Low-K Tholeiitic Signatures in Calayan Island (Northern Luzon, Philippines)

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ABSTRACT

The Calayan island is a Tertiary (7-4 Ma) volcanic island situated in the northern portion of the Philippine archipelago, a part of Babuyan segment of the Luzon arc. It is a product of subduction of South China Sea oceanic crust underneath the Philippine terrane. Rock spectrum in the island ranges from basalt to rhyolite with andesite as the most predominating lava. Geochemical signatures are characterized by low concentrations of large-ion lithophile and flat behavior of rare-earth elements, a significant type of low-K tholeiitic series. The objective of this preliminary investigation is to determine the geochemical affinities of the island and its brief correlation to the nearby island of Camiguin de Babuyanes.

Key words: *Tholeiitic series, Extinct volcanoes, Babuyan islands, Calayan, Luzon arc, Philippines*

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Introduction

In the island arc settings like the Philippine archipelago, subduction zone features like trenches and trough, are the primary cause of building of most of the 7,100 islands which dominated by active, dormant, and extinct volcanoes (e.g. volcanic plugs and domes) and as well intrusion of plutons which traversed almost parallel to this zones. The formation of almost linear chains of volcanoes divides some part of the Philippines into different arcs such as the Bicol arc and Samar-Leyte volcanics in the eastern part, the southern Mindanao arc, and the Sulu-Negros arcs and Luzon arc in the western part of the archipelago (Karig, 1983).

Calayan Island is one of the five principal islands of the Babuyan Group, which also comprises of Babuyan, Camiguin de Babuyanes, Dalupiri, and Fuga: and the islet of Didicas (Fig.-1). Calayan lies between 121° 20' and 121° 35' east longitude and 19° 15' and 19° 20' north latitude. It is approximately 18 kilometers long and 14 kilometers wide and has a total land area of 252 km^2.

The Babuyan and Batanes Group of Islands is a segment of the Luzon arc. An arc with 1,200 km long and 200 to 300 km chain comprises of stratovolcanoes and volcanic peaks stretching from Mindoro (13° N) to the Coastal Range of Taiwan (21° N) (Defant *et al.*, 1989). This arc corresponds to the eastward subduction of the South China Sea oceanic basin underneath the Luzon terrane along the Manila Trench. It is a complex zone mark by the boundary between the Eurasian and Philippine Sea Plates (Stephan *et al.*, 1986).

Geology

The general geology of Calayan was modified from the reconnaissance investigation conducted by J. R. dela Cruz (1956) and from the geochemical studies conducted by Jacques (1987) and Maury *et al.* (1988) at the Luzon arc. Jacques (1987) and Maury *et al.* (1988), divided the geology of Calayan island into four types based on the major volcanic centers namely: Mts. Nangabaywanan, Calayan, Macara, and Piddan. These volcanic centers featured by effusive and explosive volcanic eruptions. They mapped the major volcanic rock spectrum from basalt-andesite to rhyolite with andesite dominating the spectrum.

In general, the island is divided into three zones: Mt. Nangabaywanan in the western part, Mts. Macara and Calayan in the central section and Mt. Piddan in the eastern zone. Overall view, both the western and central portions are made-up of basic volcanic rocks comprises of lavas, volcanic agglomerates and pyroclastic materials of basalt, basaltic-andesite and andesite. In contrast, the eastern sections consists of acidic volcanic rocks of dacitic and rhyolitic compositions.

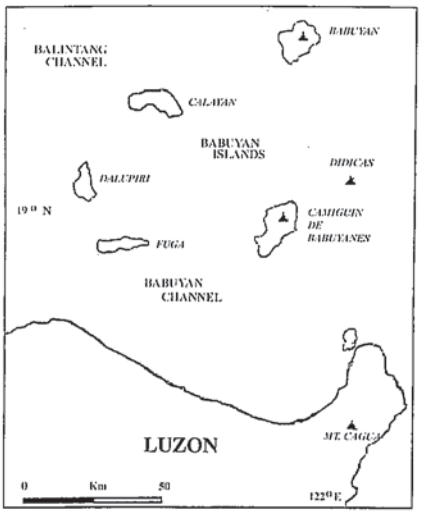

Fig. 1.- Map of Babuyan Group of Islands. Solid triangle represents active volcanoes.

Figura 1 : Mapa del Grupo de Islas Babuyan. Los triángulos representan volcanes activos.

Massive limestone deposit noted along the coastline of the island, paleontological dating yielded an age of late Miocene (Dela Cruz, 1956) and Plio-Quaternary (Jacques, 1987).

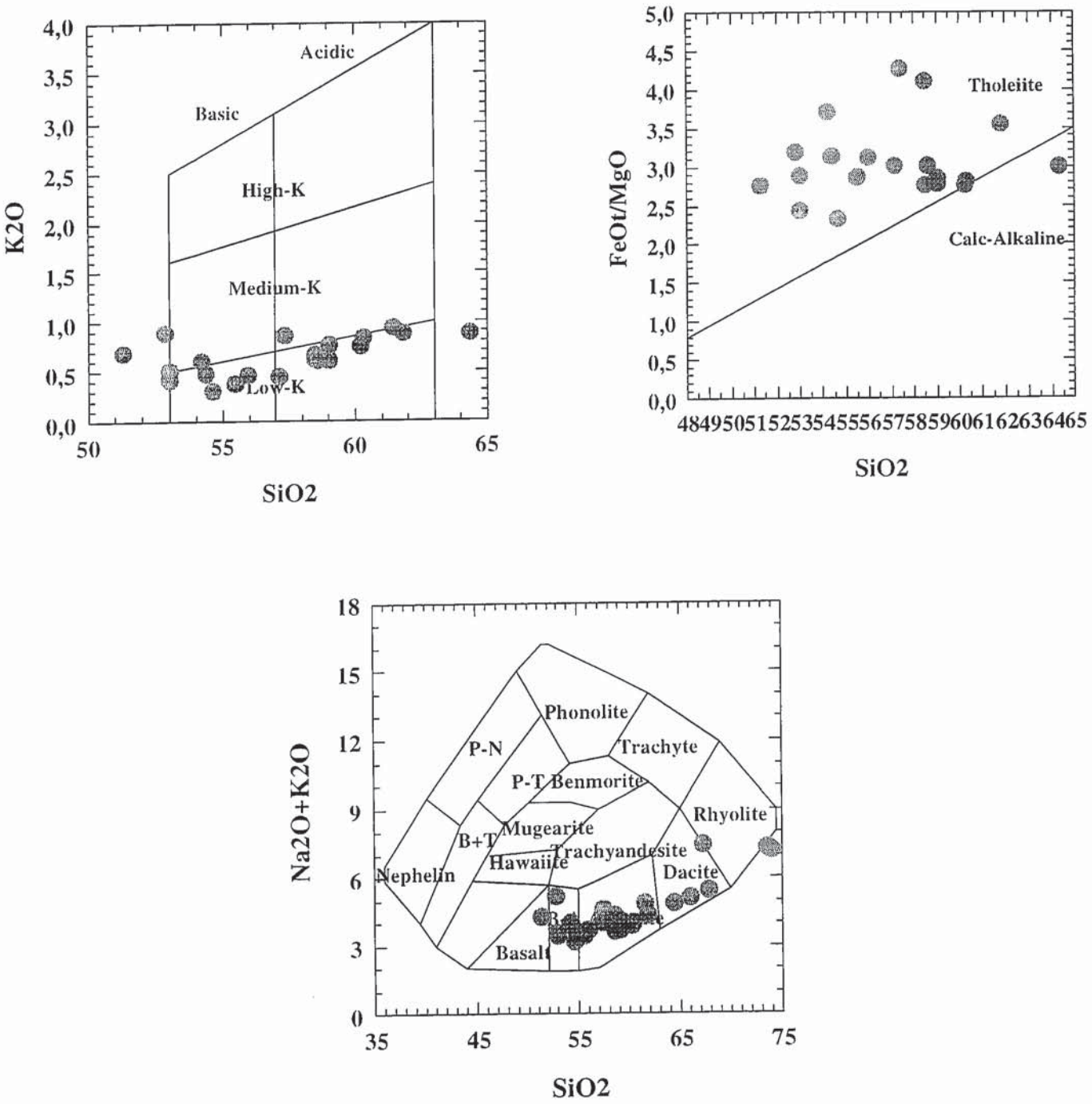

Fig. 2.- Rock Classification Diagrams of Calayan Lavas. (a) the K_2O and SiO_2 diagram (after Gill, 1981) and Na_2O+K_2O and (banda) FeOt/MgO vs SiO_2 diagram (after Irvine and Baragar 1971 and Cox et al. 1979, taken from Rollinson 1993).

Figura 2 : Diagramas de clasificación de las lavas de Calayan. (a) Diagrama de K_2O y SiO_2 (según Gill, 1981) y (b y c) diagramas Na_2O+K_2O vs FeO_2/MgO vs SiO2 y SiO_2 (según Irvine y Baragar 1971 y Cox et al., 1979, en Rollinson, 1993)

Petrology

Twenty-six rock samples were selected on the basis of geographic and stratigraphic sites, sample freshness, and degree of alteration for petrological and geochemical analysis.

The volcanism of Calayan are composed mostly of andesite, but the lava spectrum ranges from basalt to rhyolite. Majority of the volcanic rocks exhibits a porphyritic (30-70%) texture mostly in andesite, basaltic-andesite and dacite (in decreasing order) and to lesser degree in basalt, which show more vitrophyric textures. Rhyolite lava has a characteristic of subaphyric. Different rock texture types were also remarked such as glomeroporphyritic, ophitic to subophitic textures which incorporated in porphyritic andesites, while perlitic and spherulitic textures are much common in rhyolite.

Phenocrysts of plagioclase feldspar are the most abundant in almost wide variation of rock types from basalt to dacite and also in lesser extent rhyolite, followed by in-order of decreasing abundance of ferromagnesian minerals, pyroxene (clinopyroxene, orthopyroxene and augite), amphibole (hornblende), biotite and olivine (traces). Quartz formed either phenocrysts and/or matrix particularly in dacite and rhyolites, and as well in lesser degree in andesite. Phenocrysts varies from euhedral to anhedral but the bulk of the crystallinity are subhedral;

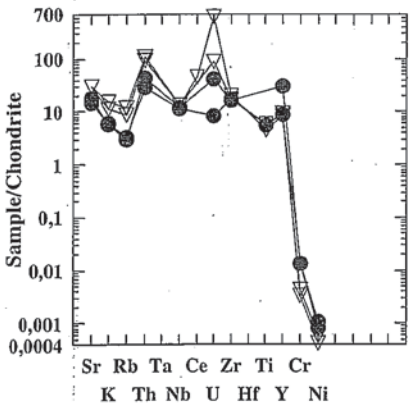

Fig. 3.- The Spider Diagram of Calayan and Camiguin de Babuyanes which characterized by Low-K Tholeiitic (closed circle) and Medium-K Calc-Alkaline (inverted open triangle) Signatures, respectively.

Figura 3 : Diagramas "spider" de las islas de Calayan y Camiguin de Babuyanes, caracterizados por el quimismo toleítico pobre en potasio (círculos) y quimismo calco-alcalino (triángulos invertidos), respectivamente.

the average size approximately 4-5 mm in plagioclase, pyroxene and also in some hornblende and quartz. Distinct shapes are noticeable such as acicular, lath-like, tabular, and platty (shabby). In addition to glass and cryptocrystalline, the matrix contains also of microcrystalline of plagioclase, and minor amounts of pyroxene, quartz and Fe-Ti-oxides. K-feldspar is relatively absent as phenocrysts in rhyolite.

Geochemistry

The general characteristics of the geochemical composition (major elements) of Calayan island indicate an orogenic affinity (Table-1). Like most island-arc elsewhere (Gill, 1981 and Ewart, 1982), the lavas from Calayan island are generally characterized by a wide range variation of SiO_2 (51-77 wt. %). In average, the K_2O is relative low in values, suggest a low-K tholeiitic association. The lavas were marked by Fe enrichment relative to Mg, which decreases from mafic to acidic. MgO values ranges from 2.8-4.9 wt. %, much lower than those normally considered as primary mantle derived magmas. Al_2O_3 content is 11-19 wt. %. The values of TiO_2 are less than 0.90 wt. %, typical of island-arc settings. Na_2O values greatly exceed than that of K_2O. The lavas gathered in Calayan represent a fresh to highly altered samples but most display a moderately freshness.

The nickel and chromium contents in Calayan lavas are generally very low, typical of orogenic lavas, with peak values of 33 ppm and 14 ppm, respectively. In general, it exhibits low abundance of large-ion lithophile elements (LILE's), K, Rb, Sr and Ba. V, Co, Cu and Zn contents are typical of island-arc magmas series. The Calayan lavas are generally characterized by low Th/U ratio (Defant *et al.*, 1990).

Using various discriminating diagrams (Fig.-2) it clearly marked that the tectono-magmatic classification of the Calayan lavas indicates signatures of sub-alkaline and tholeiitic.

The spider diagram normalized to chondrite (Fig.-3) show prominent negative anomalies much noted in Rb and Nb, and also to lesser extent in K and Ti. Very low values noted in Cr and Ni. The negative of Nb is much a particular interest in considering the petrogenesis of island-arc lavas. The elements ranges its values from more than 1.0 times (Rb) to as much as 100 times (U), with Cr and Ni contents less than 0.01 time and almost 0.001 time, respectively.

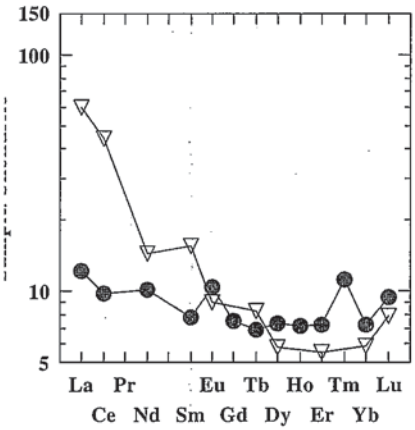

Fig. 4.- The Rare-Earth Elements of Calayan and Camiguin de Babuyanes Lavas which characterized by flat and low light REE's values of the former islands in contrast to the enrichment of the latter.

Figura 4 : Tierras raras de Calayan y Camiguin de Babuyanes. Las lavas se caracterizan por valores planos y bajo contenido en elementos de tierras raras, en la primera isla con respecto al enriquecimiento de la segunda.

Samples/ Elements (wt. %)	CAL - 01	CAL- 02A	CAL - 03	CAL- 05	CAL – 07A	CAL- 08	CAL -11	CAL- 12A	CAL- 14A	CAL- 16A	CAL- 17
SiO_2	58.58	51.30	60.22	59.05	54.38	58.48	54.62	64.33	67.29	77.22	74.05
Al_2O_3	17.02	19.08	15.70	16.20	18.01	16.01	17.22	15.1	11.3	12.44	12.36
Fe_2O_3	6.90	7.75	6.50	6.68	7.51	8.21	7.79	3.33	0.65	0.69	0.69
MnO	0.11	0.11	0.12	0.12	0.10	0.14	0.15	0.06	0.04	0.02	0.05
MgO	4.12	4.70	4.24	4.21	4.30	3.60	6.01	2.00	0.40	0.27	0.22
CaO	7.70	9.57	7.46	7.70	7.65	7.42	9.88	4.59	0.60	0.71	0.59
Na_2O	3.19	3.58	3.14	3.09	3.31	3.65	2.84	3.95	4.20	4.78	4.20
K_2O	0.60	0.69	0.75	0.60	0.48	0.66	0.31	0.87	3.25	2.71	2.97
TiO_2	0.61	0.68	0.54	0.60	0.60	0.80	0.51	0.41	0.11	0.11	0.11
P_2O_5	0.10	0.11	0.12	0.12	0.06	0.22	0.08	0.09	0.04	0.05	0.04
L.O.I	1.06	2.61	1.04	1.61	3.59	0.80	0.74	5.2	11.17	0.91	4.13
Total	99.99	100.2	99.83	99.98	99.99	99.99	100.1	99.93	99.04	99.91	99.41
V	247.2	291.5	190.0	230.8	262.6	278.7	222.1	127.1	3.1	6.9	4.5
Cr	46.9	50.9	41.2	39.2	58.4	28.7	104.0	17.6	9.1	0.5	2.6
Co	60.2	68.9	50.8	37.3	41.3	31.2	36.6	35.0	5.7	52.8	2.2
Ni	16.8	17.9	15.1	13.0	17.8	10.1	33.3	8.7	7.2	3.9	9.4
Cu	66.8	111.1	114.6	135.2	109.9	93.0	64.3	47.9	24.3	15.3	19.9
Zn	60.0	62.8	53.1	52.1	63.2	70.7	63.2	50.7	20.2	11.4	21.6
Ba	172.3	79.1	86.0	78.3	72.0	80.1	95.8	118.8	281.8	313.4	303.9
Nb	4.1	4.7	4.9	4.0	3.7	4.7	3.7	5.0	6.7	7.1	7.0
Rb	11.0	9.5	13.1	10.6	5.7	5.2	5.3	14.5	64.3	62.6	65.5
Sr	182.6	209.9	192.8	181.1	209.6	202.1	206.4	184.3	43.8	36.8	30.5
Y	22.1	21.6	24.1	20.1	17.3	31.2	16.4	22.4	20.5	21.4	21.2
Zr	89.9	99.3	109.9	95.5	78.1	95.6	55.4	142.1	79.6	84.6	84.2
U	3.3	0.3	5.0	0.0	0.0	0.6	0.0	0.6	1.3	1.0	1.4
Th	1.7	1.8	1.7	1.2	0.7	2.0	1.2	10.2	4.9	5.5	5.3
Pb	5.0	5.9	6.1	6.0	5.6	5.7	4.9	7.0	10.3	9.8	10.6

Table 1 : Selected major and trace elements samples of Calayan lavas

Tabla 1 : Elementos mayores y trazas seleccionados de las lavas de Calayan

Comparison of Calayan and Camiguin de Babuyanes Lavas

The geographical comparison between the islands of Calayan and Camiguin de Babuyanes, is that both islands are within the segment of Babuyan of the Luzon arc but however, the former belong to the West Volcanic Complex while the latter to the East Volcanic Complex (Yang *et al.*, 1996). The Calayan island is situated much closer to the Manila trench. The general model of island-arc magmatism suggest that magma erupted closer to the trench has geochemical signatures of low-K tholeiitic series while as goes further away its alkalinity content increases from low-K tholeiitic, medium-K to high-K calc-alkaline affinities. The age of volcanism correspond directly from tholeiitic which is much older to high-K much younger. In the case of the two islands, Calayan consists of tholeiitic lavas (7-4 Ma) while Camiguin de Babuyanes erupted medium-K calc-alkaline lavas (approximately 3-0.7 Ma) (Defant *et. al* 1989, 1990).

Rock spectrum in Calayan ranges from basalt to rhyolite while in Camiguin de Babuyanes from basalt to dacite. Generally, the petrographic textures in both islands characterized by porphyritic but in Calayan is relatively less and more vitrophyric, common in a tholeiitic environment.

The behavior of the elements using spider diagrams indicates relatively low concentrations of large-ion lithophile elements for Calayan island with respect to Camiguin de Babuyanes but in reversed for the transition elements such as nickel and chromium.

The diagram of the rare-earth elements configurations of Calayan and Camiguin de Babuyanes lavas (Fig.-4), normalized to chondrite, is characterized by a pattern of depleted light rare-earth elements (LREE) and heavy rare-earth elements (HREE), which is relatively almost constant flat trend for Calayan lavas. The concentration varies 10 to 20 times in the normalized values. Insignificant spikes were remarked at elements of La, Eu, Tm, and Lu and flat and constant concentrations at Gd to Er and Yb elements and as well in Ce and Pr. The trend is very much similar to the behavior of REE´s in MORB.

In contrast to the flat and depleted values of REE´s in Calayan, the calc-alkaline sample (Camiguin de Babuyanes island) exhibit an enrichment of LREE down through depleted HREE. The value of La reached to almost 80 times of the normalized concentrations and down to Eu that is just above 9 times. Elements between Tb and Lu (HREE) display a pattern of more or less level values of about 5 times.

Conclusions

The Calayan island geologically comprises of four extinct volcanic mountains namely: Mts. Nangabaywanan, Macara, Calayan and Piddan. Explosive and effusive type of eruption noted, with rock composition comprises of basalt to rhyolite with andesite as the main components. Petrographically, rock textures ranges from vitrophyric to porphyritic in basic rocks while sperulitic and perlitic textures in rhyolite. The island is generally characterized by low-K tholeiitic series, low content of large-ion lithophile elements and relatively flat behavior of normalized rare-earth elements. Wide range of SiO_2 contents is a typical characteristic of an island-arc orogenic.

In comparison, Camiguin de Babuyanes island has geochemical signatures of calc-alkaline affinity, and relatively higher contents in large-ion lithophile elements and light rare-earth elements.

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