Indonesian Journal of Physics
Vol 19 No. 1, January 2008

Anisotropy of Magnetic Susceptibility and Elemental Compositions in Andesitic Rocks

Khumaedi Sastrawiharja, Satria Bijaksana, Umar Fauzi, and Linus Ampang Pasasa
Physics of Complex System Division
Faculty of Mathematics and Natural Sciences
Institut Teknologi Bandung, Bandung
e-mail: satria@fi.itb.ac.id

Abstract

Igneous rocks, including andesites, are composed of these major elements: Si, Ti, Al, Fe, Mn, Ca, Mg, Na, K, and P. Variation in the composition of these elements, which occur mostly as oxides, determines the overall physical properties of the rocks. Not surprisingly, classification of igneous rocks is also based on the quantity of these major oxides. In this study, elemental compositions of andesitic rocks from the Island of Java will be compared to the anisotropy of magnetic susceptibility (AMS) as a part of our effort to explore the possibility of using rock magnetic parameters in classifying igneous rocks. The objective is to check whether AMS parameters could serve as alternative to chemical analysis. To do so, we have measured the AMS and geochemical composition of andesitic rock samples from 10 different sites across Central Java and Yogyakarta. The results show that there are significant correlations between the abundance of certain elements with AMS parameters, for example, the abundance of Fe and Al with magnetic lineation and the abundance of Al with degree of anisotropy. These results show that magnetic parameters have a good change to be use as predictors for major elements composition in igneous rocks.

Keywords: *Andesites, Java, magnetic anisotropy, magnetite, major elements.*

1. Introduction

Igneous rocks are formed as molten magma cool down near the Earth's surface. Depending on the cooling process and location, igneous rocks are divided into two groups, namely intrusive and extrusive rocks. Intrusive or plutonic rocks are formed from a pool of molten magma that became trapped near the top of the mantle and cooled more slowly, while the extrusive or volcanic rocks are formed from the magma that cooling and hardens on the surface of the earth[1)]. The division of these two broad categories was carried out based of the texture of rocks. Texture of the volcanic rocks tends to be fine grained or even amorphous as they cooled rapidly. On the contrary, plutonic rocks are coarse grained as they cooled slowly enabling the growth of large crystals. At elemental level, igneous rocks are composed mainly by these major elements, Si, Ti, Al, Fe, Mn, Ca, Mg, Na, K and P. The overall physical properties of igneous rocks depend on the composition of these elements, which occur mostly as oxides. Therefore its understandable that classification of igneous rocks is based on the quantity of these major oxides, most notably the silica (SiO_2).

In this study, we compared the elemental compositions of andesitic rocks from the Island of Java with measurements of anisotropy of magnetic susceptibility (AMS) as a part of our effort to explore the possibility of using rock magnetic parameters in classifying igneous rocks. The objective is to check whether magnetic parameters could serve as alternative to chemical analysis in classifying igneous rocks.

2. The Samples

Andesitic rocks are commonly produced by continues subduction of tectonic plate[2)]. The rocks can be found in many areas of Java, as it lies on the subduction zone. Andesitic rocks in Java, are numerous but complicated reflecting a complex tectonic history. In the southern side of Java, the andesitic rocks are mostly associated with the southern mountain or *Pegunungan Selatan*/*Gunung Kidul*[3)]. They are collectively termed Old Andesite[4)]. Potassium argon (K-Ar) dating showed that most of the rocks are Tertiary[5)].

In this research, we measured the AMS of as many as 88 specimens collected from 10 andesitic sites in the provinces of Central Java and Yogyakarta. Most of the sites were sampled for paleomagnetic study[6,7)]. Some samples were reported in literature as lavas, while others were reported as intrusions. Based on earlier studies, magnetite has been established as the predominant magnetic mineral in these sites[6,7)]. Table 1 lists samples identities and locations.

Table 1. Identities and locations of sampling sites[6)]

Site ID	Name	Descriptions	Coordinate
GIJ	Gunung Ijo	Andesitic Neck	7.81° S 110.083° E
GPW	Gunung Pawon	Andesitic dyke	7.78° S 110.099° E
GSR	Gunung Suru	Andesitic Lava	7.86° S 110.076° E
KLB	Kali Buko	Andesitic Lava	7.82° S 110.088° E
KSG	KaliSonggo	Andesitic Lava	7.74° S 110.197° E
PWH	Sami Galuh	Andesitic Lava	7.69° S 110.186° E
SKP	Gunung Skopiah	Andesitic Intrusion	7.78° S 110.100° E
TGR	Tegal Redjo	Andesitic Intrusion	7.81° S 110.610° E
WDR	Kali Widoro	Andesitic Lava	7.86° S 110.582° E
WTAA	Watu Adeg	Andesitic Lava	7.79° S 110.365° E

3. Measurements

The specimens for AMS measurement were either cored *in-situ* or cored from hand samples and were then sliced to form standard paleomagnetic cylindrical samples of 2.54 cm in diameter and 2.2 cm in height. DC or low field susceptibility was measured using a Bartington MS2 susceptibility meter (Bartington Instrument, Oxford, United Kingdom) with an MS2B sensor. Measurement of AMS in each specimen was carried out by measuring the susceptibility in 8 (eight) different orientations. Susceptibility is considered as a second order tensor and is expressed as three principle axes (maximum κ_{max}, intermediate κ_{int}, and minimum κ_{min}) in their respective orthogonal orientations. We define the average magnetic susceptibility $\kappa_{avg} = (\kappa_{max} + \kappa_{int} + \kappa_{min})/3$. We also calculate other anisotropy parameters such as lineation ($L = \kappa_{max}/\kappa_{int}$), foliation ($F = \kappa_{int}/\kappa_{min}$), and percent degree of anisotropy ($P(\%) = ((L/F)-1)\times 100\%$). Table 2 lists the results of AMS measurement in the form of average anisotropy parameters for each site.

Table 2. Average anisotropy parameters for each site

Site	κ_{avg} (x10^{-3} SI)	*L*	*F*	*P(%)*
GIJ	34.6	1.014	1.010	2.5
GPW	40.9	1.013	1.011	2.4
GSR	28.4	1.010	1.006	1.6
KLB	36.7	1.013	1.009	2.3
KSG	41.3	1.013	1.014	2.8
PWH	17.9	1.017	1.017	3.5
SKP	31.4	1.009	1.006	1.4
TGR	40.9	1.006	1.010	1.5
WDR	35.9	1.02	1.010	2.9
WTAA	15.2	1.009	1.010	2.0

The abundances of elements in some sites were determined using an XRF (X-rays Fluorescent) method. The analysis was carried out using an ARL Advant XP+ XRF (Thermo Electron Corp) at the Quaternary Geology Laboratory of the Indonesian Center for Geological Survey. Data for some other sites we obtained from a published paper[5)]. Table 3 lists the results of geochemical analyses for all sites. Based on chemical classification of volcanic rocks using TAS (total alkali-silica) diagram[8)], the samples, whose SiO_2 content varies from 51.5% to 59.5%, could be referred to as basalts (KLB, KSG, WTA), basaltic andesites (TGR, GPW, GIJ, PWH, SKP), and andesites (GSR, WDR).

4. Result and Discussion

When we plotted the AMS parameters as function of elemental abundances, we found an interesting correlation. Figure 1 shows that the FeO content negatively correlates with lineation with coefficient of correlation R = 0.648 (n = 10).

Table 3. Elemental compositions of sampling sites

Site	SiO2 (wt%)	TiO_2 (wt%)	Al_2O_3 (wt%)	FeO (wt%)	MnO (wt%)	MgO (wt%)	Na_2O (wt%)	K2O (wt%)
GIJ	54.8	0.5	16.4	7.81	0.19	2.74	3.00	0.94
GPW	53.1	0.78	19.0	9.80	0.18	4.57	2.55	0.95
GSR	59.5	0.62	16.3	6.15	0.17	3.09	3.09	0.99
KLB	51.5	0.67	15.7	7.27	0.14	5.07	2.59	1.04
KSG	52.0	1.90	17.1	9.79	0.15	3.79	3.33	1.01
PWH	55.8	0.58	20.9	6.81	0.12	1.55	3.00	1.49
SKP	55.9	0.68	17.8	8.58	0.16	3.12	2.75	1.20
TGR	52.8	1.83	14.8	12.01	0.18	3.03	3.06	1.81
WDR	59.2	0.63	21.5	4.72	0.07	0.53	3.44	1.32
WTAA	52.4	0.9	17.9	10.35	0.17	4.24	1.86	0.84

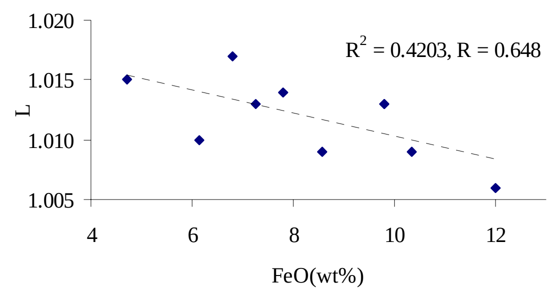

Figure 1. Plots of lineation (*L*) and FeO content showing negative correlation.

This significant negative correlation is very likely due to the way the magnetic minerals are distributed within the rocks' matrices. Higher content of iron oxides means more magnetic minerals. These grains of iron oxides are very likely to be distributed more uniformly with the rock matrices and lower the magnetic lineation.

Figure 2 shows that Al_2O_3 content correlates with lineation significantly (R = 0.657, n = 10). Al_2O_3 is a paramagnetic mineral with initial mass susceptibility of 0.82 × $10^{-8} m^3/kg$[9]. Therefore this correlation of lineation and Al_2O_3 is likely unrelated to Al_2O_3 magnetic properties but rather related to the association of Al_2O_3 and FeO. Apparently, Al_2O_3 and FeO could have negative correlation as shown in the classification of trachytes and rhyolites into comenditic and pantelleritic types. Comenditic types tend to have high values of Al_2O_3 but low values of FeO. Meanwhile, pantelleretic types tend to have low values of Al_2O_3 but high values of FeO. Figure 3 shows that based on their values of Al_2O_3 and FeO, most sites are considered to be of comenditic type.

Figure 4 shows the plots of Al_2O_3 content with percent anisotropy P(%). Percent anisotropy increases as Al_2O_3 content increases. This significant correlation (R = 0.663, n = 10) is likely due to the fact that specimens with low content of FeO (and therefore high content of Al_2O_3), tend to have fewer magnetic grains. However these grains would likely to align along certain axis, such as the flow lines of basalt, and produce higher degree of anisotropy. The specimens of this research tend to have higher degree of lineation compared to foliation (Figure 5).

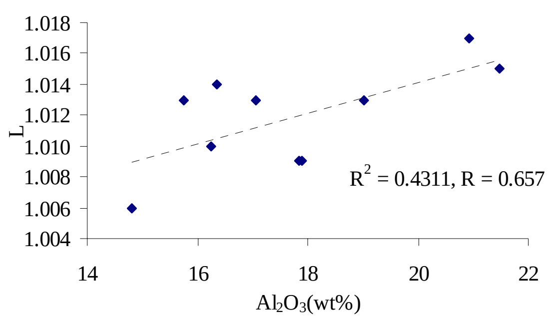

Figure 2. Plots of lineation (L) and Al_2O_3 content showing positive correlation

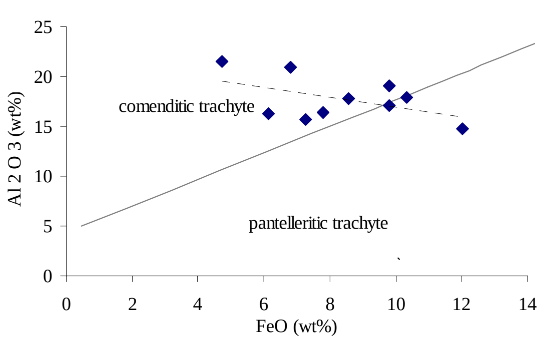

Figure 3. Plots of FeO and Al_2O_3 contents showing that most of the samples are of commenditic type.

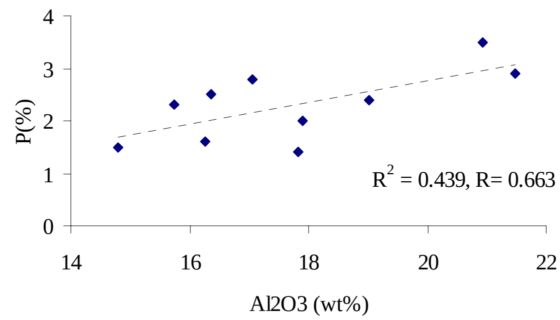

Figure 4. Plots of percent anisotropy P(%) and Al_2O_3 content showing positive correlation.

5. Conclusions

We have shown that elemental abundances, in particular Al_2O_3 and FeO, might affect and control magnetic parameters in andesitic rocks. Al_2O_3 content correlates significantly with lineation, while FeO content correlates negatively with lineation. Al_2O_3 also correlates significantly with percent anisotropy indicating that high content of Al_2O_3 (and thus low content of FeO) would likely to produce an alignment of magnetic grains giving a higher degree of lineation compared to foliation. This results show that there is a possibility to infer the elemental compositions of andesitic rocks based on magnetic parameters.

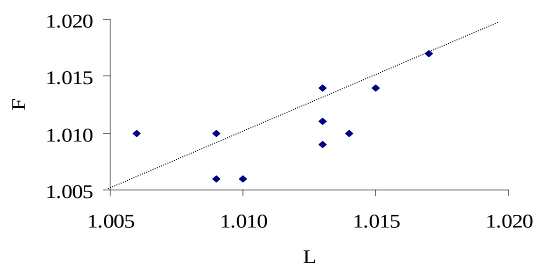

Figure 5. Plots of foliation (F) and lineation (L) for all sites showing that in most sites L is higher than F.

Acknowledgements

This research is supported financially by a research grant from The Ministry of National Education in the form of *Hibah Pascasarjana* to Satria Bijaksana.

References

1. M. Stewart, Igneous Rock, Heinemann Library, 32, 2002.
2. L. A. Raymound, Petrology: The Study of Igneous, Sedimentary and Methamorphic Rocks, McGraw-Hill, 2^{nd} Ed., 736, 2002.

3. W. Hamilton, Tectonics of Indonesian Region, United States Geological Survey Professional Paper, 1078, 1979.
4. R. W. V. van Bemmelen, The Geology of Indonesia, vol. 1, Government Printing Office, The Hague, 732, 1949.
5. R. Soeria-Atmadja *et al.*, Tertiary Magnetic Belt in Java, *J. Southeast Asian Earth Sci.*, **12, 13**, 1994.
6. L. O. Ngkoimani, Doctoral Dissertation, Bandung Institute of Technology, Bandung, 2005.
7. L. O. Ngkoimani, S. Bijaksana, and C. I. Abdullah, Proc. Jakarta2006 Int. Geosciences Conf., (August 14-16, Jakarta, Indonesia), 2006.
8. R. W. Le Maitre, *et al.*, Igneous Rocks. A Classification and Glossary of Terms, 2nd ed., Cambridge University Press, 236, 2004.
9. D. W. Collinson, Method in Rock Magnetism and Paleomagnetism Techniques and Instrumentation, Chapman and Hall, New York, 503, 1983.