Statistical Determination of Magnetic Susceptibility Domains Applied to a Preliminary AMS Study in Cretaceous Igneous Rocks of Valle Chico Complex, Uruguay

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Abstract

A preliminary AMS (Anisotropy of Magnetic Susceptibility) study on Valle Chico Complex was done to evaluate the magnetic response of its igneous structures. Due to the unavailability of appropriate outcrops for the AMS techniques, a particular treatment of the data was required. Using the magnetic susceptibility domain concept (MSD), we constructed subsets with statistically significant differences which provided us the mean tensors for each unit sampled.

Introduction

During the Jurassic and Early Cretaceous an extensional stress field was established in the vicinity of the current passive margins between Africa and South America (Franke et al., 2007 and cites therein). The resulting lithospheric weakening is usually interpreted as a product of thermal anomalies related to the presence of a mantle plume (Renne et al., 1992). The attenuated Gondwanian continental lithosphere and its final fragmentation led to a variety of basins that, before and during their development, were associated with an intense magmatism and contemporary sedimentation. Uruguayan geology is witness of such associations. Interference between prevailing cortical stress and mechanically incompetent planes directions led to a consistent behavior that was well recorded in the marginal basins developed in southeast Uruguay (e.g. Bossi, 1966; Sprechmann et al., 1981; Santa Ana et al., 1994; Veroslavsky, 1999; Ucha et al., 2004). The main pull-apart type depocentres with NE trend (Santa Lucia Basin and Laguna Merín-Pelotas Basin) are separated by a transitional zone where small grabens and hemigrabens are located (Rossello et al., 2000; Rossello et al., 2007). The studied area is surrounded by those small remnant basins and delineates the southwestern margin of the Laguna Merín-Pelotas Basin.

The AMS study was performed on quarz-syenites, trachytes and rhyolitic/trachytic dikes, which represent the igneous complex, and on basaltic lavas that partially surround the massif. All these lithostratigraphic units are part of the peripheral magmatism associated with the Paraná - Etendeka Province and have distinctive geochemical characters, product of the compositional variability across the continental lithosphere (Almeida, 1983; Kirstein et al., 2000; Muzio et al., 2002; Lustrino et al., 2005). The objetive of this study was to determine the feasibility to obtain the representative flow vectors in dykes according with the stress field acted, the hipoabisal injection mechanism

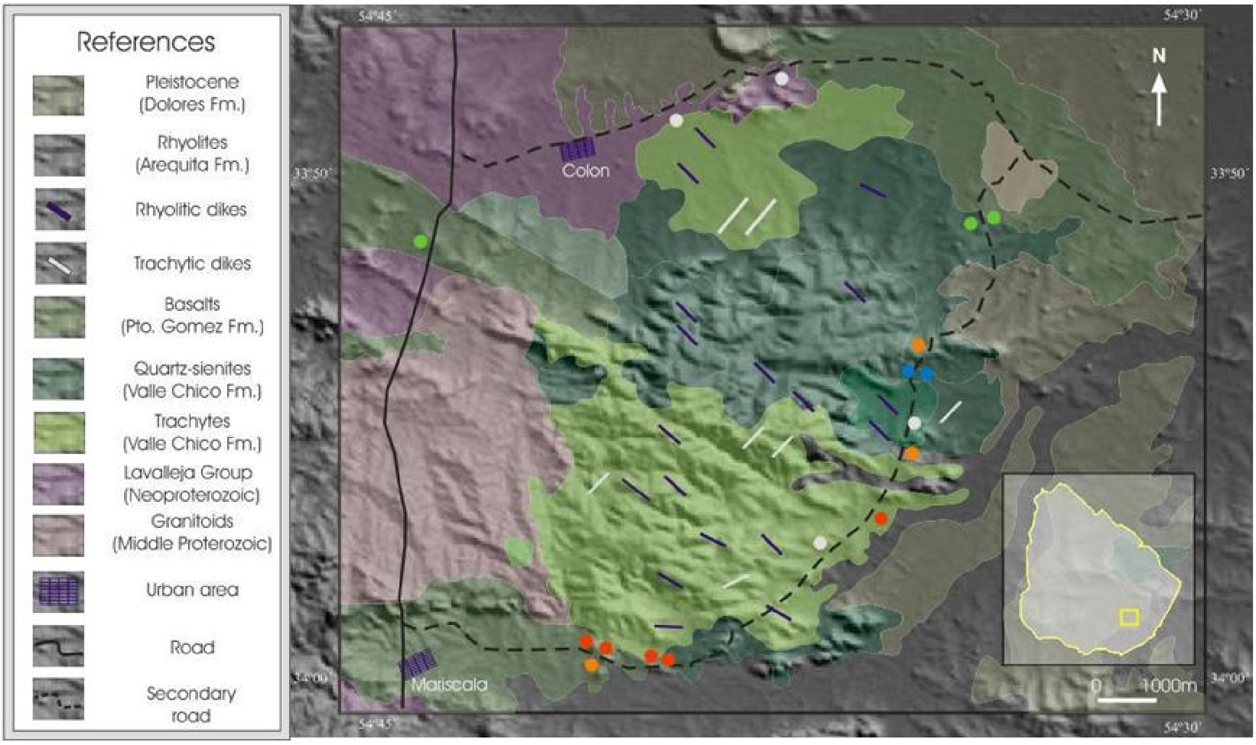

Figure 1: Geologic map of the studied area. Sites sampled marked with points –orange=syenites; blue=Trachytes; green=basalt-andesites; red=rhyolitic dike; gray=trachytic dike- (modified from Muzio, 2000; Shuttle RADAR Topography Mission, SRTM).

and the source area of the lava flows using a datailed AMS study. Samples were taken from 17 sites, mostly along a roughly NE transect, according with a local road. The low field AMS of 280 specimens was analized. Due the nature of the palaeomagnetic sampling carried out and the unavailability of appropiated out crops for the AMS techniques, an adequancy in the data processing was required.

Statistical determination of magnetic susceptibility domains prior to tensorial analysis

We present a new methodology to determine the mean AMS tensors by considering the relationship between their defining properties. The AMS can be described by a second order tensor **K** (based on Nye, 1960) and summarized with the K eigenvectors and eigenvalues, were $K_{max}>K_{int}>K_{min}$. The eigenvalues relations determine parameters which describe diferent propertys like shape, lineation, foliation, magnitude of anisotropy and bulk magnetic susceptibility (Tarling and Hrouda, 1993). Under this perspective, one lava, dike, sill or igneous body can be considered a mosaic of magnetic susceptibility domains (MSD). We define a MSD as a structure zone where the parameter values are distributed with a specific homogeneity degree. If the AMS respond to a textural flow, then the MSD will also indicate similar kinematic conditions and would have an intrinsic correspondence between eigenvalues and eigenvectors. The magnetic fabric could by described by a variable X, constructed by a lineal combination of parameters and having a continuous density of probability function. For a mosaic, the X distribution would be multimodal. Each mode would reflect the central value of the unimodal population corresponding to a MSD, among wich there would be some degree of overlap. It is a common practice to use mean parameter values to characterize the site's AMS. If the site is represented by a single MSD, all the specimens will get statistically similar parameter values. Conversely, if a site has a MSD mosaic, the specimens could be separated in subsets with similar parameters. Hypothesis tests, like t test for independent variables or the T test adaptation for a multivariance way, can be used to establish the parameter similarity.

Each specimen subset is characterized by its mean parameters. The means would be similar in the case of a single MSD. This statement is the null hypothesis used in probabilistic tests between subsets. It would be convenient that subgroups with statistically significant differences in at least one of its mean parameters, be considered as a MSD and therefore be treated independently. This analysis should be the starting point to employ the algorithms of Jelinek (1978), used in this study, or any other method of tensorial analysis. An alternative for this analysis are the K-means clustering method. However, the statistical approach is shelved in this methodology and more objetives aspects, related to the initial contour, are critically involved.

AMS Results

Two principal magnetic susceptibility properties are commonly characterized by Km ($Km=(K_{max}+K_{int}+K_{min})/3$; Nagata, 1961) and P_j ($P_j=\exp((2((\eta1-\eta m)^2+(\eta2-\eta m)^2+(\eta3-\eta m)^2))-1/2)$; $\eta_i=\ln K_i$; i=1, 2, 3; $\eta_m=(K_{max}+K_{int}+K_{min})/3$; Jelinek, 1981). In Figure 2, the 95% confidence intervals for this means parameters of each site are represented. The variability observed are corresponds with the variety of structures and lithology sampled and define the data set. In general, the low Pj highlights. In no case exceeds 1.04. The trachytes of the Volcanic Asociation (Muzio and Artur, 1998) have the lowest Km.

Such rocks, where the paramagnetic subfabric should be taken into account, are the exception in the main control of ferromagnetic sensu lato mineral fraction over the magnetic response in the whole data set. Most of the rhyolitic dikes have lower Km and P_j than those of trachytic composition, an observation that is expected.

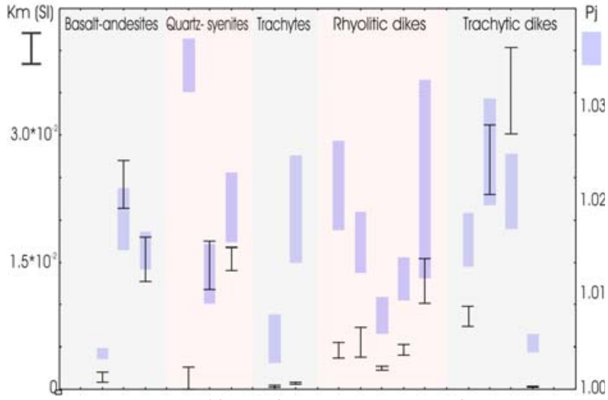

Figure 2: The 95% confidence intervals for Km and Pj of each site are shown. They are grouped according to the structure and lithologies sampled.

Figure 3 shows the mean tensors of each sampled structure. The basalt-andesitic lavas present MSDs with NNW magnetic foliation dipping less than 10º. On the northeastern margin of the igneous complex, the K_{max} are subhorizontal and have N100 ° strike, while to the west is N-S oriented. According to the classical interpretations (e.g. Khan, 1962; Rochette et al., 1991; Staudigel et al., 1992), the K_{max} suggest the flow direction. The quartz-syenites have a variable magnetic fabric, with a mean P_j of 1.02. Locally, a poor defined magnetic foliation is presented. In other site, prolate ellipsoids mayor axes dip 10º to the SSE. On the southern margin, slightly deformed syenites present N300º/11º magnetic foliation, with subvertical K_{max}. Such foliation is consistent with predominant fracture orientations in the region and more specifically with the southern structural margin of the complex observed in satellite images. Rhyolitic dikes were sampled in three different preferential directions. Magnetic foliations obtained by the defined MSDs are concordant with the structural trend and provide inclinations not found in field: NW: NE and N100º, dipping 65º, 90º and 85º, respectively. Trachytic dikes show an important indetermination in the magnetic response. However, in one case a 62º/N90º magnetic lineation was defined.

Conclusions

The determinations of MSDs take into account the internal differences of the studied rocks. Therefore, the uncertainty increase on the magnetic orientation of the fabric by the mixing of specimens representing different domains is avoided. The AMS tensors obtained from the defined MSDs are consistent with the structures observed in the field. A detailed AMS study will contribute to the knowledge of the tectonic, magmatic and kinematic events in the region.

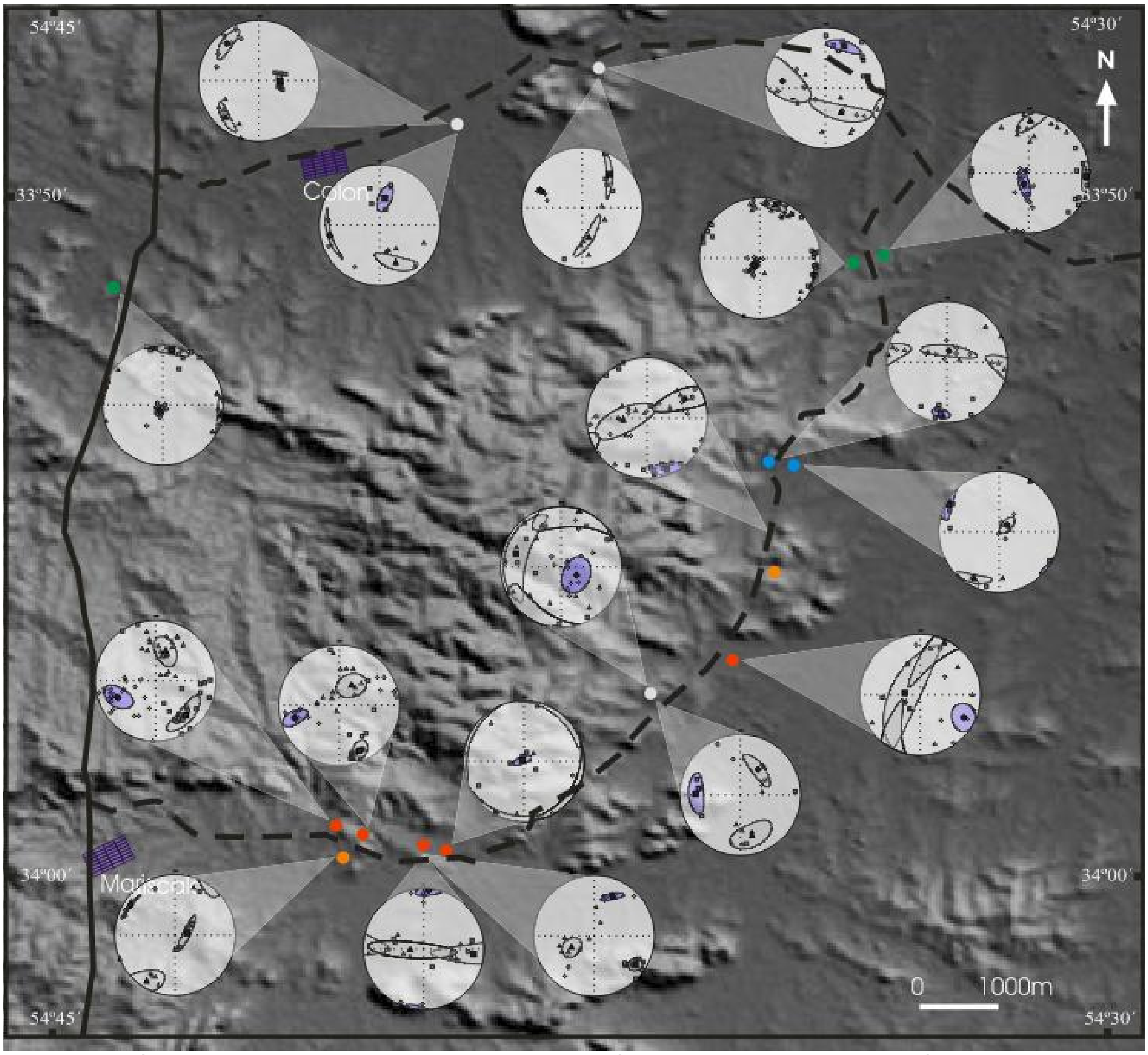

Figure 3: AMS lower hemisphere stereograms plotted over a SRTM image. Blue shaded confidence ellipses indicate the mean tensor shape. Same site = point colour code as Figure 1.

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