Comparative geomorphological analysis applied to the hazard assessment of debris flows: case study of three watersheds of the Western Cordillera of Colombia, Northern Andes.

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INTRODUCTION

Understanding of debris flows and related hazards constitutes an essential ingredient in the planning and management of mountainous towns. In this work, we analyzed geomorphological and stratigraphic data from three watersheds located in the central zone of the Cordillera Occidental of Colombia in the Northern Andes. Observations from the Tapartó and Farallones rivers and La Arboleda stream allowed the characterization of debris flow deposits under conditions of high slope, heavy rainfall and an important development of soil profile. Geomorphological and stratigraphic analyses were complemented with late-Holocene ages between 100 +/- 30 and 2010 +/- 30 ^{14}C yr BP and ^{10}Be ages between 5.68 Ka and 6.19 Ka.

1. GEOLOGIC SETTING AND BACKGROUND

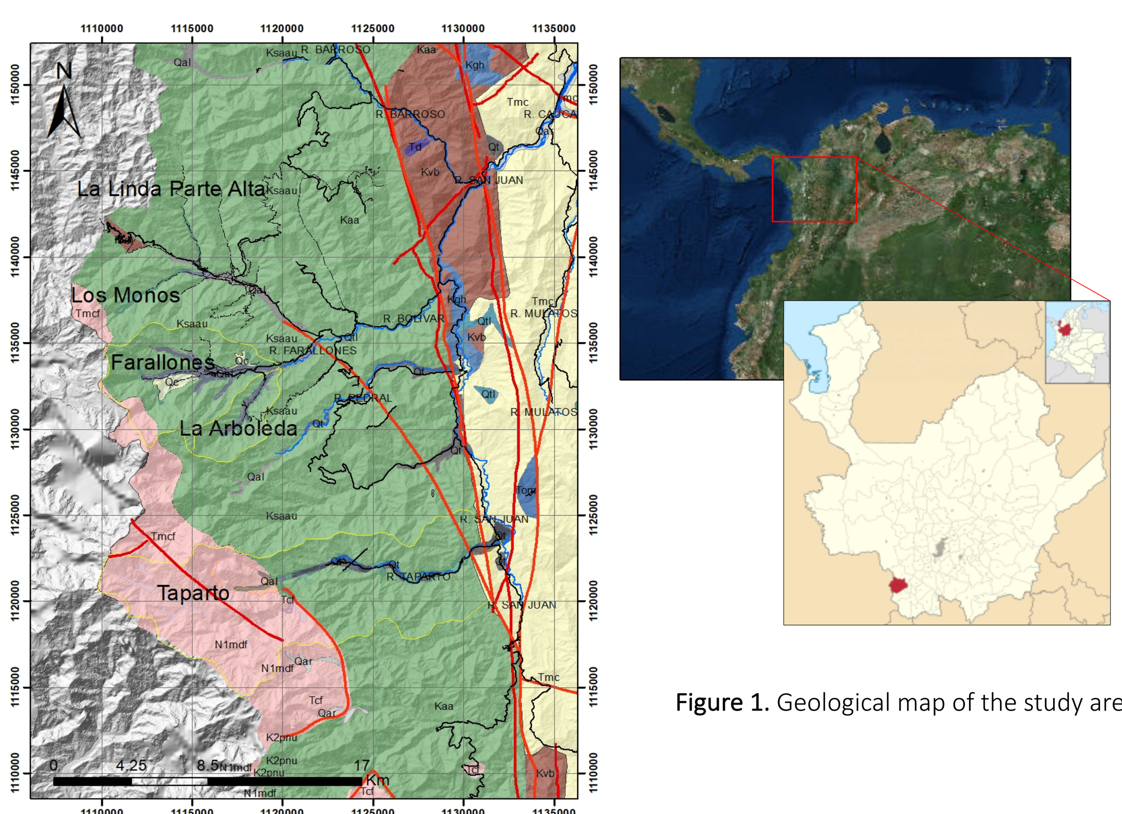

Figure 1. Geological map of the study area. Scale 1:25.000

- The area of study is located at the north of the Western Cordillera of Colombia.
- It presents metasedimentary rocks of the Cretaceous (Penderisco Formation: Urrao Member) intruded by an igneous body of the Tertiary (Farallones Batholith).
- At the structural level, it shows an important fault system associated with regional metamorphism and the intrusion of the Farallones Batholith. In addition, it presents important regional extensions of Quaternary deposits associated with a complex debris flow dynamic in the area.
- Finally, at historical level, the area shows an important recurrence of debris flow events. The topography of the zone, with elevations between ~1450 - 4020 m causes a rain-shadow effect that maintains a constant precipitation in the watersheds of this part of the world, with a mean annual precipitation of more than ~3 m/yr.

2. IMPORTANCE OF DEBRIS FLOW STUDY IN COLOMBIA

- It is one of the most important natural hazards in the country.
- There are a considerable amount of populations around the rivers and streams with this features.
- At the same time, this populations presents a high vulnerability level and low chances of recovery.

Figure 2. Tapartó river after the disaster of 1993.

3. OBJETIVES AND METHODS

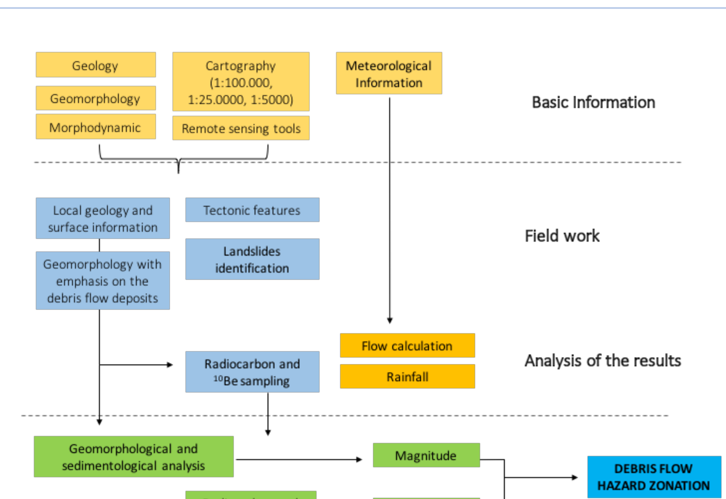

Figure 3. Methodological outline.

RESULTS

4.GEOMORPHOLOGY AND COSMOGENIC NUCLIDE ANALYSIS (RADIOCARBON AND ^{10}BE)

LA ARBOLEDA STREAM

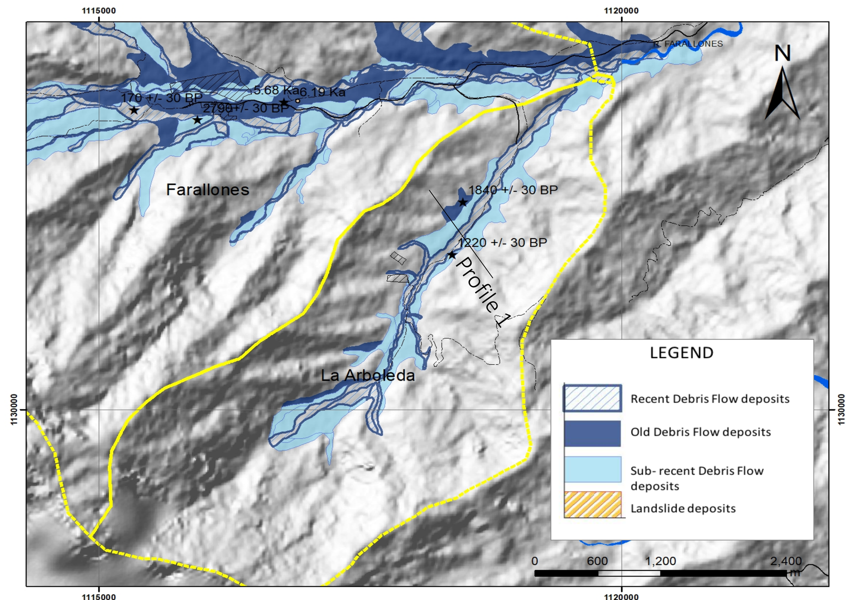

Figure 4. Geomorphological map of the debris flow deposits, with a relative age based of field work analysis and the radiocarbon ages obtained.

Figure 5. Main characteristics of the debris flow deposits in the La Arboleda watershed.

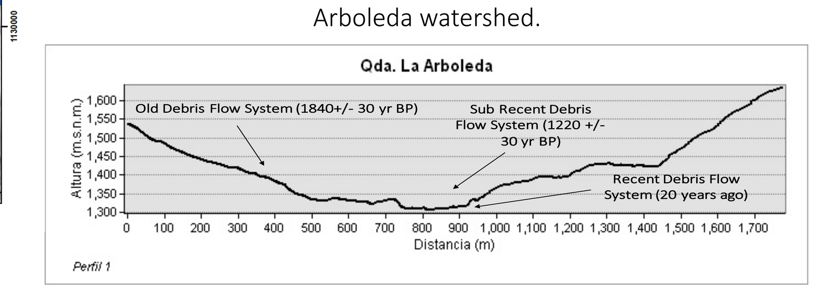

Figure 6. Profile 1 (NNW-SSE).

FARALLONES RIVER

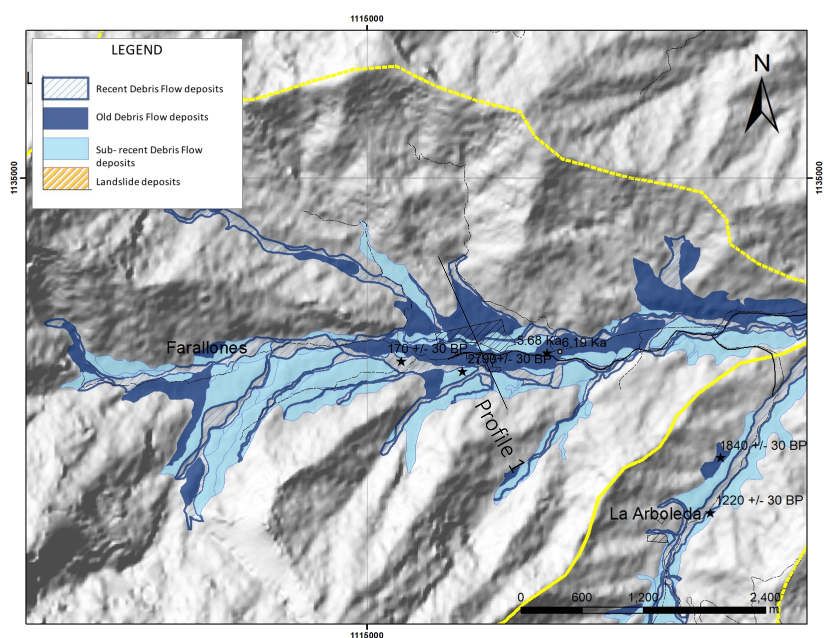

Figure 7. Geomorphological map of the debris flow deposits, with a relative age based of field work analysis and the radiocarbon and ^{10}Be ages obtained.

Figure 8. Main characteristics of the debris flow deposits in the Farallones river watershed.

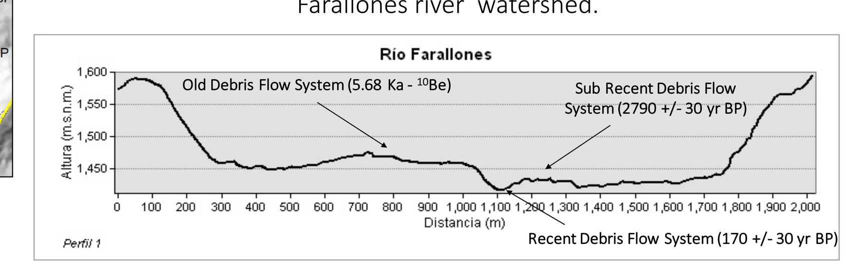

Figure 9. Profile 1 (NNW-SSE).

TAPARTÓ RIVER

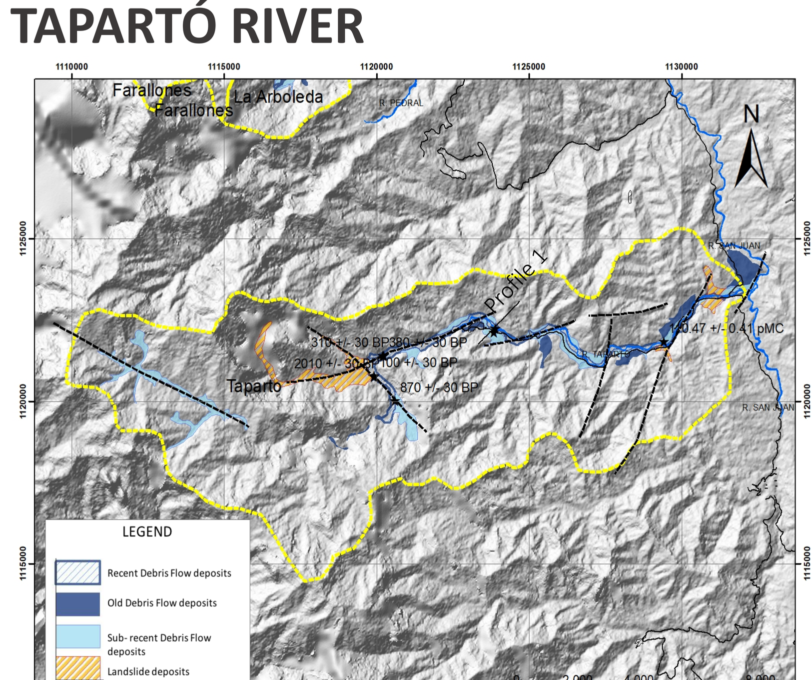

Figure 10. Geomorphological map of the debris flow deposits, with a relative age based of field work analysis and the radiocarbon ages obtained.

Figure 11. Main characteristics of the debris flow deposits in the Tapartó river watershed.

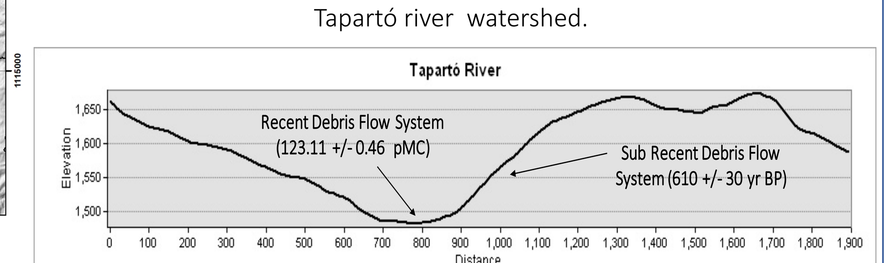

Figure 12. Profile 1 (NNW-SSE).

Outstanding questions

- What are the main features of debris flows in tropical basins?
- How geomorphological methods can support the hazard assesment of debris flows in development countries?
- Are the oldest ages indicating a climate changes including a glacial influence along the quaternary? or are they indicating a strong dynamic related with the erosion in young watersheds?

6. DISCUSSION

- The watersheds in general, present a similar geological and hydrological conditions and are separated by less than 50 km; however, they are showing important differences between the debris flow dynamic, so the first hypothesis is associate this variances with the agents that are unique in each watershed, like the structural conditions and the morphometric parameters. Both are controlling in a significant way the dynamic of the debris flow and favours the deposition or the flow in some different places of the channel.
- The Tapartó river is showing an important structural influence and a relationship between the places with photo-geological structures and the places with an important deposition of debris and also with the places with a high hazard level. However, is necessary determine if this behavior could be more significant that the geological or geomorphological variables in other watersheds.
- The ages obtained can be associated with the different stages or depositional systems, however it is necessary the correlation between those ages and the geomorphological features of the deposits. The Tapartó river shows a really complex debris flows dynamic and presents several historical and relevant hazardous events, nevertheless in relation with the Farallones watershed, is having a less extension and development. Suggesting that the Farallones watershed is older or it has a debris flow dynamic with an external agent like a glacial influence, given that the watershed is close to a 4021 m peak, which today is object of study for the determination of the glacial presence during the Last Glacial Maximum (LGM). This hypothesis has to be developed in a detailed way, because even though the deposits in this zone are suggesting an important event, this is not evidenced in other closer watersheds and there is not information yet about the behavior of the LGM in this part of the world. So the oldest ages obtained with 10Be are consistent for the depositional system dated but they could be related too with a young geomorphological system with higher erosion.

6. CONCLUSIONS

- Our observations support the existence of three morphodynamic stages related to debris flow dynamics: (1) **"old" stage** with deposits older than 2000 ^{14}C yr BP, including the ^{10}Be ages (5.68 and 6.19 Ka). In this stage we can determine that the hazard is Low.
- (2) **"sub-recent"** stage represented by deposits of age between 1200 and 2000 ^{14}C yr BP; and it is related with a moderate hazard level.
- (3) **"recent"** stage, with lowly incised deposits and ages that do not exceed 1200 ^{14}C yr BP, and a high hazard level.
- Sometimes it is possible to find differences in the rates limits in each watershed for the defined stages, due the geomorphological and field work relationships.
- Although basins studied have evidenced debris flow events of relatively high magnitude, our analyses suggest a decrease in magnitude during the last 1000 years.
- The ages allowed to establishment the calibration between the geomorphological features of the deposits with temporality, with the purpose of having the hazards levels according with the debris flow dynamic evidenced in each watershed.

7. FUTURE WORK

In the future, the main idea is applying the exercise in watersheds with different geological and hidrological features and try to establish which variable is playing a key role in the debris flow dynamic in tropical basins.

ACKNOWLEDGMENTS

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