

AGE OF THE EASTERN PARAGUAY ALKALINE MAGMATISM

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Eastern Paraguay lies in an intercratonic region which includes the westernmost side of the Paraná Basin of Brazil. It is bounded by the N-S Paraguay river lineament (Fig. 1), separating the Paraná Basin (east) from the Gran Chaco Basin (west). The basement rocks are mainly Proterozoic to Early Paleozoic granitic intrusions and high- to low-grade metasediments and are represented in two structural highs, the Caapucú, in the south, and the Apa, in the north. During Late Mesozoic times, the whole area was subjected to NE-SW-trending crust extension, probably related to the western Gondwana break-up and the opening of the South Atlantic Ocean, leading to the formation of NW-trending grabens (e.g. ASU, Asunción-Sapucaí-Villarrica), fault systems and fault-controlled sedimentary basins. This extensional tectonics, reflecting basement structures reactivated and enhanced by Early Cretaceous events, controlled the emplacement of both the alkaline magmatism in Eastern Paraguay, and of that in the eastern Paraná Basin (Fig. 2).

Eastern Paraguay is a region of particular interest considering that: 1) it has been the site of tholeiitic (Serra Geral Formation: flood basalts and dyke swarms, both represented by high-Ti and low-Ti rock-types; 133 Ma, cf. Renne et al., 1992, and Turner et al., 1994) and alkaline magmatism; 2) Early Cretaceous potassic alkaline complexes and dykes occur emplaced before and after the flood tholeiites; 3) potassic and sodic alkaline rocks are closely related in space.

On the basis of geological and geophysical evidence and geochronological data (especially 40 more recent high precision Ar/Ar ages), five main taphrogenic events are suggested for the alkaline magmatism in Eastern Paraguay since the end of Paleozoic times, the several occurrences grouped into six different provinces (Fig. 3):

1) *Triassic* sodic magmatism of the Alto Paraguay Province, I (240-250 Ma, K/Ar and Ar/Ar, cf. Gomes et al., 1996, and Velázquez et al., 1996; 241.5±1.3 Ma, Ar/Ar, cf. Comin-Chiaramonti et al., 2006), widespread at the southernmost side of the Amazon Craton (Fúlfaro, 1996; Comin-Chiaramonti et al., 2005) with the alkaline intrusions forming a narrow N-S belt along the Paraguay river;

2) *Early Cretaceous* potassic alkaline-carbonatitic complexes and dykes at the northern area (Rio Apa Province, II; Amambay Province, III), predating the tholeiitic basalts of the Serra Geral Formation and showing poorly documented ages of 138.7±0.2 Ma, Ar/Ar, for the first rocks (cf. Comin-Chiaramonti et al., 2006; ~142 Ma, K/Ar, cf. Gibson et al., 1995) and 137.6±0.7 and 139.3±0.5 Ma, Ar/Ar, for the second occurrences (cf. Comin-Chiaramonti et al., 2006; avg. 141 Ma, K/Ar and fission-track, cf. Sonoki and Garda, 1988, and Eby and Mariano, 1992, respectively);

3) *Early Cretaceous* potassic alkaline complexes and dykes with subordinate silico-carbonatite flows and dykes (Central Province, IV), mainly widespread in the Asunción-Sapucaí-Villarrica graben. Age span varies from 115 to 132 Ma, K/Ar and Rb/Sr (cf. Bitschene, 1987; Velázquez, 1992; Comin-Chiaramonti and Gomes, 1996; Comin-Chiaramonti et al., 1997, 1999), with the highest concentration of new Ar/Ar results clustering in the 126-128 Ma interval (Gomes et al., 2003); an average value of 126.4±0.4 Ma is suggested by Comin-Chiaramonti et al. (2006);

4) *Early Cretaceous* sodic alkaline plugs and dykes of the Misiones Province (V) occurring at the southern area close to the San Juan Bautista town. Similarly to the Asunción occurrences, these rocks contain spinel peridotite mantle xenoliths. A preliminary age of 120±5 Ma (cf. Comin-Chiaramonti et al., 1997) is confirmed by new available Ar/Ar data (Velázquez et al., 2003), placing this magmatism in the 116-120 Ma interval, with an average value of 118.3±1.6 Ma (cf. Comin-Chiaramonti et al., 2006);

5) *Paleocene* sodic alkaline complexes, plugs and dykes of the Asunción Province (VI) cropping out in the neighborhood of the Paraguayan capital at the western side of the Asunción-Sapucaí-Villarrica graben and having as most significant feature the presence of rocks bearing mantle xenoliths. Previous geochronological data, mostly based on K/Ar determinations (Comte and Hasui, 1971; Bitschene, 1987; Comin-Chiaramonti et al., 1991), indicated for this magmatism a large age span of 39-61 Ma, which was redefined by Gomes et al. (2003) using only new Ar/Ar results, with the histogram

showing a dominant class at 56-58 Ma; an average value of 58.7 ± 2.4 Ma is proposed by Comin-Chiaramonti et al. (2006).

Geochemical characteristics of the alkaline associations highlight systematic Nb-Ta positive anomalies and Sr-Nd isotopes trending to the depleted mantle components for the sodic rocks, contrasting with the potassic rocks and the associated tholeiitic basalts that display negative anomalies for Nb-Ta and Sr-Nd trending to the enriched mantle components (Fig. 4). The Pb

isotope vs. Sr-Nd systematics confirm the distinction, with the sodic rocks ranging from depleted components to Bulk Earth, and transitional to the Paraná tholeiites, and the potassic rocks enriched in “high radiogenic” Sr and low in “less radiogenic” Nb-Pb. The occurrence of alkaline, both sodic and potassic (and carbonatitic), and tholeiitic magmatism in the whole Paraná-Angola-Namibia Province seems to imply the existence of appropriate lithospheric source to generate the different magmatic rock-types.

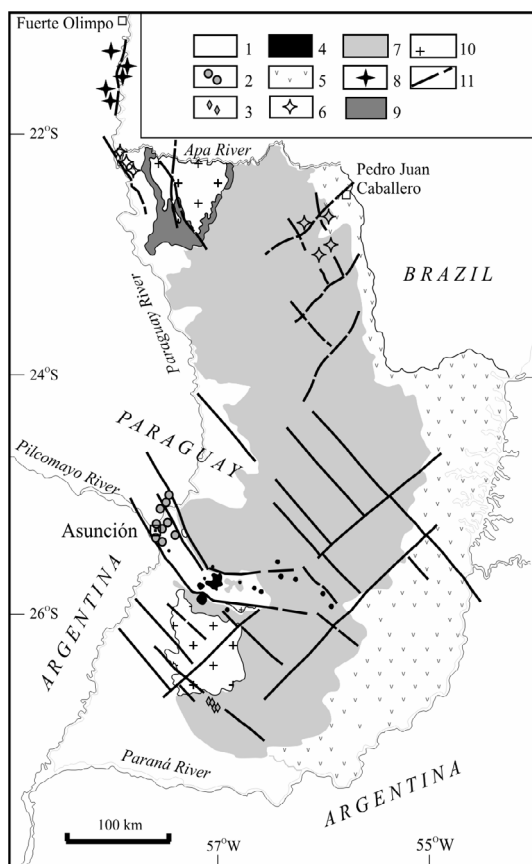


Figure 1. Geological map of Eastern Paraguay (after Comin-Chiaramonti and Gomes, 1996). 1) Quaternary and Tertiary sedimentary cover; 2) Tertiary sodic alkaline rocks; 3) Late Early Cretaceous sodic alkaline rocks; 4) Early Cretaceous potassic alkaline rocks (post-tholeiites); 5) Early Cretaceous tholeiites of the Paraná Basin; 6) Early Cretaceous potassic alkaline rocks (pre-tholeiites); 7) Paleozoic sedimentary rocks; 8) Permo-Triassic alkaline rocks; 9) Cambro-Ordovician platform carbonates; 10) Archean and Neoproterozoic crystalline basement: high- to low-grade metasedimentary rocks, metarhyolites and granitic intrusions; 11) Faults.

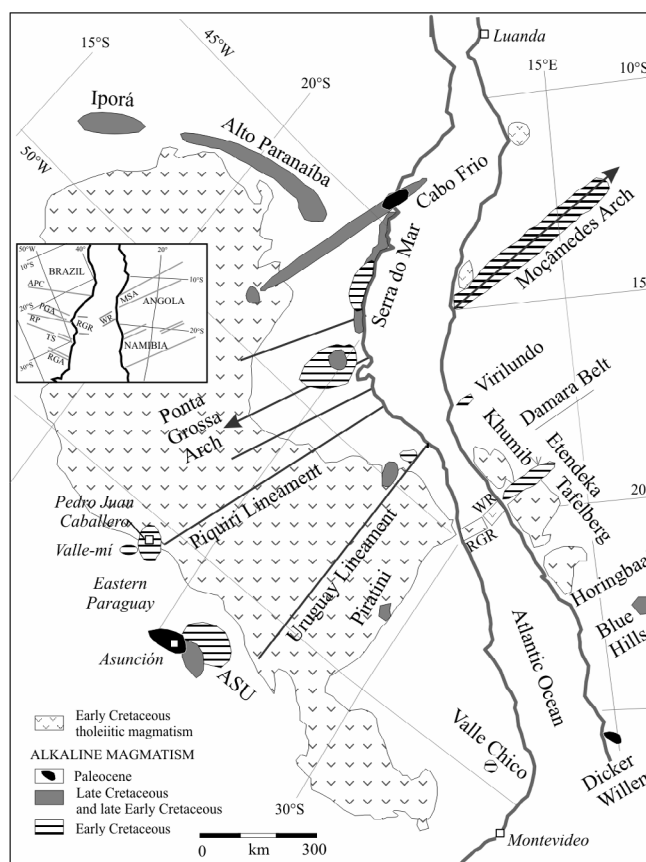


Figure 2. Schematic distribution of the magmatism in the Paraná-Angola-Namibia Province (South American and African plates, Western Gondwana, arranged at about 110 Ma; modified after Comin-Chiaramonti et al., 1997, 2005), and location of the main alkaline-carbonatitic occurrences: Ja, Jacupiranga; Ju, Juquiá; BdI, Barra do Itaipirapuã; MP, Mato Preto; RA, Rio Apa; C-S, Cerros Chirigué and Sarambá; ASU, Asunción-Sapucaí. Other abbreviations: RGR, Rio Grande Rise; WR, Walvis Ridge.

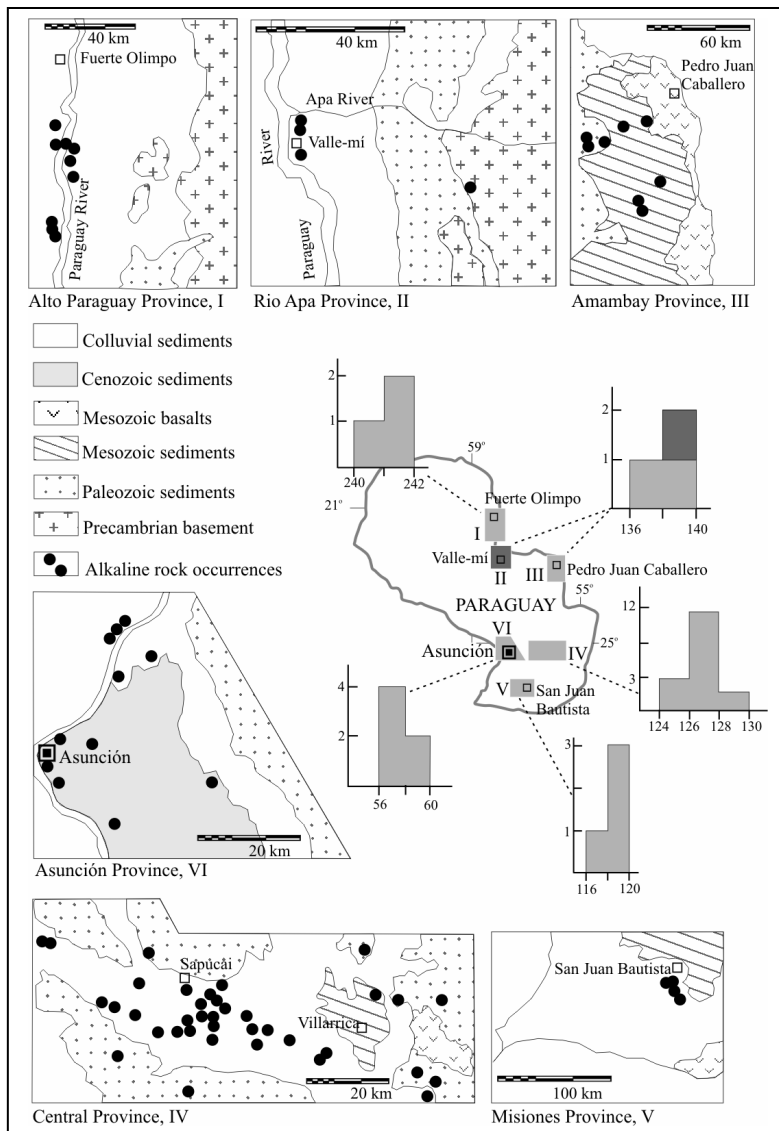


Figure 3. General distribution of the alkaline magmatism in Eastern Paraguay (modified and simplified after Comin-Chiaromonti and Gomes, 1996 and Velázquez et al., 1996). Inserts show age histograms on the basis of Ar/Ar determinations for each province.

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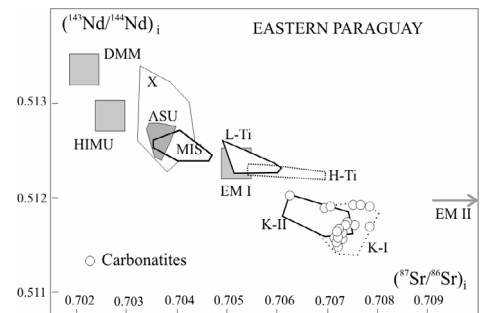


Figure 4. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ (Sr_i) vs. $^{143}\text{Nd}/^{144}\text{Nd}$ (Nd_i) correlation diagram for magmatic rocks from Eastern Paraguay (after Comin-Chiaromonti et al., 2006, modified). **Sodic rocks:** Late Early Cretaceous complexes from the Misiones Province, MIS; **Paleocene** complexes from the Asunción Province (it also includes mantle xenoliths, X). **Potassic rocks:** Early Cretaceous complexes pre- and post-dating the tholeiitic basalts of the Serra Geral Formation, K-I and K-II, respectively; Early Cretaceous tholeiitic basalts showing H-Ti and L-Ti, high and low Ti, respectively, rock-types. DMM, HIMU, EM I and EM II are approximations of mantle end-members taken from Hart et al. (1992).

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RESUMO

Magmatismo alcalino, variando em idade do Mesozóico ao Paleoceno, ocorre em muitas regiões do território paraguaio associado a zonas de subsidência tectônica de orientação NW. Ocorre também em associação com derrames de basaltos da Formação Serra Geral, mostrando formação anterior e posterior à dessas vulcânicas, além de composição extremamente variada, que inclui rochas sódicas e potássicas de granulação fina a grossa e carbonatitos maciços, estes últimos restritos à porção nordeste do país (Cerro Chiriguano e Cerro Sarambí). Com base em evidências geológicas e geofísicas e dados geocronológicos (novas idades Ar/Ar), é possível distinguir-se cinco eventos magmáticos distintos no Paraguai Oriental, com as numerosas ocorrências alcalinas enquadradas em seis diferentes províncias (Alto Paraguai, Rio Apa, Amambay, Central, Misiones and Assunção) e variando em idade do Triássico ao Paleoceno.

Geoquímicas evidências permitem distinguir as rochas alcalinas sódicas, apresentando anomalias positivas em Nb-Ta e concentrações de Sr-Nd tendendo para o campo empobrecido, das potássicas e dos basaltos toleíticos associados, ambos caracterizados por anomalias negativas em Nb-Ta e tendência de Sr-Nd no sentido do campo enriquecido. A relação dos isótopos de Pb com Sr-Nd confirma essa distinção, com as rochas sódicas variando do campo empobrecido para a Terra Global e as potássicas mostrando-se enriquecidas em Sr radiogênico e contendo menos Nd-Pb radiogênico. A ocorrência em toda a Província Paraná-Angola-Namíbia de magmatismo alcalino, representado por associações litológicas sódicas e potássicas (e carbonatíticas), ao lado de toleíticas parece implicar na existência de fonte litosférica adequada para gerar a grande diversidade de tipos petrográficos magmáticos.