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Assessment of the debris-flow susceptibility in tropical mountains using clast distribution patterns

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ABSTRACT

Channel morphometric parameters and clast distribution patterns in selected basins of the Ferriferous Quadrangle tropical mountains, Brazil, were analyzed in order to assess susceptibility to debris flows. Median bed surface clast size (D_{50}) in the main stream channel of these basins shows a coarsening downstream trend with drainage areas of up to 6 km^2, which is attributed to debris flow dominated-channels by some authors. The composition and roundness of the bed load, clast sand, and the presence of allochthonous large boulders throughout the channels also suggest the occurrence of past debris flow in the region. Luminescence Optically Stimulated (LOE) dating points out that debris flow could have occurred as a consequence of climate changes in the Late Pleistocene and Holocene and it can now be triggered by deforestation or extreme rainfall events. There has not been any record of past debris flow in the study area, or in other mountainous regions of Brazil where debris flows have recently occurred. Thus, the adopted approach can be useful to assess debris flow susceptibility in this and other similar areas.

1. Introduction

Debris flow is a very destructive kind of mass movement that may occur in many geomorphological environments (Jakob and Hungr, 2005). There are some definitions of debris flow (Costa, 1988; Hungr et al., 2001), but it is generally accepted that they consist of a rapid form of mass movement in which a combination of loose soil, rock, organic matter and water mobilize as a slurry that flows downslope.

Until the last decades of the 20th century, debris flow events had not been a matter of much concern in Brazil. However, recent catastrophic debris flows in mountainous regions of southern and southeastern Brazil have called the attention to them due to hundreds of casualties and severe property damages (Kobiyama et al., 2015). Consequently, some studies have started dealing with this subject, many of them related to risk analysis or to the modeling of debris flow susceptible basins (Gramani, 2001; Avelar, 2003; Kanji et al., 2003; Lopes, 2006; Correa et al., 2009; Rocha, 2011). It is important to note that most of those events occurred in mountainous regions covered by the remaining of tropical rainforest stretches during intense rainfall episodes (e.g.: Kanji et al., 2003).

The headwaters of the upper Velhas river are located on the ridges of Quadrilátero Ferrífero region, the main mineral province in southeastern Brazil. These headwaters present some favorable characteristics for the development of the kind of debris flows that prevails in Brazil: high declivity; a relatively thick regolith, developed in an Atlantic Tropical Rainforest context; long and narrow drainage channels; high rainfall rates concentrated in the summer months. There is no historical record of debris flows in the Upper Velhas basin, but it is important to note that this kind of mass movement usually presents long recurrence time, that can be of thousands of years in Southeastern Brazil (Bierman et al., 2014). As Europeans settled in this region only by the end of the 17th century, the lack of a historical record can be attributed to an insufficient time span of observation for these poorly active headwaters.

Recent debris flow deposits are relatively easy to identify in the field (Pierson, 2005), but older ones are more difficult to be recognized, due to the natural reworking of the thinner components of the debris flow deposits by processes with lower recurrence interval, especially floods.

However, some researchers (e.g. Brummer and Montgomery, 2003) argued that debris flow-controlled streams can show distinctive sedimentological and morphometric patterns. Indeed, these authors found in the Rocky Mountains drainage basins (Washington State, USA) a downstream coarsening of bed surface clast size in headwater streams with drainage water lower than 10 km^2. They interpreted this pattern as a consequence of debris-flow transported processes. According to Brummer and Montgomery (2003), the tendency for downstream coarsening in headwater areas where debris flow processes establish the channel gradient can also be correlated to some morphometric attributes, such as channel slope and the unit stream power. This behavior was also found in Alpine streams of Italy (Vianello and D'Agostino, 2007).

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In this research we intend to verify if the patterns observed in the Rocky Mountains and in Alpine basins also occur in a region of different geological, geomorphological, vegetation cover and weather conditions, such as the tropical mountains of the Upper Rio das Velhas basin. Additionally, we incorporate other methods, such as bed surface clast composition and roundness, as well as an investigation of size and composition of large boulders that occur throughout the study area.

We believe that this integrated methodological approach on the surface sediments in the river network will help the identification of lag deposits caused by debris flows that can have supposedly occurred at recent geological time in the region. In other regions of Brazil where debris flows have recently been triggered, no historical records of such accidents were made (Kobiyama et al., 2015), not even in the study area. Thus, if our approach proves to be successful to identify past debris flow events, it will be very important to prevent future accidents here and in other regions with similar characteristics. This kind of study is even more relevant in view that many fast growing cities in Brazil have been sprawling towards steeper slopes in mountain flanks.

1.1. The study area

The study area is situated in the headwaters of the Upper Velhas river, in Ouro Preto county, Minas Gerais state, southeastern Brazil. These headwaters drain the inner parts of the Mariana Anticline, a mega-fold in the region known as Ferriferous Quadrangle (Alkmim and Marshak, 1998). As this anticline is sculptured by fluvial erosion caused by the Velhas river, the basin is limited in the south and northeast by the Ouro Preto and Antonio Pereira ridges, respectively (Fig. 1) that constitute the limbs of the Mariana Anticline. As the resistant rocks that sustain these ridges (quartzites and itabirites) dip outwards with moderate to high angles, they form hogbacks (Huggett, 2011). Thus, the headwaters of the Upper Velhas river drains the other eroded side, the characteristically steep hogback front slope of the Ouro Preto and Antônio Pereira ridges.

The tributaries of the Upper Velhas river present long (1 to 5 km) and straight drainage channels in the hogback front slope, that is covered by a relatively thin regolith cover (Costa et al., 2014). These characteristics and the high mean annual rainfall in the region (1610 mm y^{-1} between 1988 and 2004, with a maximum of 2512 mm y^{-1} in 1990 – Castro, 2006), also favor the triggering of debris flows. It is worth mentioning that 87% of the rainfall usually is concentrated in the summer months (October to March), and that a very intense rainfall of 161 mm d^{-1} was recorded in February 1979 (Castro, 2006).

Archean rocks of Rio das Velhas Supergroup dominate in the Upper Velhas basin, whereas Upper Proterozoic rocks of the Minas Supergroup crop out in a smaller area of the headwaters (Dorr, 1969; Alkmim and Marshak, 1998 – Fig. 1).

The Rio das Velhas Supergroup is formed by the Nova Lima and Maquiné groups. The first one predominates in the basin and is mainly composed of green schists and phyllites and secondarily by quartzites,

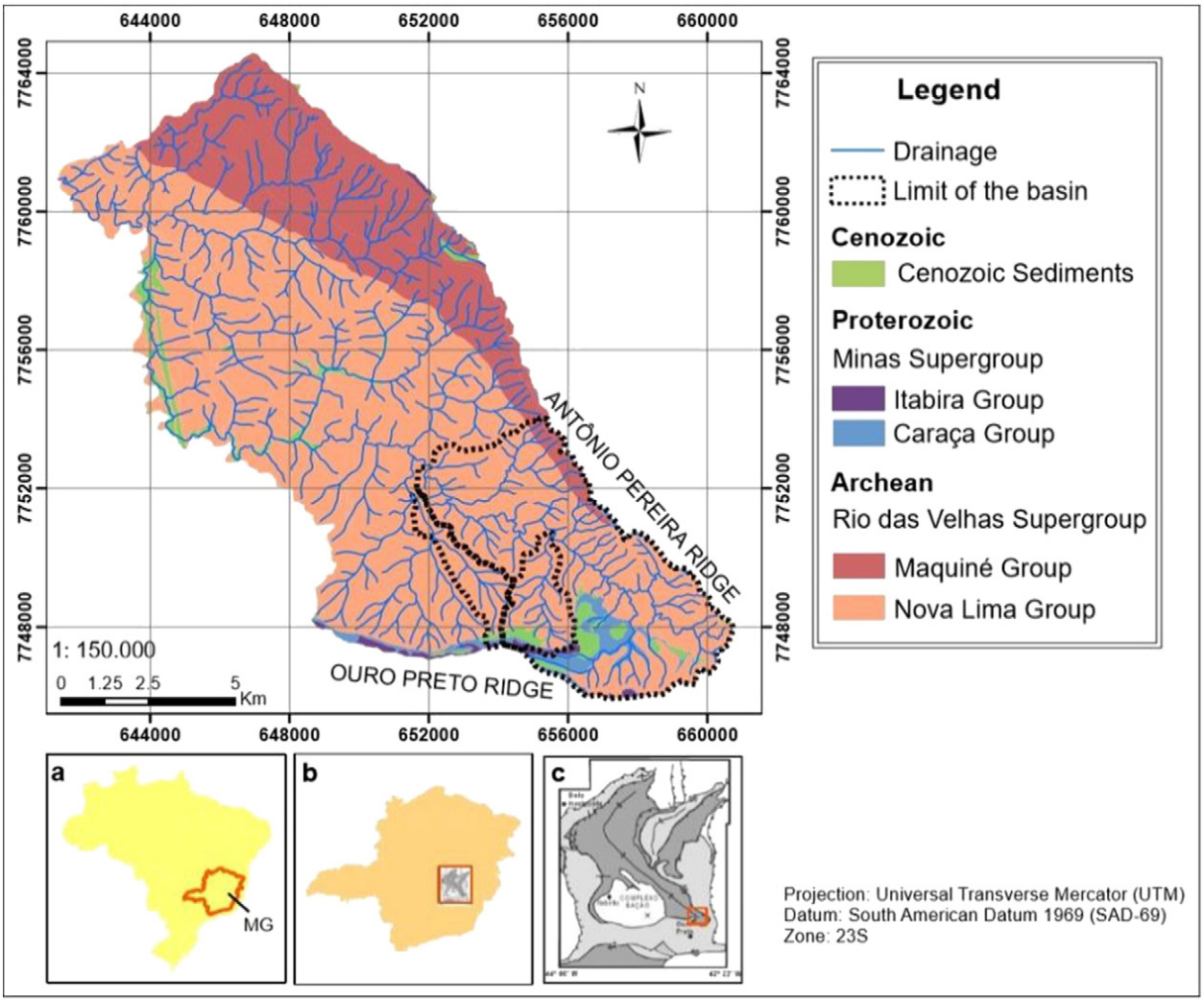

Fig. 1. Location and geological map of the Upper Velhas river basin, limited by the Ouro Preto and Antônio Pereira ridges, which conform the limbs of the bleached Mariana anticline. The dotted lines show the limits of the three basins chosen for this study. (a) - Location of Minas Gerais state (MG) in Brazil (in darker gray); (b) - Location of the Ferriferous Quadrangle; (c) - Location of the bleached Mariana Anticline in the Ferriferous Quadrangle.