Latinmag Letters, Volume 1, Special Issue (2011), C09, 1-7. Proceedings Tandil, Argentina.

MULTISAMPLE PALEOINTENSITY FROM EARLY CRETACEOUS (130 Ma) PONTA GROSSA DYKES, PARANÁ BASIN, BRAZIL

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Resumo

Foi realizado um estudo multi-amostras de paleointensidade em amostras de rochas de 130.5 Ma dos diques de Ponta Grossa. Antes das determinações de paleointensidade, uma rigorosa seleção de amostras foi tomada levando em conta a estabilidade paleomagnética das amostras e seus comportamentos magnéticos. Embora essas rochas tenham falhado em experimentos clássicos de duplos aquecimentos graduais, elas forneceram resultados coerentes no método multi-amostras para todos os sítios com exceção de um. Os resultados coerentes mostraram valores de baixa a moderada intensidade de campo, variando entre 5.7 ± 0.2 e 26.4 ± 0.7 μT (momento de dipolo virtual de 1.3 ± 0.04 a 6.0 ± 0.2 × 10^{22} Am^2). Estes resultados estão de acordo com a tendência de um momento de dipolo dominantemente baixo durante o Cretáceo Inferior, imediatamente antes do Superchron Normal do Cretáceo.

Abstract

A multisample paleointensity study on rock samples from the 130.5 Ma from Ponta Grossa Dykes was performed. Before paleointensity determinations a rigorous selection of samples was done taking into account the paleomagnetic stability of the samples and their magnetic behaviour. Although these rocks have failed the classical stepwise double-heating experiments, they yielded coherent results in the multisample method for all sites but one. The coherent sites show low to moderate field intensities between 5.7 ± 0.2 to 26.4 ± 0.7 μT (virtual dipole moments ranging from 1.3 ± 0.04 to 6.0 ± 0.2 × 10^{22} Am^2). These results are in accordance with the tendency for a dominantly low dipole moment during the Early Cretaceous, immediately prior to the Cretaceous Normal Superchron (CNS).

Introduction

Classical double-heating techniques – the Thellier-Thellier method (Thellier and Thellier, 1959) and its variants (e.g. Coe, 1967) – involve stepwise heatings with alternate in field and zero-field measurements, as well as intermediate checking-steps. This method is intrinsically dependent on the magnetic stability of minerals during heating and of their domain structure. Perfect recorders must not show chemical alteration during the long series of in-field heatings and must contain essentially single-domain grains. In consequence, this technique can be applied only to a limited number of targets. One way to circumvent these problems is to use specific material more suitable for these measurements, such as basaltic glass and single silicate crystals. An alternative approach is the use of multisample methods, which require significantly fewer steps of heating and can thus be applied to a broader class of targets. In the present study, we have applied a multisample paleointensity protocol to a set of basaltic samples from the Ponta

Grossa dykes (Late Cretaceous, Parana basin, Brazil), which have failed classical paleointensity measurements.

Geological Setting

The Paraná-Etendeka Magmatic Province (PEMP) comprises about 1.5×10^6 km^3 of volcanic and subvolcanic rocks, comprising mostly tholeiitic basalts and andesites with subordinate rhyolites and rhyodacites, which cover an area of around 1.2×10^6 km^2 (see Figure 1). This magmatic province was formed between 133 and 130 Ma. The Ponta Grossa dykes are slightly younger, with ages of 129 to 131 M (peak of 130.5Ma, Renne et al., 1996), comprising an extensive fissural magmatism that crop out around the present-day area where basaltic traps crop out. The samples used in this study come from left-over hand-samples of Raposo and Ernesto's (1995) work. We have chosen sites with normal and reverse components, and avoided sites with intermediate directions.

Magnetic Mineralogy and thermal stability

Magnetic mineralogy and thermal stability were checked using thermomagnetic curves and by monitoring the magnetic susceptibility of samples before and after heating in a paleomagnetic oven. Measurements of the magnetic susceptibility were performed in a KLY4-CS3 Kappabridge susceptometer (AGICO Ltd.). Only 24 (19 sites) of 68 samples presented less than 10% of variation on susceptibility after a heating cycle in air of 600°C. These 19 sites were selected for analysis of thermomagnetic curves.

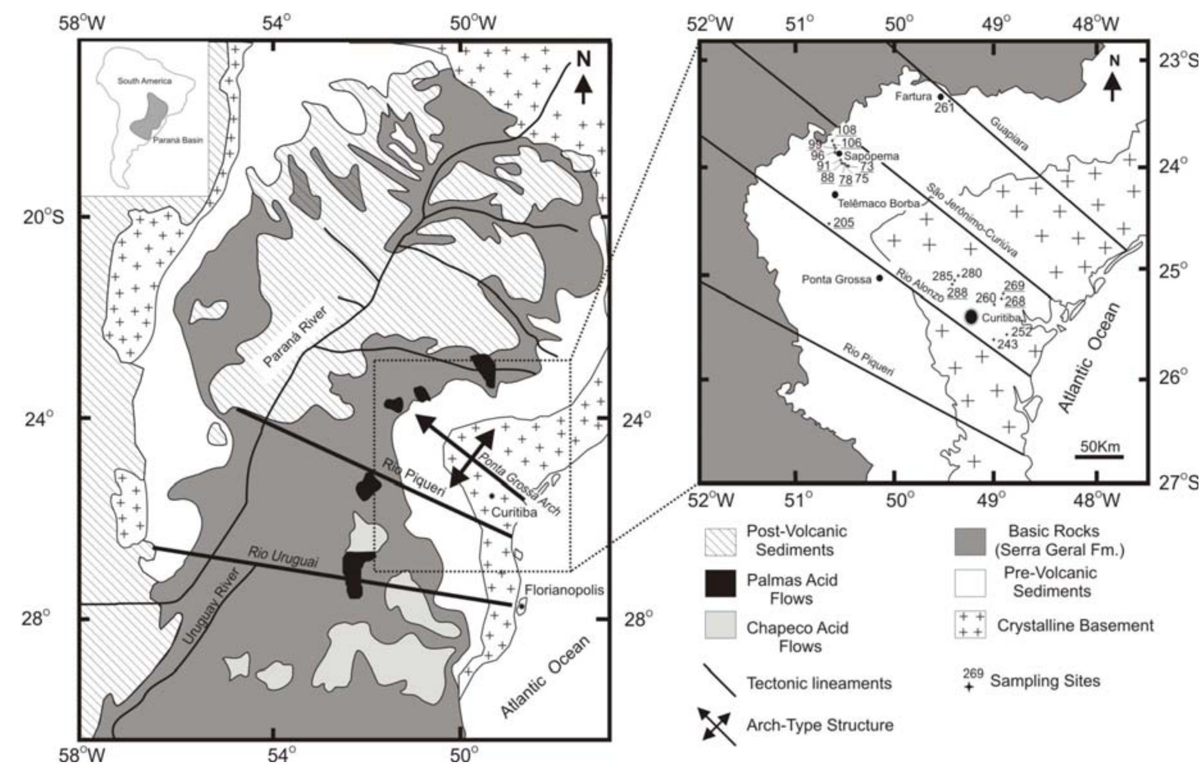

Figure 1. Schematic geological map of the Paraná basin (left) and the Ponta Grossa Arch (right) indicating the paleomagnetic sites used in this study (modified from Raposo and Ernesto, 1995). Sites with reliable paleointensity estimates are underlined.

A strong decay in susceptibility was observed between 500°C and 580°C indicating the presence of magnetite with low titanium content as the main magnetic carrier in the rocks. For most of samples, however, the thermomagnetic curves are non-reversible (Fig. 2), which attests to the low thermochemical stability of the Ponta Grossa samples.

Multisample Methodology, Results and Analysis

Methods of multisample paleointensity were developed in an attempt to reduce measurement time and simultaneously reduce the thermochemical alteration due to their very limited number of heatings per sample (Hoffman et al., 1989; Hoffman and Biggin, 2005; Dekkers and Böhnel, 2006). Multisample methods are based on the linearity of magnetization to the magnetic field (valid for low magnetic fields, in the range of the Earth's field). In practice, the multisample methods rely on the natural variations in magnetic properties at the scale of a paleomagnetic site to derive the linear relation between natural and artificial remanences.
We used a multisample protocol in which different inducing fields were applied to different specimens of the same site, with only one in-field heating. This approach yields reliable paleointensity estimates regardless of the domain state of the magnetic carriers (Dekkers and Böhnel, 2006). We investigated only the 19 sites selected after thermomagnetic measurements.
We initially performed classical paleomagnetic demagnetization to derive the unblocking temperatures for the secondary component (Tsec) and the characteristic remanence (Tch). The characteristic component (ChRM) was isolated after elimination of a secondary component (SecRM) at temperatures varying from 150ºC up to 550ºC (see more details in Brandt et al., 2009). Two samples with erratic behavior and other five samples with very high-temperature secondary components were discarded. Multisample paleointensity measurements were then performed on the remaining 12 sites.

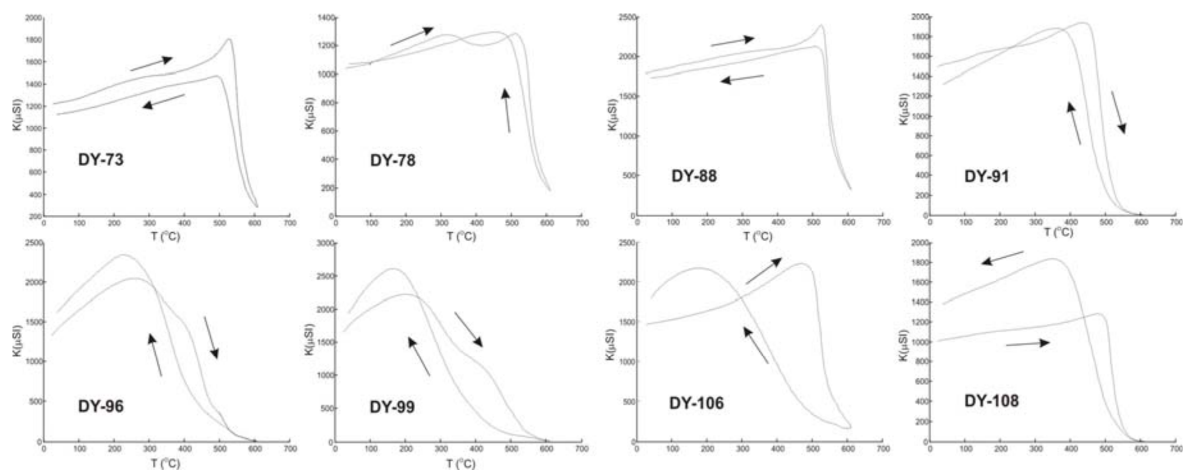

Figure 2. Thermomagnetic curves for samples from all sites analyzed by the multisample paleointensity protocol.

Multisample paleointensity estimates were performed for seven samples from each site using three heating steps: (1) a zero-field heating up to Tsec, (2) an in-field heating up to Tch, and (3) a zero-field heating up to Tsec. The remanence obtained after heating step (1) is the ChRM, and the remanence obtained after heating step (3) is the laboratory-induced pTRM. Each sample was magnetized with a different laboratory inducing field (Hlab values: 10, 20, 30, 40, 50, 60, and 70 μT). Paleointensity values were calculated using an Arai-like plot (Fig. 4). In this diagram, we plot the product of the ChRM and Hlab for each sample against the corresponding pTRM. Since ChRM.Hlab = pTRM.Ha, the ancient field (Ha) can be easily obtained from the slope of the line. To obtain this slope, we used the same least-square fitting routines used in classical double-heating protocols (e.g., York, 1966). Uncertainties correspond to the error on the best fit line. Note that each point in the Arai-like plot corresponds to an individual estimate of paleointensity; their alignment in a given site attests to within-site coherence of paleointensity estimates.

The paleointensity results are shown in Fig. 3 and Table 1. For all sites, the seven analyzed samples present a very good alignment in the Arai-like plots, indicating a strong coherence of paleointensity estimates within each site. For 11 sites, the paleointensity estimates vary between 5.7 ± 0.2 μT and 26.4 ± 0.7 μT. Site DY-96 presented an anomalously (and implausibly) high value of 415 ± 16μT. Virtual dipole moments were calculated using the inclination of the characteristic component for each site obtained from the original paleomagnetic study of Raposo and Ernesto (1995). These correspond to VDM values of 1.3 ± 0.04 to 6.0 ± 0.2 × 10^{22} Am^2 (average of 2.9 ± 0.5 × 10^{22} Am^2) (Table 1).

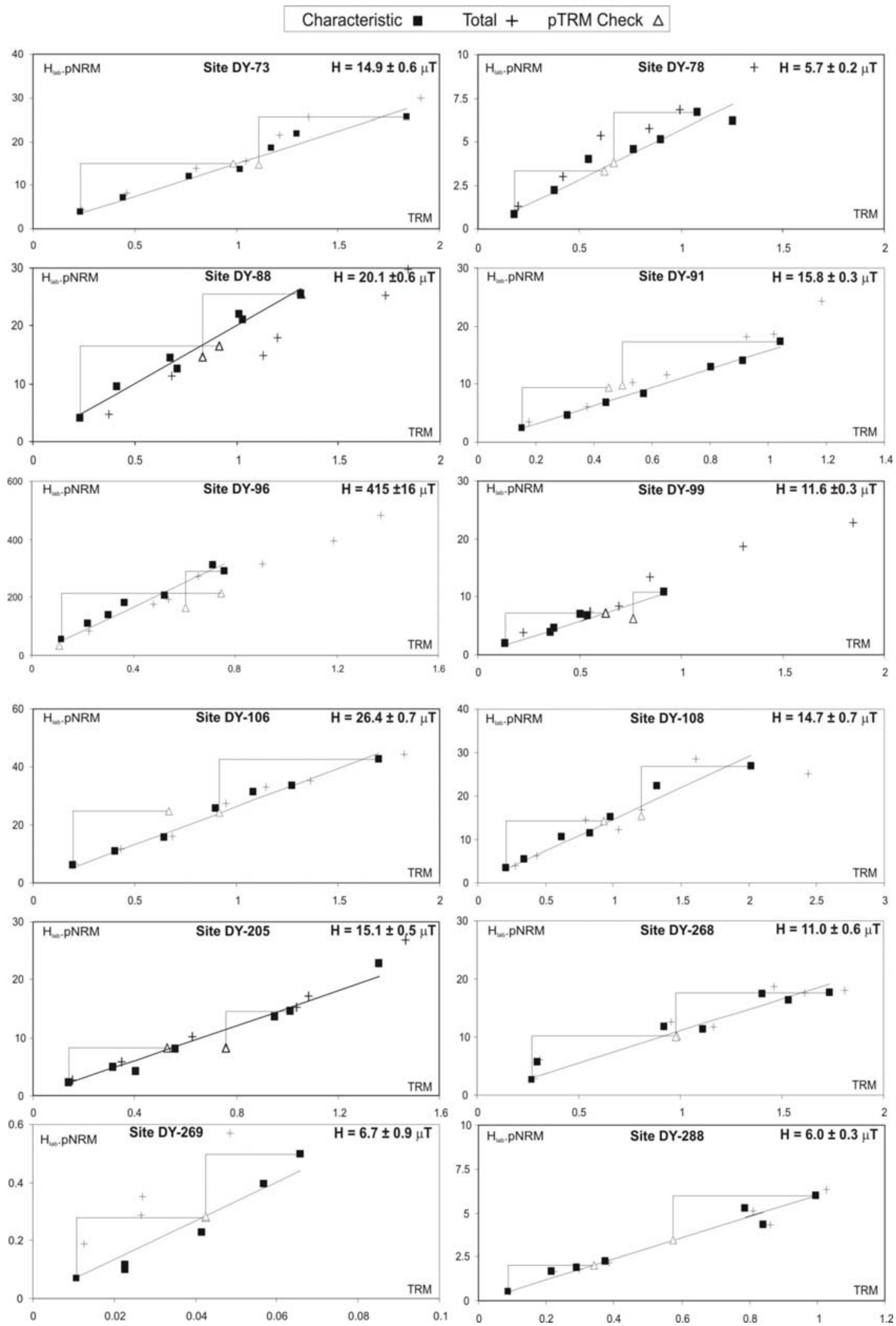

Figure 3. NRM.H_{lab}-TRM plots (Arai-like) for 12 sites. The product of H_{lab} and pNRM is given against the corresponding pTRM for seven samples. For each site, we show the results obtained for the ChRM (full squares) and the total vector (crosses). The line corresponds to the fitting of the ChRM data. Empty triangles show pTRM checks.

The thermochemical alteration during paleointensity measurements was monitored by magnetic susceptibility measurements and a pTRM check. Magnetic susceptibility was measured before heating step (1) and after heating step (3). The pTRM check envisaged here consists of a new in-field heating cycle in a different Hlab (or Hcheck) performed after the paleointensity measurement. The aim of this test is to verify that the capacity of the sample in recording a thermoremanence does not change through the two heating steps.
Site DY-96, which gives anomalously high paleointensity values, presented the highest variations in susceptibility and pTRM check. The other sites that give coherent paleointensity estimates show less variation in susceptibility and at the pTRM check.

Table 1. Multisample paleointensity results.

Site	Lat (º)	Lon (º)	Dec (º)	Inc (º)	α_{95} (º)	H(μT)	σ_H	VDM (10^{22}Am^2)	σ_{VDM}
DY-73	-24.03	-50.47	349.4	-37.8	2.6	14.9	0.6	3.3	0.12
DY-78	-24.00	-50.49	344.6	-36.3	4.8	5.7	0.2	1.3	0.04
DY-88	-23.95	-50.54	353.8	-42.7	1.8	20.1	0.6	4.2	0.13
DY-91	-23.94	-50.56	5.9	-31.4	2.3	15.8	0.3	3.7	0.07
DY-99	-23.86	-50.62	350.5	-29.1	2.8	11.6	0.3	2.7	0.08
DY-106	-23.83	-50.62	352.2	-33.4	4.6	26.4	0.7	6.0	0.17
DY-108	-23.80	-50.70	339.2	-28.0	8.1	14.7	0.7	3.5	0.17
DY-205	-24.56	-50.50	161.9	45.4	1.8	15.1	0.5	3.1	0.10
DY-268	-25.19	-48.81	354.4	-58.0	3.9	11.0	0.6	1.9	0.10
DY-269	-25.22	-48.87	171.2	45.0	4.5	6.7	0.9	1.4	0.18
DY-288	-25.09	-49.46	180.4	37.3	1.9	6.0	0.3	1.3	0.06
Mean						**13.4**	**1.9**	**2.9**	**0.4**
DY-96	*-23.88*	*-50.62*	*10.2*	*-26.5*	*5*	*415*	*16*	*99*	*4*

Lat: latitude, Lon: longitude, Dec: declination of characteristic component, Inc: inclination of characteristic component, α_{95}: confidence angle from Fisherian statistics, H and σ_H: paleofield and error, VDM and σ_{VDM}: virtual dipole moment and error. Site DY-96 was not included in the mean.

Conclusions

The multisample protocol has proven to be useful for determining paleointensities for the Ponta Grossa dikes that were not suitable for double-heating techniques (see more details in Brandt et al., 2009). The within-site consistency of thermoremanence acquisition was asserted by the analysis of mean-square fit parameters. A pTRM check was devised to account for mineralogical alteration during heating. Most of the sites have provided coherent paleointensity estimates, indicating low to moderate paleofields with a mean at 13.4 ± 1.9 μT (VDM 2.9 ± 0.5 × 10^{22} Am^2). Samples with normal and reverse polarities gave similar paleofield estimates (Table 1).

For ages closer to the lower CNS boundary, higher values were observed in two studies with mean VDMs of approximately 7 × 10^{22} Am^2 similar to the present-day field (Goguitchaichvili et al., 2002; Ruiz et al., 2006). However, other studies give systematically low dipole moments. Results from volcanics from northeast China (Zhu et al., 2003, 2004a, b) and also the data from the Serra Geral volcanics of Kosterov et al. (1998) are always below the present-day field with an average value of 3.6 × 10^{22} Am^2. Our results (average of 2.9 × 10^{22}Am^2) agree with such a tendency for low dipole moments in the Early Cretaceous, just before the CNS.

Acknowledgments

Financial support for this work comes from Brazilian agencies CNPq and FAPESP (grant 05/57782-4). We thank M. Ernesto by suggesting the use of the Ponta Grossa dikes collection in this paleointensity study.

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