# Structural analysis of clastic dikes based on Structure from Motion/Multi-View Stereo

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*Abstract*—**This work presents the development of a three-dimensional model of an outcrop of the Corumbataí Formation using Structure from Motion and Multi-View Stereo (SfM-MVS) techniques in order to provide a structural analysis of clastic dikes cutting through siltstone layers. Composed mainly of fine sand and silt, these dikes are formed by sand intrusions when a wet sandy layer is affected by earthquakes of at least 6.5 magnitude, being used as a record of such events.**

**While traditional photogrammetry requires the user to input a series of parameters related to the camera orientation and its characteristics (such as focal distance), in SfM-MVS the scene geometry, camera position and orientations are automatically determined by a bundle adjustment, an iterative procedure based on a set of overlapping images. It is considered a low-cost technique in both hardware and software, also being able to provide point density and accuracy on par to the ones obtained with terrestrial laser scanner.**

**The results acquired on this research have a good agreement with previous works, yielding a NNW main orientation for the dikes measured in the field and on the 3D model. The development of this work showed that SfM-MVS use and practice on geosciences still needs more studies on the optimization of the involved parameters (such as camera orientation, image overlap and angle of illumination), which, when accomplished, will result in less processing time and more accurate models.**

## I. Introduction

In geology, the understanding of structures can be too complex to be reached only through field methods. Remote sensing techniques are able to provide a greater amount of information, but must be appropriate to the work scale and should also offer flexibility and ease of operation. Among such techniques SfM-MVS (Structure from Motion – Multi-View Stereo) workflow has gained strength in the Geosciences over the past years, mostly because when compared to other digital surveying it is capable of producing high resolution data at low cost, fast and virtually independent of spatial scale. Within a set of images, the workflow starts with the detection of image keypoints followed by the correspondences identification between these points on different images. The next step is the SfM itself, a bundle adjustment that simultaneously estimates 3D scene geometry, camera positions and internal camera parameters resulting on a coarse point cloud. The point cloud is then scaled, georeferenced, optimized using known GCPs and densified using MVS algorithm [1].

An example of a complex structure that can take advantage of the use of SfM-MVS are clastic dikes, which are synsedimentary and metadepositional structures were the sediment injection is activated by seismic induced liquefaction, tectonic stress or excess of pore fluid pressure. Consequently, understanding the processes involved in this dynamic emplacement is of interest beyond the context of clastic transport, as clastic dikes can act as paleostress indicators, so their geological attitude is used to relate them to other tectonic events [2,3] . The study area is a NE-SW (facing NW) roadside rock outcrop near Limeira city (SP) from Corumbataí Formation (Paraná Basin), composed of a siltstone intruded by NNW-SSE to NE-SW fine siltstone subvertical clastic dikes [4].

## II. Methods

The on-site study was conducted under five different days. 60 dykes were identified, described and had their geological attitude and thickness measured.

For georeferencing, 2 fixed points were placed far apart from each other and their coordinates were obtained using a Spectra Precision SP60 GNSS receiver. The fixed points and 13 control points (printed markers) that were distributed on the outcrop were surveyed using a Topcon GPT-3200N reflectorless total station, which can provide a ±(3 mm+2 ppm x D) m.s.e. accuracy (Fig. 1).

Image acquisition was performed using two cameras. A Nikon D7000 digital camera with a 23.6 mm x 15.6 mm CMOS sensor (4 928 x 3 264 pixels) and a 35 mm focal length lens was placed on the central verge of the road, generating 4 m wide windows.



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Perpendicular and left/right oblique images were taken from 1.5 m regularly spaced spots. A Nikon Coolpix AW130 using 7.8 mm and 6.1 mm focal length was used for complementary oblique images at the same spots. The digital models were generated with Agisoft Photoscan professional edition (version 1.1.6) [5]. Image selection was primarily based on illumination criteria, as the outcrop is prone to shadowing. The images were manually masked to remove vegetation and reduce processing time. No pre-calibration or post-editing were performed.

From the 60 dikes described and measured in the field, 46 were manually identified on the digital model. The calculation of geological attitudes was made using ply2atti [6] on the same spot where traditional compass reading was performed and total angular deviation between digital and traditional measures was calculated. Considering common errors observed during sampling, three categories were created: ply2atti returned multiple measures for a single plane (A); shadowing (B); and problems during digital sampling (C).


Figure 1. Positioning of the total station (ET), fixed points (FX01 and FX02) and targets distributed on the outcrop surface (blue points).

## III. Results

The digital outcrop was constructed from 106 images and comprises 30 660 551 vertices and 6 132 109 faces (Fig. 2). The image overlap is greater than 9 for almost all the model, georeferencing total error is 0.008 m and the GSD is 0.0026 m.

Traditional compass, ply2atti and Turra [4] geological attitudes were plotted on rose diagrams (Fig. 3).

Analyzing the total angular deviation between traditional compass and ply2atti measures, 74% of the results are greater than 5º. However, if we consider the angular difference between dips, 60% of the results are less than 5º (against 42% in dip directions).

Considering the categories of errors, type B is the most common affecting 60% of measures, followed by 34% of type A and 30% of type C.

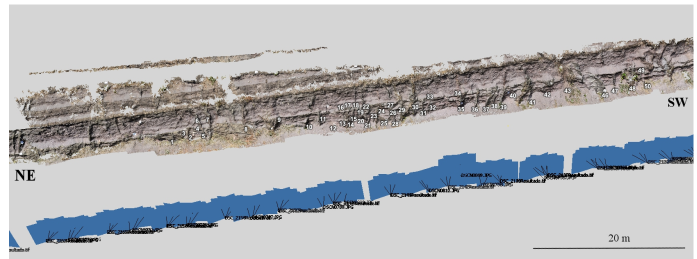


Figure 2. Screenshot of digital outcrop with camera positions (in blue) and individual dikes identified by numbers.

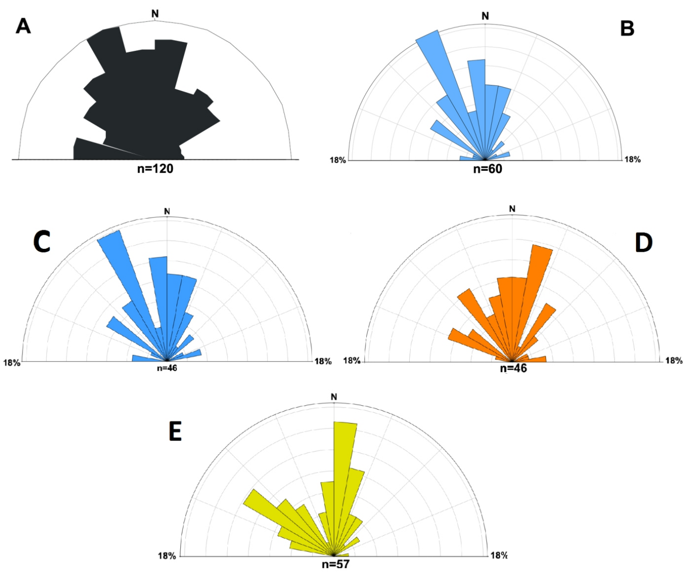


Figure 3. Rose diagrams using: (A) measures from Turra [4]; (B) all field measures; (C) field measures with digital correspondence; (D) ply2atti measures at same place than field ones; (E) ply2atti measures from full surface.

## IV. DISCUSSION

The terrain geometry and the constant activity of passing cars generated problems in the GCP target positioning, since the wind current would remove them off the outcrop, and in the measurement with the total station, that had to be constantly leveled since the wind generated misalignment. Some difficulties were encountered during image acquisition and generation of the digital model. First, for the available distance to the outcrop and the desired level of detail, the number of images obtained was



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high, consuming a lot of storage memory. The image acquisition was made avoiding the passing cars, thus no car had to be removed from the images.

Due to its more resistant composition, the dikes stand out from the surrounding rocks generating shadows depending on the direction of illumination (Fig. 4A). This shadowing effect covers surface details of the dikes and results on holes or artifacts on the digital model (Fig. 4B). To work around this problem, image sets taken at different times of the day were combined to lighten some shadow areas (Fig. 4). After this procedure, the number of holes and artifacts on the features of interest was reduced to about 10 to 15%.

The difference between the number of measures taken in this work in relation to Turra [4] is also shown in the statistics, since some dikes are now inaccessible or covered by vegetation. Because of this difference in the quantities obtained, it is possible that there is some influence in the statistical analysis that is also reflected in the rose diagrams. However, we can observe that the NNW preferential direction observed in the outcrop remains, although there is a certain NNE variation present.

Comparing the measurements obtained in the field activity of this work with the obtained by ply2atti, it is observable that there is a certain variation, although the general orientation is similar. This factor can be related to field practices, which do not necessarily provide an accurate measure due to misuse of the compass, or caused by manual adjustment of the plane.

Since the walls of the dikes present roughness and variable degree of undulation, a single measure performed with magnetic compass does not represent the best-fit plane. Ply2atti was created to provide an average geological attitude based on hundreds to millions of points on the surface, so the best practice would be to select the entire side of the dike leading to the best possible adjustment. However, as mentioned earlier, holes and artifacts caused by vegetation and shadows on the digital model segmented these surfaces. The areas compromised by the vegetation can not be corrected, since there is no real surface

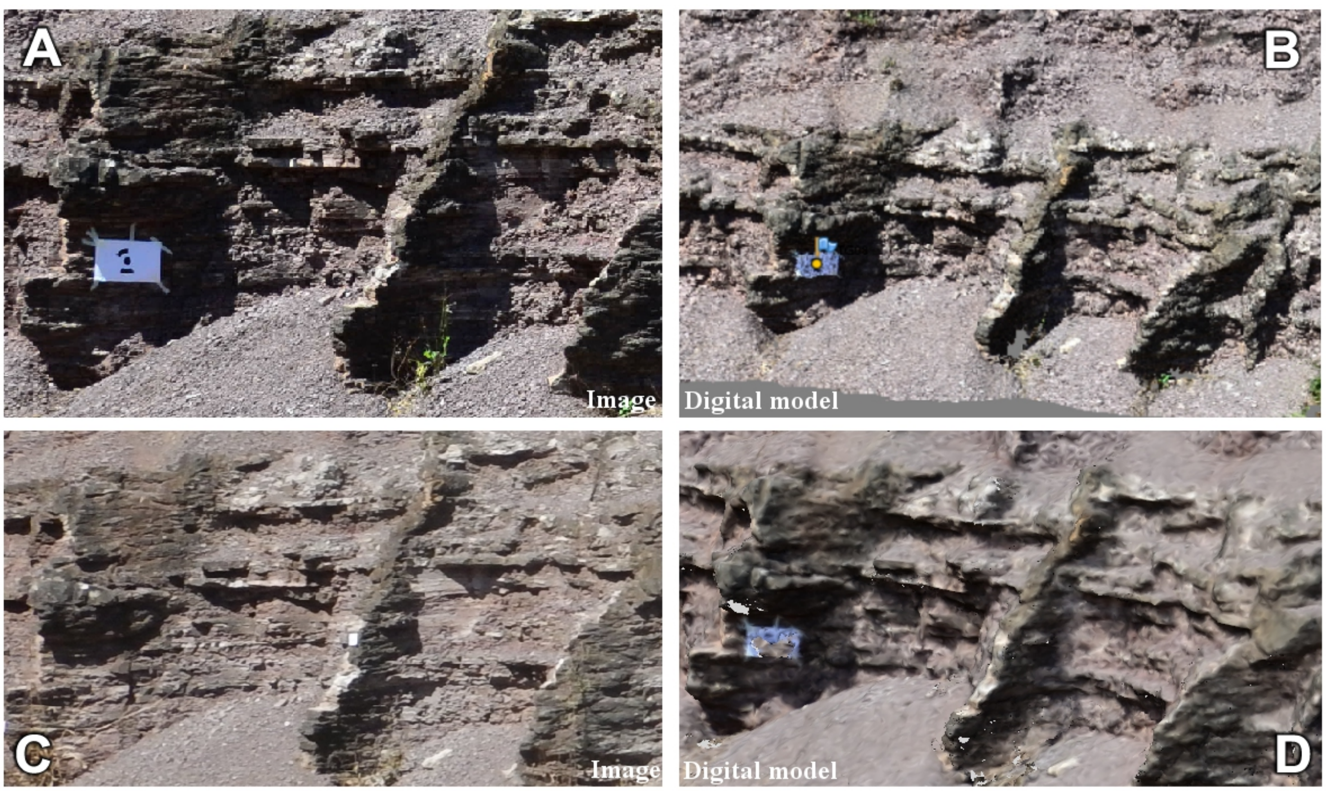


Figure 4. Comparison between the images and the resulting digital model to demonstrate illumination influence. (A) shows a Nikon D7000 image were shadows on the sides of the dikes are dark and affect the digital model (B), leading to holes and hiding surface details.(C) is a Nikon AW130 image, acquired under different light conditions, that was coupled with images from (A) to result on the final digital outcrop, increasing the detail level (D).

information. In this case the solution would be to use interpolation, which can generate false information.

Shadow areas could be reduced with more photographs of the outcrop being made on a bright cloudy day – as it is the exterior lighting equivalent of a dome light -, when the lighting is more uniform and the formation of projection shadows is very low, resulting only in small occlusions. To achieve the same conditions using artificial lights, it would be necessary an triangular arrangement with three main light sources of the same intensity with diffusers, which should ensure no visible signs of the lighting sources in the outcrop, but this solution seems impractical in the conditions of the study area. Another option would be to use post-processing techniques to close holes and remove artifacts, but this procedure could generate false data.

According to the goals established for the project, it is possible to conclude that the objectives were reached although the case addressed in this work does not represent a simple application for the chosen techniques, due to the lithological and structural complexity of the outcrop.

Three-dimensional reconstruction with SfM-MVS was successfully performed. However, it can still be improved. A study on the combination of the following factors can provide answers on this question: resolution of the photographs, area of overlap, imaging geometry (perpendicular to the outcrop or convergent) and influence of the direction of illumination.

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