A review of Holocene climate-change signatures of SW Antioquian region. Northwestern Colombian Andes

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PREFACIO

El siguiente trabajo se compone de un artículo investigativo titulado: *A review of the Holocene climate-changes signatures of SW Antioquian region. Northwestern Colombian Andes*, a ser publicado en el Boletín de la Universidad Industrial de Santander. Este trabajo se realizó con el apoyo del convenio ECOS-NORD.

Anexo 1 Geodatabase
Anexo 2 Base de Datos Bibliográfica.
Anexo 3. Tabla de cálculos cosmogénicos

TABLE OF CONTENTS

A review of the Holocene climate-changes signatures of SW Antioquian region. Northwestern Colombian Andes

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ABSTRACT

The climate changes have been present along the geological time, registered in palynomorphs, stratigraphy, and radioactive isotopes. Here we review the signatures of those changes in the Northwestern Colombian Andes, specifically from the Belmira and Frontino pàramo, and the San Nicolas fluvial terrace, comparing them with global scale events. The aim of this study consists in the review of data as a proxy for paleoclimatic reconstructions and potential relationships with timing control of climate-triggered hillslope deposits. These data like temperature, precipitation, organic material (OM) and the torrential events, which allow us to propose a regional climate framework for the ^{10}Be calculated ages in some debris flow deposits close the Farallones del Citará, in western Cordillera of Colombia. Comparing local and regional records of paleoclimatic events after the Pleistocene- Holocene transition show a directed relationship between warm and humid periods with the increasing of the Andean forest and torrential events dated at 8k ^{10}Be, 6,77K ^{10}Be and 6,22K ^{10}Be.

Keywords: Palynomorphs, Paleoclimate records, Terrestrial Cosmogenic Nuclides, Hillsope deposits, Farallones del Citará.

1. INTRODUCTION

Along the last few million years the climate of the planet has changed into cold and warm, also called glacial and interglacial ages, inside the glaciations have shown colder average temperature (on the order of 3 degrees below actual mean temperature) (Burrows, 1979; Clapperton 1981). This phenomenon happens as a consequence of changes on the Earth's orbital parameters, with a roughly duration from 400.000 years to 22.000 years BP (Feng and Bailer-Jones, 2015; Delcourt and Hazel, 1993; Hays et al., 1976).

There are different shorter cyclic oscillations as millennia, centuries, decades or even years, which are registered along with the whole paleoclimatic history. These records have been studied through different environments such as lacustrine sediment, marine or ice cores, growth rings on trees, among others (Hooghiemstra, 1984; Kuhry, 1988; Melief, 1985; Monsalve, 2004; Muñoz *et al.,* 2009; Van der Hammen, 1973).

Until now, the most used indicators and techniques are: palynomorphs studies, stratigraphy, geochemistry and radioactive isotopes, in combination with dating techniques. During the last few years, the study of the paleoclimatic history, has became an important target of significant research around the world, because it becomes a key to the oncoming climate behavior, its conditions, and some events as glaciations, deglaciations, floods, droughts, and debris flow (Nishiizumi et al., 1989); being these the reasons of infrastructure and economic losses (including human lives) (references! For example…Stromberg, 2007; Petley, 2012, Lima, et al., 1991; Alcántara-Ayala, 2002; WorldBank, 2011). Here we use the ages given by the terrestrial cosmogenic nuclide (TCN) for the first time in debris flows deposits in the

Farallones watershed, to use them a proxy for the paleoclimatic history together with the available database along the Western Cordillera and the Cauca River in the vicinity of the Antioquia department (FIGURE 1).

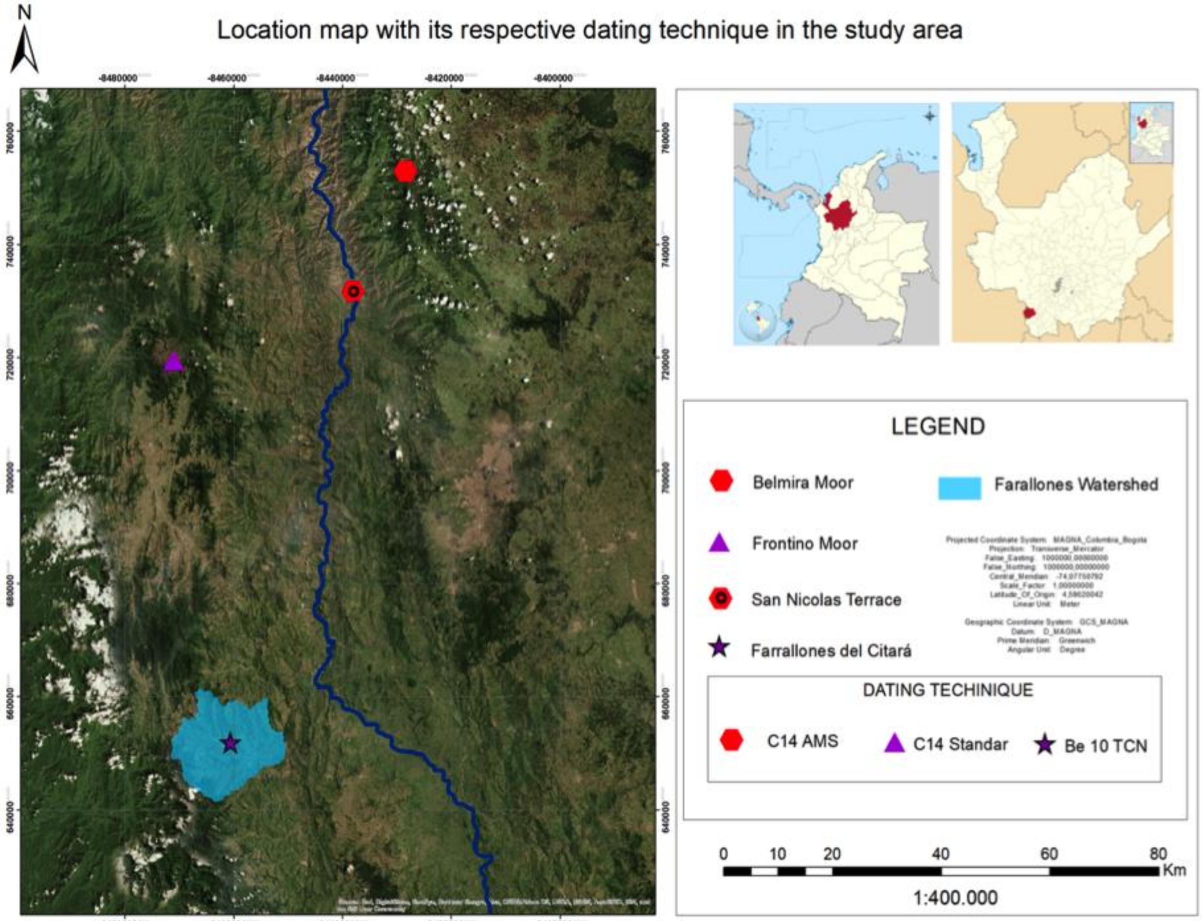


FIGURE 1. Location map with its respective dating technique in the study area (Farallones de Citara) en Cordillera Central y occidental.

2. CONCEPTUAL FRAMEWORK

As a starting point, we need to be clear about the differences between weather and climate, because they can be confused by their similarity and mutual relationship; both of these have specific characteristics, and the phenomena caused because of their change as debris flow and landslides (Figure 2). Below we explain the main differences.

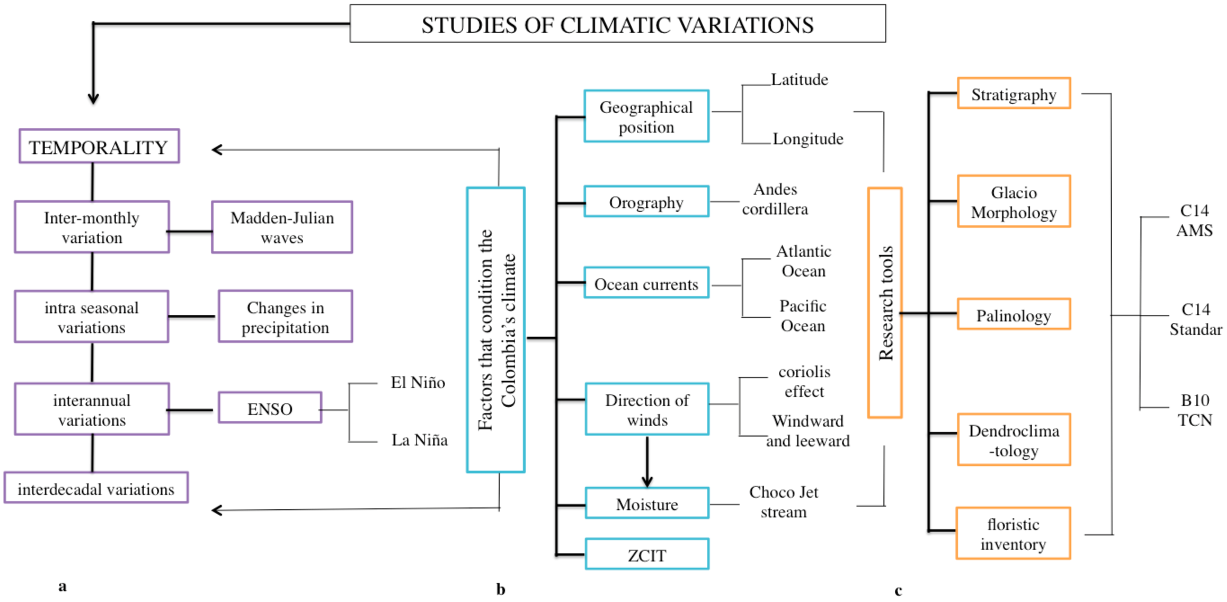


FIGURE 2. Study flowchart for climatic variations: (a) Temporality and recurrence of climate changes and their origin (b) Factors that condition the Colombia's climate (c) Researching tools for the study of paleoclimate.

2.1. Climate

The climate is the combination of the current meteorological components, temperature, humidity, wind direction and speed, amount and type of precipitation, evapotranspiration, sunshine hours, condensation, cloud cover, etc, at a global or regional scale. The climate describes the long term (i.e. >30 years) and average weather conditions for a specific region (Poveda, 2006). Examples: maritime climate, cold-dry desert climate, tropical climate. Global climate classification maps highlight the high variety of climates (FIGURE 2a). The climate is composed of different components and factors and these are dynamic and change permanently.

For the SW Antioquian region, the climate is characterized for the elevation of the Andes. The cold climate is present between 2,000 and 3,000 meters (6,562 and 9,843 ft) above sea level and is characterized for having Andean mountainous forest. This altitudinal zone is characterized for presenting an average temperature ranging between 10 and 17 °C while rainfall reaches a yearly average of 2,000 mm. The Paramo condition (i.e. special humid forest) are present between 3,000 and 4,000 meters (9,843 and 13,123 ft) above sea level and the temperature is lower than 10°C with icy winds, rare rainfall but frequent snowfall (Poveda, 2006).

2.2. Weather

The weather is defining a short time period up to several days and its conditions are defined during a defined period from one up to several weeks. Weather condition is describing typical weather phenomena, such as a series of thunderstorm in hot summer, foggy month in autumn or other weather conditions, which are typical for a specific region and/or season (Escobar *et al*., 1992; FIGURA 2a).

For the SW Antioquian region depends on the location of the ZTCI, since this is responsible for two main rainy periods at year, although it is very frequent the foggy months and orographic rainfalls by the humidity brought by the CJ (IDEAM – UNAL, 2018).

2.3. Bond cycle

They are climate fluctuations that have occurred periodically every ≈1,470 ± 500 years during the Holocene. Eight of these periods have been identified, based mainly on fluctuations in the rocky debris transported by icebergs. The cycles of Bond can be the integrating equivalents of the Dansgaard-Oeschger cycles of the last ice age (Wanner *et al* 2011). The causes and determining factors of the cycle are under study, the main possible origins being variations in tidal cycles, solar cycles or reorganizations of the atmospheric circulation (Wanner *et al* 2011).

The existence of these cycles is well supported by the results of the study of the ice cores of the last glacial period. For the current period, the evidence is somewhat weaker. Bond (1997) maintains a periodicity close to 1470 ± 500 in the North Atlantic region, which results in a variation of the climate. In his opinion, many if not most of the Dansgaard-Oeschger cycles of the last ice age follow a pattern of 1500 years, as do the closest events in time, such as the small ice age.

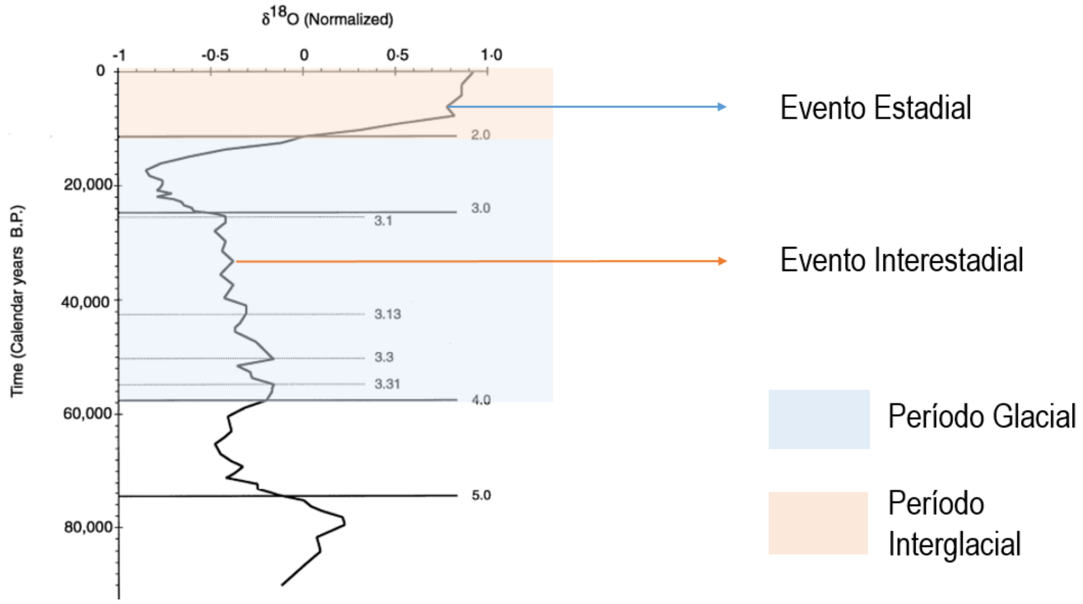


Figura 2. Periodos Glaciales e interglaciales con eventos estadiales e interestadiales (modificado de Renssen, 2009)

2.4. Debris flow

Debris flow as many others flows or mass movements involving water and sediments occurring on steep slopes in mountainous areas. These hillslope deposits (such as flood, solid transport, hyperconcentrated flows, mudflows, debris flows, Mars, granular flows, landslides, debris avalanches, etc.), may be hard to distinguish and need a detailed sedimentological and stratigraphical observations from the field (Coussot, 1996). Johnson and Rodine (1984) have described the most representative characteristics of debris flows as: "*A wall of boulders, rocks of all sizes, and oozing mud suddenly appear around the bend in a canyon preceded by a thunderous roar. As the boulder-choked wall passes, the channel remains filled with a debris-laden torrent of mud and boulders clanking and grinding together. The debris flows across an alluvial fan, engulfing structures and cars in its path, covering roads, fields and pastures with a blanket of muck, and slowly coming to a stop as the debris spreads in a lobate form with steep terminal snout and margins*." This kind of phenomenon obviously occurs in mountainous regions where the slopes are quite strong and have big amounts of precipitation in a small area, on different scales throughout the world (Coussot, 1996).

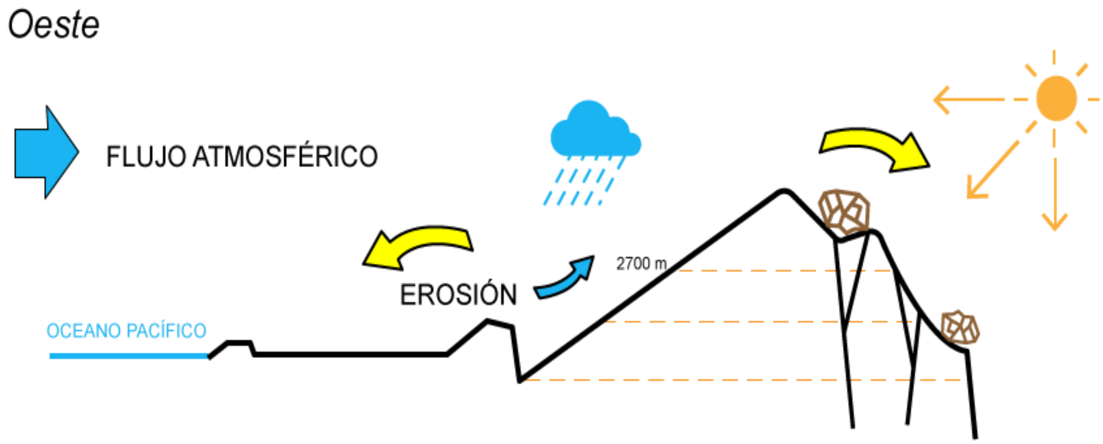
The debris flow, in general terms are phenomena which involve streams of water, mud, fragments of rock and debris in different proportions and sizes (Bloom, 1991) grouping a large number of flows, such as flows of mud and/or debris, avalanches, lahars, hyperconcentrated and super-concentrated flows, among others (Costa, 1988; Coussot and Meunier, 1996; Díaz-Onofre, 2008; Lavigne and Suba, 2004; Medina, 1991); characterized by its short duration, its unpredictable nature, in addition to its long periods of recurrence and an erratic spatial and temporal distribution (Durán et al., 1985; Parra, 1998; Piedrahita, 1996). Usually associated with watersheds that, due to their morphometric parameters (i.e. area-slope relationship), can be affected homogeneously by the same rain in the same period of time; Riedl and Zachar (1984) propose an area between 0.3 and 150 km^2 and González and Hermelin (2004) up to 300 km^2 for some wathersheds in the center of the country.

For the SW Antioquian region in the period between 1895 and 2014, there have been around 177 reported torrential events, in which, according to DAPARD records, 217 people lost their lives and millions of economic losses were generated. For the watersheds associated with the Farallones del Citará area, in the southwestern of the department, there have been numerous recent events of significant magnitude, the most recent of which occurred in the La Liboriana stream in the municipality of Salgar, on May 18 2018 Likewise, there are the debris flow of the Tapartó River in the municipality of Andes, in which two recent events of great magnitude have been presented, the first one on April 26, 1993, causing more than 120 deaths, around 320 victims and more than 1000 million pesos in losses (Piedrahita, 1996).

2.5. Timing of climate changes

According to Noller *et al*. (2000) the dating techniques for quaternary phenomena can be divided into four categories: numerical ages, calibrated ages, relative ages and correlated ages. The terrestrial cosmogenic nuclides (TCN), is a numerical age derivate from the accumulation of cosmic rays on the surface of rocks with production rates controlled by altitude, latitude, topographic shield, and burial depth (Gosse and Phillips, 2000; Kurz, 1986; Lal, 1991; Nishiizumi *et al*., 1986; Phillips et al., 1986). The concentration of the cosmogenic isotopes on the surface, whether from a rocky mass or from a deposit with the presence of blocks, is a morphological marker of the time that these have been directly exposed on the surface to the constant bombardment of cosmic rays (Lal et al., 1991).

Cosmic Ray Exposure (CRE) is a geochronological dating method that is based on the accumulation of Terrestrial Cosmogenic Nuclides (TCNs, such as ^{36}Cl, ^{10}Be, or ^{26}Al) in superficial rocks and/or landsforms (Bierman and Caffee, 2001). TCNs are produced within mineral lattice through nuclear reactions between the nucleus of the elements that form the minerals and the incident secondary cosmic ray particles derived from the high-energy galactic cosmic radiation (Gosse and Phillips, 2001); because the production rate of these in situ TCNs decreases exponentially with depth (Lal, 1991), their concentrations are directly related to the near-surface exposure history of the analyzed samples and allow determining the exposure ages of the sampled surfaces (Schwartz, 2016). With the analysis of ^{10}Be and ^{26}Al cosmogenic isotopes Agliardi et al., (2009), McCalpin et al., (2011), and McCalpin and Irvine, (1995), could get a better resolution of the deposits chronology; with all of this and others elements as geomorphology, sedimentology, seismic and meteorology, using them as a proxy, could get an average of the behavior of the climatic history (FIGURE 2c).



3. The study site: SW Antioquian region

3.1. Geodynamic setting

The configuration of Colombian Andes is composed for three different mountains belts (FIGURE 3): Western, Central and Eastern Cordilleras, where different kinds of rock as sedimentary, igneous and metamorphic. . (Kennan and Pindell, 2009; Restrepo-Moreno *et al.,* 2009; Restrepo and Toussaint, 1988; Taboada *et al.,* 2000). These belts were affected by collision events and rearrangement between lithosphere fragments of different scales (Duque-Caro, 1990; Restrepo-Moreno *et al.,* 2009). The romeral fault separates the Western and Central Cordillera and has been interpreted as a suture zone (Gómez-Tapias et al., 2015).

The Western Cordillera consists mainly of Cretaceous tholeitic basalt and deeep- water sediment facies resting on oceanic crust (Barrero, 1979). (Toussaint, 1978) Reported Ophiolitic rocks in the Baudó range in the Western Cordillera. The basement of the central cordillera consist of metapelitic and metavolcanic units permo-triassic (Cochrane et al., 2014a), with volcano-sedimentary cover ranging in age from jurassic to cretaceous (Spikings et al., 2015) and sediments Paleozoic to Tertiary age (Aspden et al., 1987). The Eastern Cordillera is composed by a metamorphic rocks and precambrian igneous rocks basement (Restrepo y Pace et al., 1997), with extensional basins covered for continental jurassic sediments and oceanic cretaceous sediments (Álvarez et al., 1979; Toussaint y Restrepo et al., 1996; Villagómez et al., 2011).(5)

This orogeny carries a remarkable weight in the climatic conditions of the country. The interaction of the trade winds circulation in big scale with the orogenic system makes huge climatic regions in the territory (IDEAM-UNAL, 2018). Because of this is possible to find rainiest zones in the eastern zone of the Eastern Cordillera and in the western zone of the western cordillera, this rain is a consequence of the humidity streams carried by the Chocó-Jet (CJ), which it is an important atmospheric feature of Colombian and northern South America hydro-climatology (Poveda, 2006). The CJ consists of a westerly low-level circulation over the eastern tropical Pacific that enters into the continent nearly at 5°N, carrying moisture from the Pacific Ocean to western and central Colombia (Arias *et al.*, 2015; Corredor, 2011; Poveda and Mesa 2000).

Otherwise, the precipitation in the interandeans valleys are less. This complex orogeny has uncountable valleys and mountains of different elevation above the sea level, which induces different kind of meso and microclimate. This also causes that the Colombian climate has so many altitudinal climatic zones from the Warm humid equatorial floor to the typical mountain glaciers mountain height (IDEAM-UNAL, 2018). It is important to consider that is not possible to study every microclimate as a separate and independent one from the other, because all of these have a direct interconnection through all the watersheds that mold the landscape (Velazquez and Hooghiemstra, 2013). Currently the study zone of this works, Farallones del Citará is characterized for its elevation above 3000 msnm and an average annual precipitation that is in the range of 2300 to 2368 mm/year and therefore this wasteland can be classified as wet (COROANTIOQUIA, 2014). Its geology is composed by rocky outcrops of monzodiorites and their residual soils of which are reached form very thin thicknesses by accumulation of weathered materials over time until the next episode of rains arrives and removes them, because of its strong slopes and heavy rains (COROANTIOQUIA, 2014).

3.2. Geomorphological features

In the Colombia’s territory the system of the Andes becomes into three different mountains belts (Ramos, 2009). This orography influences in a remarkable way in the climatic conditions of the country. The interaction of circulation systems large-scale trade winds and large systems orographies organize large regions climatic on the territory. Thus, it is possible find that the rainiest areas are on the eastern slope of the mountain range east and on the western slope of the western cordillera, while in the inter-Andean valleys the precipitations are minors. The complex orography also It comprises innumerable amount of valleys and mountains that induce a diversity of meso and microclimates (IDEAM – UNAL, 2018).

The orography also induces that diverse places and regions are at different heights above sea level. This generates, in turn, that the climate of Colombia has different altitudinal climatic zones that range from the humid warm equatorial floor until the snow-capped mountain glaciers (FIGURA 3).

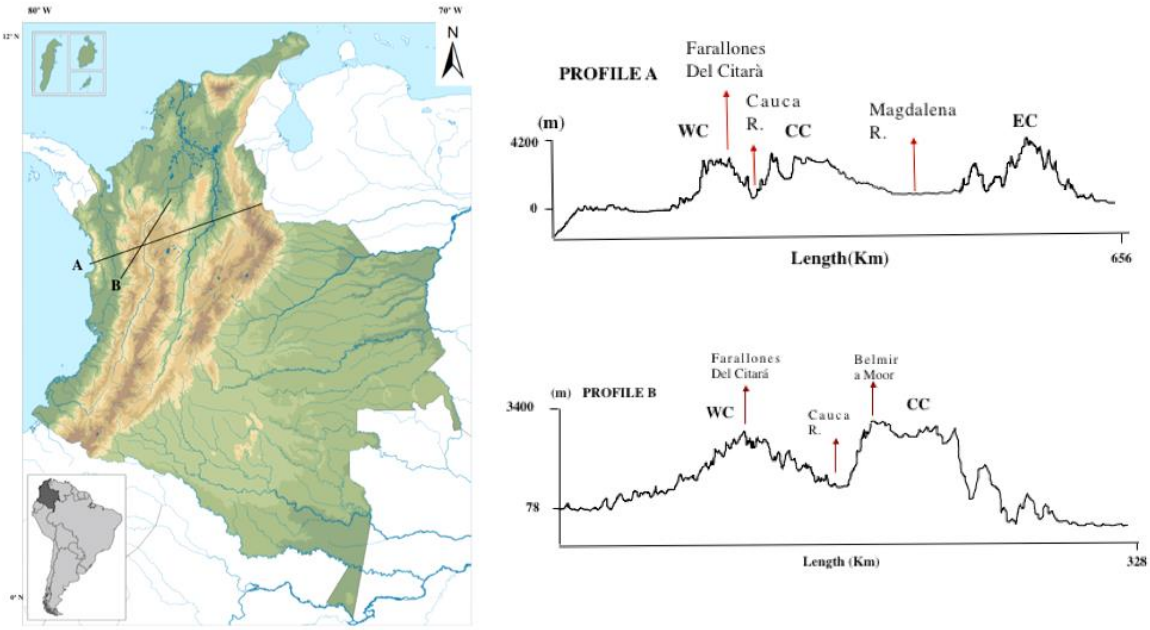


FIGURE 3. . Longitudinal and transverse topographic profiles across the Northern Andes. Longitudinal profiles of cordilleran massif display topography, maximum/minimum elevations, degree of fluvial incision (main rivers labeled in red arrows). Note that the WC exhibits the highest incision, followed by the EC and CC. The latter shows a bimodal character, with high incision in the central part and low incision (i.e., AP) in the northern portion. WC Western Cordillera, CC Central Cordillera, EC Eastern Cordillera.

In the eastern flank of the western cordillera, the humidity brought by the CJ, made of this zone, an area with heavy raining seasons that caused that all vestiges of the last glaciations have eroded and only a hanging valley located in the southern sector of the páramo (i.e. elevations above 3200 masl), which currently forms the lagoon of Santa Rita, about 110 m in diameter, apparently resulting from glacial abrasion of the rocks (COROANTIOQUIA, 2014).

IDEAM, (2010), indicate that the study zone is localized in high – middle mountain, which is characterized because it brings together the altitudinal culminations of the Andes mountain system, or areas of higher orogenic and therefore higher available energy and potential instability that is manifested in the transfer of materials to the low areas by hillslope processes (Figure 4). This macro-unit includes morphogenetic systems that were, or still are, affected by direct and indirect glacial and glaciar actions; It also includes the lower contact of the glacial models affected by instability linked to abrupt change of slope. Bioclimatically, this mountain classification corresponds to the bioclimatic flats of glacial, páramo and high Andean (IDEAM, 2010).

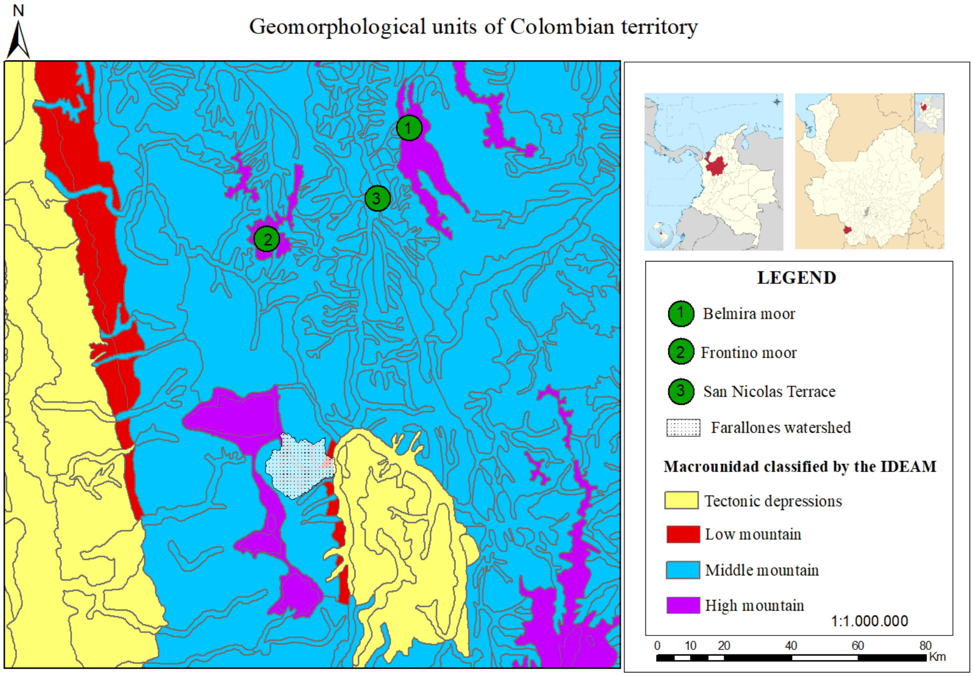


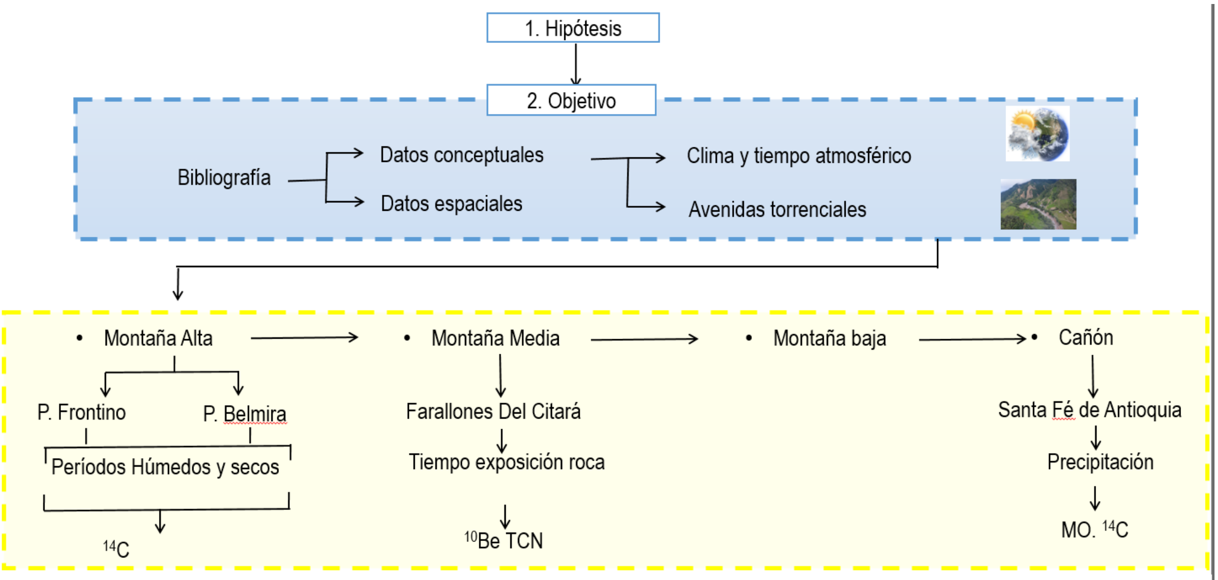
FIGURE 4. Position of the Farallones watershed in relation to the morphogenic systems of Colombia, Belmira (1) and Frontino (2) moor classified as high mountain sytem.

4. Methodology

The development of this work consists in the researching of existing data, that can be used as proxies that help the paleoclimatic reconstruction in the Northwestern Colombian Andes.

for this, strategic places were chosen as a regional study zone, Belmira páramo, Santa Fe de Antioquia, Frontino Páramo, Tatamá Farallones, which are located in the Central Cordillera, Canyon of the Cauca River, and Western Cordillera respectively, these data were published by different authors such as (Castro, 2011; Velasquez-Montoya, 2013; Velasquez, 1999) and for a local study zone Farallones del Citará.

In order to reach that, this work starts with the researching of different works as paleoecology and paleoclimatic reconstructions, which provides different paleoclimate information, particularly in the Western and Central Cordillera of Colombia, more specifically, in Belmira and Frontino moor and Santa fe de Antioquia (see Figure 1). After this, we do a data collection, where the counting of palynomorfs, florist inventory, and stratigraphy are the main target because these can be used as paleoclimate reconstructions proxies, for the easy development and creation of a data inventory (Author, data type and chronology technique) these were processed and saved in an Arcgis shapefile. These types of data are indicator of sedimentary environments, which helps the description of different processes that occurred in a certain place, and the dating technique locates them in the geological time helping to limit and be this investigation even more precise and future ones. After this, the collected date are saved in an attribute table, proceeding to the creation of a database that allows and helps the understanding of the paleoclimate in the Northwestern Colombian Andes (FIGURE 5).



Flujograma 1. Metodología implementada

FIGURE 5. Methodology applied the collection of results data for paleoclimatic reconstructions

Acoording to the methods explaned before, Terrestrial cosmogenic nuclides, the isotope choosen for the dating technique depends of the minerals target, and n this work, the dominant endogenous lithology of the bedrock (i.e. granitic rocks with high bulk quartz content) favored the use of the in-situ produced ^{10}Be cosmogenic nuclide within quartz and these exposure ages were calculated on Fri Jun 01 2018, using the online CREp calculator (Granger *et al.,* 2001). They are computed using the scaling scheme LSD (Lifton *et al*., 2008), with the ERA-40 (Uppala *et a*l., 2005), the geomagnetic record of Lifton 2016 VDM (Pavón-Carrasco *et al.,* 2014) and the production rates calibrated by Balco *et al*. (2009); Goehring *et al*. (2012); Gosse *et al*. (1995).

5. Results

5.1. Paleoclimatic records

Belmira and Frontino paramo next to San Nicolas terrace were choosen as strategic places to understand the variations in the upper part of the northwestern Colombian Andes, so it was decided to create a database using ArcGis version 10.5® for the registration and easy access of this information. Table 1 shown a representation of the attribute table of the contained information.

TABLE 1. Paleoclimatic data collected with their respective authors and study sites.

Study Area	Coordinates	Ages	Author
Belmira moor	6º42’07,88’’ N y 75º40’50,74’’ W	Accelerator Mass Spectrometry (AMS) technic shows that the climate between 34875 cal yr BP and ~17000-12000 Cal yr BP as wet and cold time; and The period 12000-11092 cal yr BP) is a gradual warming time.	Velasquez-Montoya, 2013
Cauca River	San Nicolás Terrace 6,5º N and 75, 5º W	6054 - 3986 Cal yr BP with gelled phytoclasts; 3986 - 2613 Cal yr BP with altered phytoclasts; 2613 - 2355 Cal yr BP with pole; 2355 - 1252? Cal years BP translucent phytoclasts; 1252? - 241 Cal yr BP with altered phytoclasts; 241 - 149? Cal yr BP with a decrease of translucent phytoclasts.	Castro, 2011

Frontino moor	6° 29' N and 76° 6' W	Method C14 7500 yr BP, 7180 yr BP, 2930 years BP, 1459 years BP.	Velásquez, 1999
Farallones del Citará	5º 46' 00" N and 76º04'00'W	Cosmic Ray Exposure 10Be, 8000 yrs, 6730 yrs, 6220 yrs, exposed rock ages.	Perez *et al.,* 2018

Taking into account the high, medium and low mountain system as a connected one, it is feasible to think that the processes that happen in high mountain are registered in medium mountain and consequently in low mountain therefore, it is necessary to review not only the upper zone of the Andes, but also the canyons, as illustrated in (FIGURE 8) the percentage of MO is related to the fluvial influence of the adjacent watersheds.

Paleoclimatic registers from the Belmira moor range between 34,875 cal years BP and the discordance is estimated to cover part of the Pleniglacial period. Cold conditions between 34,875 cal years BF and 15,000 cal years BP with a similar average temperature to the current one. Some dry pulses in the end of the period between 15,000 cal years BP and 12,646 cal years BP were the dominant climatic characteristic were cold and humid. Warm and humid conditions between 12,464 cal years BP and 11.092 cal years BP. The páramo vegetation dominated in the surroundings, but in some points, it had similarity with the current landscape; on the other hand, the period (12,000-11,092 cal yr BP) marks the beginning of the Holocene and there were drastic changes in climate and vegetation registered there. The lagoon, until its own edge, was surrounded by Andean forest and the páramo was restricted to small refuges in the highest parts of this mountainous massif (Velasquez-Montoya, 2013, FIGURA 6).

The explained ages for the Frontino moor register that in the part of the Western Cordillera, the period between 13000-12900 cal years B.P., represents the final phase of a warm and relatively humid time; the period between 12900-12100 cal years B.P. It's a cold and humid phase in which the forest line descended to 3150m. and the minimum temperature was 1.8 ° C below the current one. The period between ca.12100-11300 cal B.P. it's mainly warm but interrupted by a dry cold pulse. The period between 11300- 10200 cal B.P. represents a cold and humid period, the average temperature could have been about 3 ° C below the maximum of the previous zone and almost 2 ° C below the current. The period between 10200- 9500 cal B.P. goes from a cold period to a dry and warm one; in the period between 9500-9100 cal B.P. there is a short change in the decreasing of the temperature and increased moisture; and the period between 9100-7100 cal B.P. It is characterized as a warm phase in which the Andean forest covered the entire upper part of the mountain range (Velasquez, 1999, FIGURA 7).

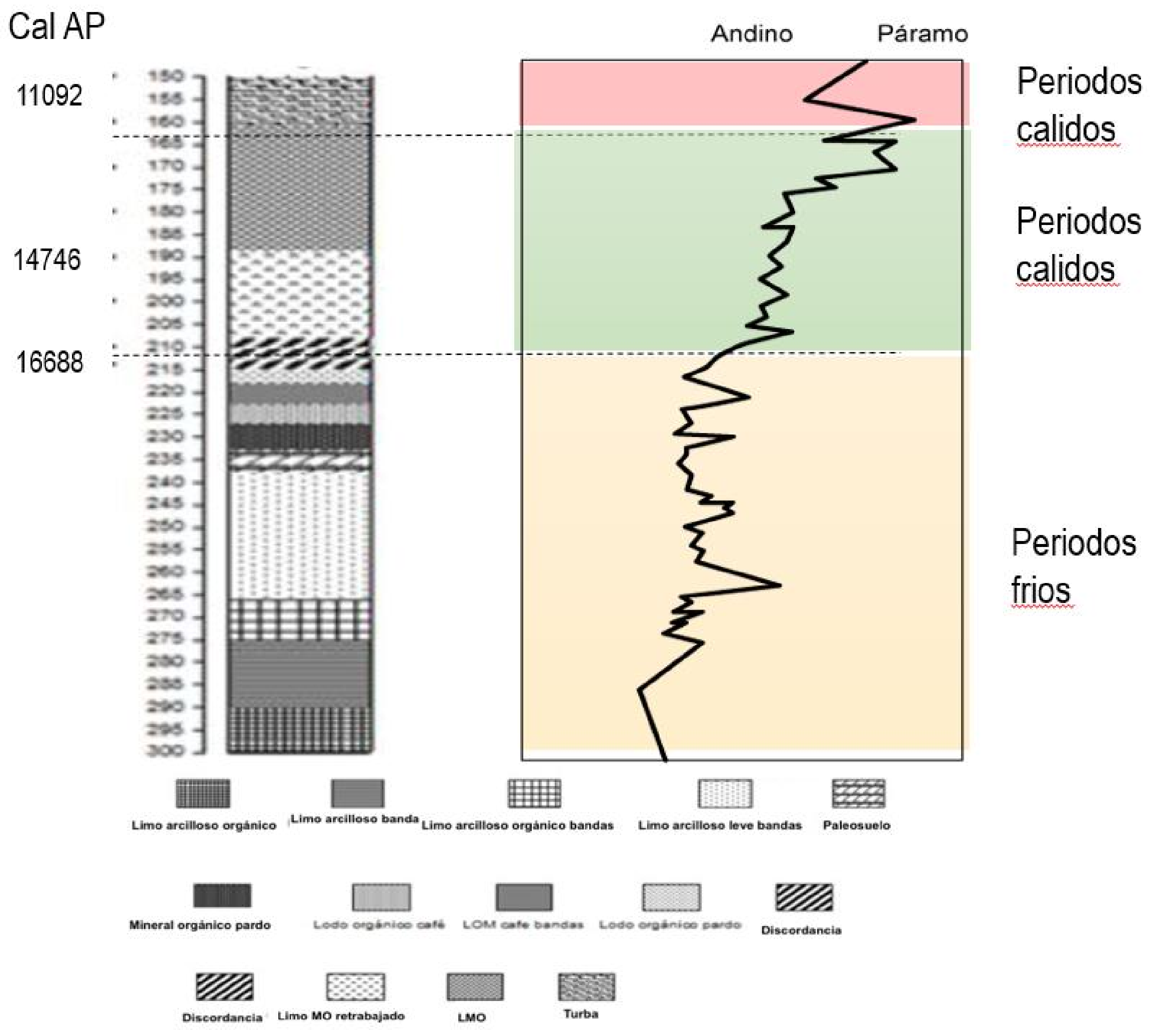


FIGURE 6. Results of chronology, stratigraphy and sum of ecological groups delivered by the palinogram taken from Velasquez-Montoya, (2013)

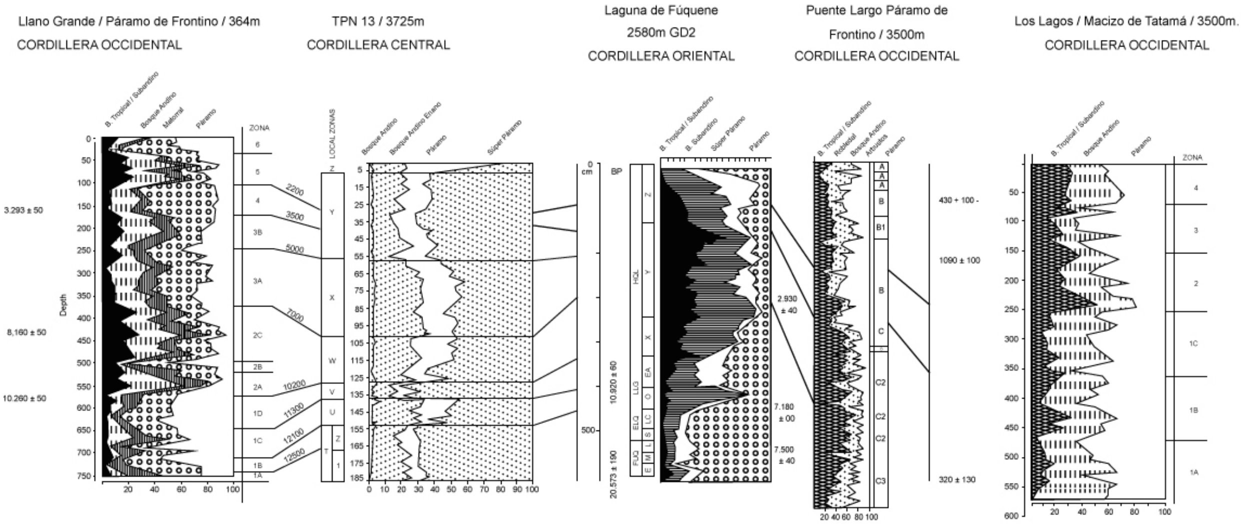


Figura. Correlación de los registros polinicos de los núcleos Llano Grande, Puente Largo y Los Lagos de la Cordillera Occidental; T P N 13 Cordillera Central y Laguna Fúquene, Cordillera Oriental, basada en 12 fechas de radio carbono.

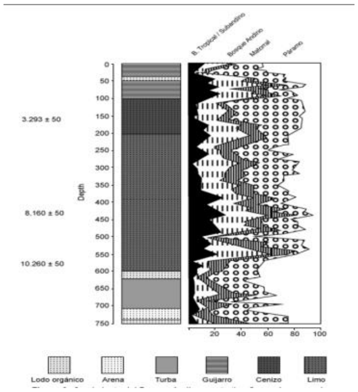


FIGURE 7. Correlation of pollen nuclei Llano grande, Puente largo and Western Cordillera lakes; TPN 13 Central Cordillera and Fuquene lake, Eastern Cordillera with 12 C14 ages taken from Velasquez et al. 1999

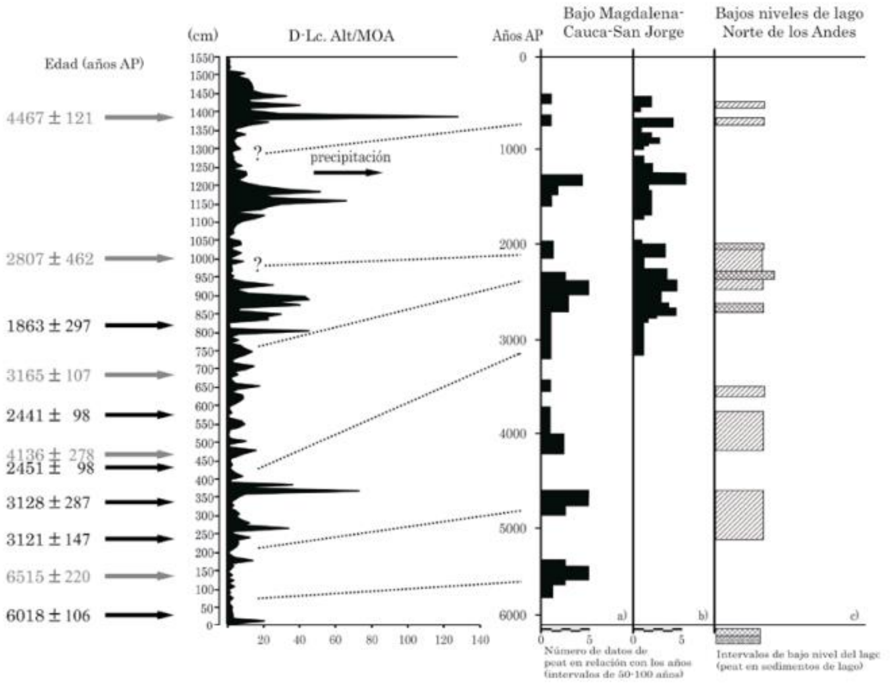
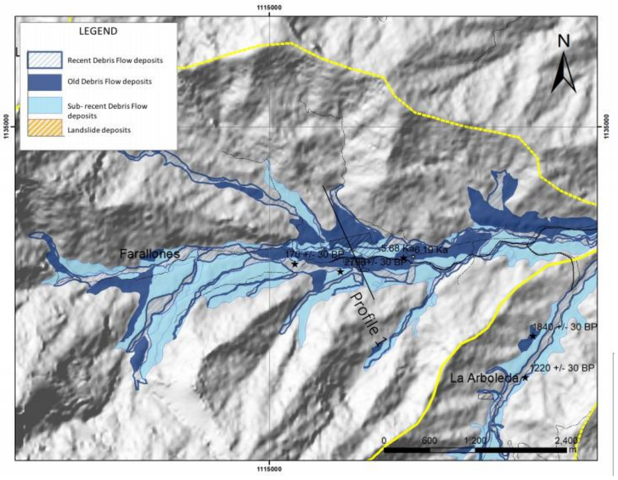


FIGURE 8. Relationship in the periods of inferred drought in the terrace of San Nicolas, with the registry of the basin of the low Magdalena- Cauca- San jorge, and with periods of low level of the lakes of the Andes. From left to right: ages in years BP (in gray ages attributed to reworking), relationship D-Lc. Alt / MOA, layers of peat in the lower Magdalena-Cauca-San Jorge taken from Castro, (2013)

The Northwestern Andean Cordillera is a tropical mountains belt, which its vegetation changes with its height because this is linked with the temperature and the geomorphology of each place (Hooghiemstra & Van der Hammen, 2004), also depends of every taxa adaptability (Velasquez-Montoya, 2013, FIGURE 8).

5.2. Debris flow deposits chronology

Cosmogenic nuclides are produced in the atmosphere and in mineral grains near the ground surface as the product of nuclear reactions induced by these cosmic rays (Lal and Peters, 1967) what indicated that before the ages calculated, the rock was not accumulating isotopes, that means, that was covered.



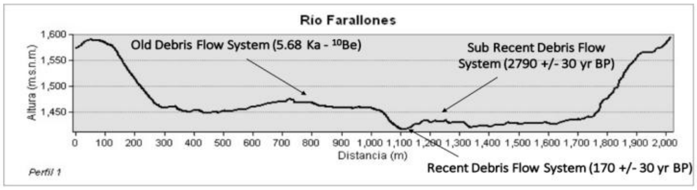


TABLE 2. Concentration of Be10 on rocks and calculated ages

Measured ^{10}Be concentrations table 2 shows the sample 16-FAR-04 as has been exposed to the accumulation of isotopes more time, indicating a different event from the samples 16-FAR-01 and 16-FAR-02 Although you have different ages, it can be inferred that they were affected by the outbreak of the same weather that predominated at that time

5.3. Cauca River Deposits

The San Nicolás terrace, shows fluctuations in the abundance reflect fluvial influence which is linked to events of greater or lesser rainfall, which allows us to say, in the core studied by (Castro, 2011) shows that the C14 ages reported in table 1 represents the ENSO temporality influences because is possible to see changes in the percentage of the MOA/D-lc.AH.

6. DISCUSSION

There are many different effective techniques as C14, palynology, descriptions and stratigraphic correlations, polinist inventory, which are well known in helping with the paleoclimate reconstructions, (González, 1963; Hooghiemstra, 1984; Jaramillo & Parra 2005; Kuhry, 1988; Melief, 1985; Monsalve, 2004; Muñoz *et al* 2009; Rangel *et al.,* 2005; Salomons, 1986; Velásquez *et al.,* 2012; Van der Hammen, 2004; Thouret & Van der Hammen, 1983). However we have decided to use terrestrial cosmogenic isotopes as a proxy for the study of the paleoclimate, because of its precision and without time restriction for the study geological processes (i.e. ancient magmatism, evolution of the earth's crust) (Gosse and Phillips, 2000). Anyhow, it is important to consider that limitations of the TCN dating exist. These limitations are mostly related to inheritance and erosion of the rock surface (Dunai and Lifton, 2014). Inheritance is a concentration of a specific TCN, which is present in the rock surface previous the geological processes of interest occur (Ciner *et al.,* 2017; Darnault *et al.,* 2012).

As we well know, in this work we have three different cosmogenic ages which correspond to three different torrential events in the Farallones watershed which were triggered by the increase of the flow, causing the dragging of the blocks from the upper part of the watershed, which were covered by ice mass CORANTIOQUIA, (2003); this flow may increased by the melting of the same ice mass. This idea is also supported by the data given by Velasquez-Montoya, (2013) because it suggests that through all the pleistocene and Holocene, the climate changed into cold to warm and dry to wet periods, causing changes in the vegetation (Van der Hammen, 1978), in this case in the Belmira moor, this effect of constant change is also visible in the Frontino moor Velasquez et al. (1999); Where exposes that from 13000 cal years BP to 10200 cal years BP the climate was in a periodic change from warm to cold periods and with dry pulses between these (FIGURE 3); following these changes a warming time started in this zone of the Western Cordillera, which allow us to think that this same behavior was also in the Farallones del Citara, and as consequences of this, the ice/snow in this zone melts and increases the flow giving rise to different torrential events, dated with TCN, 8000 years BP, 6730 years BP and 6220 years BP.

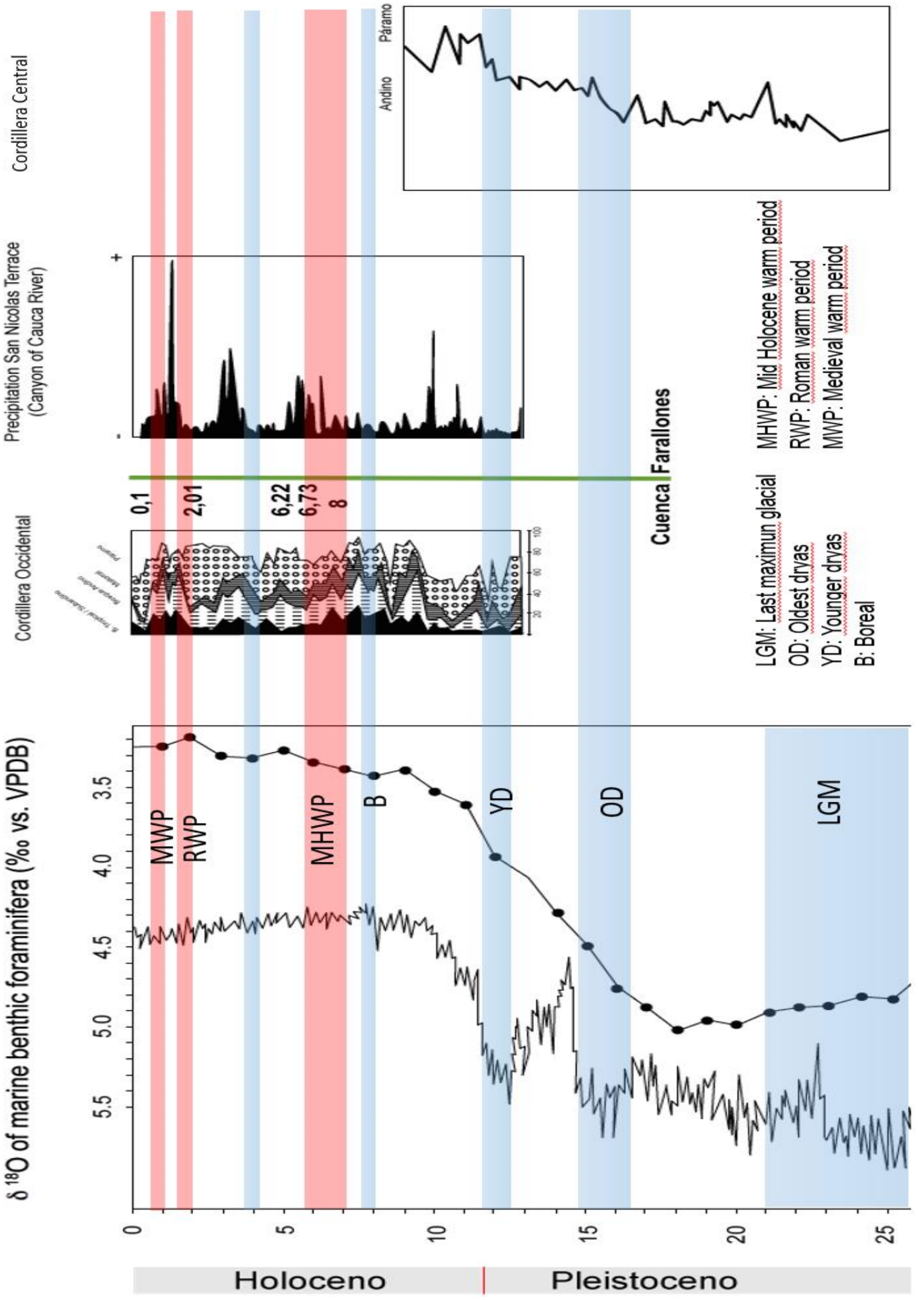


FIGURE 9. Comparison of local and regional records of paleoclimatic events after the Pleistocene- Holocene transition (Perez et at., 2018; velasquez- Montoya, 2013; Castro, 2011; Velasquez, 1999; Easterbrook, 2011; Walker et al., 2012; Carlson, 2013; Rasmussen, 2014)

Thinking in this as a connected system, we hope that mostly of the regional events that happened in the upper part of the Central and western Cordilleras Have incidence in the lower part, canyon of the Cauca River, and Castro, (2011) exposes C14 ages and MO% indicating that this one is directly proportional to precipitation periods, as fluvial influence. It is to be expected that the past periods to 8000 years BP, this zone, The San Nicolas terrace, is mainly influenced by fluvial system for what we said in the previous paragraph about the torrential events, whoever there isn't any register until 6054 years (FIGURE 4), where is easy to see fluctuations in the MO% supporting even more the hypothesis initially raised.

Reviewed paleoclimatic data and measured ^{10}Be ages range in the Pleistocene-Holocene transition, indicating a segmented record of the oldest dryas (last 16.1 ky). Particularly these dataset record the last glacial maximum (LGM) and the posterior climatic fluctuations represented in Figure 9 indicate the relationship between global recorded cold and warm periods and records from the study site. Where it's possible to see the direct relationship between the global average temperatures and the Andean forest growing with the warm and humid periods and with timing control of climate-triggered hillslope deposits.

7. CONCLUSIONS

Based on the analyzed data we could conclude that:

i) Paleoclimatic records in different geomorphic settings of the SW Antioquian region show a correlation with the global climate signal trend. Sites as Frontino and Belmira Páramo show that the periods of the Andean forest increasing depending on the hot periods globally and the highest precipitation recorded in the canyon of the Cauca River.

ii) Debris flow deposits in the Farallones watershed exhibit ^{10}Be ages, which fall in the Holocene Thermal Maximum (i.e. 6-10 ky) indicating a climatic control of hillslope processes.

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