GEOMORPHIC INDICES FOR NEOTECTONIC ANALYSIS OF A BASIN CONTROLLED BY THE SOAPAGA FAULT IN THE EASTERN ANDEAN CORDILLERA OF COLOMBIA

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ABSTRACT

The High-Chicamocha River Basin in the Colombian Andes is a region structurally controlled by the southern termination of the Bucaramanga fault system, particularly by the Soapaga Fault, categorized as potentially active. We analyzed the active tectonics in a basin related to the High-Chicamocha in an axial part of the Colombian Eastern Andes using geomorphic indices derived from a digital surface model (DSM). The asymmetry factor (AF) evidenced uplift with the Soapaga Fault thrust and transpressive behavior. Therefore, the stream-length index (SL) and the sinuosity mountain front (Smf) showed regions with active structural control over the drainage network. Compared with lithological/structural data, those results proved that the geomorphic indices are reliable for assessing active tectonics in the Eastern Colombian Andes.

Keywords **—** Geomorphic indices, tectonic activity, Soapaga fault, Chicamocha River.

1. INTRODUCTION

The geomorphologic data analysis in mountain belts offers an effective approach to characterizing neotectonics [1]. River networks often provide clues about vertical movement rates or Quaternary deformation in an area [2]. Drainage pattern anomalies such as changes in channel morphology and abnormal curves may also reveal underlying active tectonics [3]. A relevant tool to assess basin and drainage morphologies is the geomorphic indices; these are efficient in quantifying topographic parameters and the morphometric features of hydrographic basins [4], which can differentiate the intensity of deformation in zones affected by active tectonics (e.g., [2]).

The southern termination of the Bucaramanga fault system corresponds to sinistral and subparallel faults, with a structural style of a transpressive system in a domino pattern [5]. This system captured the Boyacá and Soapaga faults, two Early Mesozoic rift structures inverted during the Neogene [6]. Both the Soapaga and Boyacá faults are structures categorized as potentially active [7]. The Soapaga fault structurally controls the High-Chicamocha River on its pass for the Sogamoso and Corrales municipalities in the axial part of the Colombian Eastern Cordillera. This study aims to evaluate the utility of geomorphic indices to assess active tectonics of a wide High-Chicamocha Basin. To achieve this, topographic and morphometric parameters were extracted and quantified in 3 geomorphic indices: AF, SL, and SNF.

2. MATERIAL AND METHODS

The drainage network was extracted from the 30m spatial resolution Digital Surface Model ALOS World 3D using the ArcMap Hydrology toolset. The main basin was divided into 15 sub-basins using flow points extracted from the drainage network. Based on the sub-basins morphology, 3 geomorphic indices were calculated. The AF is defined by the following formula AF=100(Ar/At) [8], where Ar is the rightward area of the basin and At is the total area. Using the Stream Order tool of ArcMap, we extracted the main drainage of each sub-basin. This drainage was used as the basin divisor to determine the Ar and the At, and those areas were measured using the geodesic model of ArcMap. The Smf quantifies the tectonic changes that suffer the mountain fronts, relating the planimetric length of the mountain front Lmf with a straight line of the same section Ls, and can be calculated with the formula Smf = Lmf/Ls [9]. Using ArcMap, we identified the steepness at each cell of the DMS and constructed a slope map. After that, the valley was delimitated based on slopes less than 7%. Once delimitated, the valley was divided into 12 representative sections, to which the Smf index was calculated. To analyze the longitudinal profiles of the main drainages, the SL index defined by SL = (ΔH * L)/ΔL was calculated [10]. ΔH/ΔL represents the slope of the channel or the gradient of a particular section, and L is the total length from the section of interest's midpoint to the upstream channel's highest point. The main drainages were divided into 25m sections; at the midpoint of each section, the SL index was calculated using the DSM. The calculation process was automatized using a script with the Rgdal, sp, rgeos, raster, and circular R libraries. The resulting points were interpolated using the Kriging tool of ArcMap. AF results were divided into 4 classes proposed by Perez-Peña et al. [8]: AF= 5–10 (gently asymmetric basins), AF = 10 –15 (moderately asymmetric basins), and AF > 15 (strongly asymmetric basins). Furthermore, Smf results were classified into 3 classes proposed by Bull [9]: Smf 1 – 1.5 (highly active mountain fronts), Smf = 1.5 – 3 (moderately active mountain fronts), and Smf > 3 (inactive mountain fronts).

3. RESULTS

3.1. Asymmetry factor

AF results of each sub-basin were mapped in figure 1. The highest value of AF is 33.08, corresponding to the Chicamocha River's closure (the basin's main drainage) to the basin division and the piedmont. This area coincides with the Soapaga fault trace and the Chicamocha River encounter, where the Chicamocha River course changes from ~325º to ~73º. It represents a structural control of the Soapaga Fault over a river with a high flow rate and erosive capacity. On the SW region of the study area, at the Soapaga's fault hanging wall, a similar tilting behavior toward NE occurs with a basin of AF 22.1. Three basins are strongly asymmetric eastward the study area with 27.48, 25.92, and 16.12 AF values. Those basins are located in the Soapaga's fault footwall, in a geomorphologic region known as the "Cobertera Plegada", characterized by high lithologic variability of faulted and folded Neocretaceous-Cenozoic sedimentary rocks. At the northern part of the study area, another highly asymmetric basin with a 20.19 AF value shows a tilting toward the NW, according to the direction of strike faults that cut the Soapaga fault.

3.2. Stream-length index

The spatial distribution of the SL index shows low values over the valley of the study area (Figure 2). It is due to the low-topography variation of the study area's quaternary deposits that compose the valley. SL index values tend to increase in mountainous regions. At the SW part of the study area, in the Soapaga's fault hanging wall, the SL index reaches ~350. The highest values of the SL index (~770) in the Soapaga's fault hanging wall occur at the northern Soapaga fault trace, close to the basin boundary, where a strike fault cuts it. In this region, the lithological variability is product of the thrust faulting that contacts Eocene claystones (From the "Cobertera Plegada") with Low-Cretaceous calcareous rocks and Upper-Jurassic sandstones from the Floresta Massif. Eastward of the study area, in the Soapaga's fault footwall, locates the highest values of the SL index in this study, standing out two hotspots of high SL values. One hotspot at the north of the basin, in a region dominated by thrust faulting of the Topaga fault, with SL values reaching ~1200. The second hotspot (SL values reaching ~1000), and the most extensive, occurs in a structurally complex area, with several compressive faulting and folding, which is reflected by the convergence of the Vallados, Monguí, Topaga, and Gameza faults. At this hotspot, the high SL values coincide with valley areas covered by Quaternary deposits of alluvial origin.

3.3. Sinuosity Mountain Front

Of the 12 representative mountain fronts, 2 are highly active, 6 are moderately active, and 4 are inactive mountain fronts (Figure 3). The lowest values of Smf categorized as active mountain fronts are directly related to the Soapaga fault trace and have Smf values of 1.35 and 1.4. Those active mountain fronts are located at the southern trace of the Soapaga Fault, where the Pesca River flows closer to the piedmont than toward the valley's centre. At the northern Soapaga's fault trace, two moderately active mountain fronts with Smf values of 2.33 and 2.10 occur in a geologically complex region where faulting puts in contact the Floresta Massif with the "Cobertera Plegada". In the eastern part of the valley, we found 3 moderately active mountain fronts with 1.58, 2.12, and 1.68 Smf values. At this region of the valley exist a structural control of the Gameza and other thrust faults over the mountain fronts in the lack of a significant river. It is an exception at the valley's southern end, where the Soapaga fault domain the Pesca River.

4. DISCUSSION

Morphometric parameters indicate landscape control in drainage networks and basins from factors such as lithology, tectonic activity, and climate (rock erosion and sediment deposition). Each index gives a different insight from the processes domaining in the study area. The AF results are mainly related to the current control of the high compressive stresses that shaped the region during the Neogene inversion [6]. Notably, the tilting direction of strongly asymmetric basins coincides with the transpressive system of the southern termination of the Bucaramanga fault observed by Velandia et al. [5]. This system captures the Soapaga fault and explains why the tilting occurs parallel to the fault direction instead of perpendicular. Furthermore, the SL index is more likely associated with rock resistance variability due to changes in lithology. The lithological control or rock resistance is evident as the highest values of the SL index occur at the Soapaga's fault hanging wall, where the intensive thrust faulting and folding affect many chronostratigraphic units from the "Cobertera Plegada". The Smf results provide information about dominant processes in the valley piedmonts. Overall, the study area presents moderately active structural control over the mountain fronts, with the highest active region associated with the southern Soapaga fault trace.

The indices have a low spatial correlation since each analyzes a different morphometric feature. However, they can be complementary and potentially provide valuable information about neotectonics. The Smf and AF results seem to have the highest correlation with active tectonics since both show active structural control of the Soapaga fault over the drainage network, especially toward the western study area. SL index results can indicate structurally complex regions where it is suitable to carry out field observations and data collection to corroborate evidence of neotectonics.

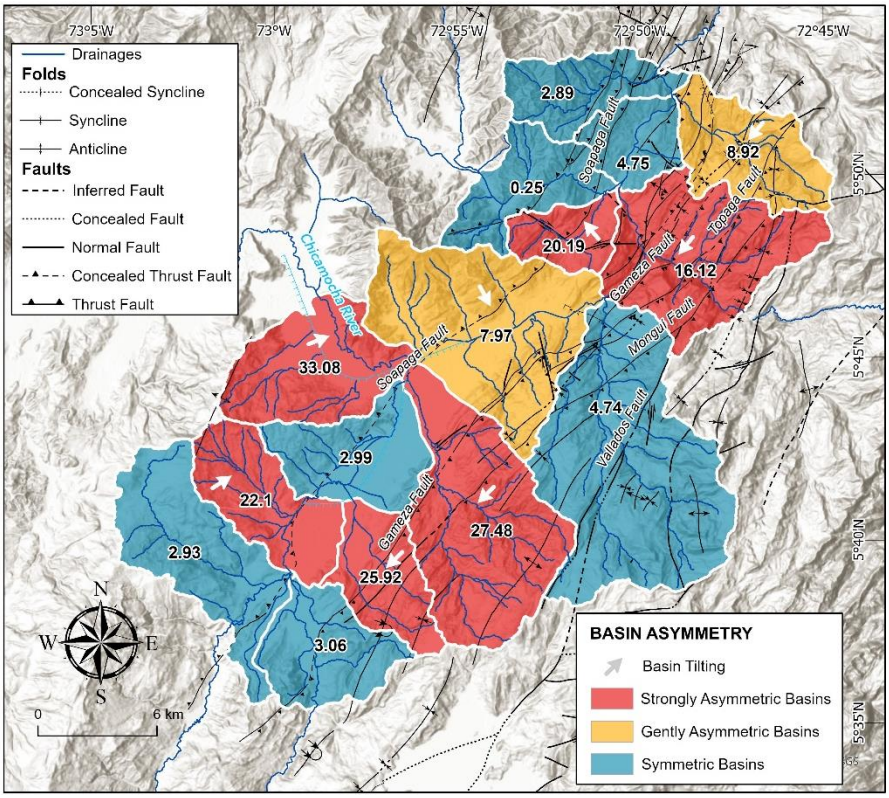


Figure 1. Basin asymmetry results and inferred tilting direction of each sub-basin in the study area.

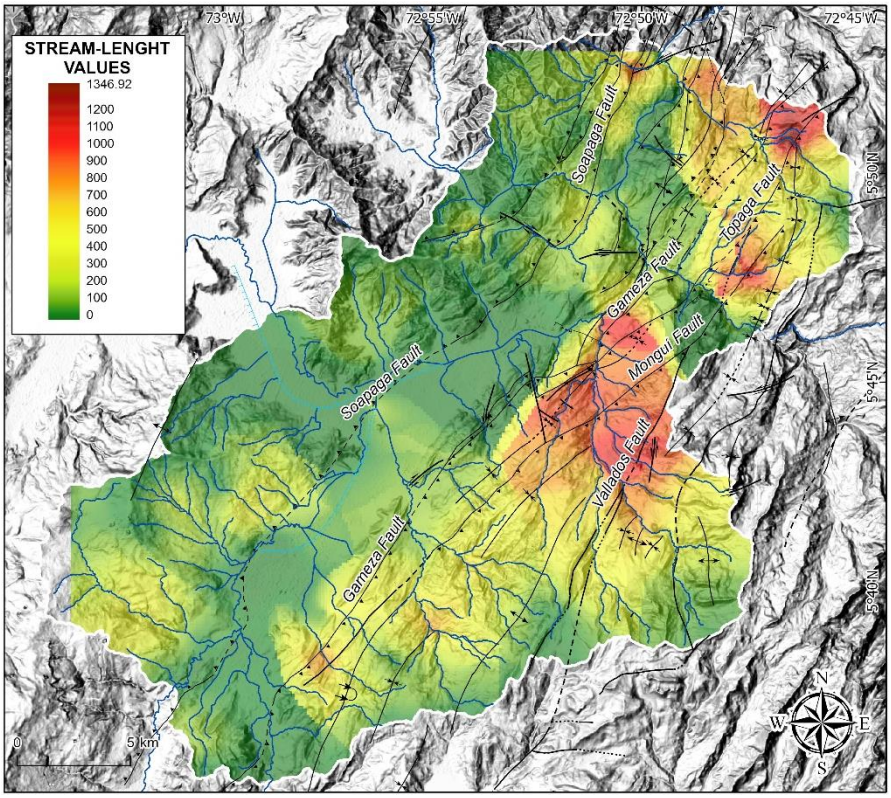


Figure 2. Spatial distribution of SL values in the studied basin.

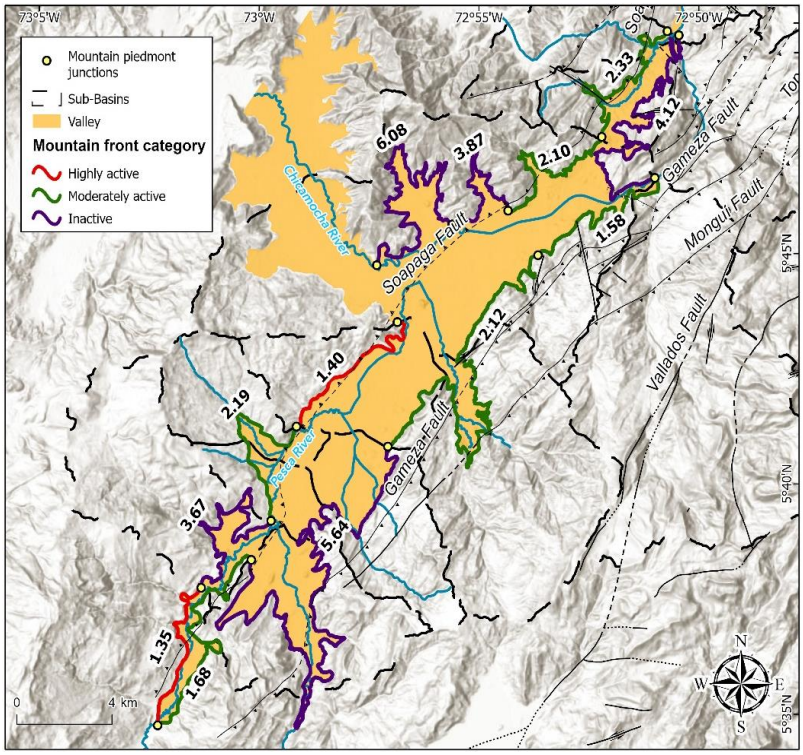


Figure 3. Valley areas, piedmont junctions, and sinuosity mountain front results/classification.

5. CONCLUSIONS

The analysis of morphometric features of basins through geomorphic indices provided quantifiable elements to improve the knowledge of the tectonic activity in this axial region of the Colombian Eastern Andes. They represent a pre-field work tool, as they use geoprocessing to spatially determine areas of higher or lower probability of tectonic activity. In the southwest study area, the Soapaga fault active control high-flow rivers (Chicamocha and Pesca rivers), which suggests neotectonics and active tilting in the study area. Field geological and structural survey, with Quaternary deposits data collection, will provide the definitive evidence to categorize the Soapaga fault as an active structure. The geomorphic indices allowed the definition of the morphostructural style of the Soapaga Fault, confirming that transpressive stresses actively affect this portion of the fault.

6. REFERENCES

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