

Geochemical evolution of the Panamanian Cretaceous-Paleogene volcanic arc: Insights from the Azuero Peninsula, SW Panama

Evolución geoquímica del arco volcánico Cretácico-Paleógeno Panameño: Análisis de la Península de Azuero, SO Panamá.

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RESUMEN

La evolución geológica de Panamá está directamente relacionada con la subducción de la placa de Nazca bajo la placa Caribeña durante el Cretácico-Paleógeno, desarrollando un arco volcánico en el margen occidental de ésta. Nos centraremos en la tectonoestratigrafía y geoquímica del arco Cretácico-Paleógeno panameño, presentando nuevos datos geoquímicos obtenidos a lo largo de todo el arco, permitiéndonos inferir la evolución geoquímica del arco volcánico en esta zona. Se han diferenciado cuatro grandes unidades: (1) Basamento Ígneo de Azuero (BIA), (2) Proto-arco de Azuero (PAA), (3) Arco Volcánico de Azuero (AVA) y (4) Formación Tonosí. El BIA es de carácter toleítico, con una alta relación en (Nb/La) y baja en (La/Sm). Se caracteriza por una tendencia compatible con afinidad de plateau oceánico. El PAA es similar al BIA, carácter toleítico pero para el mismo contenido de (La/Sm) presenta menor (Nb/La). La afinidad sigue siendo de plateau, enriquecida en Ba y empobrecida en Nb y Ti. El AVA es de carácter calco-alcalino, con valores bajos de (Nb/La) y altos en (La/Sm). Su afinidad es de arco volcánico. Esto sugiere una evolución del arco panameño desde el Cretácico hasta el Paleógeno desde un magmatismo de plateau oceánico (AIB) inicialmente hasta un magmatismo de arco volcánico (AVA) en los estadios finales, con estadios intermedios transicionales correspondientes al Proto-arco de Azuero (PAA).

Palabras clave: Panamá, Península de Azuero, arco volcánico, plateau oceánico, evolución geoquímica.

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Introduction

Volcanic arcs are complex systems that are initiated and evolve in response to regional tectonic/geodynamic regime (Gurnis *et al.*, 2004) and according to the nature of the subducting plate. The Azuero Peninsula provides distinctive exposures for the evolution study of an intraoceanic arc, the Panamanian Cretaceous-Paleogene volcanic arc. Exposures of arc basement rocks and arc related sediments and intrusive provides an exceptional setting to unraveling the geodynamic and geochemical evolution of this type of volcanic arc.

Geologic Setting

Panama is situated between Colombia and Costa Rica in the southern part of Central America and constitutes the youngest segment of the land bridge

between North and South American plates. The Panama microplate lies at the junction of four major tectonic plates; Caribbean, South America, Cocos and Nazca.

During Late Cretaceous period this region was characterized by the subduction of the Farallon plate beneath the Caribbean plate. Subsequently, an arc-magmatism developed on top of the Caribbean plate. The evolution of the volcanic arc since Late Cretaceous to present determined the morphology of Panama. The Azuero Peninsula is located in the western Pacific coastline of Panama (Fig. 1A).

Two major tectonic structures in the Azuero Peninsula are observed. The regional NW-SE Soná-Azuero Fault (SAF) is found in the SW of the Azuero Peninsula. The Río Joaquín Fault Zone (RJFZ) is observed in the central part of the Azuero Peninsula. This fault system has a NW-SE trend, subvertical

dips and reverse sense of offset, although left-lateral strike-slip motion has been recognized along this fault (Corral *et al.*, *in press*).

The materials of the Azuero Peninsula are constituted by four major units summarized in the Río Quema stratigraphic section (Fig. 1B):

(1) The Azuero Igneous Basement (AIB). It is composed of massive, agglomerated and pillowed basaltic lavas, diabbases, gabbros, minor occurrences of hemipelagic sediments interlayered with lavas, and basaltic dikes crosscutting all materials, outcropping between the SAF and the RJFZ. The age of this unit is poorly constrained and Turonian to Santonian (Lissinna, 2005), Coanacian (Kolarsky *et al.*, 1995) and Coniacian-Early Santonian (Buchs *et al.*, 2009) ages are proposed.

(2) The Azuero Proto-arc group (APAG). It is composed of massive and pillowed basaltic lavas of irregu-

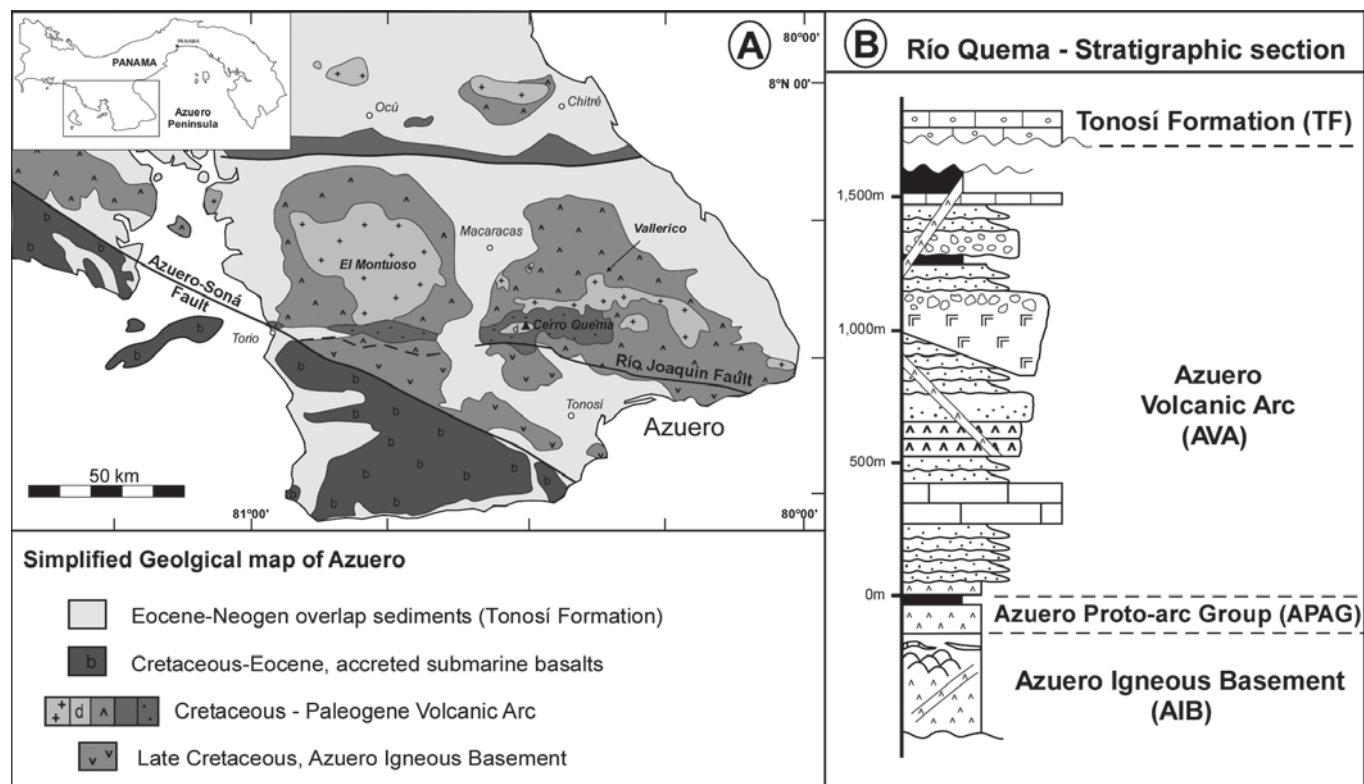


Fig. 1.- Summary of the Azuero Peninsula's geology. A; Simplified geological map of the Azuero Peninsula, modified from DGRM (1976) and Corral *et al.* (in press). B: Río Quema stratigraphic section, adapted from Corral *et al.* (in press).

Fig. 1.- Sumario de la geología de la Península de Azuero. A; Mapa geológico simplificado de la Península de Azuero, modificado de DGRM (1976) y de Corral *et al.* (en prensa). B: Sección estratigráfica del Río Quema, adaptada de Corral *et al.* (en prensa).

lar thickness overlain by well bedded greenish shales, cherts and thin basaltic lava flows, firstly described by Buchs (2008) and Buchs *et al.* (2010). The APAG locally overlies the AIB, and outcrops in the central Azuero Peninsula, north of the RJFZ. The age of this group is not well known but Buchs *et al.* (2010) propose a Late Campanian (~75-73Ma) age.

(3) Arc group. This unit is composed of the Río Quema Formation (RQF), a fore-arc basin infill sequence (Corral *et al.*, in press) and the quartz-diorite batholiths of «El Montuoso» and «Vallerico» and related volcanic rocks. Both units represent sedimentary, volcanoclastic extrusive and volcanic rocks and quartz-diorite batholiths overlying both the AIB and locally the APAG. This group crops out at the central and northern part of the Azuero Peninsula, always in the north of the RJFZ. Ages of these igneous rocks range from 66 to 42 Ma (Maury *et al.*, 1995; Lissinna, 2005; Wörner *et al.*, 2009). A recent study of Wenger *et al.* (in press), reported an age of 71 Ma for a dacite of the Arc Group.

The Tonosí Formation. It is a sedimentary sequence unconformably

overlapping all previous units. It was firstly described by Recchi and Miranda (1977) and redefined by (Kolarsky *et al.*, 1995 and Krawinkel *et al.*, 1994). The Tonosí formation is composed of minor coal seams, conglomerates, coarse sandstones and reefal limestones, and marine interbedded sandstones, siltstones and calcarenites. Ages for the formation ranges from middle Eocene to early Miocene (~40 to 15 Ma), (Kolarsky *et al.*, 1995; Krawinkel *et al.*, 1994; Krawinkel *et al.*, 1999).

Sampling and Analytical methods

Whole rock analysis (major, trace and REE elements) was performed on eighteen representative samples of igneous rocks from the Central Azuero Peninsula. Samples were mainly collected in rivers and in some tracks. The sampling includes three samples from the AIB, four samples from the APAG and eleven samples from the Arc group (nine from the RQF and two from the quartz-diorite batholiths), representing the entire sequence of the arc.

Samples were cut, crushed and reduced to powder using a tungsten carbide mill. Analyses were carried out

by Actlabs (Canada) using X-ray fluorescence (XRF) and inductively coupled plasma-mass spectroscopy (ICP-MS).

Chemistry of the Azuero Igneous Basement (AIB)

This group is characterized by a high-Fe and low-K (tholeiitic) differentiation trend (Fig. 2A and 2B). In terms of incompatible elements, as shown in figure 2C, AIB display relatively high values of (Nb/La) and generally low values of (La/Sm). The trace element content (normalized to Primitive Mantle, McDonough and Sun, 1995) of this group has a flat or slightly enriched pattern, typical of plateau-like affinities (Fig. 2D).

Chemistry of the Azuero Proto-arc group (APAG)

The rocks of this group are geochemically characterized by a differentiation trend similar to AIB with high-Fe and low-K (tholeiitic) trend (Fig. 2A and 2B). APAG is slightly dissimilar to AIB in terms of incompatible elements and have lower values of (Nb/La) for

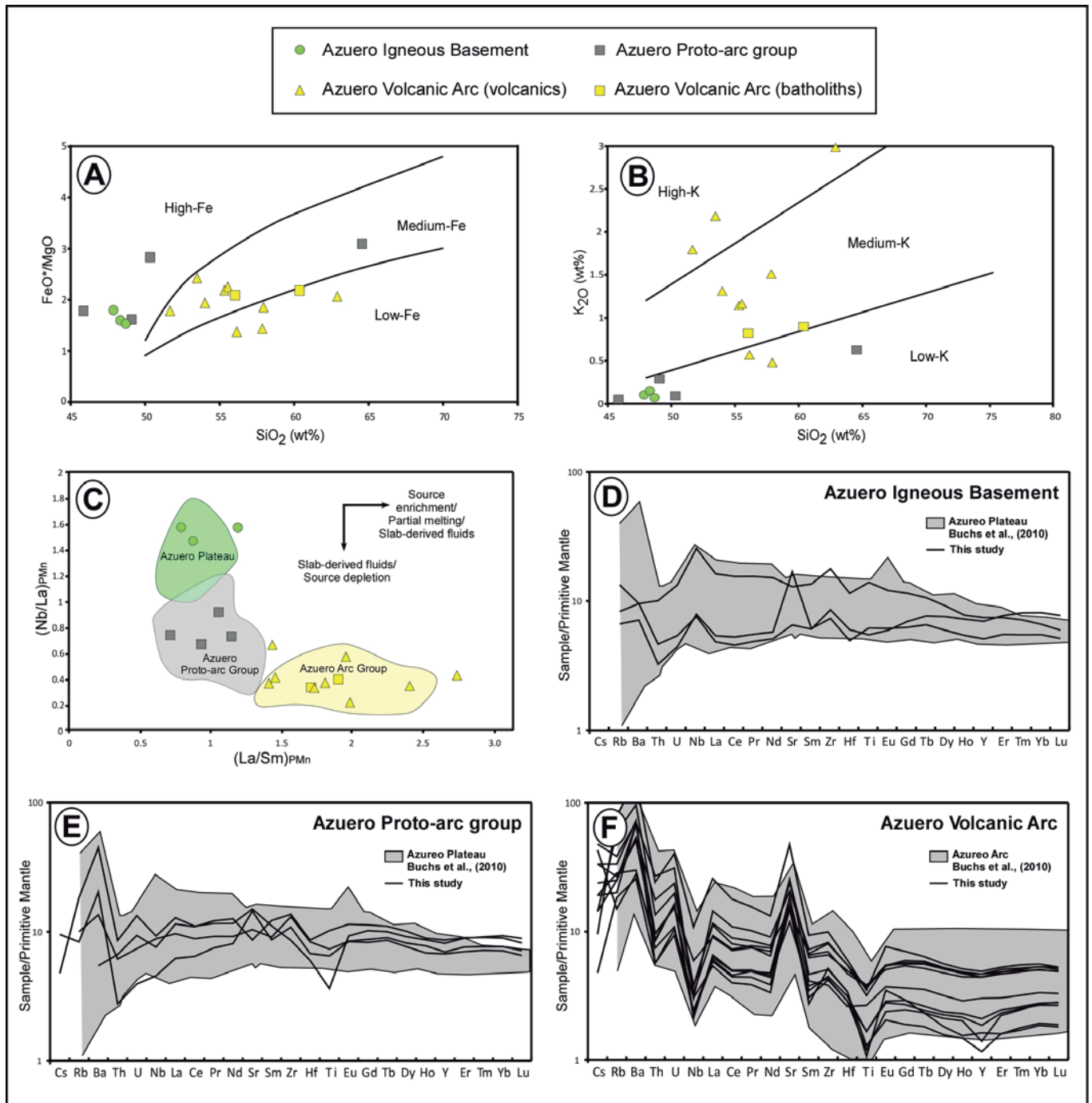


Fig. 2.- Geochemistry of the igneous rocks of the Azuero Peninsula. A; FeO^*-SiO_2 diagram after Arculus (2003). B; K_2O-SiO_2 diagram after Le Maitre *et al.* (1989). C; Plot of $(La/Sm)_{PMn}$ vs. $(Nb/La)_{PMn}$. Primitive mantle from McDonough and Sun (1995). Azuero Plateau, Azuero Proto-arc group and Azuero Arc group after Buchs *et al.* (2010). D-F; Primitive mantle-normalized multi-element diagrams of the AIB, APAG and AVA (black lines). Primitive mantle from McDonough and Sun (1995). Azuero Plateau and Azuero Arc (gray area) after Buchs *et al.*, 2010.

Fig. 2.- Geoquímica de las rocas ígneas de la Península de Azuero. A; Diagrama FeO^*-SiO_2 (Arculus, 2003). B; Diagrama K_2O-SiO_2 (Le Maitre *et al.*, 1989). C; Gráfico $(La/Sm)_{PMn}$ vs. $(Nb/La)_{PMn}$. Manto primitivo (McDonough y Sun, 1995). Azuero Plateau, Azuero Proto-arc group y Azuero Arc group de Buchs *et al.* (2010). D-F; Diagramas multielementales normalizados al Manto primitivo de AIB, APAG y AVA (líneas negras). Manto primitivo de McDonough y Sun, (1995). Azuero Plateau y Azuero Arc (área gris) de Buchs *et al.*, 2010.

approximately the same values of (La/Sm) , as shown in figure 2C, and have a slightly different trace element content in comparison with AIB, displaying a flat pattern with enrichment in Ba and depletion in Nb and Ti (Fig. 2E).

Chemistry of the Azuero Volcanic Arc (AVA)

The volcanic arc group is characterized by a medium-Fe to low-Fe and medium-K to high-K (calc-alkaline)

differentiation trend (Fig. 2A and 2B.) Arc rocks, contrary to AIB and APAG display relatively large values and higher range of (La/Sm) , and lower values of (Nb/La) (Fig. 2C). This group contains the most different trace element content and pattern

of these units, and presents volcanic arc affinities, variably enriched in fluid-mobile elements and with flat and depleted heavy REE's (Fig. 2F).

Discussions and Conclusion

According to our results, AIB formation is compatible with the presence of a mantle plume under the Panamanian block, approximately between Turonian to Santonian times, generating massive, agglomerated and pillowed basaltic lavas and gabbros which are locally interlayered with hemipelagic sediments. This basement has a Tholeiitic character with plateau-like affinities (Fig. 1A, 1B and 1D), corresponding to the Caribbean Large Igneous Province (CLIP).

During Late Campanian times (~75-73Ma) the Nazca plate started to subduct beneath the Caribbean plate, generating massive and pillowed basaltic lavas interlayered with shales and cherts. Because of the influence of the subducting slab derived fluids the composition of the AIB changed to the APAG with Tholeiitic character and slightly enriched fluid-mobile elements and depleted in Nb and Ti. Another change was produced in the content of incompatible elements as the values of (Nb/La) decreased with respect to the original composition.

Once the arc matured (Late Cretaceous-Paleogene), it generated more acidic rocks such as andesites, dacites, quartz-diorites, and the chemistry changed to Calc-alkaline character with volcanic arc affinities and with a totally different content in incompatible elements, lower values of (Nb/La) and higher values of (La/Sm), denoting the a strong influence of the subducting slab.

In summary, the geochemical evolution of these rocks indicates that a primitive tholeiitic volcanic arc was

developed on an oceanic plateau and evolved over time to calc-alkaline. That fact establishes the onset of the subduction in the Late Campanian.

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