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Chaotic flow and fragmentation patterns in acidic conduits from the Paraná–Etendeka Magmatic Province (PEMP)

Cristina P. De Campos[1, 2], Letícia F. Guimarães[1], Evandro F. de Lima[2], Valdecir de A. Janasi[1], Daniele Giordano[3]

[1]IGc, USP, São Paulo, SP, Brazil; [2]Dept. of Earth and Environmental Sc., LMU, Munich, Germany; 3 Geociências, UFRGS, Porto Alegre, RGS, Brazil; [4]University of Torino, Italy; decampos@lmu.de; leticia.guimaraes@usp.br

1) INTRODUCTION:

Large volumes of silicic volcanic products erupted during a relatively short time span in the Paraná-Etendeka province. Comparable volumes in the Snake River province are known to have erupted during a shorter time span (figs. 1 and 2).

The conduits for the eruption of these large volumes of acidic volcanic products have been recently recognized by Lima et al., 2012, in the region of São Marcos, Rio Grande do Sul, in Brazil. They are now being studied in more detail.

Silicic Volcanism

Paraná-Etendeka vs. Snake River

A volume around 20,000m km^3 (DRE) erupted from 135.6 until 134.4 Ma.

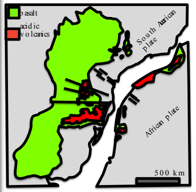


Fig. 1: Sketch map from the Paraná-Etendeka magmatic province PEMP (mod. after Peate 1997).

A volume between 10,000 and 30,000 km^3 (DRE) erupted from 14 until 6 Ma.

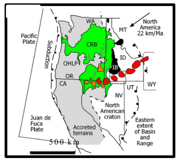


Fig. 2: Sketch map from the Snake River magmatic province (after Ellis et al. 2013).

2) BACKGROUND AND METHODOLOGY

In fluid dynamics the repeated process of stretching and folding is known to generate fractal morphologies, which are controlled by the mixing of the fluids (in our case, magmas) involved in the process (e.g. Flinders and Clemens 1996; Perugini et al. 2006). Fig. 3 is a schematic example of the time evolution of a chaotic pattern.

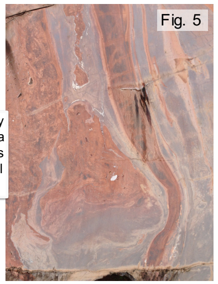
Due to the complex dynamics, length variation between flow interfaces is a function of mixing times (e.g. Perugini et al. 2014). Previous experimental and numerical studies pointed towards increase of fractal dimensions with mixing time (e.g. Morgavi et al. 2013).

We quantified the morphology of stretching and folding patterns (mixing) patterns at different scales by measuring their fractal dimension (FD). Then we used measured FD to separate different flow and fragmentation patterns, as showed in Perugini et al. 2011 and De Campos 2015, and references therein.

Polished slab with extreme deformation, re-melting and refolding of flow filaments (Fig. 4), probably due to successive replenishing events. Colors have been enhanced.

How to measure FD

The simplest and most widely used technique to measure FD on images is the "box-counting" method. The interface between two different melts or flows was measured from black and white images, using the ImageJ software (Abramoff et al . 2004). See poster T33F-2994 for results in pyroclastic products and deposits.



Disrupted partially re-melted breccia and flow bands (Fig. 5), Natural colors.

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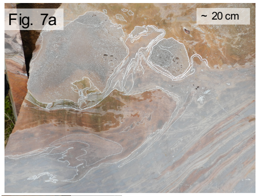
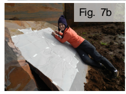
THIS WORK:

Detailed studies of volcanic conduits in the region of São Marcos, RGS, Brazil, reveal a very complex internal structure. For the description and characterization of internal domains we measured their fractal dimensions. For further information on the conduits see also poster T33F-2994.

3) MOTIVATION





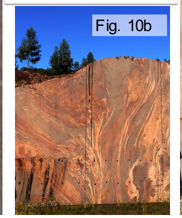
Stretched / folded flows and pumice fragmentation (Figs. 7a and b).

An example of flow interface is highlighted in Fig. 6. Natural colors.

Pumice fragmentation along flow bands (Fig.8). Natural colors.

Chaotic flow patterns :

1) a large bubble inside the conduit moves up (buoyancy - Fig. 9);
2) successive stretching and folding episodes during extrusion of large volumes of lava flows (dome formation?) Figs.10a and b, natural and enhanced colors).



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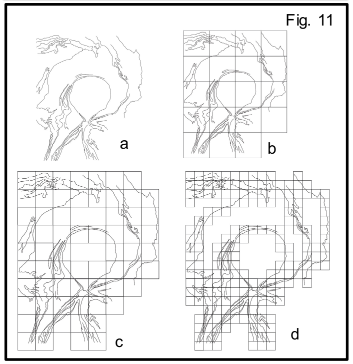
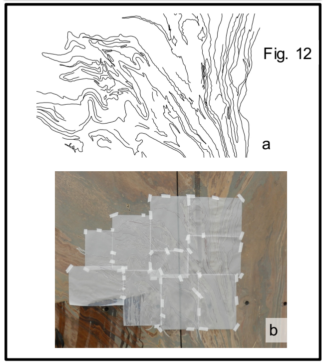
4) RESULTS: FROM COMPLEX FLOW PATTERNS TO FRACTAL DIMENSIONS

For the box-counting technique, a square mesh of size r is laid over the image and the number of boxes Nr containing black pixels and belonging to the interface between the two melts is counted (e.g. Mandelbrot 1982).

To produce the black and white images used for the calculations, all patterns have been first copied by hand at outcrop scales. Fig.11 is a blow-up of the wall on Fig.9. Fig.12 is a blow-up of Fig.10.





For fractal patterns, the following relationship is satisfied:

$$N_r = r^{-D_{box}} \quad \text{Eq. (1)}$$

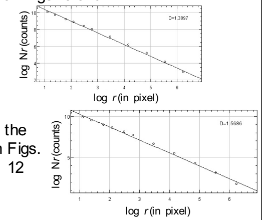
Using logarithms, Eq. (1) can also be written as:

$$\log(N_r) = D_{box} \, .(r) \quad \text{Eq. (2)}$$

A structure is considered as fractal if the obtained data lie on a straight line in a log–log plot. The fractal dimension (D_{box}) is estimated from the slope resulting from the linear interpolation of the log(r) versus log(N_r) graph. In our case, the routine of the used software counts the number of boxes of given size needed to cover a one-pixel-wide, binary (black on white) border. The procedure is then repeated for boxes that are 2 to 1,024 pixels wide. Pixels have been recalculated as millimeters and rescaled for the different images (see poster T33F-2994). Graphs in Fig. 13 depict log–log plots for images 9 and 10.

FD for the flow around the big bubble on Figs. 9 and 11.

FD for the flow on Figs. 10 and 12



Obs.: pixels corresponding to the measured A_4 images should be rescaled to the outcrop size. For A_4 1 pixel = 0.26458333 mm

5) CONCLUSIONS:

- Detailed studies of volcanic conduits from the region of São Marcos reveal a very complex internal structure.
- Determination of fractal dimension greatly helped the recognition and description of repetitive domains. This is a powerful tool for quantification and accurate comparative studies.
- A peculiar new competing process between sub-parallel flow and fragmentation zones along linear fissures is under study.
- The repetition of flow and fragmentation patterns at different scales reveal a chaotic and very efficient feeding process for generating large volumes of acidic products during a relatively short time span.