz Diorite and the Biotite Diorite. (A) A stereographic projection showing the natural remanent magnetizations (NRM : large circles) and the change of directions (small circles) during alternating field (AF) demagnetization. MN represents magnetic north. Open and solid cirles denote upward and downward, respectively. (B) AF demagnetization curves.

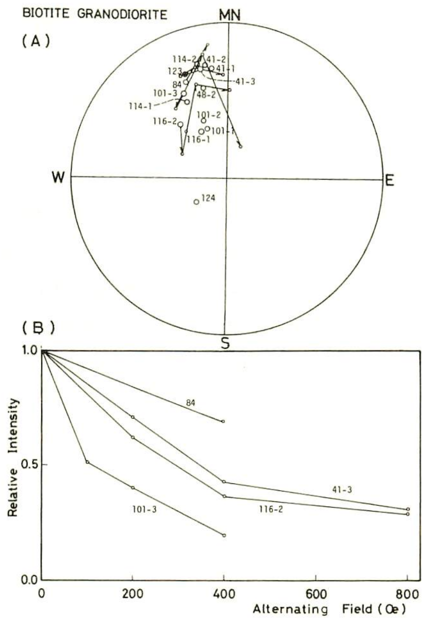

Fig. 3 Magnetism of the Biotite Granodiorite. (A) Astereographic projection showing the NRM and the change of directions during AF demagnetization. Symboles are the same as those in Fig. 2. (B) AF demagnetization curves.

Quartz Diorite. Hence the alteration of the Biotite Diorite was altered at the normal geomagnetic period after the intrusion of the Kaverong Quartz Diorite. PAGE and MCDOUGALL (1972) determined the age of the alteration to 3.4 $\pm$ 0.5 Ma.

One sample near the intense mineralization zone shows a reversed polarity (PG 127-1, 2 ; Table 1).

Biotite Granodiorite : The AF demagnetization curves (Fig. 3b) show that all samples have relatively stable remanent magnetization, and the magnetic directions do not change greatly during AF demagnetization (Fig. 3a). Thus the magnetic directions of samples are available for paleomagnetic study. The two kinds of samples ; unaltered and argillized rocks, were measured. All samples have normal remanent magntization.

Leucocratic Quartz Diorite : The directions of the remanent magnetizations of the samples differ widely from each other, and the magnetic intensity during AF demagnetization decreases sharply (Fig. 4). This unstability might be explained by the from effect of magnetic anisotropy: A fair amount of secondary magnetites crystallize along the vein wall in a thickness of 1 to 5 mm. Hence the magnetic direction has a tendency to incline toward the direction of vein. The magnetic direction changes to typical reversed direction during demagnetization.

The temperature of magnetization is thought to be above the filling temperature of fluid inclusions in quartz (400 to 750°C; EASTOE, 1978), and above the temperature of the deposition of sulfide minerals in quartz veins. EASTOE (1983) estimated the temperature by the sulfur isotopic geothermometer to be 416 to 844°C. There are also magmatic magnetites, but they might have renewed its magnetization at the alteratin and mineralization stages. It can be considered that the magnetization extends at the reversed geomagnetic period.

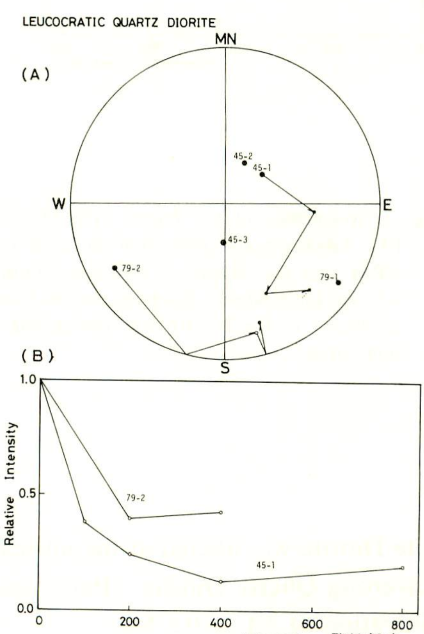

Fig. 4 Magnetism of the Leucocratic Quartz Diorite. (A) Astereographic projection showing the NRM and the change of direction during AF demagnetization. Symboles are same as those in Fig. 2. (B) AF demagnetization curves.

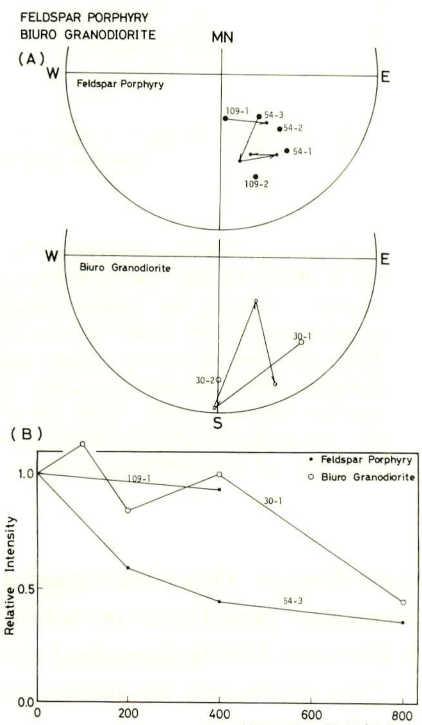

Fig. 5 Magnetism of the Feldspar Porphyry and the Biuro Granodiorite. (A) A stereographic projection showing the NRM and the change of directions during AF demagnetization. Symboles are the same as those in Fig. 2. (B) AF demagnetization curves.

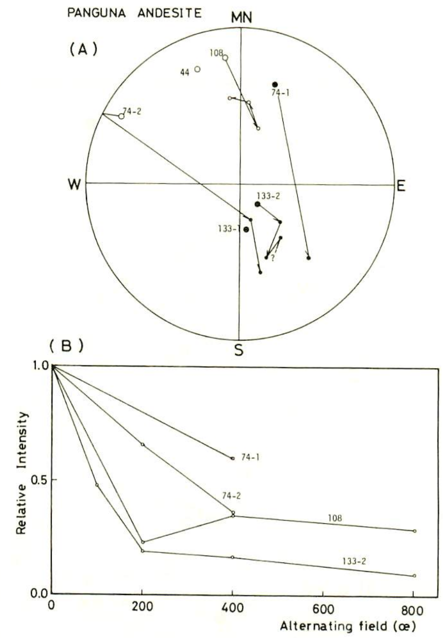

Fig. 6 Magnetism of the Panguna Andesite. (A) A stereographic projection showing the NRM and the change of directions during AF demagnetization. Symboles are the same as those in Fig. 2. (B) AF demagnetization curves.

Feldspar Porphyry : As found in Fig. 5, this rock has a stable magnetization, and the samples show reversed remanent magnetization. It is clear that the rock was magnetized at a different geomagnetic period from the Biotite Diorite and the Biotite Granodiorite. Futhermore, the Feldspar Porphyry obtained the remanent magnetization at a different, reversed geomagnetic period from the Kaverong Quartz Diorite. We know this because the Feldspar Porphyry postdated the Biotite Granodiorite which had postdated the Kaverong Quartz Diorite.

Biuro Granodiorite : The fresh rock exhibits a reversed polarity, and has a stable remanent magnetization (Fig. 5). The K-Ar age of the intrusive is known to be 3.5 $\pm$ 0.3 Ma (PAGE and McDOUGALL, 1972). Consequently, the Biuro Granodiorite intruded at the reversed geomagnetic period (3.40 to 3.80 Ma ; Fig. 1).

Panguna Andesite : Samples of this rock were collected from : the southern margin of the open-pit, and the areas around the Biotite Diorite, the Biotite Granodiorite, the Feldspar Porphyry and the Leucocratic Quartz Diorite. As shown in Fig. 6, there are three kinds of remanent magnetizations. The freshest rock collected from the southern margin of the open-pit has the most unstable magnetization (PG74-1,2). During AF demagnetization, the direction changes from normal to reversed. Although data are poor, the Panguna Andesite might extrude at the normal geomagnetic period of the upper Oligocene to the lower Miocene age.

The other rocks of the Panguna Andesite have a stable remanent magnetization.

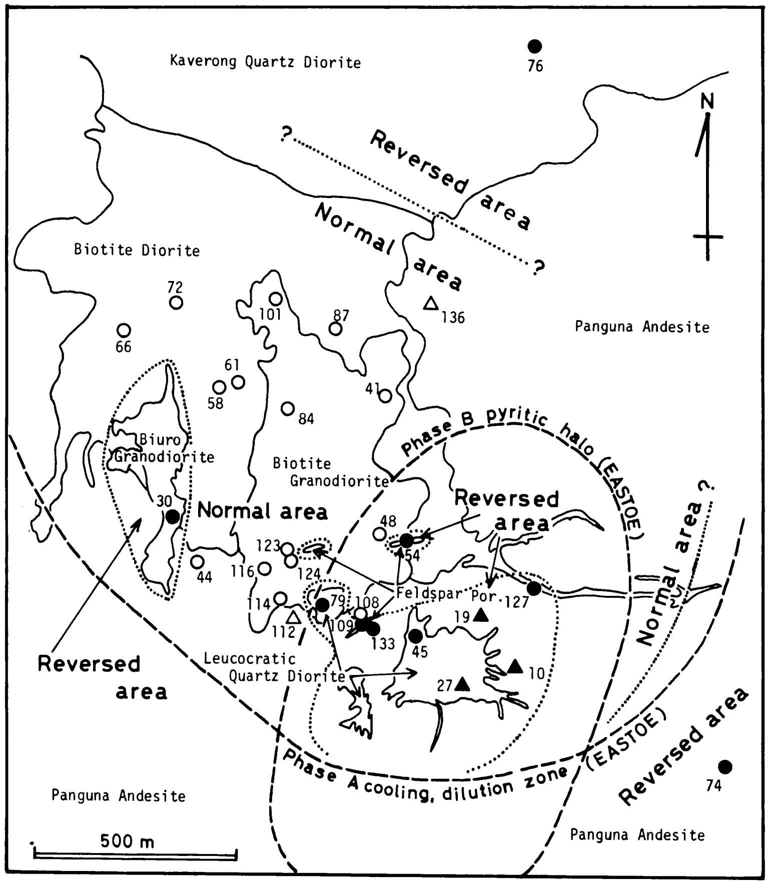

Fig. 7 Magnetic polarities of rocks. Open (solid) circles denote normal (reversed) polarities of rocks. Open (solid) triangles also denote normal (reversed) polarities, but these data were obtained by informal measurements. Dotted lines represent the boundary between the areas of rocks having normal and reversed polarities. Dashed lines represent the boundary estimated by EASTOE (1978).

The rocks surrounding the Biotite Diorite and the Biotite Granodiorite (PG44, PG108, PG112, PG136 ; Fig. 7) have normal remanent magnetization. On the other hand, the rocks surrounding the Leucocratic Quartz Diorite and Feldspar Porphyry (PG10, PG19, PG133 ; Fig. 7) have reversed magnetization.

Discussion

Although there is little magnetic data on the rocks, the present results and the geolgical evidences may allow an improved interpretation.

The Kaverong Quartz Diorite and the Biuro Granodiorite emplaced at the different reversed geomagnetic periods as discussed in the previous section.

The Biotite Diorite are both the altered and marginal parts of the Kaverong Quartz Diorite. As the magnetic polarity differs from that of the Kaverong Quartz Diorite, the biotitization associated with the copper-iron mineralization is thougth to extend at a different geomagnetic period. On the other hand, the biotitization extends around the Biotite Granodiorite. The Biotite Granodiorite has normal remanent magnetization. The hydrothermal biotites and feldspars in these two rock types have the same K-Ar age of 3.4 $\pm$ 0.3 Ma. These data suggest that the biotitization might followed the Biotite Granodiorite at the same normal geomagnetic period.

The age of these geological events might be thought to be 3.15 to 3.40 Ma (MANKINEN and DALRYMPLE, 1979). However, it is thought that the Biuro Granodiorite which postdated the biotitization intruded at the reversed geomagnetic period of 3.40 to 3.80 Ma. Thus a possible interpretation is as follow : The K-Ar ratio had been frozen at the argillic alteration stage postdating the biotitization. Becauce of the low temperature of the argillization, the remanent magnetizations of the Biotite Diorite and the Biotite Granodiorite have remained unchanged.

Consequently, it is thought that the Biotite Granodiorite intruded at the normal geomagnetic period before the reversed period of 3.40 to 3.40 Ma. On the other hand, the field evdences show that the Biotite Granodiorite postdated the Kaverong Quartz Diorite, which intruded at the reversed geomagnetic period from 4.0 to 5.0 Ma. Hence the age of the intrusion of the Biotite Granodiorite and the following biotitization in one of 3.80 to 3.90, 4.05 to 4.20, and 4.32 to 4.47 Ma.

The Leucocratic Quartz Diorite which postdated the Granodiorite, might have predated the Biuro Granodiorite. The alteration and mineralization on the Leucocratic Quartz Diorite might have expanded at the reversed geomagnetic period of 3.40 to 3.80 Ma. Unfortunately, the age of the intrusion is not determined. The Feldsper Porphyry can be considered to intrude at the same time with the mineralization in or around the Leucocratic Quartz Diorite.

The magnetic history of the Panguna Andesite is complex. A possible hypothesis is as follows. The Panguna Andesite might extrude at the reversed geomagnetic period of the upper Oligocene to the lower Miocene. The heat from the Biotite Granodiorite might change the polarity of remanent magnetization of the Panguna Andesite from reversed to normal around the Biotite Granodiorite. Futhermore, the heat from the mineralization on the Leucocratic Quartz Diorite and/or the the Feldspar Porphyry changed the magnetic polarity of the Panguna Andesite to a reversed direction around the intrusive bodies.

As shown in Fig. 7, the spacial distribution of magnetic polarities also interpretates the temporal relationship between intrusions and mineralizations.

EASTOE (1978) distinguished the three phases ; A, B and C of mineralization in this deposit. The distribution of the phases A and B of mineralization are also illustrated in Fig. 7. The area of phase B goes well with reversely magnetized area in and around the Leucocratic Quartz Diorite and the Feldspar Porphyry. The phase A might correspond to the Biotite Diorite, the Biotite Granodiorite, and surrounding Panguna Andesite which have normal magnetic polarities. EASTOE (1978) thought that the Kaverong Quartz Diorite was followed by the phase A. However, this study shows that there is a time gap between the intrusion of the Kaverong Quartz Diorite, the biotitization of the Biotite Diorite, and the intrusion of the Biotite Granodiorite.

EASTOE (1978) also recognized the phase C of mineralization, which expanded after the intrusion of the Biuro Granodiorite. The Biuro Granodiorite has reversed remanent magnetization, but the rocks in the area corresponding to phase C (in the Biotite Diorite and the Biotite Granodiorite bodies) have normal magnetization. It might be thought that, as the mineralization of phase C expanded far under the Curie temperature, the remanent magnetization obtained at the mineralization of phase B has remained unchanged.

Finally, according to the geochemical data of the intrusives (e. g. MASON and MCDONALD, 1978), it is emphasized that the higher K_2O intrusive; the Kaverong Quartz Diorite, Predated the other lower K_2O intrusives, and the major mineralizations are closely associated with the later intrusives with lower K_2O contents. This paleomagnetic study confirms the proposal by MASON and MCDONALD (1978).

Table 2 The geological sequence of intrusion and mineralization of the Panguna porphyry copper deposit.

IGNEOUS EVENTS	HYDROTHERMAL and/or PNEUMATRITIC EVENTS	MAGNETIC POLARITY	AGE (Ma)
	Pebble dyke		
Biuro Granodiorite	(Pyrite-clay veining)	Reversed	
Feldspar Porphyry		Reversed	
	Quartz-Cu,Fe,Mo sulfide veining		3.80-3.40
Brecciation (?)	Amphibole-magnetite-quartz veining	Reversed	
Leucocratic Quartz Diorite		?	
	Argillization		
	Pyrite-clay veining		
	Quartz-Cu,Fe,Mo sulfide veining		
Brecciation (?)	Magnetite-biotite dissemination (Biotite Diorite)	Normal	3.90-3.80, 4.20-4.05, or 4.47-4.32
Biotite Granodiorite		Normal	
	(Quartz-Cu,Fe sulfide veining)		
Kaverong Quartz Diorite		Reversed	4.05-3.90, 4.32-4.20, or 4.85-4.47
(Biotite Diorite ?)			
Panguna Andesite		Reversed (?)	Oligocene - Miocene

Summary

The temporal relationship between the intrusives and the mineralization of the Panguna porphyry copper deposit can be summarized as follows (Table 2). At first, the Kaverong Quartz Diorite intruded at the reversed geomagnetic period. The rock contains rather high K_2O, and was followed by no mineralization. After the geomagnetic polarity changed, the Biotite Granodiorite intruded. The Biotite Granodiorite was accompanied by intense biotitization and the first mineralization. The Biotite Granodiorite and surrounding rocks obtained normal remanent magnetization. After this, the second mineralization expanded in and around the Leucocratic Quartz Diorite at the reversed geomagnetic period, when the Feldspar porphyry and Biuro Granodiorite might also intruded. The age of the intrusion of the Leucocratic Quartz Diorite is not known, but may be slightly earlier than the second mineralization. It can be concluded that the first and second mineralization are closely related to the intrusives of lower K_2O nature.

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