PRELIMINARY PALEOMAGNETIC SURVEY OF CRETACEOUS DYKES FROM EASTERN PARAGUAY

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ABSTRACT

We present preliminary rock magnetic results and paleodirections from a Cretaceous alkaline dyke swarm in the Asunción Rift, Eastern Paraguay. Previous investigations suggest that these dykes extruded in a rather short period of time, in the period 126-127 Ma, during normal and reversed polarity field configuration (Velazquez *et al*., 2011). Paleodirectional results of alternating field and thermal demagnetization showed linear vector diagrams, but also two components and erratic behavior. Six out of 22 sites have clustered directions with a $\alpha_{95} \leq 10.0°$. Most of the accepted sites reveal inverse polarity, but we also observe reliable normal and intermediate polarity sites. Rock magnetic experiments yield reversible thermomagnetic curves with magnetite as carrier of remanence in 67% of the studied cases and samples characterized by pseudo single-domain (PSD) behavior. The present preliminary study will be complemented with further rock magnetic measurements, directional determinations and paleointensity experiments.

Keywords: Paleodirections, Rock magnetism, Cretaceous, Eastern Paraguay

RESUMEN

Se presentan resultados preliminares de magnetismo de las rocas y paleodirecciones de un enjambre de diques alcalinos cretácicos del Rift de Asunción, en Paraguay oriental. Investigaciones previas sugieren que el emplazamiento de estos diques habría tenido lugar en un periodo corto entre 126-127 Ma, y con el campo magnético terrestre con polaridad normal e invertida (Velázquez *et al*., 2011). Los resultados paleodireccionales obtenidos mediante análisis paleomagnético con desmagnetización por campos alternos y desmagnetización térmica mostraron diagramas vectoriales lineales, pero también de dos componentes así como un comportamiento errático algunos casos. En seis de 22 sitios las direcciones se agrupan con un $\alpha95 \leq 10.0°$. La mayoría de los sitios aceptados revela una polaridad inversa, pero también hemos observado sitios diques con direcciones fiables de polaridad normal e intermedia. Los experimentos de magnetismo de las rocas revelaron curvas termomagnéticas reversibles con magnetita como portador de remanencia en el 67% de los casos estudiados y muestras caracterizadas por estructura seudo monodominio (PSD). El presente estudio preliminar se complementará con más experimentos de magnetismo de las rocas, determinaciones direccionales y experimentos de paleointensidad.

Palabras Clave: Paleodirecciones, Magnetismo de rocas, Cretácico, Paraguay oriental

Background

The reconstruction of the paleomagnetic field components from magmatic rocks can offer a variety of insights on the evolution of the Earth magnetic field in the past. The understanding of the geomagnetic field fluctuation on Earth's surface as well as their corresponding magmatic events is closely related to the condition and activity of the Earth's liquid core. Of special interest are polarity reversals of the geomagnetic field, frequency patterns of polarity changes, and long periods of constant polarity, so called superchrons. The youngest superchron, the Cretaceous normal superchron (CNS), is a time interval during which the geomagnetic field remained in a constant normal polarity from 125 to 84 Ma (Cande and Kent, 1995).

Previous paleointensity studies on rocks recording the field during and before the CNS do not show a clear trend, but rather a broad range of data (*e.g*. Tauxe and Yamazaki, 2007). In particular, the field just before the onset of the CNS could be characterized by low intensity values (Zhu *et al*., 2003; Qin *et al*., 2011). Geomagnetic poles determined from magmatic rocks can give another insight on the reconstruction of paleomagnetic field direction. Paleomagnetic data can also be used for the analysis of tectonic problems. Paleomagnetic results from stable parts of continental plates, for instance, can give rise to a better understanding of the movement of the continents. However, especially for the South American area precisely defined paleopoles are still scarce for the CNS. Cretaceous paleopoles for this area obtained from previous studies show a rather large dispersion (*e.g*. Cervantes Solano *et al*., 2015). In order to study Cretaceous geomagnetic field variations in South America, dykes offer to be promising magmatic structures. Dyke intrusions through the lithosphere to the upper crust are often considered as main channel transfer routes of mantle-derived molten material (Velazquez *et al*., 2011).

The present study is being performed to try to find suitable recorders of the paleointensity just before the onset and during the CNS and to obtain new Cretaceous paleomagnetic data for South America. With these two aims in mind, 22 Cretaceous dykes were sampled in the Paraguarí area in Eastern Paraguay (Fig. 1).

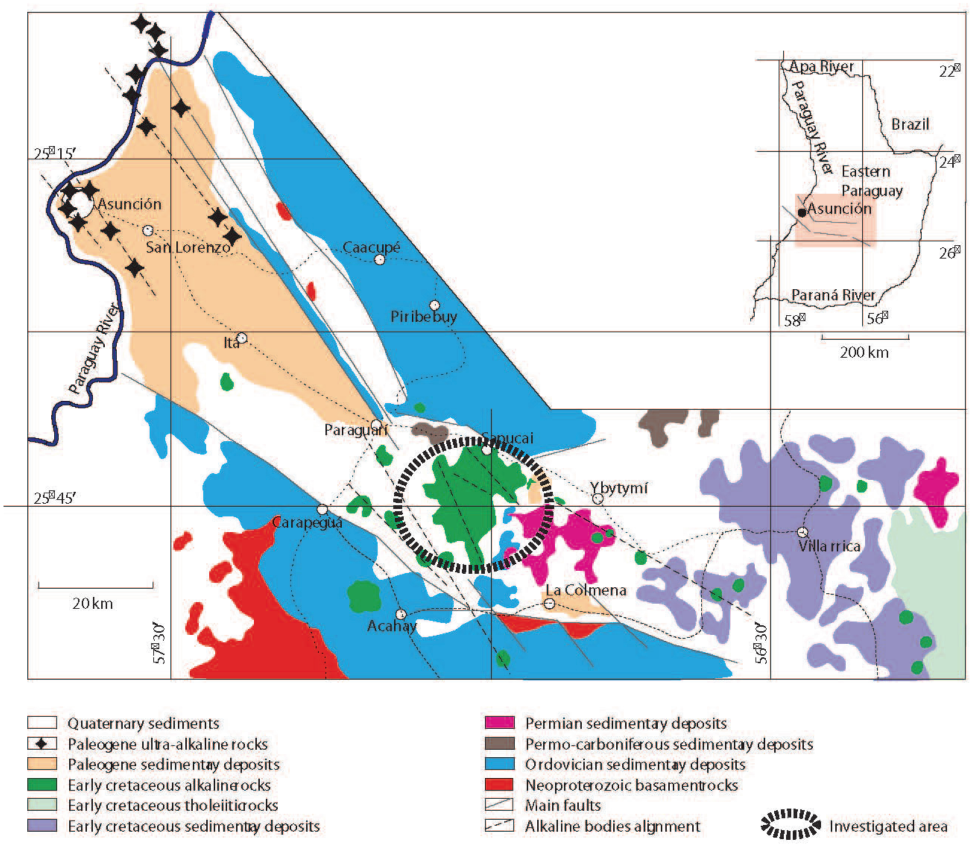

Figure 1. Geological map of the Asunción Rift and associated alkaline occurrences and sampling area (modified after Velázquez *et al*., 2011 and references therein).

Geological Context and Ages

The studied area, Eastern Paraguay, is an intracratonic region situated in the westernmost border of the Paraná basin. During Cretaceous this region was affected by an important tectonomagmatic event related to the opening of the South Atlantic Ocean, which caused a series of alkaline magmatic episodes and gave rise to the Paraná-Etendeka large igneous province. The major faulting zone of this tectonomagmatic event is the Asunción Rift, which developed during the Cretaceous (Fig. 1). This process was responsible for multiple diachronous events of potassic alkaline magmatism. The most significant magmatic event of the province is represented by hypabyssal rocks, occurring largely as individual dykes (Velazquez *et al*., 2011).

A wide age range has been proposed for the Central Province of Paraguay (130-125 Ma; Velazquez *et al*, 2011). However, two studies provide high precision $^{40}Ar/^{39}Ar$ ages of the alkaline potassic magmatism of this region giving a very well defined age interval between 126-127 Ma (Velazquez *et al*, 2011 and references therein). The authors suggest that the dyke swarm extruded in a very short time period of less than 1 Ma. Paleomagnetic data further show that the dykes were probably formed during normal and reversed polarity of the geomagnetic field (Velazquez *et al*., 2011).

Magnetic Experiments

In total, 22 dyke structures were sampled (Fig. 1). From each structure six to eleven samples were collected; all of them oriented *in situ* using both a magnetic and sun compass. The samples were cut into standard paleomagnetic cylindrical specimens of 2 cm diameter.

Rock magnetic experiments were carried out to characterize the type of carriers of the remanent magnetization, to estimate their grain sizes and to determine the stability of the paleomagnetic signal. From 12 out of 22 dykes a sample per dyke was selected for these experiments, which included the measurement of strong-field magnetisation versus temperature (M_S-T) curves, the determination of hysteresis parameters and the measurement of isothermal remanent magnetisation (IRM) acquisition curves. All these measurements were carried out on whole-rock powdered specimens with a Variable Field Translation Balance (VFTB) at the paleomagnetic laboratory of the University of Burgos (Spain). Thermomagnetic curves were measured in air heating the samples up to 600º C and cooling them down to room temperature. Three different types of behaviour could be distinguished: Type H samples (8 samples) display reversible curves with a single ferromagnetic phase with a high Curie temperature near 580° C that corresponds to magnetite. We considered a curve to be reversible if the difference between initial magnetisation before heating had started and final magnetisation after cooling had been completed was larger than ±15%. Type M samples (3 samples) show mainly magnetite and a relatively weak intermediate low Curie temperature (300º C and 400° C) phase in the heating curve. In the cooling curve only magnetite can be recognized. Type-I sample (1 sample) is characterized by a single phase in the heating curve (magnetite) and two phases (magnetite and another high Curie-temperature phase) in the cooling curve. Isothermal remanent magnetisation (IRM) acquisition curves recorded in a maximum applied field of approximately 1T point to low-coercivity phases as main carriers of remanence. Analysis of hysteresis parameters (saturation magnetization, saturation remanence, coercivity and coercivity of remanence) shows that the samples have PSD (pseudo-single-domain) structure. This behavior might also be explained by a mixture of single-domain (SD) and multi-domain (MD) particles (Dunlop, 2002).

Thermal (TH) and alternating field (AF) demagnetization treatments were used to isolate the Characteristic Remanent Magnetization (ChRM). In total 172 specimens were subjected to demagnetization, and a maximum of 14 AF steps or 15 TH steps were used to demagnetize them. TH demagnetization was performed using an ASC scientific model TD-48 Thermal Specimen Demagnetizer, AF demagnetization using an LDA-3 demagnetizer, and remanent magnetization was measured on an Agico JR5 spinner magnetometer. Measurements were analyzed using Remasoft 3.0 paleomagnetic data browser and analyzer (Chadima and

Hrouda, 2006), and declination and inclination were obtained using principle component analysis (PCA). In order to select the directional results with the highest quality we accepted only directions obtained with a minimum number of points of five in the PCA, and with a maximum angular deviation, MAD ≤ 12º. After averaging specimens of the same site, we rejected sites with a confidence interval of the average direction, $\alpha_{95} \geq 20.0°$ and with a minimum of four specimens used for the site average. As a result 12 out of 22 sites were accepted, with six sites having a $\alpha_{95} \leq 10.0°$ (Tab. 1, Fig. 2a-c).

Tabla 1. Directional results of the successful sites (α95 ≤ 20º). D is declination, I inclination, N the number of specimens used for the mean, k is the precision parameter, α95 the semi-angle of dispersion, P_Lat and P_Lon the latitude and longitude of the virtual geomagnetic paleopoles, respectively, and Polarity giving normal (n), intermediate (i) or reversed (r) polarity.

Site	D [º]	I [º]	N	k	α95 [º]	P_Lat [º]	P_Lon [º]	Polarity
PA4	36.6	-27	4	22.5	19.8	53.9	21.8	n
PA7	240.7	6.8	8	10.7	17.7	-27.8	-157.3	i
PA11	17.4	-50.6	6	42.6	10.4	73.7	57.5	n
PA12	289.6	-46.5	8	103.2	5.5	28	-166.3	i
PA14	187.6	19.5	8	163.3	4.3	-72.8	149.2	r
PA15	184.8	11.8	8	9.5	18.9	-69.8	137	r
PA16	171.5	57.3	7	117	5.6	-75.8	-28.4	r
PA17	194	50.9	6	49.5	9.6	-76.4	-117.7	r
PA18	278.2	-10	6	14.9	17.9	9.6	-148	i
PA19	179.4	25.5	6	44.2	10.2	-77.7	120.2	r
PA20	172.9	5.3	7	79.4	6.8	-66	105.4	r
PA22	217.4	5	8	46.2	8.2	-47.3	-173.6	r

In general, vector diagrams show very variable demagnetization behaviors, which can be summarized to three types: (1) linear diagrams with a ChRM and a viscous component (Figs. 3a, 3c); (2) two distinct components in nearly opposite directions (Fig. 3b); and (3) erratic behavior without clear direction (not shown). The viscous component is in general removed by a low field of 5 mT or a temperature of 100 ºC,

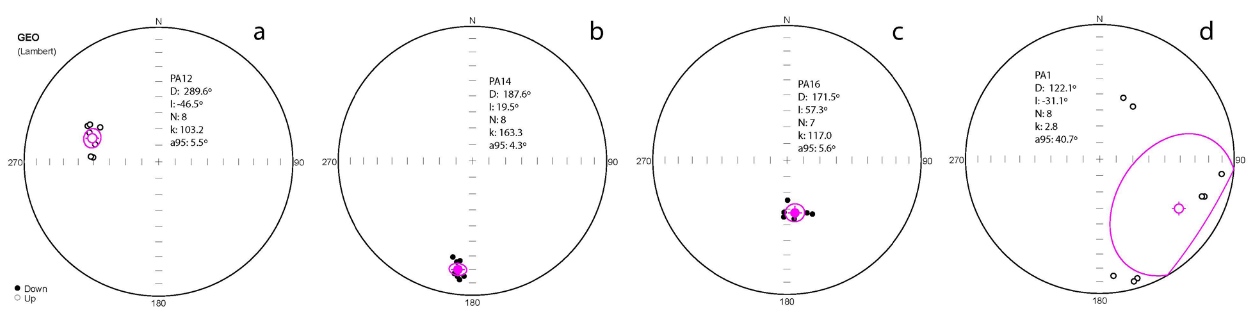

Figure 2. Stereoplots of the three most successful sites and one unsuccessful, and their corresponding statistical parameters.

but in a few cases it is up to 25% of the NRM (Fig. 3c). Specimens from group (1) are from dykes PA1, PA3, PA5, PA7, PA8, PA9, PA12, PA15, and PA22. However, not all of those sites show the most well grouped directions (Tab. 1, Fig. 2d). For specimens of the second group we chose in the PCA the high field/temperature component pointing to the origin (Fig. 3b). In the TH demagnetization diagrams we observe as well a large variety: some specimens are demagnetized at 580º C or at lower temperatures (Fig. 3a, inset), pointing to (titano) magnetite as main magnetic carrier; whereas others still have up to 60% of their NRM at this temperature, which can be indicative of a high-coercivity mineral such as hematite (Fig. 3b, inset). In the AF demagnetization diagrams the majority of the specimens was demagnetized at low field strengths, at about 10 mT, whereas some were demagnetized at larger field strengths, *e.g.* at 55 mT (Fig. 2c). After the analysis of the mean site directions and their Virtual Geomagnetic Poles (VGPs) two sites show a normal polarity, three an intermediate polarity with a paleolatitude < ±45º, a cut-off angle suggested by McElhinny and McFadden (1997), and seven sites a reversed one (Tab. 1).

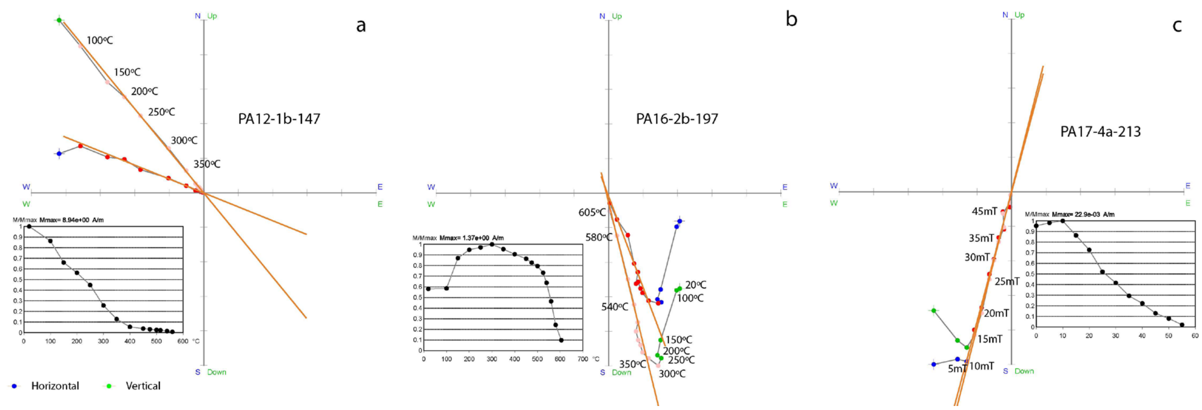

Figure 3. Vector diagrams from (a-b) TH demagnetizations and (c) AF demagnetization with their demagnetization diagrams in the insets.

Discussion and Outlook

Preliminary directional investigations of Eastern Paraguayan dykes show highly clustered promising results with six out of 22 sites having an $\alpha_{95} \leq 10.0°$. Most of the sites show a reversed polarity; however, one intermediate polarity site has very clustered directions (PA12: $\alpha_{95} = 5.5º$). This and the occurrence of normal polarity sites suggest that the dykes may have not appeared at the same time but rather during the transition from normal to reversed polarity right before the CNS at around 126-127 Ma. Further investigation is needed to confirm the reliability of specimens showing two components. Additionally, obtained paleomagnetic poles will be compared to reference poles from Besse and Courtillot (2002).

Specimens from nine sites are promising for paleointensity determination due to their linear vector diagrams showing one component, the occurrence of magnetite as magnetic carrier, and their magnetic stability.

Future work will be focused on a more concise investigation of the directions. This includes the measurement of specimens from a second field campaign located close to the first one. Furthermore, paleointensity determinations are planned, after choosing the most successful specimens.

Acknowledgments

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