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# Photogrammetry with a Drone "DJI Phantom 2 Vision Plus": 3D Model of an Area Deformed by Neotectonics in the Venezuelan Andes

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**Abstract:** A commercial drone was used to acquire a series of images in an area in the Venezuelan Andes characterized by the deformation of a regional strike-slip fault. The digital model obtained by processing the images has allowed to obtain quantitative measurements of the fault displacement and to test geological concepts related to the structure evolution. The test has proven several benefits in applying the drone technology to support the classic geological field work.

**Keywords:** Drone, DJI, Phantom, Photogrammetry, Digital Model, Venezuelan Andes, Boconó Fault

## 1. Introduction

The availability of affordable commercial drones and dedicated software is making it possible to easily acquire a grid of images over an area and process them to obtain a digital model of the topography. This technology can be very useful when applied to the geological field work, where data are traditionally collected with the aim of reconstructing complex three dimensional geometries.

In order to test the benefits of this technology when applied to geology, a drone acquisition was planned in the Venezuelan Andes, in an area where the topography is clearly expressing the deformation induced by active tectonic. The area was thoroughly studied during the past decades by means of traditional field work and several papers were published describing its features and evolution, therefore a wealth of information was available as a useful reference for the flight planning and for the validation of the drone acquisition.

## 2. Geological Background

The Venezuelan Andes are characterized by the presence of a major tectonic lineament, the Boconó strike-slip fault (Figure 1), which is the result of the northward extrusion of the Maracaibo block as a consequence of the convergence between the Nazca and the South America plates (Figure 2) [1] [2]. The relative motion along this fault has displaced several landscape features like the "Los Zerpa" moraine system (Figure 3) which formed during the last glaciation in Pleistocene-Holocene age [3] [4] [5] [6]. Its northern tip crosses the Boconó fault and is displaced 100 m towards NE.

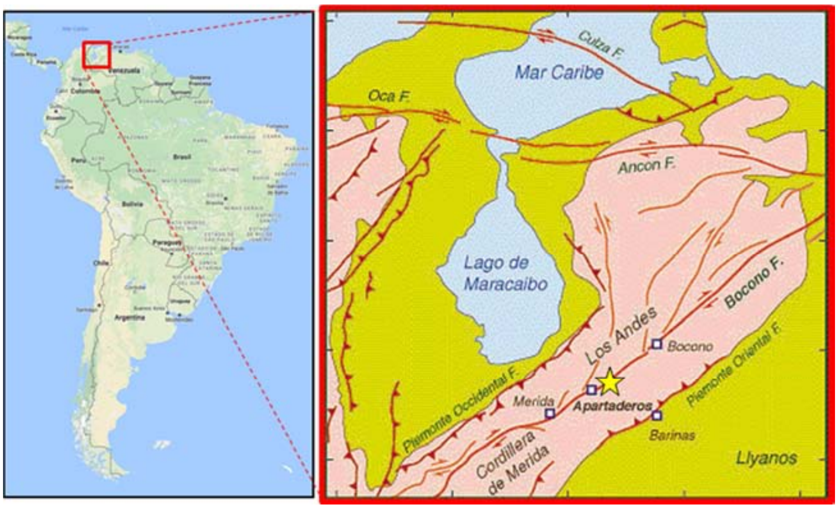


***Figure 1.*** *Geographic location of the study area (yellow star): 5 km north-east of the locality “Apartaderos”, along the Boconó fault, in the Venezuelan Andes.*

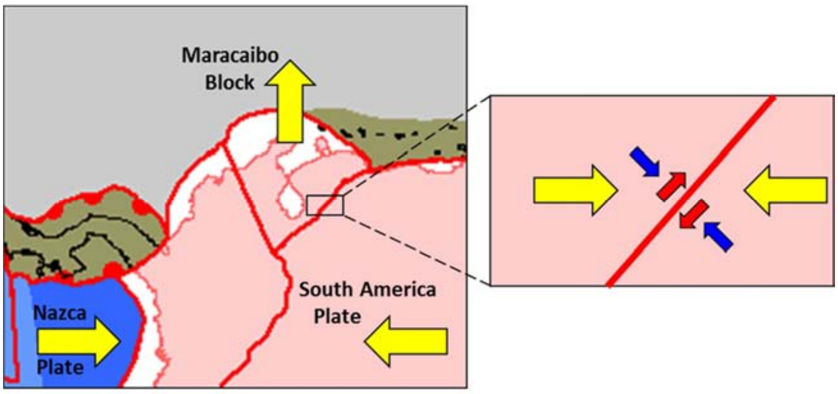


***Figure 2.*** *Tectonic setting of the Boconó fault: the strike slip movement along the fault is interpreted to be the result of the extrusion of the Maracaibo block, as a consequence of the convergence between the Nazca and the South America plates (image edited from [2]).*

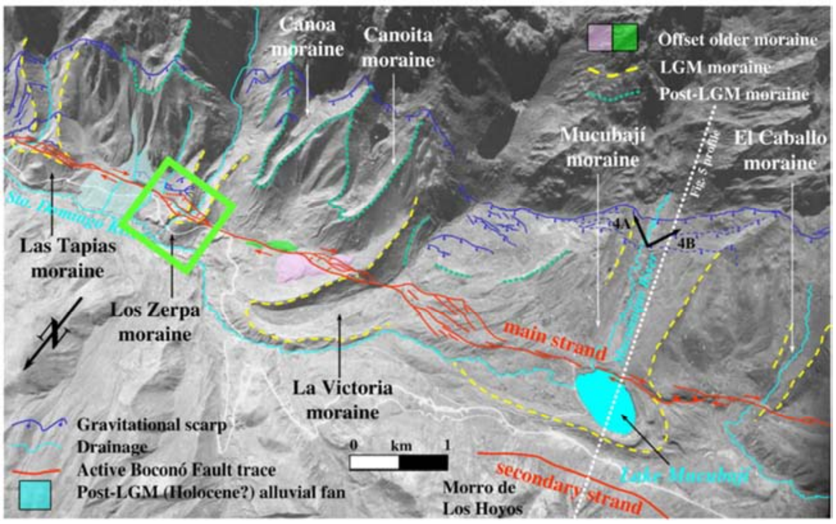


***Figure 3.*** *Location of the “Los Zerpa” moraine (green box) selected for the acquisition with the drone. It is one of the many topographic features (such as rivers and glacial moraines) that appear displaced by the trace of the Boconó fault (image edited from [5]).*

# 3. Moraine System Evolution

A model for the moraine evolution was proposed by C. Schubert in 1983 [7] and then confirmed by other authors more recently [8] [9], highlighting the interaction between the activity along the Boconó fault and the sedimentary processes in the moraine system (Figure 4). The model implies that the waters from the glacial valley were initially drained by a river that was flowing through the frontal part of the moraine (Figure 4.A, B, C).

In a later stage, the movements along the Boconó fault opened a breach across the lateral moraine, the river was deviated to the right and started to flow through this new escape route. The original route through the frontal moraine was abandoned and is preserved nowadays as a dry incision. The change in the drainage pattern caused the river to start eroding the sediments that were filling the valley. The level of the original filling is witnessed nowadays by the presence of two erosional terraces along the flanks of the moraine (Figure 4.D, E, F).

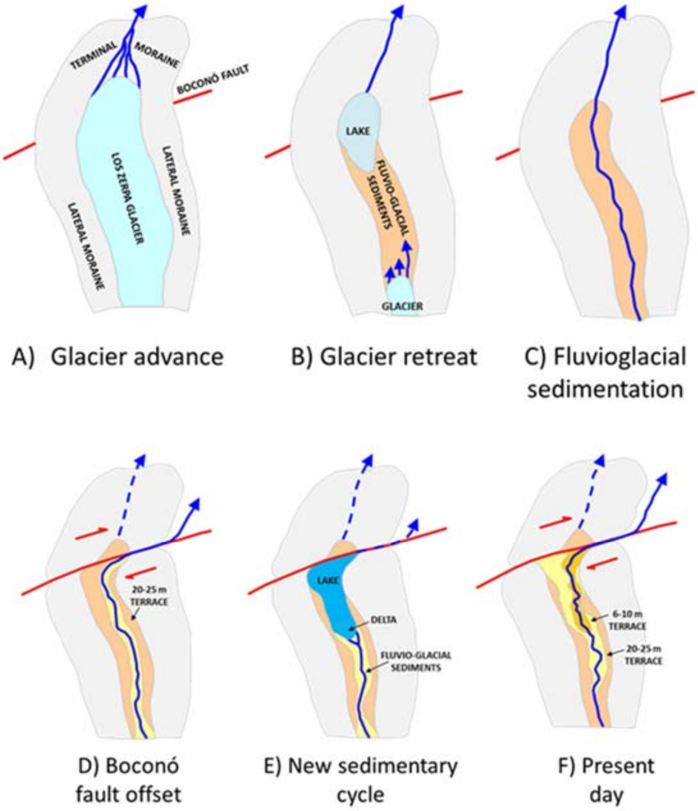


***Figure 4.*** *Model of the evolution of the "Los Zerpa" moraine system according to C. Schubert 1983 (images edited from [7]).*

# 4. Acquisition and Preliminary Analysis of the Digital Model

The acquisition was performed with a drone model "DJI Phantom 2 Vision Plus", acquiring about 300 images over an area of 400 x 600 m (Figure 5).

The digital model was generated by processing the images with the software Pix4Dmapper.


***Figure 5.*** *The drone "DJI Phantom 2 Vision Plus" that was used for the acquisition, the location of the images (green dots) acquired over the area of interest, and the Logo of the processing software Pix4D.*

The digital model generated after processing the images, allows identifying several geomorphologic features related to the interaction between the Boconó fault and the moraine deposits (Figure 6):

(1) tectonic scarps identifying the fault trace

(2) a 90° sharp bend of the river running down the glacial valley, where it gets captured and deviated along the fault strike

(3) the 100 m dextral displacement of the lateral moraines and glacial valley as they cross the fault

(4) two terraces witnessing past periods of fluvial infill within the glacial valley, later eroded when the fault activity opened a fluvial escape through the right lateral moraine

(5) the abandoned fluvial valley that used to drain the moraine system before it was breached by the fault

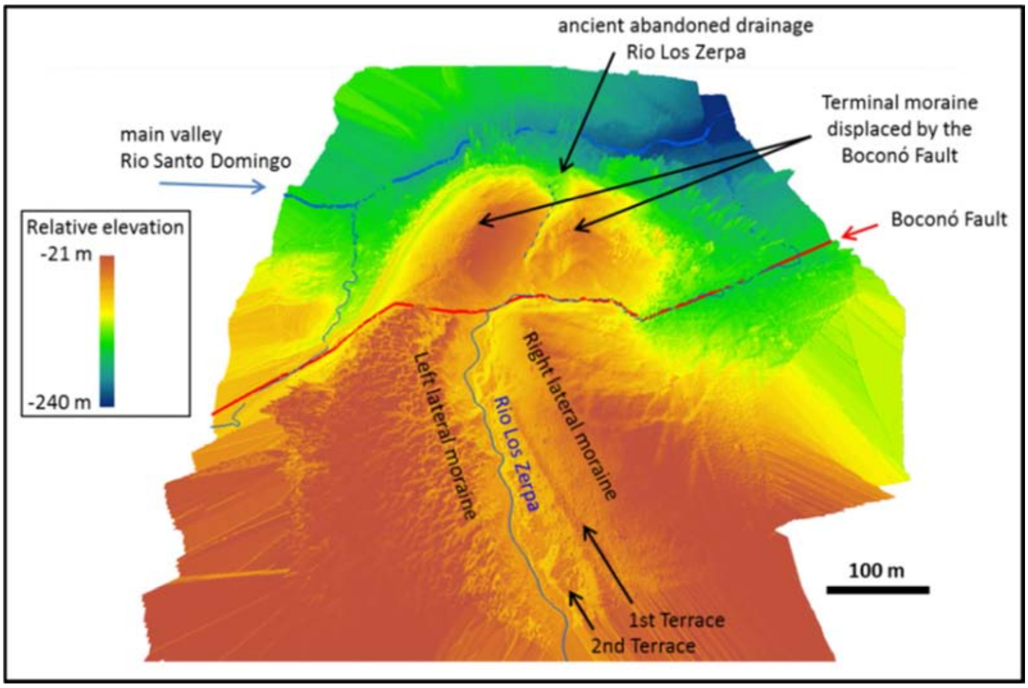


***Figure 6.*** *The digital model obtained after processing the images acquired with the drone. Several geomorphologic features can be identified that highlight the interaction between the Boconó fault and the moraine system.*

## 5. Modeling the Fault Displacement

One practical application of the digital model is to perform quantitative measurements of the geological features. The following example describes the process implemented to measure the rate of displacement along the Boconó fault (Figure 7).

A) Initially, the fault trace is outlined by identifying specific features like scarps in the topography and sharp bends in the present day rivers drainage.

B) After drawing the geometry of the fault, its displacement becomes evident by observing the deviations in the present day drainage and the displacement in the topographic crests

C) Finally, a simple structural restoration is applied by aligning the displaced elements on either side of the fault: the corresponding portions of the moraine crests and the present day fluvial valley with the ancient abandoned drainage that incides the frontal moraine. The restoration allows measuring a 100 m displacement along the fault.

This displacement records the deformation of the moraine since the time when the glacier retreated and stopped remodeling and regenerating the moraine. Glaciers retreated in the late Pleistocene in this area of the Andes [7] [8] [9] [10], that is about 16000 years ago. Dividing 100 m by 16000 years yields an average shift along the Boconó fault of 6.25 mm per year, which is reasonably close to the present day shift of 7-10 mm per year measured by GPS [11] [12].

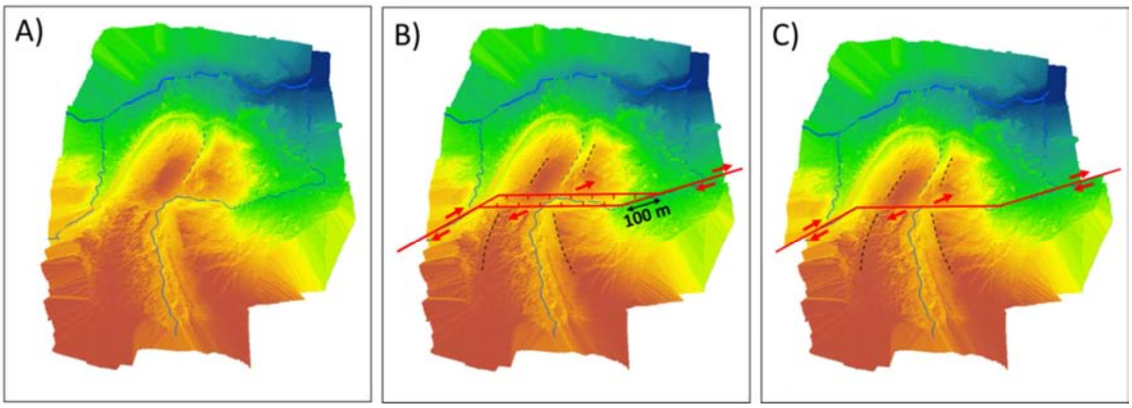


***Figure 7.*** *Structural restoration of the moraine system and quantification of the displacement along the Boconó fault (100 m).*

## 6. Testing Schubert Model

Another application of the digital model was to test the geometrical consistency of the evolution model described by C. Schubert [7].

For this purpose, the digital model was loaded in Arc Scene and combined with some geometrical elements: the cross sections across the upper part of the glacial valley and across the frontal moraine, the river profile, and the alluvial surfaces at present day (Figure 8.A).

The main objective of this test was to explain the origin of the incision in the frontal moraine. Supposing that it is an abandoned river bed, it is evident that it was not generated by the present day river because the geometrical reconstruction shows that its level is too deep to be able to reach and flow through that incision (Figure 8.B).

But the model indicates that the river was flowing at a higher level when the valley was filled with sediments in the initial stage of its evolution. These sediments were later eroded, but their original level is witnessed by the presence of two erosional terraces that are visible nowadays along the flanks of the valley.

A paleo alluvial surface was reconstructed by generating a plane parallel to the present day alluvial surface, but shifted 17 meters upwards until it intersects the marks of the upper terrace (figure 8.C). The frontal part of this plane reaches very precisely the height of the dry abandoned incision and confirms the theory that this was the initial route of the drainage flowing out of the glacial valley at a time when the valley was completely filled with sediments (Figure 8.D).

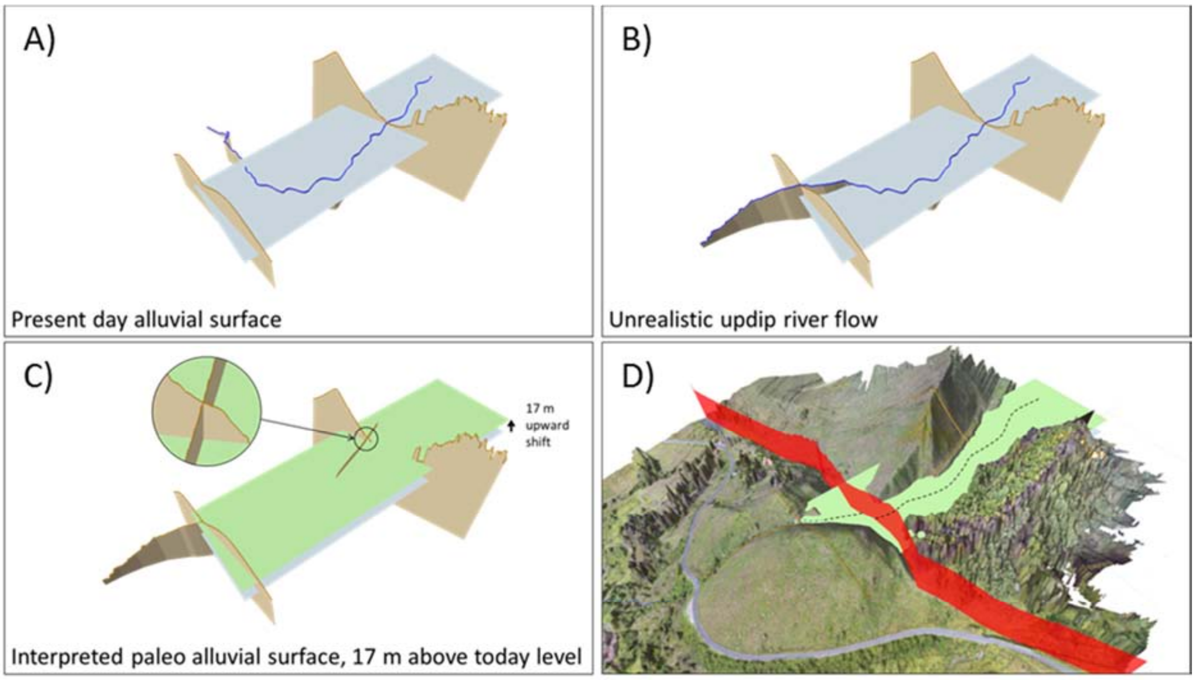


***Figure 8.*** *Testing the geometrical consistency of the evolution model described by C. Schubert (refer to the text for explanation).*

## 7. Conclusions

This experience has proven several benefits in using a drone-based technology in the geological field work:

(a) the acquisition can be made in remote impervious areas with difficult access.

(b) maps can be acquired at low cost and high resolution (typically a few cm per pixel).

(c) 3D models are generated at true scale and can be used to measure distances, thicknesses and volumes.

(d) geological features can be observed from the most favorable point of view.

More specifically in this experience the digital model has allowed testing geological concepts in three dimensions in a much more effective way than with the classic representations of 2D maps and sections.

The continuous improvements and the affordability of both hardware and software invite to think of applying this technology widely in support of the classic geological field work.

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