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Knickpoint finder: A software tool that improves neotectonic analysis

G.L. Queiroz*, E. Salamuni[1], E.R. Nascimento

The Federal University of Paraná, Neotectonics Research Group, Curitiba, PR, Brazil

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ABSTRACT

This work presents a new software tool for morphometric analysis of drainage networks based on the methods of Hack (1973) and Etchebehere et al. (2004). This tool is applicable to studies of morphotectonics and neotectonics. The software used a digital elevation model (DEM) to identify the relief breakpoints along drainage profiles (knickpoints). The program was coded in Python for use on the ArcGIS platform and is called *Knickpoint Finder*. A study area was selected to test and evaluate the software's ability to analyze and identify neotectonic morphostructures based on the morphology of the terrain. For an assessment of its validity, we chose an area of the James River basin, which covers most of the Piedmont area of Virginia (USA), which is an area of constant intraplate seismicity and non-orogenic active tectonics and exhibits a relatively homogeneous geodesic surface currently being altered by the seismogenic features of the region. After using the tool in the chosen area, we found that the knickpoint locations are associated with the geologic structures, epicenters of recent earthquakes, and drainages with rectilinear anomalies. The regional analysis demanded the use of a spatial representation of the data after processing using *Knickpoint Finder*. The results were satisfactory in terms of the correlation of dense areas of knickpoints with active lineaments and the rapidity of the identification of deformed areas. Therefore, this software tool may be considered useful in neotectonic analyses of large areas and may be applied to any area where there is DEM coverage.

1. Introduction

Morphometric analysis of drainage networks in studies with a neotectonic emphasis has been used by several authors (e.g., Volkov et al., 1967; Hack, 1973; Burnett and Schumm, 1983; Seeber and Gornitz, 1983; McKeown et al., 1988; Marple and Talwani, 1993; Merrits and Hesterberg, 1994; Schumm and Spitz, 1996; Rodriguez and Suguio, 1992; Etchebehere et al., 2004 and Martinez et al., 2011).

Current knowledge of geomorphic systems and drainage network behavior indicates that natural drainage channels are sensitive to changes in geodesic reference levels, particularly when such changes occur quickly, and are the first element of the landscape to respond to deformations imposed by active tectonic systems. Morphotectonic elements, namely morphologic structures created by tectonic processes, are features derived from crustal deformation at the geodesic level, and in the case of rivers, disparities in relief are one of the most notable features of the crustal surface. These relief breaks are important drainage gradient anomalies that, together with other anomalies, for example, the watersheds of rivers, presence of bends or abrupt deviations, the subsidence of restricted portions of the watershed basin or the formation of structural patterns, indicate that the major traits of the primitive landscape of a region are controlled by its tectonic structure, primarily by the distortion of primitive flat surfaces. This situation is amply demonstrated in the Mississippi River basin.

Hack (1973) proposed the use of the SL index (ratio of slope to length), which was applied in studies with a neotectonic focus in diverse areas of the rivers in the Arkansas Valley, Boston Mountains and Salem Plateau and was applied by Seeber and Gornitz (1983) in the Himalayas and in the USA by McKeown et al. (1988) in Arkansas and Missouri, by Merrits and Hesterberg (1994) in areas crossed by the San Andreas fault, and by Marple and Talwani (1993) in South Carolina. In Brazil, this index was used in the Peixe (Fish) River basin by Etchebehere et al. (2004) and in the Pirapó River basin by Martinez et al. (2011).

Although these studies constituted effective geomorphic analyses, the complexity of manual analysis makes the use of the SL index difficult in large areas with a relatively high level of detail. For this reason, a software program called *Knickpoint Finder* was developed, programmed in the Python language. This program was developed with the goal of accelerating the process of geomorphic and morphometric analysis, using digital topographic data in a matrix format, and allows a greater degree of accuracy and detail in studies of regional neotectonics.

* Corresponding author.
E-mail addresses: gustavo.queiroz@ufpr.br (G.L. Queiroz), salamuni@ufpr.br (E. Salamuni), deni_ern@ufpr.br (E.R. Nascimento).
[1] Tel: +55 41 3361 3691.

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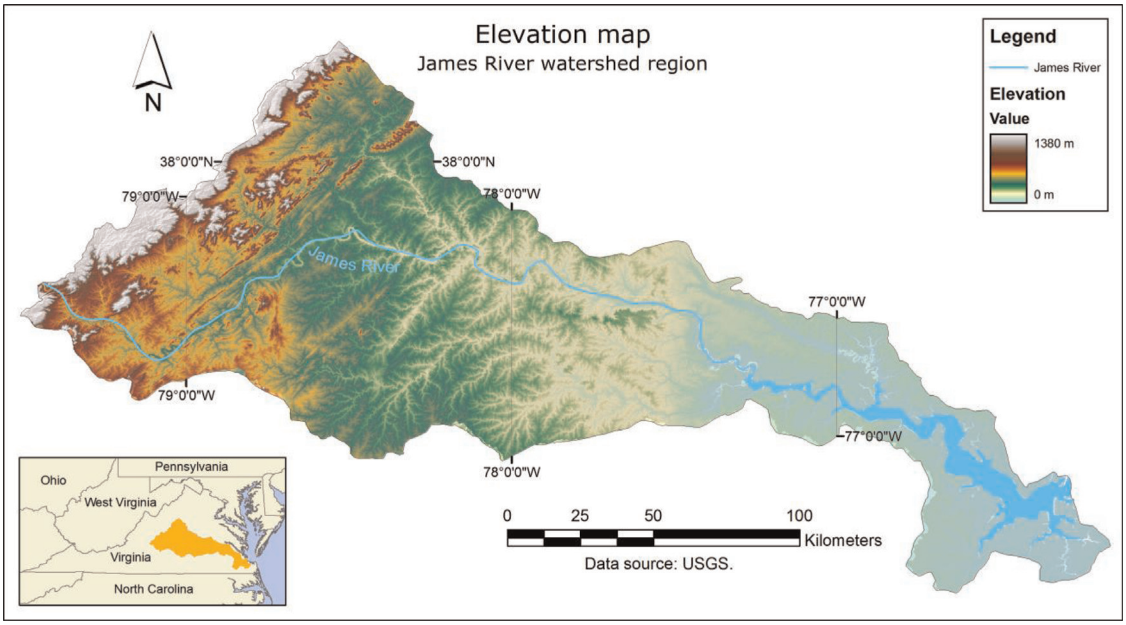

Fig. 1. Location and hypsometric map of the study area.
Source: National Elevation Dataset (NED).

The primary objective of this paper is to describe the development of the software. The application of *Knick Point Finder* in the Piedmont Virginia (USA) seismogenic area (Fig. 1) is a case study, with the aim to evaluate the ability of the software to identify individual knickpoints, which are structures that relate to current seismogenic processes, resulted from the active tectonics in central Virginia. The seismic events in this area have been studied by several authors, such as Bollinger and Hopper (1971), Bollinger and Sibol (1985), Bollinger and Costain (1988), Çoruh et al. (1988), Obermeier and McNulty (1998), Zoback (1992), Wheeler (2006), Hough (2012) and Wolin et al. (2012). Most of these studies used seismic data that revealed a need to identify morphotectonic elements that assist in the interpretation of recent crustal movements. The software was designed to characterize these relief breaks (knickpoints) and facilitate their identification.

2. Methods and theoretical bases

The theoretical approach to the development of the software was based on a geomorphometric parameter proposed by Hack (1973), the stream length-gradient (SL) index. This parameter pertains to the longitudinal profiles of rivers or drainage stretches and has been called the *Hack index* in the literature. This parameter is calculated by multiplying the slope gradient of the stretch of river by the distance between this stretch and the source of the river, which then determines the knickpoints of interest in morphotectonic, morphostructural and neotectonic studies. Keller and Pinter (1996) found that the SL index in the San Gabriel Mountains, southern California, displays abnormally high values, which are linked to high rates of uplift.

Etchebehere et al. (2004) proposed a derivative of the Hack Index, the relative slope-extension (RDE) index, which gives an indication of the current energy in a particular drainage stretch and varies with the slope of its surface and the discharge of water at the end of the stretch. According to these authors, the RDE index for a stretch (RDEs) may be calculated using the relationship (Fig. 2)

$$\mathrm{RDEs}=(\Delta H/\Delta L).\ L \quad (1)$$

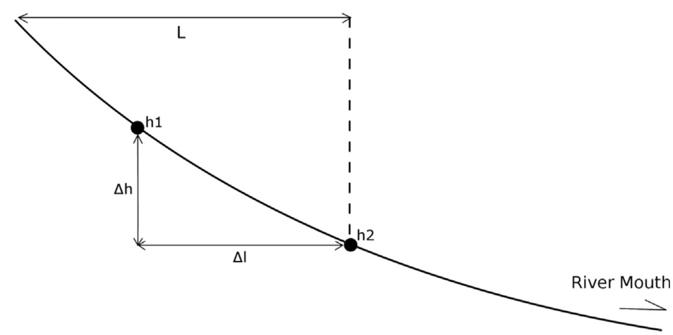

Fig. 2. Longitudinal profile of a river showing how the RDEs index is measured for a stretch with a length of Δl, an elevation difference of Δh, and a distance L from the source of the river to the point measured ($h2$).

where ΔH=the elevation difference between the two extremities of a stretch along a river; ΔL=the length of the stretch being studied; and L=the distance between the lower end of this stretch and the source of the river.

The total RDE index (RDEt), which in turn refers to the total length of a river, takes into account the total slope between the source and mouth and the natural logarithm of its entire length (Seeber and Gornitz, 1983; Etchebehere et al., 2006). This index is calculated using the relationship

$$\mathrm{RDEt}=(\Delta H/\Delta L).\ln(L) \quad (2)$$

The final goal, after measuring the RDES indexes of various stretches and the RDET indexes of their respective drainages, is to compare them to determine which stretches have anomalous slopes. According to , when the value of the ratio RDEs/RDEt ≥ 2, the drainage stretch under analysis can be considered anomalous. A value of RDEs/RDEt between 2 and 10 represents an anomaly of the 2nd order, whereas a value of RDEs/RDEt greater than 10 is an anomaly of the 1st order.

3. Software development

The RDE index was used to create an algorithm that identifies knickpoints, which in turn was used as the basis for developing a