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Geochemistry of arc volcanic rocks in Central Luzon, Philippines

G.P. YUMUL JR.[1], C.B. DIMALANTA[1,2], J.V. DE JESUS[1], D.V. FAUSTINO[1], E.J. MARQUES[1], J.L. BARRETTO[1], K.L. QUEAÑO[1] AND F.A. JIMENEZ[1]

[1]Rushurgent Working Group
National Institute of Geological Sciences
College of Science, University of the Philippines
Diliman, Quezon City, Philippines

[2]Ocean Research Institute
University of Tokyo
Tokyo, Japan

Abstract: The different volcanoes and volcanic centers in Central Luzon, Philippines define two volcanic chains — the Western and Eastern Volcanic Chains. The Western Volcanic Chains include volcanic rocks generated in the forearc and main volcanic arc regions with respect to the Manila Trench. The Eastern Volcanic Chains, on the other hand, were extruded on the back arc side. Across- and along-arc variations are present in these two volcanic chains. These variations can be attributed to the interplay of several geochemical processes that occurred in source regions that manifest island arc affinity. An adakite-tholeiitic/calc-alkaline-adakitic rock across-arc variation is recognized in Central Luzon.

INTRODUCTION

The last three decades saw the introduction of new ideas, innovations to recycling of old models related to arc magmagenesis. The 60's and 70's were characterized by models of the subducted slab totally melting and producing across-arc variation (Ringwood, 1975) from tholeiitic through calc-alkaline to alkaline/shoshonitic from the trench towards the back-arc side. The 1980's saw the emergence of ideas which call for the peridotites in the upper mantle wedge above the subducting slab to be the principal source of arc magmas. The basalts and sediments of the ocean floor undergo ocean floor metamorphism resulting into the formation of hydrous metamorphic minerals. Upon subduction, these hydrous minerals break down, dehydrate and metasomatize the overlying upper mantle wedge peridotite (e.g. Tatsumi *et al.*, 1992; Davies, 1994). The introduction of water results into the lowering of the melting temperature of the upper mantle wedge refractory peridotite (e.g. Arculus, 1994; Pearce and Peate, 1995). The observed decrease in volcanoes going towards the back-arc side is attributed to the decrease of water and involvement of less magma supply (e.g. Kushiro, 1990).

Generation of andesites by lower crust melting has also been forwarded in the middle 80's (Takahashi, 1986). Implicit to this model is the assumption that the lower crust is made up of amphibolites as confirmed by studies made on roots of island arcs. Partial melting of amphibolites in the lower crust can be initiated by basaltic underplating or the introduction of hot mantle diapirs (e.g. Rudnick, 1995; Taylor and McLennan, 1995). The crystallization of the underplated basalts raises the temperature which maybe enough to initiate anatexis or lower crust melting. Not surprisingly, the 1990's marked studies dealing with the partial melting of the subducted slab (e.g. Yogodzinski *et al.*, 1995). Numerical, experimental, field and geochemical evidence were forwarded to prove this point (e.g. Sajona *et al.*, 1993; Peacock *et al.*, 1994; Maury *et al.*, 1996). This was brought about by the recognition of a suite of high-Mg andesite in Adak island, the Aleutians that cannot be accounted for by simple fractionation or even the partial melting of peridotite (Kay, 1978). Defant and Drummond (1990) called this group of rocks as adakites.

It is the purpose of this paper to give an overview of the geochemistry of the different volcanic rocks of Central Luzon, Philippines. It will be shown that the across- and along-arc variations observed among the different volcanic rocks resulted from the interplay of various geochemical processes that occurred within source regions that manifest island arc affinity.

GEOLOGIC OUTLINE

Luzon island is bounded on the west by the east-dipping Manila Trench and on the east by the west-dipping East Luzon Trough-Philippine Trench. The Oligocene to Miocene (32–17 Ma) South China Sea plate subducts along the Manila Trench while the Eocene to Miocene West Philippine Sea plate subducts along the East Luzon Trough-Philippine Trench. Volcanism in Central Luzon is associated with the subduction of the South China Sea plate along the Manila Trench (Fig. 1). The basement for the volcanoes and volcanic centers in Central Luzon is associated with mafic-ultramafic rock suites that comprise the Zambales Ophiolite Complex and the Southern Sierra Madre-Angat Ophiolitic Complex. Most of the volcanic centers are exposed on the fringes of the Zambales Ophiolite Complex and along the central portion of the Central Luzon Basin forming two volcanic chains (e.g. Datuin, 1982). The Western Volcanic Chain is made up of the Mount Pinatubo-Mount Natib-Mount Mariveles volcanoes together with parasitic volcanoes (e.g. Mount Samat, Mount Limay), andesitic to dacitic plugs and necks (e.g. Simsiman, Balaybay, Bubilao, Sta. Elena, Malasimbo, Tarlac) (Fig. 1). The Eastern Volcanic Chain, on the other hand, is made up of Mount Arayat, andesitic to dacitic plugs (Mount Balungao, Cuyapo and Amorong which are collectively called as the Paniqui Plugs) and a tuff cone deposit (Mount Bangcay) (Fig. 1). The Paniqui Plugs, together with Mount Bangcay, are found at the northern portion while Mount Arayat is at the southern end of the Eastern Volcanic Chain.

The Western Volcanic Chain corresponds to the forearc — main volcanic arc while the Eastern Volcanic Chain corresponds to the backarc side with respect to the Manila Trench. The physical sizes observed among the different volcanic centers show that the Western Volcanic Chain is characterized by larger magma supplies as compared to the magma supplies received by the Eastern Volcanic Chain. Previous workers recognized the existence of across-arc variation in this part of Luzon (e.g. Balce *et al.*, 1979; de Boer *et al.*, 1980). The reported across arc variation is from *tholeiitic* through *calc-alkaline* to *alkaline/shoshonitic* rock association from west to east. The Western Volcanic Chain has K-Ar datings ranging from almost 5 Ma to 600 years before present while the Eastern Volcanic Chain has K-Ar ages of 0.50 Ma (Mount Arayat) to almost 1.60 Ma (Mount Cuyapo) (Wolfe, 1981). Our K-Ar datings of samples from the Paniqui Plugs are younger than 0.50 Ma (paper in preparation).

PETROGRAPHY AND METHODOLOGY

The samples from the Western Volcanic Chain are made up of basalts, andesites and dacites. Clinopyroxene and plagioclase are the dominant phenocryst and groundmass minerals although olivine, orthopyroxene, hornblende and biotite are also present. Textures range from glomeroporphyritic, porphyritic, trachytic to pilotaxitic. Intergranular texture is noted, too. Disequilibrium assemblage of olivine, quartz and amphiboles has been reported (e.g. Pallister *et al.*, 1992). The Eastern Volcanic Chain, although composed of basalts, andesites and dacites, define a distinct mineral assemblage compared to the rocks of the Western Volcanic Chain. The samples from Mount Arayat, Cuyapo, Balungao and Amorong, aside from exhibiting plagioclase, clinopyroxene, olivine and iron oxides, contain more orthopyroxene, magmatic hornblende and biotite. Ophacitization is prevalent. Textures range from hyalohyaline, intergranular, pilotaxitic to porphyritic.

Whole rock geochemistry done involved the analyses of glass beads and pressed pellets using the XRF (Philips PW 1480) at the Geological Institute of the University of Tokyo. The procedure, accuracy, reproducibility and lower limit of detection are reported elsewhere (Yoshida and Takahashi, 1997). Table 1 shows representative analyses of the volcanic rocks in Central Luzon.

DISCUSSIONS

a. Geochemistry of the Eastern and Western Volcanic Chains

The present day tectonic setting shows that the Western and Eastern Volcanic Chains are in the forearc/main volcanic front and back arc sides with respect to the Manila Trench. The Western Volcanic Chain is made up of medium-K, tholeiitic to calc-alkaline rocks composed of basalt, basaltic andesites, andesites and dacites. On the other hand, the Eastern Volcanic Chain is characterized by high-K calc-alkaline basalts, andesites and dacites. This observed geochemical diversity is attributed to the involvement of pelagic continental sediments or mantle metasomatism coupled with low degrees of partial melting (e.g. Knittel and Defant, 1988; Castillo, 1996; Maury *et al.*, 1998).

The total alkalis (Na_2O + K_2O wt %) versus SiO_2 (wt %) plot show that for the Western Volcanic

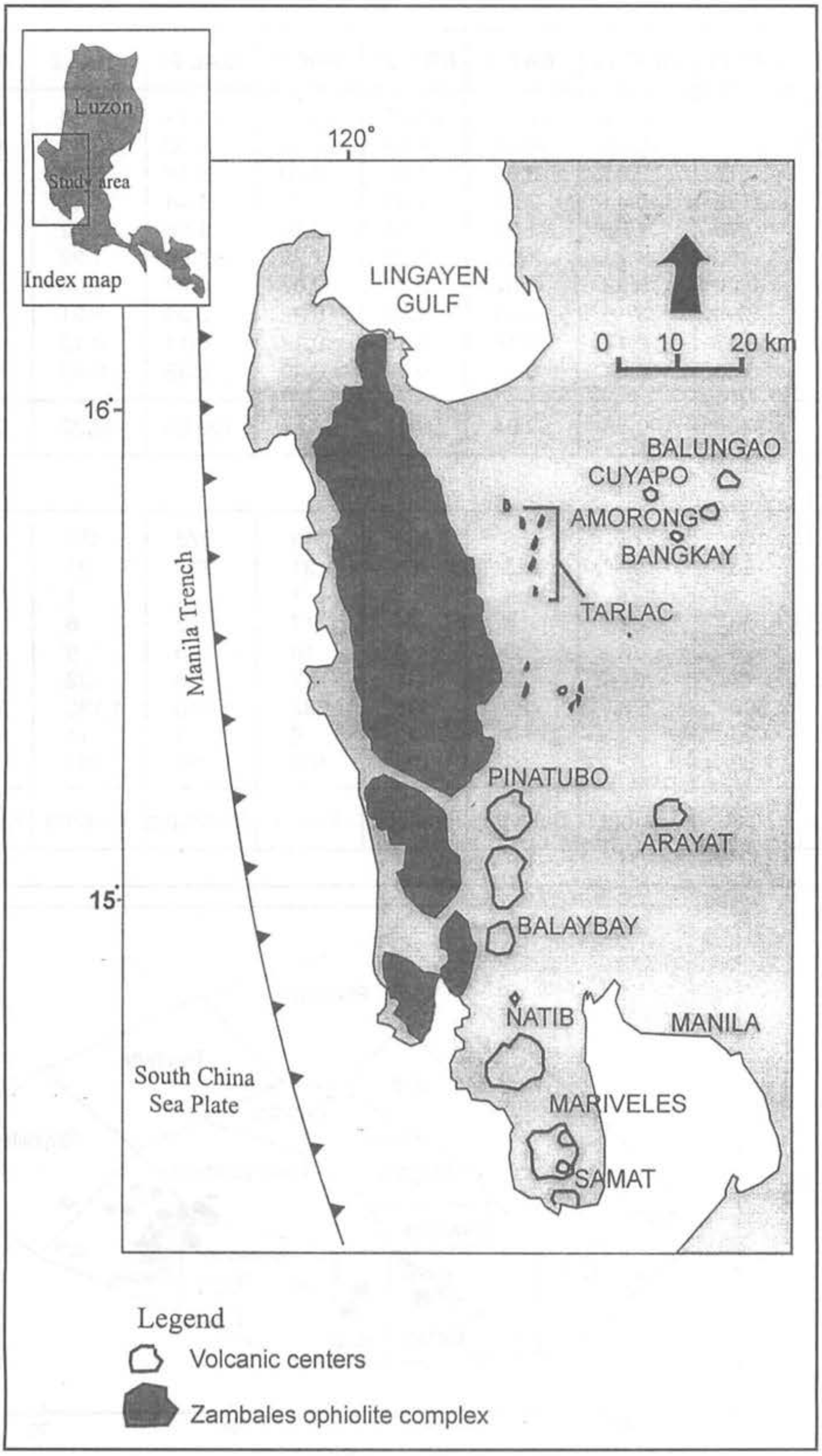

Figure 1. Volcanism in Central Luzon is associated with the subduction of the South China Sea plate along the Manila Trench. The locations of volcanic centers and the distribution of the Zambales Ophiolite Complex are shown. The Western Volcanic Chain is made up of the Mount Pinatubo-Mount Natib-Mount Mariveles volcanoes with some smaller parasitic volcanoes like Mount Samat. The Eastern Volcanic Chain, on the other hand, is made up of Mount Arayat, the dacite plugs of Mounts Balungao, Cuyapo and Amorong and the Mount Bangcay tuff cone.

Table 1. Whole rock analyses of Central Luzon volcanoes/volcanic centers.

	ARC-7	ARC-22	ARC-14	BAY-1	ARC-37	POE-1	BAL-20	CUY-2	AM-13	ARC-58
wt %										
SiO_2	60.20	55.48	52.04	67.64	63.65	66.53	61.74	61.16	50.71	47.78
Al_2O_3	18.23	17.65	18.39	16.94	16.83	16.85	16.02	18.81	17.60	15.02
CaO	7.35	8.17	9.01	3.89	4.96	3.00	5.48	5.06	8.89	11.65
Fe_2O_3	6.06	8.75	10.44	3.28	4.33	3.09	4.44	4.67	8.74	11.44
K_2O	1.02	0.70	1.06	1.27	1.54	2.16	1.65	1.72	2.25	1.08
MgO	2.43	4.66	4.72	1.34	2.23	1.39	5.64	1.92	5.49	7.73
MnO	0.14	0.20	0.22	0.07	0.10	0.07	0.07	0.09	0.17	0.18
Na_2O	3.25	3.99	3.16	4.84	4.76	5.22	5.04	5.21	3.83	2.92
P_2O_5	0.15	0.17	0.17	0.18	0.19	0.17	0.14	0.12	0.44	0.34
TiO_2	0.47	0.83	0.87	0.39	0.52	0.40	0.38	0.46	1.34	1.36
Total	99.30	100.60	100.08	99.84	99.11	98.88	100.60	99.22	99.46	99.50
ppm										
Ba	255	162	274	356	433	349	378	452	489	322
Cr	40	183	95	23	65	31	297	31	93	187
Nb	1	1	1	1	3	1	1	1	2	2
Ni	6	36	22	8	24	17	82	6	30	35
Pb	6	5	6	9	9	19	10	9	8	2
Rb	29	17	24	40	41	47	28	32	59	18
Sr	379	300	298	480	563	832	1,036	1,133	966	390
Y	12	20	22	7	12	8	5	11	22	17
Zr	72	82	62	93	120	103	95	107	116	78
	Mariveles	Natib	Samat	Balaybay	Pinatubo	Poelis	Balungao	Cuyapo	Amorong	Arayat

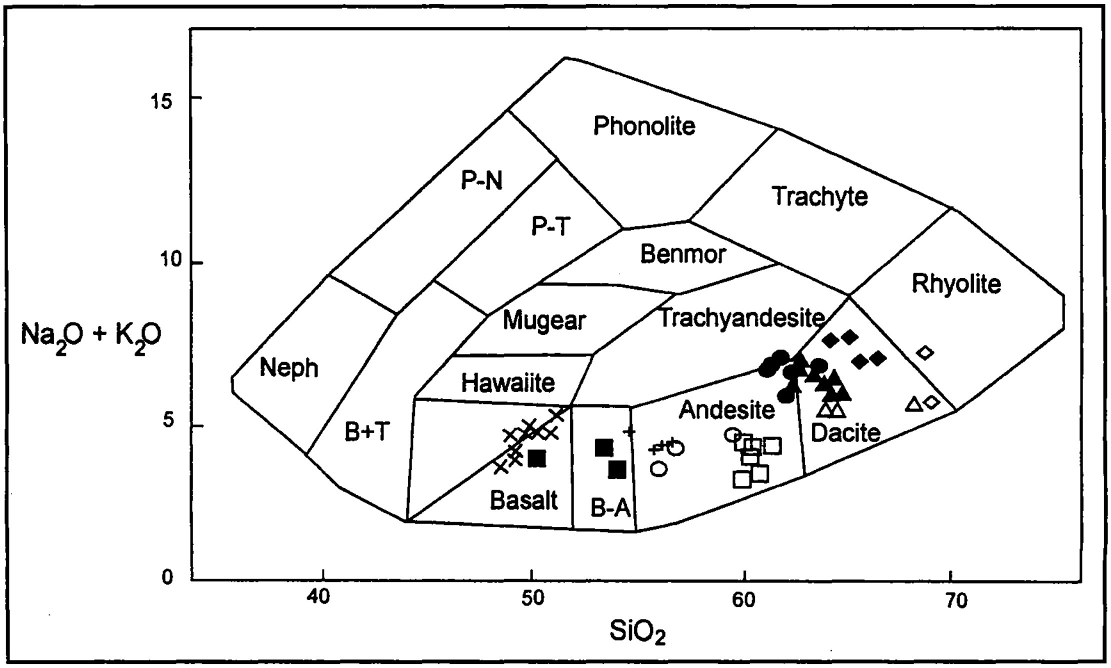

Figure 2. The total alkalis ($Na_2O + K_2O$ wt %) versus SiO_2 (wt %) plot show that for the Western Volcanic Chain, andesites are found in the Simsiman Plug and Mount Mariveles; basaltic andesites to andesites in Mounts Samat and Natib; andesites to dacites in Mount Pinatubo and dacites to rhyolite in the Balaybay Plug and the Tarlac Plugs. The Eastern Volcanic Chain exposes basalts to basaltic andesites in Mount Arayat, dacites in Mount Balungao, andesites in Mount Cuyapo and basalt to andesite in Mount Amorong.

Western Volcanic Chain: □ – Simsiman Plug, ○ – Mt. Mariveles, ■ – Mt. Samat, + – Mt. Natib, ▲ – Mt. Pinatubo, △ – Balaybay Plugs, ◇ – Tarlac dacite plugs

Eastern Volcanic Chain: **x** – Mt. Arayat, ◆ – Mt. Balungao, ● – Mt. Cuyapo

Chain, andesites are found in the Simsiman Plug and Mt. Mariveles, basaltic andesites to andesites in Mt. Samat and Mt. Natib, andesites to dacites in Mount Pinatubo and dacites to rhyolite in Balaybay Plug and the Tarlac Plugs (Fig. 2). The Eastern Volcanic Chain exposes basalts to basaltic andesites in Mount Arayat, dacites in Mt. Balungao, andesites to dacites in Mt. Cuyapo and basalt to andesite in Mt. Amorong. The samples plot in the calc-alkaline field although the Mount Arayat and Samat samples straddle the calc-alkaline–tholeiitic boundary in the AFM diagram (Fig. 3).

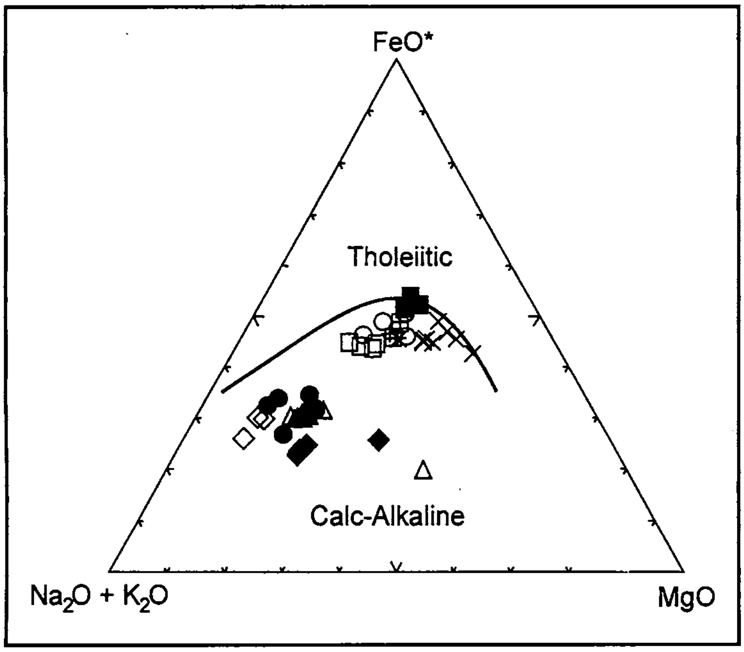

Figure 3. Almost all of the samples plot in the calc-alkaline field although the Mount Arayat and Samat samples straddle the calc-alkaline–tholeiitic boundary in the AFM diagram. Symbols as in Figure 2.

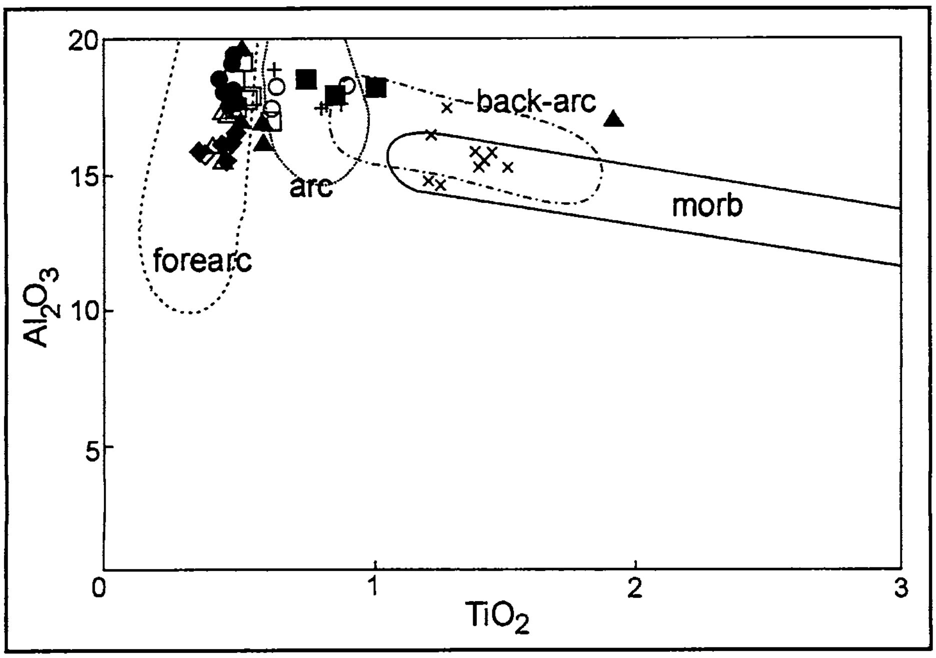

Figure 4. The Al_2O_3 versus TiO_2 plot of the sample set manifests their affinity with the forearc and island arc settings with the exception of Mount Arayat, and to a certain extent, Mounts Natib and Samat which plot in the back-arc field (Arculus, 1994). Symbols as in Figure 2.

b. Source region character and tectonic setting of the arc volcanic rocks

The Al_2O_3 versus TiO_2 plot of the sample set manifest their affinity with the forearc and island arc settings with the exception of Mount Arayat, and to a certain extent, Mounts Natib and Samat which plot in the back-arc field (Arculus, 1994) (Fig. 4). The close affinity of the samples with the island arc setting is consistent with its present-day setting. Interestingly, the Mounts Balungao and Cuyapo samples cluster in the forearc-island arc region inspite of its back-arc location. This is due to its lower TiO_2 content typical of siliceous rocks.

The dacites plotted in the granitoid tectonic discrimination diagrams of Maniar and Piccoli (1989) which include a.) K_2O versus SiO_2, b.) Al_2O_3 versus SiO_2, c.) FeO* versus MgO and d.) FeO* + MgO versus CaO show that the majority of the silicic rocks have source regions of Island Arc Granitoid (IAG) + Continental Arc Granitoids (CAG) + Continental Collision Granitoids (CCG) affinity (Fig. 5). There are no field, geochemical or geophysical evidence to support the presence of a continental slab or a continental collision zone beneath Central Luzon. The continental signature is provided by the subducted continental sediments eroded from the Eurasian margin (e.g. Mukasa *et al.*, 1987; Chen *et al.*, 1990).

c. Across- and along-arc variation

The common notion of a tholeiite–calc-alkaline–alkaline/shoshonite across arc variation from west to east in Central Luzon needs some modification. Adakites and adakitic rocks were recognized in the forearc, main volcanic arc and back-arc regions of Central Luzon (Fig. 6) (paper in preparation). Furthermore, the rocks of Mount Arayat are found to be high-K calc-alkaline rocks and are not shoshonitic (e.g. Bau and Knittel, 1993; Yumul *et al.*, 1998). The across arc variation in the Central

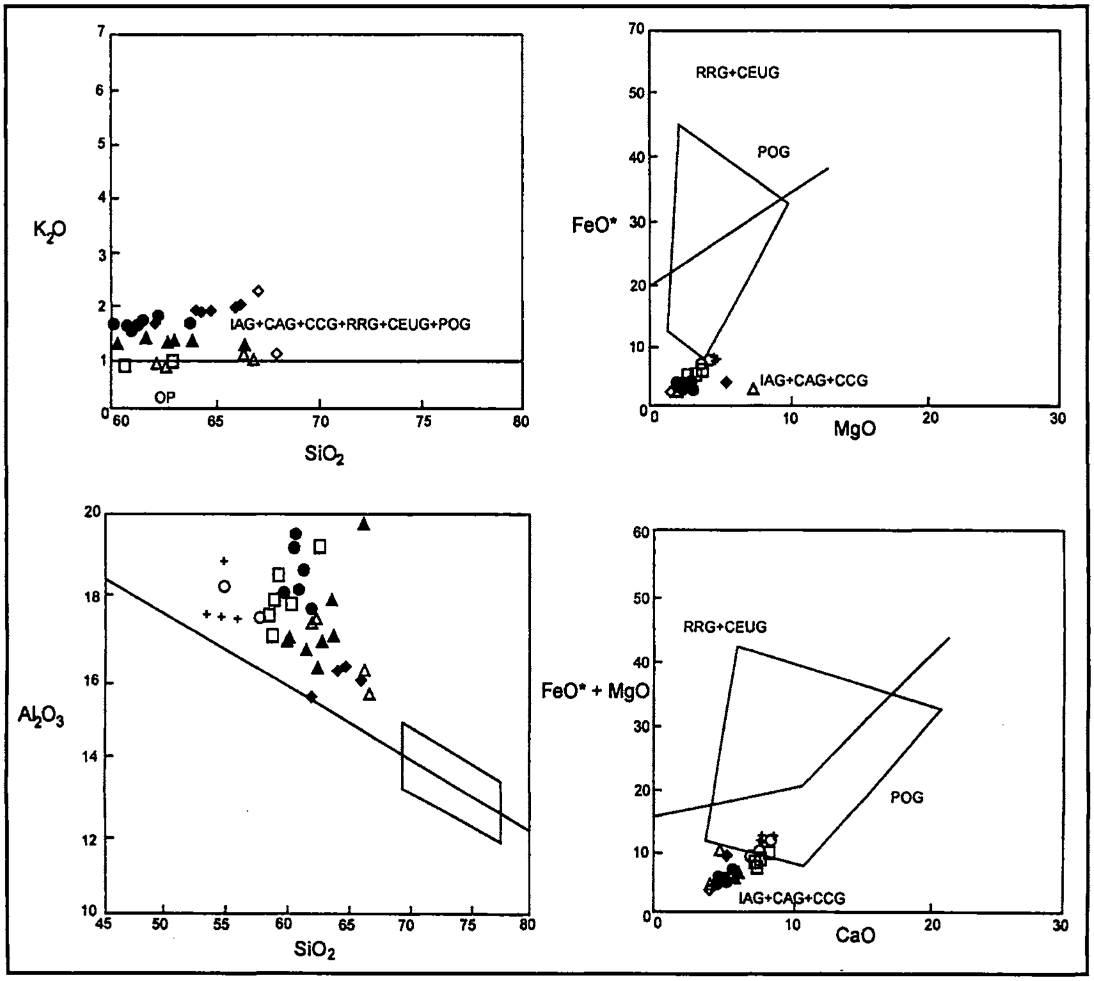

Figure 5. The dacites plotted in the granitoid tectonic discrimination diagrams of Maniar and Piccoli (1989) which include a) K_2O versus SiO_2, b) Al_2O_3 versus SiO_2, c) FeO* versus MgO and d) FeO* + MgO versus CaO show that the majority of the silicic rocks have source regions of Island Arc Granitoid (IAG) + Continental Arc Granitoids (CAG) + Continental Collision Granitoids (CCG) affinity. See text for discussion. Symbols as in Figure 2.

Luzon area can be succinctly described by an ***ADAKITE–THOLEIITIC/CALC-ALKALINE–ADAKITIC*** rock sequence from west to east (Yumul *et al.*, 1998). The forearc to main volcanic arc contain adakites that are both slab and lower crust melts that have interacted with the ophiolite platform (e.g. Bernard *et al.*, 1996; Castillo, 1998). This is represented by the Balaybay group of dacite plugs in Zambales and Mount Pinatubo in Tarlac; the tholeiitic–calc-alkaline group is made up of Mount Mariveles, Mount Natib, Mount Samat, Mount Limay, and the associated plugs while the adakitic rocks encompass the Paniqui Plugs which were generated by lower crustal melting (Yumul *et al.*, 1998). The along arc variation in the Eastern Volcanic Chain (Paniqui Plugs — adakitic to Mount Arayat — high K calc-alkaline) is more pronounced than that of the Western Volcanic Chain. This can be attributed to the interplay of various factors involving the subducted slab, upper mantle wedge and the lower crust (paper in preparation).

CONCLUSIONS

Our present data shows that across- and along-arc variations exist in Central Luzon. Adakites and adakitic rocks are present in the forearc, main volcanic arc and back-arc region of the study area. The source region of all the siliceous rocks exhibit island arc affinity. An adakite–tholeiitic/calc-alkaline–adakitic rock across-arc variation best describes the observed distribution of volcanic centers in Central Luzon. The differences in the geochemistry of the various volcanic rocks is a result of the interplay between various geochemical processes and source region character.

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REFERENCES

ARCULUS, R.J., 1994. Aspects of magma genesis in arcs. *Lithos* 33, 189–208.

BALCE, G.R., ENCINA, R.Y., MOMONGAN, A. AND LARA, E., 1979. Geology of the Baguio District and its implication on the tectonic development of the Luzon Cordillera Central. *Phil. Bu. Mines Rpt., Manila,* 123p.

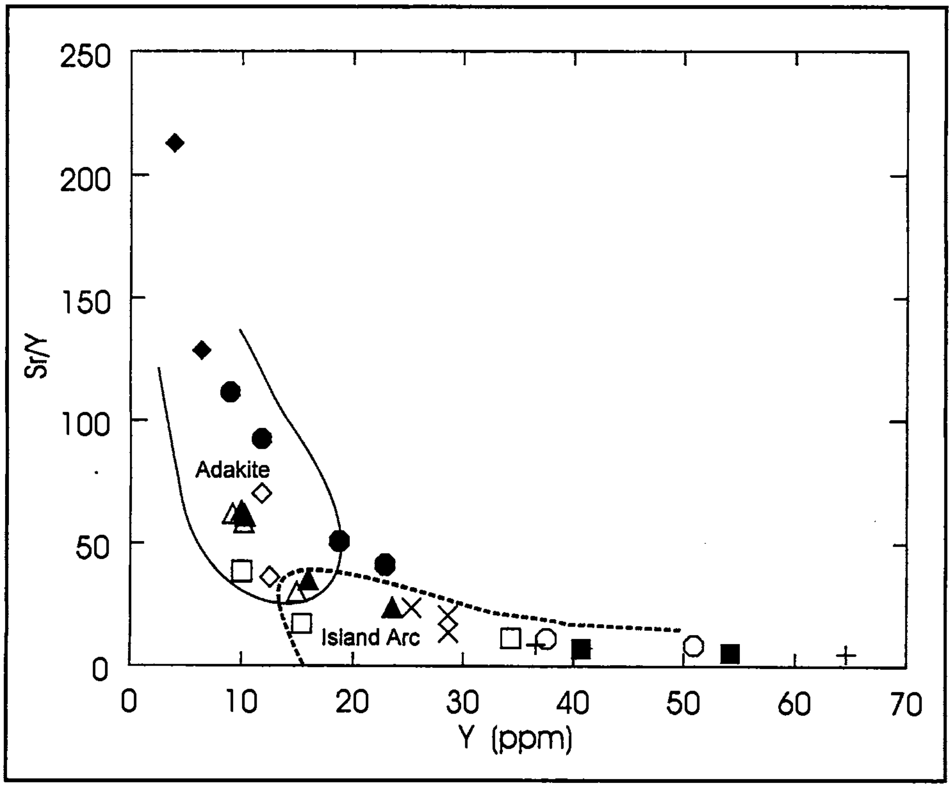

Figure 6. Adakites and adakitic rocks were recognized in the forearc, main volcanic arc and back-arc regions of Central Luzon. Boundaries after Defant and Drummond (1990). See text for discussion. Symbols as in Figure 2.

BAU, M. AND KNITTEL, U., 1993. Significance of slab-derived partial melts and aqueous fluids for teh genesis of tholeiitic and calc-alkaline island-arc basalts: Evidence from Mt. Arayat, Philippines. *Chem. Geol. 105,* 233–251.

BERNARD, A., KNITTEL, U., WEBER, B., WEIS, D., ALBRECHT, A., HATTORI, K., KLEIN, J. AND OLES, D., 1996. Petrology and geochemistry of the 1991 eruption products of Mount Pinatubo, *In:* C.G. Newhall and R.S. Punongbayan (Eds.), Fire and Mud, Eruptions and Lahars of Mount Pinatubo, Philippines. *Phil. Inst. Volcanol. Seismo. and Univ. of Washington Press,* 767–797.

CASTILLO, P.R., 1996. Origin and geodynamic implication of the Dupal isotopic anomaly in volcanic rocks from the Philippine island arcs. *Geology 24,* 271–274.

CASTILLO, P.R., 1998. Petrogenesis of the 1991 Mount Pinatubo volcanic rocks: Insights into the source of adakite-like lavas in the Luzon Arc, Philippines. Abstract, *AGU-Western Pacific Geophysics Meeting Abstract Vol.,* p. W123.

CHEN, C.H., SHIEH, Y.N., LEE, T., CHEN, C-H., AND MERTZMAN, S.A., 1990. Nd-Sr-O isotopic evidence for source contamination and an unusual mantle component under Luzon arc. *Geochim. Cosmochim. Acta 54,* 2473–2483.

DATUIN, R., 1982. An insight on Quaternary volcanoes and volcanic rocks of the Philippines. *J. Geol. Soc. Phil. 36,* 1–11.

DAVIES, J.H., 1994. Lateral water transport across a dynamic mantle wedge: A model for subduction zone magmatism. *In:* Ryan, M.P. (Ed.), *Magmatic Systems.* Academic Press, Inc., 197–221.

DE BOER, J., ODOM, L.A., RAGLAND, P.C., SNIDER, F.G. AND TILFORD, N.R., 1980. The Bataan orogene: Eastward subduction, tectonic rotations and volcanism in the western Pacific (Philippines). *Tectonophysics 67,* 251–282.

DEFANT, M.A. AND DRUMMOND, M.S., 1990. Derivation of some modern arc magmas by melting of young subducted lithosphere. *Nature 347,* 662–665.

ELLAM, R.M., 1992. Lithospheric thickness as a control on basalt geochemistry. *Geology 20,* 153–156.

KAY, R.W., 1978. Aleutian magnesian andesites: melts from subducted Pacific Ocean crust. *J. Volcanol. Geotherm. Res. 4,* 117–132.

KNITTEL, U. AND DEFANT, M.J., 1988. Sr-isotopic and trace element variations in Oligocene to Recent igneous rocks from the Philippine island arc: Evidence for Recent enrichment in the sub-Philippine mantle. *Earth Planet. Sci. Lett. 87,* 87–99.

KUSHIRO, I., 1990. Partial melting of mantle wedge and evolution of island arc crust. *J. Geophys. Res. 95, 15,* 929–15, 939.

MANIAR, P.D. AND PICCOLI, P.M., 1989. Tectonic discrimination of granitoids. *Geol. Soc. Am. Bull. 101,* 635–643.

MAURY, R.C., DEFANT, M.J., BELLON, H., JACQUES, D., JORON, J-L., MCDERMOTT, F. AND VIDAL, P., 1998. Temporal geochemical trends in northern Luzon arc lavas (Philippines): implications on metasomatic processes in the island arc mantle. *Bull. Soc. Geol. France 169,* 69–80.

MAURY, R.C., SAJONA, F.G., PUBELLIER, M., BELLON, H. AND DEFANT, M.J., 1996. Fusion de la croute oceanique dans les zones de subduction/collision recentes: l' exemple de Mindanao, Philippines. *Bull. Soc. Geol. Fr 167,* 579–595.

MUKASA, S.B., MCCABE, R. AND GILL, J.B., 1987. Pb isotopic compositions of volcanics rocks in the west and east Philippine island arcs: presence of Dupal isotopic anomaly. *Earth Planet. Sci. Lett. 84,* 153–164.

PALLISTER, J.S., HOBLITT, R.P. AND REYES, A.G., 1992. A basalt trigger for the 1991 eruptions of Pinatubo volcano? *Nature 356,* 426–428.

PEACOCK, S.M., RUSHMER, T. AND THOMPSON, A.B., 1994. Partial melting of subducting oceanic crust. *Earth Planet. Sci. Lett. 121,* 227–244.

PEARCE, J.A. AND PEATE, D.W., 1995. Tectonic implications of the composition of volcanic arc magmas. *Ann. Rev. Earth Planet Sci. 23,* 251–285.

RINGWOOD, A.E., 1975. *Composition and Petrology of the Earth's Mantle.* McGraw-Hill, New York, N.Y., 618p.

RUDNICK, R.L., 1995. Making continental crust. *Nature 378,* 571–578.

SAJONA, F.G., MAURY, R.C., BELLON, H., COTTEN, J., DEFANT, M.J. AND PUBELLIER, M., 1993. Initiation of subduction and the generation of slab melts in western and eastern Mindanao, Philippines. *Geology 21,* 1007–1010.

TAKAHASHI, E., 1986. Genesis of calc-alkali andesite magma in a hydrous mantle-crust boundary: Petrology of lherzolite xenoliths from the Ichinomegata crater, Oga peninsula, northeast Japan, Part II. *J. Volcanol. Geotherm. Res. 29,* 355–395.

TATSUMI, Y., MURASAKI, M. AND NOHDA, S., 1992. Across-arc variation of lava chemistry in the Izu-Bonin arc: Identification of subduction components. *J. Volcanol. Geotherm. Res. 49,* 179–190.

TAYLOR, S.R. AND MCLENNAN, S.M., 1995. The geochemical evolution of the continental crust. *Rev. Geophys. 33,* 241–265.

WOLFE, J.A., 1981. Philippine geochronology. *J. Geol. Soc. Phil. 35,* 1–30.

YOGODZINSKI, G.M., KAY, R.W., VOLYNETS, O.N., KOLOSKOV, A.V. AND KAY, S.M., 1995. Magnesian andesite in the western Aleutian Komandorsky region: Implications for slab melting and processes in the mantle wedge. *GSA Bull. 107,* 505–519.

YOSHIDA, H. AND TAKAHASHI, N., 1996. Behavior of whole rock chemistry in the Horoman mantle diapir, Hidaka Belt, Hokkaido, Japan. Submitted to *J. Min. Petr. Econ. Geol.*

YUMUL, G.P., JR., DIMALANTA, C.B., FAUSTINO, D.V. AND DE JESUS, J.V., 1998. Arc volcanism in Central Luzon, Philippines. Subducted slab or lower crust melts? Abstract, *AGU-Western Pacific Geophysics Meeting Abstract Vol.,* p. W122.

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