**Geoheritage**

**CERRO MACHIN VOLCANO (CMV), COLOMBIA: IMPLICATIONS AS GEOHERITAGE - CULTURAL LANDSCAPE**

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CERRO MACHIN VOLCANO (CMV), COLOMBIA: IMPLICATIONS AS GEOHERITAGE - CULTURAL LANDSCAPE

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Abstract

The article seeks to position Cerro Machin Volcano (CMV) geosite in the context of Del Ruiz Volcanic Geopark project and its implications as a geoheritage. The research also intends to develop knowledge about risk threats of CMV. This implies a scale of methodological and theoretical approach from geographical interpretation. On the one hand, it is about the pertinence of the geographical reflection on the risk-threat-heritage phenomenon, through a certain management conditioned by impacts at different regional levels. And to the other, it develops understanding of geoheritage as cultural landscape or vice versa.

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Keywords
Del Ruiz Volcanic Geopark, Geoheritage Cultural Landscape, Cerro Machin Volcano geosite, volcanic threat

Introduction

Recently proposed by Colombian Geological Survey (SGC), Del Ruiz Volcanic Geopark (DRVG) and Machin-Cerro Bravo Volcanic Complex are located on Central Cordillera in Colombia and inscribed into a wide environmental management of Colombia’s Coffee Ecoregion area. The complex belongs also to Los Nevados National Natural Park (LNNP). Its volcanic threat is related to five active volcanoes: Nevado del Ruiz Volcano (NRV), Nevado de Santa Isabel Volcano, Cerro Machin Volcano (CMV), Cerro Bravo Volcano (CBV) and Nevado del Tolima Volcano (NTV) (Villegas 2003). Of the above, NRV and CMV are the most active. Their behavior shows different fluctuations in the release of seismic energy and other geophysical, geodetic and geochemical parameters since 2007 approximately1. A regional geological setting places CMV in The San Diego - Cerro Machín Volcano Tectonic Province (SCVTP) (Murcia et al 2018).

Caracterised for a high explosivity (VEI 5), CMV has been case of research studies (Brown et al 2015; Calvo, Piñeros 2013; Cano, López 2017; Cárdenas, Pulido 2012; Henao 2014; INGEOMINAS 2002, 2003; Laeger et al 2013; Loughlin et al 2015; Macías et al 2005, 2008; Murcia et al 2010, 2018; Núñez et al 2001; Obando et al 2003; Ordoñez et al 2015; Piedrahita et al 2018; Rueda et al 2004; Sánchez, Calvache 2018; SGC 2012; Vargas et al 2005; Vega 2009, 2013, 2013a). Due the above, identifying Cerro Machin Volcano (CMV) geosite in the context of DRVG project it is required to determine its implications as a geoheritage, having into account preexisting cultural

landscape values and additionally, its advantages to bring scientific research and sustainable activities to educational and appropriation enforcement by communities not only locals but along the region and visitors around the world.

Coffee Ecoregion is more known for NRV eruption disaster of 1985 (Cano, López 2017; Duque 2010, 2013; Herd 1986; IDEAM 2012; Londoño et al 1998; Mileti et al 1991; National Geographic Society 1986; Nelson 2016; Sigurðsson, Carey 1986; Sigurðsson 1999; Voight 1990). Coffee Ecoregion understanding explains how landscape is configured and linked with volcanic system of Central Cordillera in Colombian Andes, concentrated mostly in Los Nevados National Natural Park (LNNP) (Villegas 2003) in whose western foothills is located the Coffee Cultural Landscape of Colombia (CCLC) inscribed in World Heritage List2. Fundamentally, CCLC characterises Colombian culture, and it means a significant portion of altitudinal territory between 1.000 and 2.000 m.a.s.l. on which strong cultural manifestations are represented. As a result of an activity of more than 12,000 years ago (Cano, López, 2017), ecoregion volcanism explains late conformation of very fertile soils related to thermal floors structure. Geoforms and equatorial zone location made possible coffee cultivation since its introduction a hundred years ago in South America transforming a famous and unique landscape for producing at some stage of the 20th century, the best mild coffee in the world.

Coffee Ecoregion is characterised for being a territory with priority ecological units for generation and regulation of water. Priority ecosystems such as paramos and sub-paramos represents an enormous water potential represented by 38 large basins, 111 supply micro-basins, lakes, lagoons, dams and groundwater. It is important to visualise dimension heights variability of volcanic complex in Central Cordillera. For example, CMV geosite is lower (2,600 m.a.s.l.) and frames as a transitional volcanic ring between lowlands and highlands, contrary to NRV, located in highlands (5,400 m.a.s.l.).

CCLC and Coffee Ecoregion are a sample of a bigger landscape that embraces Colombian cultural identity. It is featured by cultivation of coffee micro-crops on steep slopes. Its biodiversity is combined with the physiography of valleys from gentle slopes up to glaciers and volcanoes on the summits of mountain ranges, crossed by native forests and biological corridors which are considered strategic for the conservation of the world's biodiversity. Ecoregion covers an area of 28,563 square kilometers and a population of 4.1 million inhabitants. Ecological structure is composed by ecosystems of basins, slopes and plains; snowed highlands, paramos, volcanoes, coffee ecosystems, agricultural production by multi cropping and urban corridors (CARDER 2002).

Map 1. Location of the Study Area, the Colombian Massif and the Central Cordillera


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2 Unesco.org /1211/
Ecoregion also means water supplying to regional urban centers and waters depositing on the Magdalena and Cauca rivers. On west side of Central Cordillera, the Cauca River basin conformed watersheds zones of La Vieja, Otún, Chinchiná, Combeima, La Miel, Campoalegre, Guarinó, Tulúa and Risaralda rivers. On the eastern slope the most important hydrogeological province is the Magdalena River Valley, where an intense agricultural and livestock activity is carried out. The aquifer units are located in flat areas built from geological processes of accumulation of sediments: in the southern sector the most important aquifer units are constituted by volcanic-flow deposits, generated by CMV and NTV volcanoes activity, such as the Ibagué, Guamo and Espinal geological fans (CARDER 2002).

From its part, LNNP is one of priority ecological units of Coffee Ecoregion. It responds to a system or volcanic arc belonging to CBV (northbound) and CMV (southbound) and covers an approximate area of 58,300 hectares in departments of Caldas (municipality of Villamaría), Risaralda (municipalities of Santa Rosa de Cabal and Pereira), Quindío (municipality of Salento) and Tolima (municipalities of Ibagué, Anzoátegui, Santa Isabel, Murillo, Villahermosa, Casabianca and Herveo). Glacial water flows in LNNP and its area of influence serves the needs of more than two million people. Its protection and conservation becomes a key element for socio-environmental development and an articulating axis of regional conservation initiatives.

**The Coffee Ecoregion biodiversity**

The CMV stands in the middle of native forests and biological corridors, considered strategic for the conservation of global biodiversity. According to CEPF (2015:vii), Tropical Andes Hotspot in Coffee Ecoregion is the most diverse in the world, leading the list of 35 hotspots with the highest species richness and endemism. It contains about one sixth of all plant life in the world, including 30,000 species of vascular plants, the largest hotspot in plants diversity. It has the largest variety of amphibian, insects, birds and mammal species, and ranks second among Mesoamerican hotspots in terms of reptile’s diversity.

Tropical Andes Hotspot contains Key Biodiversity Hotspots (KBH) and priority corridors which refer to delimited reserves within a biodiverse territory. “All KBH in Central Cordillera of Colombia, represent the last remnants of Andean mountain forest in a landscape largely affected by urban sprawl, livestock grazing, coffee plantations” (CEPF 2015:35) plus strong volcanic processes that have transformed the landscape a long time ago. This circumstance suggests that protection of KBH is fundamental for water provision for human use and agriculture

Specific hotspot location in Sub-Andean life zone (1,100-2,350 m.a.s.l.), are characterized by highlands geoforms transiting to mountains through lowlands of inter-Andean valleys. In the mountains predominates shrubs and herbaceous vegetation of paramos, the high Andean and sub-Andean humid forests, the lacustrine zones, as well as enclaves of high Andean dry vegetation and semi-arid sub-Andean vegetation. In the lowlands of warm valleys, vegetation is characterized by humid forest, dry and gallery forests, bushes, plateau wetlands and lacustrine areas. “Climate is varied, with great diversity in distribution and amount of rainfall, ranging from humid to arid conditions. Thermal floors are: Warm, Temperate, Cold, Very Cold, Extremely Cold and Nival” (Latorre et al 2014:23).

According to the above, 3 districts are identified in the natural landscape:

1. **High Forest Andean - Eastern Cordillera Central Slope – Del Ruiz volcanic complex - Santa Isabel District:**
   On its eastern side, there is a strip of high Andean high forest associated with semi-humid climatic

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conditions in the departments of Caldas, Quindío and Tolima. The eastern slope drains to the Magdalena River basin and presents lower rainfall; this varies in a range of 1,100 to 1,800 mm/year. Central Cordillera volcanism has caused an accumulation of ash layers masking most of landforms. The geological influence of volcanism is evidenced by a substrate of andesitic rocks and diabases that alternate with volcanic tuffs and metamorphic-sedimentary formations.

2. Herbaceous shrub vegetation of high Andean Central Cordillera - Del Ruiz Santa Isabel volcanic complex District: This biogeographic unit is located in 3,500 - 5,400 m.a.s.l. altitudinal range, located in highest parts glaciers of VNR (5,400 m), NTV (5,200 m) and Santa Isabel (4,920 m). As evidence of the different volcanic events, there is lava flow accumulation, volcanic ash and lapilli layers (Huggel 2007). In addition to volcanic dynamics and geofoms, action of glacial events is represented by U-shaped valleys and glacial cirques. Representative vegetation of the district is shrub and high Andean herbaceous vegetation. In addition, there are small extensions of Andean Glaciers, Andean Wetlands, Andean peat bogs and bodies of water derived from glacial dynamics.

3. High Forest Andean - Western Cordillera Central Slope - Del Ruiz volcanic complex - Santa Isabel District: bordering its Western side, there is a strip of high Andean forest crossing along Central Cordillera, by departments of Caldas, Quindío, Risaralda and Tolima. This district is located in strong volcanic influence areas; therefore, there are evidences of volcano-detrital flows, lahars, pumitical flows and ignimbrites. At present, volcanic cover is positioned residually due to rains mechanical action. Most of volcanic formations have been altered and transformed into clays due to terrain high humidity from rainfall ranging from 1,600 to 2,800 mm/year. Dominant substrates are metamorphic and granitic rocks from which arteries are derived with thicknesses of up to 7 meters. (Latorre et al 2014:28).

Map 2 Geographic locations of Los Nevados National Park, the Coffee Cultural Landscape and the Cerro Machín Volcano in the Coffee Ecoregion

Source: Author

The threat of CMV

Due to explosivity stratovolcanic events of Mount Saint Helens (MSH, 1980), Nevado del Ruiz Volcano (NRV, 1985), Pinatubo Volcano (PV, 1991) are similar to CMV (INGEOMINAS, 2002:27-30; Murcia et al 2008:208; Kusky, 2008:17). Some recent events characterised by stratovolcanic configuration are related as samples of activity presented also at Mount Bromo and Sinabung Volcano, Indonesia; Mount Redoubt, Alaska; Mount Ontake, Japan; Calbuco Volcano, Chile; and Fuego Volcano, Guatemala.

Stratovolcanoes are feasible to relate its evident risks and conditions of threats around them. But most importantly, it allows constructing a panorama of the events that Ecorregion landscape would face. Volcanic risk can be defined looming over this territory as an area of study and implies a given ‘synapse’ and also between territories or geographical (cultural) landscape superimposed on an older volcanic landscape (natural). The comprehension of volcanic nature and the cause-effect elements of this unique condition -of high scientific specificity-, starts by

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4 Signed by the Global Vulcanism Program and Database of the Smithsonian Institute from information provided by Colombian Geological Survey (SGO) http://volcano.si.edu/volcano.cfm?vn=351040 http://www2.sgc.gov.co/Manizales/Volcanes/Volcan-Cerro-Machin/Generalidades.aspx
identification of the type of volcanism, magmatic-tectonic composition, behavior, presences and regional-global characteristics reinforces the bases to support an interpretation-modeling and sizing of CMV threat risk.

CMV (2,750 m.a.s.l.) is a Quaternary dacitic volcano (Macías et al. 2005; Murcia et al. 2008, 2018; Piedrahita et al. 2018; Thouret et al. 1995). Its origin is linked to development of a pulled apart basin bounded by Machín and Cajamarca faults. Detailed stratigraphy and radiocarbon dating indicate that six eruptions have taken place during Holocene period. Each eruptive event established a Plinian column that deposited pumice fall deposits followed by the collapse of the column ensuing pumiceous pyroclastic flows, surges and secondary lahars. CMV’s pyroclastic fall deposits have dispersal axes to the Norwest are exposed up to 60 km from crater and cover an approximated area of 2000 km² with a volume of 4.9 km³. Calculated column heights oscillate between 19 and 32 km. The collapse of these columns generated pyroclastic flow deposits that traveled up to 15 km around the volcano infilling the Coello valley. Some pyroclastic flows were able to surmount 200 m. high topographic barriers. Remobilisation by water of this unconsolidated material generated lahars that followed the Coello and Magdalena Rivers and traveled up to 115 km from the volcano covering and area of 1,000 km². The deposits of all these eruptions have affected large areas where the modern important cities of Colombia are now located, as well as main highways of great economic importance. Although CMV is in a quiescent state it must be closely monitored since it has produced cataclysmic eruptions every 900-1,000 yrs. (Macías et al. 2005:1).

CMV presents a volcanic cone formed by a complex of pyroclastic ash tuff rings (Murcia et al. 2010; Piedrahita et al. 2018:44). Its 2.4 km wide crater hosts three domes presenting thermal activity expressed in fumarolic fields and thermal sources located inside and outside the building and sporadic seismicity. The volcanic building is located on the rocks of the Cajamarca Group5 of the Paleozoic. According to Henao (2014:157), they are rocks that lie between 2,400 and 3,550 m.a.s.l. Gently slopes to strongly inclined, affects by regional folding and particularly by the ‘Romeral’ fault system. Steep morphology is formed by resistant rocks (schists, phyllites and quartzites), evolves moderately inclined on slopes of chlorite schist rocks and recent deposits of colluvial and volcanic origin; and to semi flat to flat in the areas of alluvial terraces mainly of drainages. (Laeger et al. 2013; Murcia et al. 2008, 2010).

CMV is one of the most dangerous active volcanoes in Colombia, taking into account its highly explosive potential, its dacitic composition and the magnitude of past eruptions (Cano, López 2017; Murcia et al. 2008, 2018; Macías et al. 2005). “The greatest volcanic threat in Colombia is in the CMV, where neighboring towns of Cajamarca and Anaime would have no option in the event of possible pyroclastic flows, in accordance with the threat map prepared by INGEOMINAS” (Duque, 2013:33).

Located in Toche, municipality of Ibagué, 17 km Northwest of Ibagué City, department of Tolima; 30 km east of Armenia City, department of Quindío and 150 km southwest of Bogotá D.C., capital of Colombia, CMV’s summit is at 4 ° 29’ N - 75 ° 22’ W. “Volcanic geof orm is confused with topography, so it could go unnoticed to who do not know about its existence” (Cárdenas, Pulido 2012:65). “Its shape makes it confused with the topography going unnoticed by those who do not know it, which has contributed to the settlement of populations both within the volcano, and in its foothills and surroundings” (Henao, 2014:157). “The Machín, almost unknown to Colombians, was reactivated in October 2008. Its large prehistoric eruptions covered enormous tracts of land.” (Comunidad

5 This is the name given to the metamorphic rocks that make up the core of the Central Mountain Range studied along the route of Armenia-Ibagué highway. This denomination is used with some restrictions regarding its lithology and geographical extension. Obando et al (2003). The Cajamarca Complex includes paragneous and orthoraphic formations, phyllites, quartzites, green shales, graphite shales and marbles. These rocks were deposited during the Triassic rifting between South America and North America. The Cajamarca Complex represents a part of the continental crust of the Central Cordillera that defines the pre-Cretaceous continental margin. On the basis of geophysical data, the Cajamarca Complex seems to define a broad syncline, reaching a maximum thickness of 10 km, supported by amphibolites. (Murcia et al 2018:2) Due to Triassic rifting, magmatism related to subduction along the Colombian margin occurred 180-147 Ma. In the Cajamarca Complex, this phase is represented by the intrusion and contact metamorphism by Jurassic granitoids, calc-alkaline type I of the batholith of Ibagué. Rift means the process of cracking in the Earth's lithosphere as a result of the rise of very hot magmatic masses. (Laeger et al 2013:195)
Andina, 2009:101). Nearly 100,000 people live in a high threat zone, on the foothills and valleys, among which the Combeima rivers (NTV basin) and the Coello-Toche river (CMV basin) stand out. In the potentially affected area within the valley of the Combeima River, the southern sector of the city of Ibagué is included. Likewise, in the distal sectors of the rivers Recio, Lagunillas and Gualí, populations such as Honda, former Armero and Ambalema are involved. “The main phenomenon involved near mud flows and far pyroclastic flows, the latter being very significant in The Machín case” (CARDER, 2002:118).

Among recorded events, Plinian eruptions less than 2 km from Tolima (10,000 BP) and Quindío (9,000 BP) stand out; less 1 km$^3$ pyroclastic flow than NTV (1,600 AP) and NRV (1,200 AP and 1,595 AP). Exception is a 5 km$^3$ Holocene pyroclastic flow associated with CMV. According to Thouret et al (1995) and INGEOMINAS (2002), the last Plinian type prehistoric eruptions and dated pyroclastic flows are from the VCM, CBV, NTV and NRV (900 BP, 1.250 AP and 1.600 AP respectively) (Calvo, Piñeros 2013; Duque 2013).

Neighbor of CMV, NTV (covered with ice and with fumarolic activity) is the second highest volcano within the complex, located 25 km NRV southbound. It belongs to the most recent composite andesitic generation of a dacitic stratovolcanic formation of the late Pleistocene and Holocene. Both (Machín-Tolima) have a high population (approximately 300,000 people) in influence area of the municipalities of Ibagué and Cajamarca (located 7 kilometers from the CMV) (Thouret et al 1995).

The CMV has produced six eruptive periods (four Plinian and two by collapse of domes) during the Holocene, the last 800 years ago; has produced domes, eruption columns greater than 20 km above the crater, pyroclastic flows and waves, and large volumes of lahars deposits (debris and hyper-concentrated flows) that cover an area slightly larger than 1,000 km$^2$ to the east, in the valley of the Magdalena River. Research on its geologic history indicates its eruptions have covered territories with vast materials in departments of Tolima, Quindío, Risaralda, Cundinamarca and Valle del Cauca in repeated opportunities (Duque 2013; Henao 2014; Vega 2013).

According to Brown et al (2015:17) CMV belongs to South America 15 Region in which Colombia has 15 volcanoes out of a total of 225 existing in this continental part. Of all most are stratovolcanoes. Based on differentiated ranges of volcanic morphology and types of rock, the region registers a range of activity styles and magnitudes of eruptions dating from the Holocene, with VEI scale of 0 to 6 eruptions. Region volcanism is closely related to Nazca Plate subduction under South American platform.

Jenkins et al (2015) points out that Galeras Volcano and the NRV have caused life losses but VCM “has not caused fatalities, but recent disturbances have been demonstrated, and its geological record indicates the possibility of explosive eruptions, violent and destructive” (Jenkins et al 2015:636).

In 2002 INGEOMINAS carried out the first scientific study on the CMV threat entitled “Evaluation of potential Cerro Machín Volcanic threat (Department of Tolima, Colombia)”$^8$. The goal of the study was to develop potential eruptive scenarios of the volcano and to identify zones that could be affected based on the results geological studies. The construction of the future scenario considered to evaluate the volcanic threat has as reference past eruptive history of CMV, its current state and geomorphology. INGEOMINAS took into account similarities between CMV and Mount Pinatubo considering parameters as geotectonic environment, age and eruptive history, composition and

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$^6$ According to the National Administrative Department of Statistics, DANE (2015) the municipality of Ibagué has a population of 686,675 inhabitants, and urban area 593,068.

$^7$ According to the DANE (2015) the municipality of Cajamarca has a population of 19,656 inhabitants, and the urban area 9,968.

$^8$ Developed by scientists of INGEOMINAS: Méndez R, Cortés G, Cepeda H and Calvache M as Project Manager.
volume of products emitted, trigger events of eruptions, eruptive style, resting times between eruptions, emitted volumes, geomorphological forms and processes and climate.

The potential eruptive scenario concluded in a volcanic system equipped with a rich and volatile magma plugged on the surface by domes, with areas of weakness around the plug, which can initiate a cleaning of the conduit, a production of major eruptions, destruction of the domes and subsequent crater unclogging; and with presence of a confined basin of the Coello River that will cause greater flows and pyroclastic surges by narrow and deep valleys, with mighty currents that would favor lahars formation (INGEOMINAS 2002; Vega 2013).

Map 3. Volcanoes threat zones in Colombia


According to evidence on volcanic activity of the CMV, it is likely that the risk would have affected to prehispanic indigenous communities established in the region. The study of INGEOMINAS (2002) cites works of Méndez in 1997 that states indigenous population “must have suffered great destructions due to the pyroclastic flows originated in recent times by the CMV, especially those originated 820 ± 100 years ago and 1,205 ± 185 years ago”. Later, Méndez established a parallel between C14 radiometric dates of carbonized wood in deposits of pyroclastic flows of CMV and some results of explorations and archaeological excavations carried out in the Cordillera Central, a sector corresponding to the department of Tolima, where it was found evidences associated with two eruptive events about 10,000–5,100 years BP and 3,600 BP scenarios (INGEOMINAS, 2002:16). Salgado and Varón set eruptive periods during the Holocene for CMV “between 10,000 BP (9470 ± 795 BP, JGP 63-3-1) and the 9th century AD (820 ± 100 BP, GrN 15,740)” (Salgado, Varón 2018:3). “Dates are from charcoal formed naturally as a consequence of the phases of volcanic events of Cerro Machín” (Salgado, Varón 2018:6). Same archaeological dates are confirmed by Dickau et al (2015:52). This can be considered as contributions from a geoaarchaeological perspective. “The scope of these investigations has been crucial, since they have managed to correlate palaeoecological data, volcanic products and archaeological contexts” (Cano, López, 2017:45).

In recent studies on the volcano's pyroclastic activity, Murcia et al (2010) and Rueda (2005) defines the following six eruptive events that occurred during the last 5,000 years. Piedrahita et al (2018:1) states “CMV is undoubtedly a polygenetic volcano” (Murcia et al 2018:2). These units consist of the event called Espartillal (5000-5100), the Anaime-El Tigre (P0) event (4,600-4,700) and the Toche (P1) event (3,600) in which waves and deposits of pyroclastic pumice flows fell, “which is considered of greater magnitude and whose deposits are easily identifiable in a radius of 20 km” (Cano, López, 2017:45). Subsequently, the El Guaico event (2,600) was presented, characterized by the emission of ash blocks and pyroclastic pumice deposits; P2 event (1,200) pyroclastic falls and deposits of pumice flows are identified; and the event called the Ring (900) that had falls of blocks, ash and pyroclastic deposits. The pyroclastic flows and deposits associated with the Espartillal, P0, P1 and P2 events were produced by Plinian eruptions. On the contrary, the deposits of pyroclastic flows associated with the El Guaico and El Anillo events were generated by destruction of lava domes from the summit during volcanic activity. Each of these events, with the exception of Espartillal, can be correlated with five deposits of lahars located tens of kilometers downstream from the volcano near the towns of Espinal and Guamo (INGEOMINAS, 2002:47; Murcia et al 2010:162).

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9 In 10,000 years of CMV activity there have been at least seven (7) major eruptions of which geological records were found. A tool used to know the dates in which such eruptions occurred are the radiometric dating by the Carbon 14 method. To this end, 30 samples of charred wood or paleosols were dated. Radiometric dating indicates that in the last 10,000 years the smallest intervals between eruptions are of the order of 400 years and those greater than 3,500 years. Contingency Plan for effects produced by Cerro Machín Volcano (Colombian Red Cross, 2009).
In 2009, PIGA\textsuperscript{10} carried out on behalf of Cortolima\textsuperscript{11} “Studies of Vulnerability and Risk in a Sector of the Area of Influence of Machin Volcano”. Due INGEOMINAS study did not evaluate in detail volcanic seismicity or its collateral effects (landslides threats), the PIGA study complemented scenarios evaluation onset of crisis and eruption threats and confirmed behavior predicted by large-scale scenarios applied to a smaller study area. It provided greater certainty applied to risk management on landslides incidence for its management and confirmed the eruptive scenarios in the threat zones identified by INGEOMINAS (Vega, 2009, 2013).

**Map 4. Regional Geologic Map (CMV-NTV)**


**Table 1. CMV Eruptive History**

*Before Common Era*

Source: [http://volcano.si.edu/volcano.cfm?vn=351040](http://volcano.si.edu/volcano.cfm?vn=351040)

**Threat zoning**

INGEOMINAS (2002:41) identified the great explosive potential of CMV “due to its chemical composition, the magnitude of its eruptions and the great extension of its deposits allow it to be classified as one of the most dangerous volcanoes in Colombia, whose future activity could affect long time (months to years) one of the most strategic regions of the country”. A proposed sequence of potential eruptive scenario events defined threat zoning and considered the following:

1. Eruptive activity has 10,000 years known geological record represented in threats like pyroclastic falls, waves and pyroclastic flows, location of domes and lahars.

2. Weakness zones were identified in current volcanic building which may be considered as possible future eruptive foci.

3. Specific types of threats contained in past eruptive scenarios were selected, equivalent to the maximum expected scenarios. Those were used to evaluate potential threat and obtained areas that may be affected by each type of volcanic event.

4. Explosive eruptions would be accompanied by seismicity, emission of gases and generation of shock waves in addition to emission of solid material. (INGEOMINAS 2002:41)

**Map 5. Map of CMV threat**


\textsuperscript{10} PIGA Research Group: Policy, Information and Environmental Management of the Faculty of Engineering, Department of Civil and Agricultural Engineering, National University of Colombia.

\textsuperscript{11} Regional environmental protection agency of Tolima.
Given the above, INGEOMINAS generated a zoning of threat that determines pyroclastic falls zones by wind transport, by ballistic projection, by flows and pyroclastic waves. Also it defined threat zones due to location of domes, lahars of hyperconcentrated flows and lahars of debris flows.

In 2004 swarms of surface earthquakes accompanied by soil deformation, variations in temperature and composition of thermal water cations and radon outflows led scientists to consider CMV was under a before crisis period. Hydrothermal and seismicity increased (Murcia et al. 2010). Seismic monitoring recorded by Vulcanological and Seismological Observatory of Manizales (VSOM) detected 12 events in the year 2000, 94 in 2003, 316 in 2005, 787 in 2006, up to 1,014 events in 2007. VSOM-INGEOMINAS reported that at 0732 hours on September 9, 2008, a volcano-tectonic earthquake of 3.6 magnitude occurred below the CMV main lava dome at a depth of 3.2 km. The alert level maintained in III-yellow, “changes in the behavior of volcanic activity”.

From 2000 to 2010, seismic activity has increased to reach 9000 (VT) annual volcano-tectonic earthquakes. According to Laeger (2013) around 2,000 VT earthquakes were recorded in 2011 and 2012. Two VT earthquakes reached magnitudes of 4.7 and 4.1 on October 7, 2012. Locations of hypocentres clearly demonstrated three main seismic zones; one located under central dome 3.5 km deep, second located SE of central dome (5 km) at 5.8 km depth; and third was 8.10 kilometers SE of central dome, 12.18 km deep. It seems these seismic sources can represent a system of faults related to main path of magma rise to CMV. In February 2013, swarms of volcano-tectonic events were monitored at the volcano. On the other hand, evidence of soil deformation, changes in the composition and temperature of hot springs and fumarolic activity were accompanied by radon emissions, suggesting that the volcano has gradually increased its activity.

During November 2018 recent “seismic activity associated with fracturing of rocks registered an increase in number of events and in seismic energy released, respect to previous month. This type of activity was located in the South, Southwest and West of the main dome, at depths between 1.5 and 11.3 km. The highest magnitude recorded during the month was 2.1 LM (Local Magnitude), corresponding to the earthquake occurred on November 13 at 16:24 hr (Local Time), located west of the main dome, at a depth of 3.4 km. Deformation measurements and other parameters monitored did not show significant changes”. Yellow alert remains activated by VSOM until now.

Map 6. CMV-NTV-VNR threat zoning overlay


Map 7. Contours of CMV

Source: Author from https://earthexplorer.usgs.gov/ processed by SIG

The risks of the CMV threat


12 https://www2.sgc.gov.co/Noticias/boletinesDocumentos/Bolet%C3%ADn%20Informativo%20No%202918%20noviembre%202018.pdf
Accessed: January 29, 2019
Obando et al. (2003); Tilling (1989, 2009); Vargas et al. (2005) and Vega (2009) have warned that one of the most volcanic critical scenarios could be related to a CMV explosion. In its area of influence, approximately 700 thousand people are exposed, in addition to the geostrategic risk importance it represents for Colombia. According to VSOM devastated association to CMV activity includes: 240 km² of potential area affected by pyroclastic flows, which includes the municipal capitals of Cajamarca and Coello, corregimiento of Anaime, Toche and Tapias (municipality of Ibague) in Tolima. Threat by lahars, corresponds to the basin of the Magdalena River, a zone of more than 1,000 km² mainly along the Coello River and on left side of the Magdalena River plain. Another threat zone is related to pyroclasts fall covering an area of 2,000 km² located towards volcano west flank.

Lahars related with potential eruptive scenario would have pyroclastic products as main components from explosive eruptions and water of acid rains, fluvial currents and dams produced by obstructions in rivers channels (Bermellón, Toche, Tochecito and Coello). Its origin becomes by transitions from pyroclastic flows to lahars, erosion-transport of loose pyroclastic material on hillsides by rainwater and fluvial currents and dams breakage. The first expected lahars will be able to transit with channels current conditions, but their successive and extended occurrence in time (months, years), the occurrence of new important eruptive events (months) and the changes in meteorological and hydrological conditions produce transformations in the channels morphological characteristics and hydraulic conditions of the basins. This causes hydraulic behavior of lahars which affects distribution and final coverage of all the lahar units. The main covered area is dominated by the Guamo event and was defined as the maximum scenario by hyperconcentrated flows in lahars. Debris flows affects Chicoral unit whose maximum coverage area is included in the hyperconcentrated. Affected area is expected to cover a total area of approximately 3,000 km. It is expected cities annihilation as Saldaña, Guamo and Espinal vicinities in Tolima region.

Vega (2009) established bases of a new conceptual and methodological framework for integral evaluation of risk, allowing analysis tools and information processing that confirms INGEOMINAS (2009) findings. According to all risks maps for each analysis scenario it is evident that in the event of an eruption of the CMV, the population centers of Anaime, Cajamarca, Coello-Cocora, Tapias and Toche, as well as Pan-American highway between Ibague and Cajamarca section would be seriously compromised.

Duque (2008) has been one of the disseminators of the risk of CMV disaster. Through a series of lectures, writings and blogs, he has manifested about the threat:

Not all volcanoes are the same and this is the most unique. It is an active and highly explosive volcano according to the geological record of six eruptions. In the last 5,000 years El Machín has been characterized by producing eruptive columns several tens of kilometers high depositing ash layers of several tens of centimeters in areas such as Armenia, pyroclastic flows hundreds of meters thick that filled the valleys of the rivers that drain the volcano and lahars that reached to reach the Magdalena River forming huge alluvial fans in the areas of Chicoral, Espinal, Guamo and Saldaña. The last eruption occurred approximately 850 years ago and it is remembered in an indigenous legend of the region. An easy calculation indicates that, in geological terms, we are close to a new eruption and it could happen anytime. Other manifestations of volcanic activity are: presence of fumaroles, permanent microsismicity, thermal waters inside and greater presence of radon gas, well-preserved geoforms of volcanic building and in vicinity of the crater. From the beginning CMV was cataloged as a somma volcano or plinian, precisely those of greater danger by the dimension and characteristics of their eruptions. Same type as CMV has been Krakatoa, Vezymianny, Vesuvius, or Mount Saint Helens. The record of previous eruptions indicates that they have always been explosive, very strong, and have covered a wide territory in the departments of Tolima, Quindío, Risaralda, Valle del Cauca and Cundinamarca (Duque, 2008:1).

Subsequently, Duque claimed:

[…]The greatest volcanic threat in Colombia is Cerro Machita. Neighboring towns of Cajamarca and Anaime would have no option in event of possible pyroclastic flows, in accordance with hazard map drawn up by INGEOMINAS points out. In case of eruption, the eruptive column would collapse as in the case of Cerro Bravo, given the high intermediate explosive coefficient of its magma. To this is added the spatial scope of mud flows of Tolima volcano, which will reach the Magdalena valley, as well as CMV’s explosive lavas,
without snow. Ash fall from CMV would probably affect western region, reaching several municipalities of Quindío, such as Armenia, Pijao and Salento, among others. (Duque, 2013:33)

Map 8. CMV Threat Map and Geopark Overlay

Source: Author from Google Earth Pro and http://srvags.sgc.gov.co/Amenazas/MAPA_AMENAZA_MACHIN.pdf

CMV geodiversity site connected to a cultural landscape

Ecosystems of high biodiverse natural values of region affected by CMV are indisputable inside the previous developed knowledge. However, it should be noted that cultural implications need to be studied in greater depth. Man-nature relationship due to deep links between nature and culture are expressed in a symbolic-anthropological and geographical space (Cleere 1995, Cosgrove 1984, 1985, 1994; Cosgrove, Daniels 1988; Hirsch, O’Hanlon 1995, Sauer 1925; Wagstaff 1987). This is referred in a framework of cultural landscapes since indigenous people developed an understanding of geography by setting living, funeral, agricultural spaces, and broad communication systems of paths across the Cordilleras. But since 1992, the World Heritage Convention influenced positively becoming definitions more universal, integrated and interdisciplinary through recent time to achieve a terms for a cultural landscape supported on exceptional values (Isaza, Velandia 2018; Plachter, Rössler 1995; Sabaté 2004, 2010; Rössler 1993, 2003, 2009; Von Droste et al 1995; UNESCO 1999).

Cultural landscape concept is articulated with geological heritage and volcanic landscape (Németh et al 2017) and integrated as complementary knowledge. Complexity of these relations is related also with its implications of volcanic hazards on world heritage sites, especially in cultural landscapes (Németh et al 2017; Pavlova et al 2017; UNESCO 2014, 2016; Wood 2009). According to this, geodiversity is an attribute of natural landscape that contains a strong set of cultural values (Brocx, Semeniuk 2015; Tavera et al 2017). As Ssepeszi (2017:2) quotes, geodiversity “is connected to land use traditions of the cultural landscape”. An extended assessment of CMV geosite has to “evaluate the scientific, cultural/historical, aesthetic and socio-economic values and helps to define priorities in site management. In addition to the scientifically important geosites, the traditional land use of cultural landscape generates sites that do not have particular scientific values but significant record of human impact on landscape […] which are representing cultural and natural values at the same time” (Ssepeszi 2017:12).

Németh et al (2017) contributes bringing the concept shaped as “volcanic heritage” as a “recognition of the heritage values of geological features implies that Earth systems have a story to tell in the ongoing history of human development, provide resources for the development and growth of communities and social structures, define our sense of place and encompass multiple values such as scientific historical, cultural, aesthetic and religious. Gravis (2017:1) implies geoheritage values may change over time, which may be reflected in elevated interest in geoconservation and/or geotouristic purposes, in turn, triggering a more thorough examination of geological features. It can be stated that geoheritage values of CMV are highlighted by a geosite or geomorphosite which are “commonly defined as landforms or geological formations which represent social human or cultural-scientific values” (Gravis I, et al 2017:3).

Towards a conclusion: Articulating Geoparks with cultural landscapes

During the 38th Session of the General Conference of UNESCO (2015) the States Parties approved the statutes of the International Geosciences and Geoparks Program (IGGP), which is composed of two subprogrammes: 1) the
International Geosciences Program (IGCP), a joint program of UNESCO and the International Union of Geological Sciences (UICG), which since 1973 has encouraged comparative studies in the field of earth sciences; and 2) the UNESCO World Geoparks Program, which seeks to increase awareness of geodiversity and promote best practices in protection, education and tourism.

Calvache (2018) director of SGC, considers that its participation in World Geoparks Program in order to give viability to the development of international cooperation in earth sciences and a response to geoparks initiatives of communities of several regions around the world. SGC applied as a representative of the International Geopark and Geoparks Program (PIGG) and then initiative of Del Ruiz Volcanic Geopark (DRVG) is proposed. Considering DRVG is much larger than the LNNP (both in Coffee Ecoregion) and to that extent they overlap; however, legally, this overlapping it would allow a more complete protection, because the geological and paleontological components are included and complemented it, since apart from its geoheritage values, a Geopark is conceived as a tool for sustainable development.

The CMV geosite is an exceptional site for research also for biodiversity. Its zone contains one of the highest populations of wax palm (Ceroxylon quindiuense) identified in the South American Vegetation Chart (UNESCO, 1981). The wax palm forest represents a high value ecosystem so current research is directed to management plans and characterization of its sustainability, due high endemicism in flora and endangered fauna, especially birds13 (González-Rivillas et al 2018; López-Lanús et al 2000; Ríos 2004; Salaman P et al 1999; Sanín, Galeano 2011).

Image 1. CMV dome and wax palms forest
Source: Author

The possibilities multiply when integrating the knowledge of geodiversity research and cultural landscapes. The conjunction of symbolic landscape and geodiversity represent an opportunity to contribute to a more solid proposal for the preservation and protection of CMV geoheritage. It is a need to research deep into geoheritage values and significance to set a framework to build a new concept as Geocultural Landscape. There is still a long way to go for the DRVG initiative and a lot of challenges regarding recognition, management and development of sustainable activities as geoconservation and geoeducation (Nemeth et al 2017:252). For example, to promote a geotourism model specified by Tavera et al (2017) to help appropriation processes of knowledge at the level of local people, developing routes and an interpretation center. Thanks to SGC, there is a possibility to enter into the process of the World Geoparks Program and the inscription in the tentative list of UNESCO’s world heritage.

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Map 4 image authorised by Dr Leonel Vega.

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