DOUBLE-DATING APPLIED TO PROVENANCE STUDY IN ACTUAL RIVERS IN THE FOOTHILLS OF THE EASTERN CORDILLERA, COLOMBIA.

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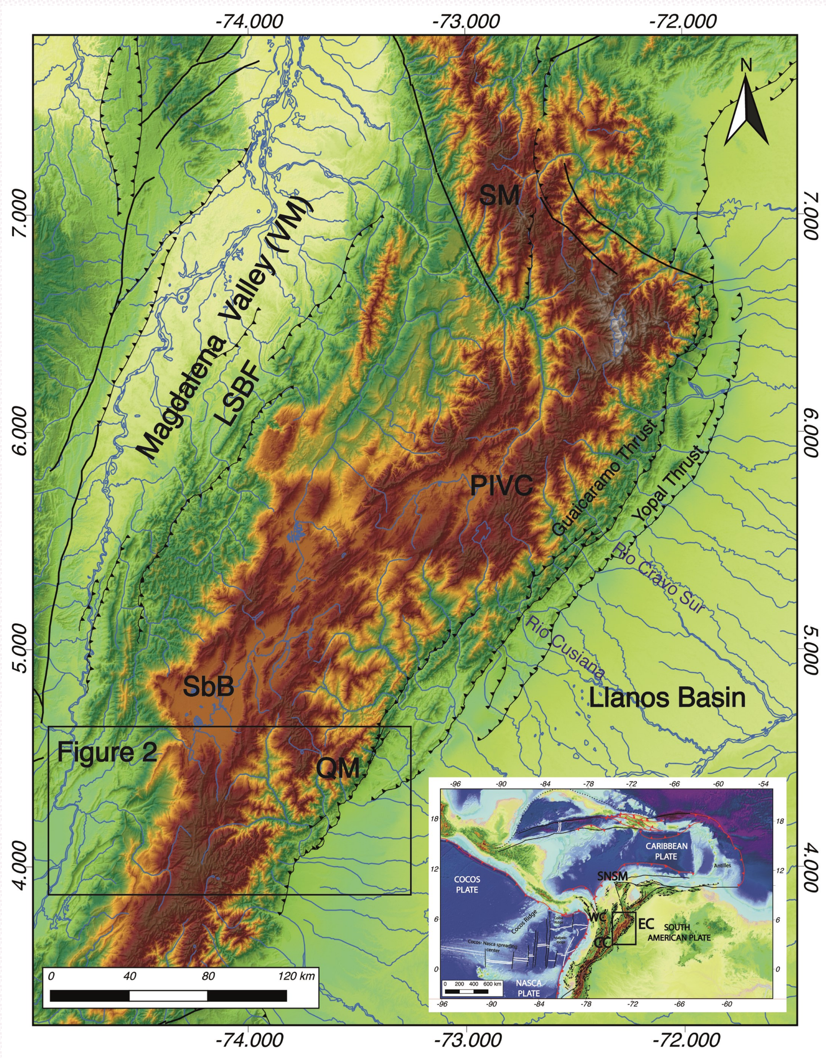
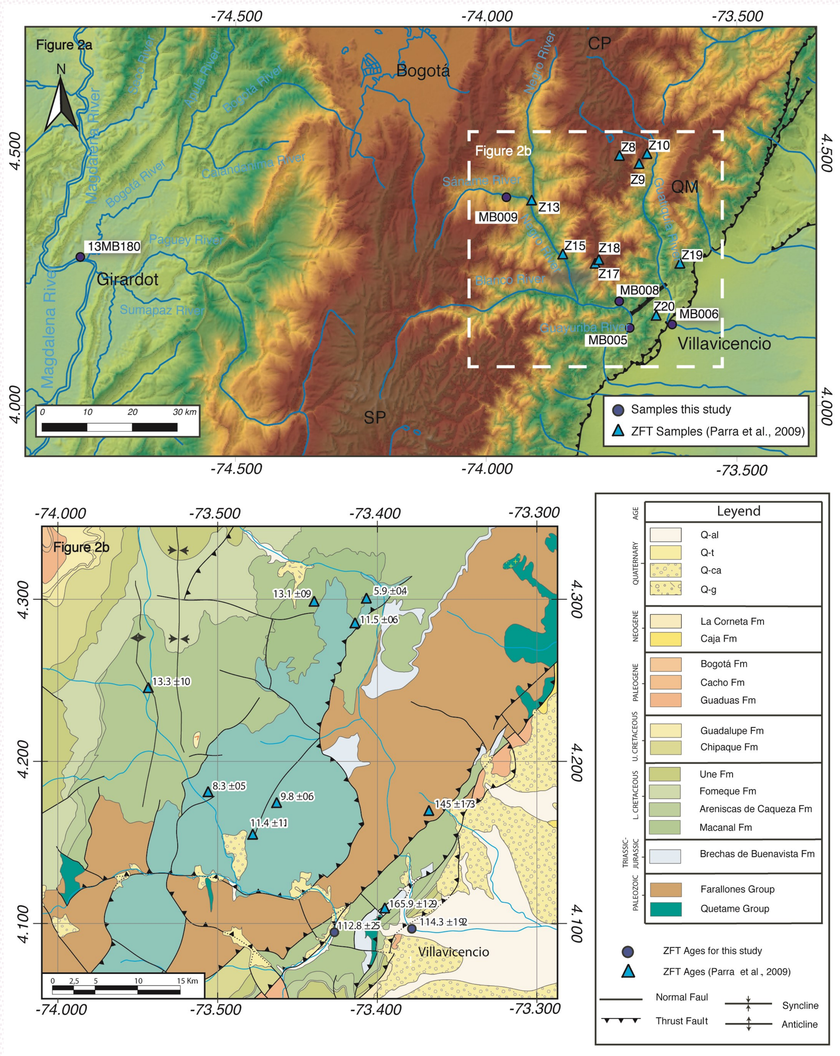
INTRODUCTION

The combination of different thermochronologic techniques on the same samples or even the same grains has become in a useful tool, to establish a complete history of the geological process that has controlled a rock, and for gaining information on sediment provenance and the exhumation of sediment source areas. Determination of crystallization and cooling ages of detrital zircon from modern river sediments is a powerful method for tracing sediment provenance and exhumation of orogenic mountain belts.

In this work we explain with new examples of modern river samples from the Colombian Andes how zircon fission-track (ZFT) and U-Pb dating can be used in provenance studies to better understand the temporal association between source and depositional site and how the evolution of orogenic mountain belts from such data in a setting where large amounts of sediment are recycled from sedimentary source rocks and volcanic input may complicate the exhumational signal (e.g. Jourdan, et al., 2013; Carter & Moss, 1999). Whereas the ZFT data provide information about the most recent thermal history and exhumation of the source rocks, they are complementary to U-Pb data which reflect the original zircon crystallization age and its ultimate provenance.

The study contains data of detrital zircon U-Pb and zircon fission-track dating from modern river sediments of the Guatiquia and Guayuriba rivers in the eastern foothills of the Eastern Cordillera, and the Magdalena River at Girardot on the western flank of the Eastern Cordillera. Each individual dating technique offers unique information with respect to provenance and exhumation.





GEOLOGICAL SETTING

The geology of Colombia is characterized tectonically and morphologically by the stable Precambrian basement of the Amazon Craton in the eastern part of the country, and the highlands of the Andean Belt with its three Cordilleras separated from each other by intermountain valleys. Rivers such as the Bogota River drain the Eastern Cordillera to the west into the Magdalena River. The Magdalena River is one of the most important drainage systems of the Northern Andes, as it crosses Colombia from south to north for over 1000 km, collecting all tributaries coming from the western flank of the Eastern Cordillera, the eastern flank of the Central Cordillera, and further downstream the western Cordillera at the confluence with the Cauca River near Magangué.

On the east side of the Eastern Cordillera, the drainage configuration is different. The rivers run from the foothills across the Llanos basin in a west to east direction, to ultimately join either the Orinoco or the Amazon Rivers. The Guatiquia and Guayuriba rivers are two of the most important tributaries of the Meta River, part of the Orinoco drainage basin. With their springs in the Paramo de Chingaza and Sumapaz in the Eastern Cordillera, they drain Precambrian (Garzón massif), Paleozoic (Quetame massif), as well as Cretaceous sedimentary cover rocks (Urueña et al., *in press*).

The uplift, exhumation and deformation history of the Eastern Cordillera involved the drainage and sedimentary basin evolution of the Llanos foreland, limited by the Guaicaramo fault system (Mora, *et al.*, 2008). The evolution of the Eastern Cordillera as a highland started during the middle Eocene to Oligocene, and intensified during the Miocene-Pliocene after tectonic inversion (Colleta, *et al.*, 1990; Cooper, *et al.*, 1995; Mora, *et al.*, 2006; Sarmiento-Rojas, *et al.*, 2006) of preexisting Jurassic and Early Cretaceous graben structures and mid-crustal low-angle detachment faults (Dengo & Covey, 1993; Mora *et al.* 2009).

The initial surface uplift was probably moderate, but since the Oligocene, the rise of the Eastern Cordillera blocked the arrival of zircons derived from the Guyana shield to the hinterland interior. This dramatic change in the local topography caused a shift in sediment provenance of sedimentary units deposited in the intermontane Magdalena River basin (Horton, *et al.*, 2010; Nie, *et al.*, 2010), which developed between the Central and Eastern Cordillera since the Eocene.

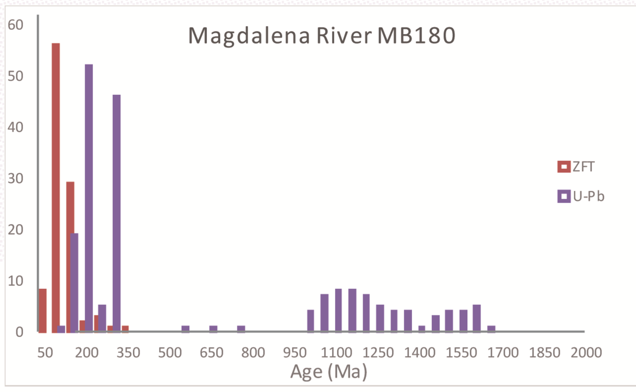
RESULTS

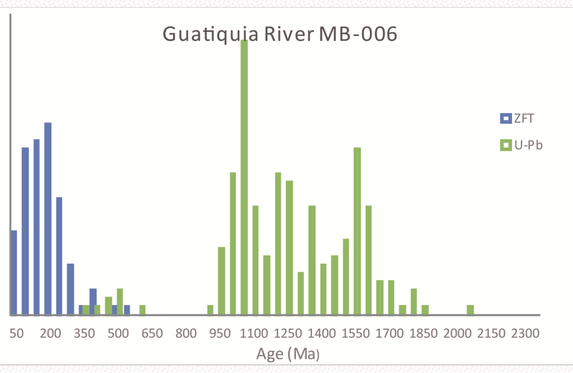
Detrital zircon U-Pb ages of modern river sands from the eastern flank of the Eastern Cordillera show a distribution between 830 to 1830 Ma .

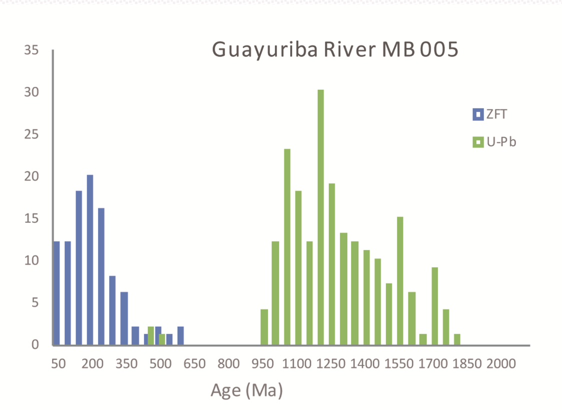
Detrital zircon age spectra from from our Magdalena River sample is markedly different, represented by four populations separated in two broad age ranges: the first range is represented by peaks between 156.76±0.45 Ma and 268.56±0.9 Ma, and the second range is represented by peaks between 1068.9±4.8 Ma and 1483.6±6.5 Ma .

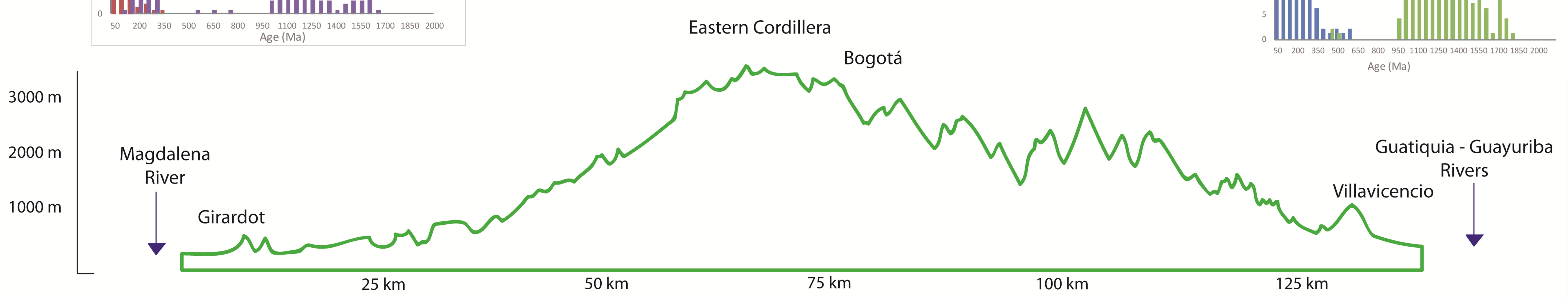
Fission-track ages obtained for the Guayuriba and Guatiquia samples) show a similar grain age distribution between from 8.8 to 530.1 Ma and 19.4 to 476.0 Ma,

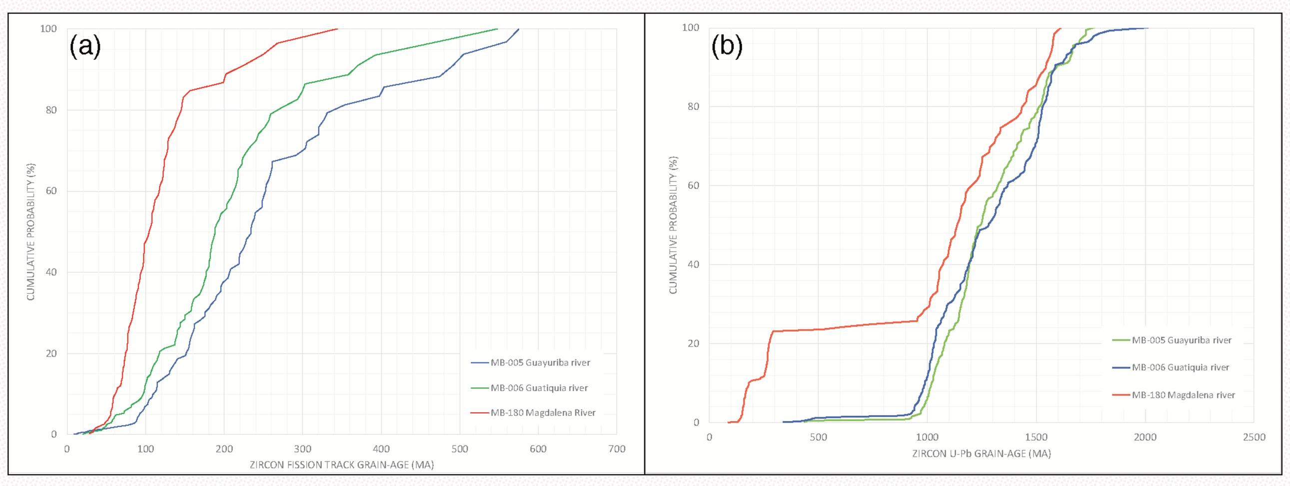
The Magdalena River sample shows an age range from 28.1 to 327.9 Ma with 36.3% dispersion

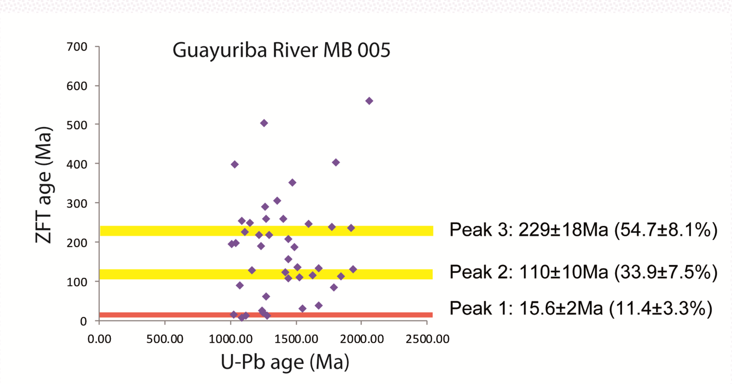


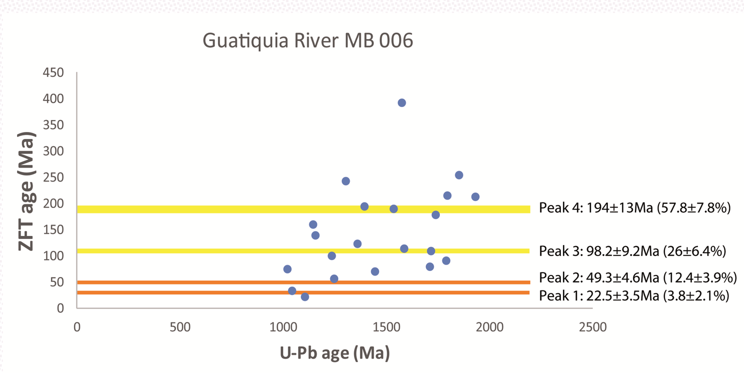












DISCUSION AND CONCLUSIONS

The combination of U-Pb and ZFT data presented here allow us to make first-order observations about the provenance signals in modern rivers on the east and west flanks of the Eastern Cordillera, close to the Villavicencio and Girardot areas. On the east flank of the Eastern Cordillera, our data clearly show that the zircon U-Pb age spectra of the Paleozoic through Mesozoic sedimentary section being eroded are related to sources in the Amazon Craton. On the other hand, the Magdalena River sample indicates the presence of these same Eastern Cordillera sources plus the addition of younger Permo-Triassic and Jurassic zircons derived from the reworking of Upper Magdalena Valley sedimentary units and/or the crystalline basement of the Central Cordillera

Using Kolmogorov-Smirnov (KS) statistics we compared the grain-age distribution between Guayuriba River and Guatiquia River samples, which are very similar and in contrast, the Magdalena River sample shows that the grain age distributions are significantly different. The Magdalena River sample detrital zircon U-Pb data reflect the zircon U-Pb ages of the upper Magdalena River drainage basin, which covers the western flank of the Eastern Cordillera and the eastern flank of the Central Cordillera. The graphic shows the differences between the detrital zircon age distributions found in the rivers on the east flank of the Eastern Cordillera and those the west flank, as represented by the Magdalena River, thus denoting the influence of the sediments of the Central Cordillera

The modern river detrital zircon U-Pb spectra of the Guayuriba and Guatiquia river samples indicate that the formation of the Eastern Cordillera, which has been forming since the Eocene, is not detectable in the zircon U-Pb record. These zircons are simply recycled from the sedimentary cover units or sourced from the Precambrian basement; however, no zircons with U-Pb ages reflecting the Eastern Cordilleran orogenesis exist. This interpretation is complemented by CL images showing zircons with internal oscillatory zoning related to primary magmatic sources and recrystallized edges due to ancient metamorphic events.

The ZFT data presented here complement the existing record of recent exhumation for the Eastern Cordillera determined based on the dating of bedrock samples, thus indicating that moderate exhumation rates occurred over the last 20 Myr and verifying the asymmetric nature of the surface uplift occurring across the length of the Eastern Cordillera fold-and-thrust belt.

The detrital zircon FT peak ages can be used to estimate the long-term average exhumation rates within the drainage basins, assuming a monotonous cooling history, using the age2edot software of Brandon (see Ehlers, et al., 2005). Zircons with apparent Miocene cooling ages from the fastest exhuming areas in the Eastern Cordillera indicate exhumation rates on the order of approximately 0.3-0.4 km/Myr

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