

**Geological Classification of Modern Soils or Regolith, Proposal for a New Structure of  
Classification and Nomenclature**

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## **DEDICATORIA**

### **Gladys Avendaño**

*A mis padres Cesar Avendaño y Miriam Sánchez,  
A quienes amo y respeto por darme la vida y su tiempo, a quienes debo todo lo que soy.*

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## Introduction

In the study of soil formation, parental rock has been considered as an important precursor to this process, but the role of geology goes further, since it plays a fundamental role in the formation of different soil profiles, starting from the fact that a soil is generated over a specific parental deposits or rocks.

Once parental materials are exposed to the atmosphere or hydrosphere external conditions during a period of not depositing / not erosion, the factors that generate groups of soils related to each other within the geoform begin to take place, among these factors are the climatic ones that will be given according to the geometry of the geoform and the runoff water, which generates differential weathering along the geoform and the parental material, giving rise to the availability of nutrients coming from the rock and a horizon of soil where the groundwater will be accumulated. These factors will give rise to different types of vegetation that generate depletion, precipitation and retention of particular materials. But it must be emphasized that all this process depends on a geoform developed according to the characteristics of the set of lithologies present in it.

Numerous soil classifications have been developed in response to the needs of the industry in different fields, but have not taken into account the analysis of the materials that make up the soil and how the behavior of these can vary according to the nature of its components when they are subjected to the conditions of the dynamics of the planet. Some of the most representative classifications have resulted from the field of agriculture, where they are based on the selection of diagnostic characteristics, ignoring soil formation processes (e.g. Soil Survey Staff, 1999) (IUSS

Working Group WRB, 2014). While the classifications developed for engineering are based on physical features such as grain size and plasticity (for example, Casagrande, 1948) (The Unified Soil Classification System (USCS) 2004).

Our proposal is based on the idea that a modern soil will be affected by variables such as geomorphology and different climate regimes related to humidity conditions, vegetation cover, winds and precipitation in specific places that allow the formation of different kind of materials. This is the basis for the proposal of a new classification of soils that highlights the role of the geological component, because soils consist of three types of fundamental materials that are inherited materials, incorporated materials and transformed materials.

## **1. Objectives**

### **1.1 General objective**

Propose a new geological naming and classification of soils or regoliths.

### **1.2 Specific objectives**

- Propose a new naming to classify modern soils, according to their content of parental, incorporated and transformed materials.
- List the different incorporated, transformed and inherited materials.
- List the main processes that affect the percentage relationship between these three types of materials in the soil profile.
- Make patterns examples where characterization of the parental rock and the regolith generated are made, establishing the relationship between them. These examples will be studied in different lithologies and under conditions that encompass various climate regimes.

## **2. Methodology**

### **2.1 Field work**

Initially, five field areas were selected with accessibility and civil works in progress and different parental lithology, outcrops that allowed the study of recent and fresh soil cuts. Parental lithology selected include quartz sandstones, calcareous, granites and gneisses rocks and recent

unconsolidated sedimentary deposits. In each selected place the following activities were carried out:

**2.1.1 Description of the field sampling site.** The description proposed by Schoeneberger, P.J., D.A. Wysocki, E.C. Benham & Soil Survey Staff (2012) were used, which emphasizes the location description with climate data, slope, slope direction, slope gradient, slope complexity, slope segment relative position, slope shape, natural soil drainage, the dominant land cover at the site and estimation of the dominant type of erosion at the site.

**2.1.2 Description of the soil profile.** The description proposed by Schoeneberger et al., (2012) were used, which includes the cross sectional form of contact between horizons, color of the horizon according to the Munsell soil color table, horizon materials, nodules, estimation of the relative roundness of the fragments, relative strength or energy required to dig the soil, record of the quantity, size and location of the roots in each horizon, description of the quantity and size of the pores by horizon in a horizontal plane and record of depth, size and type of cracks.

**2.1.3 Collection of soil samples in the field.** A study outcrop was prepared, remove de altered surface and cleaning with plastic brush, to a total depth of the outcrop and 3 meters wide, 3 to 5 soil sampling levels were located by site which included at least one sample from each different soil horizon, and more than one sample from the thicker horizons. Samples were collected in plastic bags and mark with fundamental information, and transported to the laboratory, opened and allowed to air dry.

## 2.2 Laboratory tests

The collected regolith samples were used to determine physicochemical and geotechnical characterization tests, such as pH and soil conductivity, grain size determination of the solid materials, and Atterberg limits standard laboratory tests (plasticity index, liquid and plastic limits), this test allows to obtain the limits of the humidity range within which the soil is kept in plastic state, and are used to classify the soil in the Unified Soil Classification System (USCS). Additionally, the finer soil materials (clays) soil materials were characterized by using thin sections and X-ray diffractometry technique to determine their composition.

**2.2.1 pH and soil conductivity determination.** Based on standard test for determination of pH and electrical conductivity of soils respectively Norma Técnica Colombiana (NTC) 2008 5264 and 5596 were used. Initially the suspension of each of the samples was prepared by taking a representative portion of the soil between 10 and 20g, and it was deposited in the vessel, then a water equivalent volume to the weight of the sample was added to complete the ratio w/v 1:1. The suspension obtained was shaken using stirring apparatus for 20min or intermittent for 1h, when stirring performed manually it's allowed to stand for 30min to 3h maximum. When the soil type generated an excessively pasty solution with the 1:1 to 1: 2 ratios was used to perform the test. Finally, pH and electrical conductivity were measured with Hach multi-parameter HQ40d.

**2.2.2 Soil solid materials sizes determination.** Based on standard American Society for Testing and Materials (ASTM) 2007, D422-63. Initially total either moist and air-dried soil mass was determined using precision scales, then total sample was separated on selected size for the test using US sieve mesh and manual sieving operation, the series of size fractions sieve mesh used was 75mm (3in), 50mm (2in), 37.5mm (1½in), 25.0mm (1in), 19.0mm (¾in), 9.5mm (3/8in),

4.75mm (US sieve size No.4), 2.00mm (US sieve size No.10), 850 $\mu$ m (US sieve size No.20), 425 $\mu$ m (US sieve size No.40), 250 $\mu$ m (US sieve size No.60), 150 $\mu$ m (US sieve size No.100) and 75 $\mu$ m (US sieve size No.200). The manual sieving operation used start with 3in sieve mesh and continue with 2in sieve mesh and so on, make each sieve operating individually. Initially the sieve mesh with sample is shaken with a lateral and vertical movement accompanied by vibration and circling circumferences, so that the sample is kept in motion continued on the meshes, then the sieves retained materials are removed and it is verified that no more than 1% of the retained portion is sieved during one minute, then the particles trapped in the mesh are separated with a brush to collect them with the sieve retained materials, then the mass of each fraction obtained is determined on a precision scale with a sensitivity of 0.1% taking into account that the sum of the masses of all fractions and the initial mass of the sample shall not differ by more than 1%. Finally, particle sizes and percentages of each material are reported, taking into account the following criteria: Gravel material that passes the 75mm (3in) sieve and is retained in the 4.75mm (No.4) sieve, coarse sand material that passes the 4.75mm (No.4) sieve and is retained in the 2.0mm (No.10) sieve, medium sand material that passes the 2.0mm (No.10) sieve and is retained in the 425 $\mu$ m (No.40) sieve, fine sand material that passes the sieve of 425 $\mu$ m (No.40) and is retained in the 75 $\mu$ m (No.200) sieve, Silt and clay sizes material that passes the 75 $\mu$ m (No.200) sieve.

**2.2.3 Liquid limit soils determination.** Based on the standard ASTM 2010 D4318-10, the Wet Preparation Method was used for the samples obtained from the whole material passed through the 425 $\mu$ m (US sieve mesh, No.40), the specimens did not present any material retained on the 425 $\mu$ m (No.40) sieve, whereby 200g of material was prepared by intimate mixing with water in the mixing vessel using the spatula. The liquid limit was determined by Method A - determination of the liquid limit with several test points as follows: 1. The specimen is completely

remixed, adjusting its water content to achieve a consistency requiring between 40 and 50 strokes of the pan to close the groove that forms on the floor. An adequate amount of soil is placed in the pan above the point where it rests on the base and is compressed and extended with the spatula to level it and at the same time leave it with a depth of 10 mm at the point of its maximum thickness.

2. The floor placed on the brass pan is divided with a firm pass of the grooving tool.
3. It is verified that there are no remains of soil neither in the base nor in the bottom of the casserole. It then rises and hits the pan by rotating the handle at a speed of 1.9 to 2.1 revolutions per second, until the two halves of the ground paste are brought into contact at the bottom of the slot.
4. It is verified that the groove has not been closed prematurely because of an air bubble trapped in the ground by observing that both sides of the groove have flowed in a similar manner.
5. The number of strokes,  $N$ , required to close the slot is recorded, a 10mm slice of soil is taken, taking part on either side and at right angles to the groove, including the portion of the groove in which it was contacted and placed in a known mass container and capped.
6. The leftover soil is transferred to the mixing vessel; the pan and the router should be washed and dried to have them ready for the next groove.
7. The remaining soil is remixed in the vessel adding enough water to bring it into a more fluid state and steps 1 to 6 are repeated. The purpose of this procedure is to obtain samples with such consistencies that at least one of the determinations of the number of strokes required to close the groove of the floor is at each of the following intervals: 40-50; 30-40; 20-30 and 10-20.
8. The container is taken with the soil portion (see numeral 5), weighed and the value obtained is recorded. It is then placed into the oven at  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ) until a constant mass is obtained and reweighed as soon as it has cooled down and before it can absorb hygroscopic moisture. This mass is recorded, as well as the mass loss due to drying. Determination of the initial mass (vessel plus moist soil portion) was performed immediately the assay was terminated.

**2.2.3.1 Calculations for determining the liquid limit of soils.** Based on the standard ASTM 2010 D4318-10, the water content of each soil portion is calculated, expressed as a percentage of the mass of soil dried in the kiln, as follows:

$$\text{Water content} = \frac{\text{Water mass}}{\text{kiln} - \text{dried soil mass}} * 100$$

Preparation of the flow curve - The "flow curve", which represents the relation between the moisture content and the corresponding number of strokes of the bronze casseroles, was drawn in a semi-logarithmic graph, with the water content as ordered on the arithmetic scale and the number of strokes as abscissa on the logarithmic scale. The flow curve is an average straight line passing as close as possible to the four points drawn. Finally, there is the Liquid Limit - The water content corresponding to the intersection of the fluidity curve with the abscissa of 25 strokes is taken as the Liquid Limit of the soil and rounded to the nearest whole number.

**2.2.4 Plastic boundary soils determination.** Based on the standard ASTM 2010 D4318-10, the preparation of the test specimen consisted of taking a 20g portion of the soil prepared for the test of the liquid limit, reducing the water content of this portion of soil to a consistency that allow it to be rolled up without sticking to the hands, extending or mixing continuously on the glass plate or in the mixing and storage vessel.

The procedure for determining the plastic boundary was performed as follows: 1) from the test specimen, a portion of 1.5 to 2.0g is selected with which an ellipsoidal mass is formed. 2. Rolls are formed with the ground mass by the manual method. - The ground mass is rolled between the palm of the hand or the fingers and the glass plate, with the pressure strictly necessary to form a roll of uniform diameter in their entire length. The roll should be thinned more with each rotation

until its diameter reaches 3.2mm (1/8in), taking no more than two minutes for it 3. The 3.2mm roll is divided into several pieces and are compressed between the thumbs and the other fingers of both hands forming a uniform mass of ellipsoidal shape and rolled again. This procedure is repeated, starting, kneading, kneading and rolling until the roll of 3.2mm diameter collapses under the pressure required for rolling and the soil cannot be rolled further into 3.2mm diameter cylinders 4. The crumbling soil portions are collected and placed in a suitable container of known mass. 5. Other portions of 1.5 to 2g of the plastic boundary specimen are selected and the operations described in 2 to 4 are repeated until the container has a minimum of 6g of soil. 6. The operations described in items 1 to 5 shall be repeated to obtain another container containing at least 6g of soil. 7. The water content of the soils contained in the two containers consists in taking a sample of the wet material to a furnace at  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ) and dry it to a constant mass. It is considered that the mass lost due to drying is water and that the remaining mass corresponds to the dry sample. The water content is calculated by relating the mass of water in the wet sample to the mass of the dry sample and recording the results.

**2.2.4.1 Calculations for plastic boundary soils determination.** Based on standard ASTM 2010 D4318-10, calculate the water content of the material with the formula:

$$w = \frac{W_1 - W_2}{W_2 - W_C} * 100 = \frac{W_w}{W_s} * 100$$

Where: w: Water content, %; W1: Mass of the vessel with the wet specimen, g; W2: Mass of the vessel with the dry specimen, g; Wc: Mass of the vessel, g; Ww: Water mass, g; Ws: Mass of solid particles, g. Finally, the average of the two water contents (scores of the plastic limit) is calculated and the value obtained is rounded to the nearest whole number. This value is the plastic limit (LP).

**2.2.5 Plasticity index soils determination.** Based on the standard ASTM 2010 D4318-10, the plasticity index is calculated by subtracting the plastic limit from the liquid limit. The plasticity index (IP) is calculated as follows:

$$LL - LP = IP$$

Where LL: Liquid limit (whole number); LP: Plastic limit (whole number).

**2.2.6 Textural and compositional soil materials determination.** 10 thin sections of soil were made by recommendation of William Mantilla (Verbal communication). Conventional thin section rock elaboration was used and 10 thin sections were prepared, in the case of fragile sample we use the technique of impregnation and hardening explain by Kawai and Oyama (1962), it was impregnate with polylite and use vacuum desiccators. It is important that materials for hardening soils should have excellent permeable power and harden soils, without disturbing the natural fabrics of the soils, and incidentally, these materials should not become soft by the heat of friction at grinding.

**2.2.7 Clay fraction soil composition determination.** By predominant qualitative technique X-ray diffraction analysis, based on the procedure proposed by Mantilla (2003), in the first instance the elimination of any residue of supergenic alteration that each sample could have. For the preparation of the sample the mechanical disintegration method was used, for which the sample had to be hammered very gently, on a clean white paper in a metallic base (anvil), since the paper avoids the loss of part of the sample. disintegrated material, from which 300g are subsequently poured into a precipitated beaker with 1.5 liters of distilled water and subjected to mechanical stirring for 8 hours (intercalating 45 minutes of stirring and 15 minutes of rest, regulating this with a timer), then of which the sample is allowed to stand for 12 hours. Separation of the suspension with the fractions of interest was carried out using a hose, avoiding the reactance

and therefore the incorporation of thicker particles remaining in the bottom of the precipitated vessel, the suspension was withdrawn, that is, the distilled water with the particles of the size of interest in suspension. To concentrate the particles in suspension the water was evaporated with the aid of an oven at 40°C. After separating the suspensions with the fractions of interest, the fractions were studied in a powder diffractometer brand BRUKER model D8 ADVANCE with DaVinci Geometry under the following conditions: Voltage 40kV; Current 40mA; Divergence 0.6mm; Slit Soller Primary and Secondary 2,5°; Sampling 0.02035° 2Theta; Measurement Range 2° -40° 2Theta; CuK $\alpha$  I radiation; Filter Nickel; Use of Anti-Air Sprayer Yes; LynxEye Linear Detector; Type of sweep A steps; Sampling time 0.6 seconds.

**2.2.8 Soil Total Organic Carbon (TOC) determination.** Based on the common standard procedure that is described in (Al-Selwi & Joshi, 2015), we determine Total Organic Carbon in each horizon of every sampling place, except in limestone where only the most superficial horizon was analyzed.

### **2.2.9 Climate**

The climatic data have been extrapolated from the interactive atlas of the IDEAM, which allows visualize a large number of climatic variables at Colombia and departmental levels, with a multiannual, annual and monthly period depending on the variable and the amount of installed capacity of the national climatological network.

The information was recorded in form of screenshots of different climatic variables in the department of Santander with a monthly temporality. These include: solar brightness, evaporation, relative humidity, surface wind speed (10m), average precipitation, maximum rainfall in 24 hours,

number of days that it rains per month and maximum monthly average temperatures, averages and minimum.

Once the information was collected and it have been georeferenced using GIS software (in this case Arcgis). Then the data have been extrapolated by manually reading the variations that occurred in the 5 sampling points made.

With this it was possible to obtain information already processed which has been acquired with a multi temporality that goes from 1981 to 2010. Whit this information it was possible to make a local climatic analysis with more accuracy for the sampling points.

### 3. Theoretical bases

Specific weathering process in the formation of soils and regoliths include: (1) Volume loss by compaction-reorganization of solid materials and eluviation-expulsion of water and dissolved or suspended material (ions and clays); (2) preservation of inherited parent materials: sediments, rock fragments, and grains minerals (e.g. quartz, zircon...); (3) weathering alteration-deterioration of inorganic materials (e.g. feldspar, biotite,...) with formation of weathering alteration materials, e.g. layer-clay-aluminosilicates (Wilson 1975, 2013); (4) deposition-incorporation of new inorganic materials, e.g. aerosol (cloud and water suspension solid fine materials); (5) redistribution of materials (ions and clay) with formation-concentration-coating of isolated clay aggregates or structural clay and fine silt bridging material between grains and clay layers (Kew and Gilkes, 2006); (6) incorporation of new materials by the biological activity and productivity, that includes among others bio-corporal materials and organic compounds; (7) deterioration-reorganization-transformation of materials by biological activities, e.g. bioturbation process by organisms; (8) deterioration-reorganization-transformation of new and preexisting biogenic organic compounds by mixing process chemical-biological (e.g. bacterial activity over organic materials like nucleic acids, proteins, carbohydrates, lignin, lipids and resin); (9) precipitation-cementation of new solid materials (e.g. iron oxides), include formation of some structures (vadose pisolites) isolated or forming layers; (10) erosion caused by swiftly moving water, can scoop out scour holes or irregular erosion surface (named scoured structures); and (11) ice wedging and/or frost and freezing, those induced by regolith ice wedging and freezing (e.g. Udden, 1918; Dylík and Maarleveld, 1967; Benedict, 1979), that forms ice wedging and/or frost and freezing fissuring materials.

Collection of the main processes that allow the development and the formation of soils, allowing the variation in percentage of the different inherited, transformed and incorporated materials that compose each horizon of every soil profile are presented in tables (1, 2, 3, 4, 5, 6, 7 and 8).

*Table 1. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.*

<b>Process</b>	<b>Description</b>	<b>Materials</b>
<p><b>Eluviation</b> (Nye, P. H. 1955) (Nesbitt and Young, 1984) (Carrasco, 2015)</p>	<p>Elements are leached from minerals in the near-surface environment and are transported downward in ion form along with suspended clay-sized particles.</p>	<p>Redistributed materials (Rtdrm)</p>
<p><b>Illuviation</b> (McKeague, et al. 1978)(Nesbitt and Young, 1984) (Carrasco, 2015)</p>	<p>Leached elements, along with suspended clay particles, are adsorbed, exchanged, or deposited within areas of the less weathered regolith.</p>	<p>Redistributed materials (Rtdrm)</p>
<p><b>Leaching</b> (Johnson and Cole, 1980 ) (Cole and Gessel, 1965) (Sorrenti and Toselli, 2016)</p>	<p>Elements are leached from minerals in the near-surface environment and are transported downward in ion form along with suspended clay-sized particles.</p>	<p>Incorporated (Rim), transformed and redistributed materials (Rtdrm)</p>
<p><b>Cumulization</b> (Riecken and Poetsch, 1960) (Johnson, 1985)</p>	<p>The soil surface accretes sediment slowly and continuously, while the profile “grows” upward into the surrounding sediment. ‘Developmental upbuilding’ is driven not only by slopewash sediment, but also aeolian and anthropogenic additions of mineral particles to the soil surface of a soil.</p>	<p>Incorporated materials (Rim)</p>
<p><b>Lessivage</b> (Jamagne, 1973) (Dultz,2000) (WRB, 2006)</p>	<p>Also called argilluviation, consists of a substantial vertical transfer of fine particles ranging in size from less than 2 µm to 10 µm from a superficial horizon, called the eluviated horizon or E-horizon, to another horizon, called the illuviated or B-horizon. Mobilisation and deposition are due to a complex combination of chemical and physico-chemical mechanisms, and to physical and mechanical mechanisms.</p>	<p>Clay coatings and fillings Redistributed materials (Rtdrm)</p>

Table 2. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<p><b>Enrichment</b> (Eswaran and Sys, 1979)(Walker and Chittleborough, 1986) Birkeland (1999)</p>	<p>Processes that account for enrichment: (i) translocation of clay from eluvial to illuvial horizons; (ii) translocation of clay contributed by aeolian processes to illuvial horizons; (iii) weathering of silt-size or coarser particles into clay-size material in situ; and (iv) synthesis of clays from the soil solution. Mechanisms involved in formation of clay-enriched horizons, including (i) dispersion, (ii) translocation, and (iii) accumulation.</p>	<p>Residual silica concentration</p>	<p>Incorporated (Rim), transformed and redistributed materials (Rtdrm)</p>
<p><b>Podzolization</b> (Ugolini and Dahlgren, 1987) (Gustafsson et al., 1995)(U.S. Lundström et al., 1999)</p>	<p>Two major groups of processes have been proposed to explain podzolization: i). formation and downward transport of complexes of organic acids with Al and Fe; and ii). silicate weathering followed by downward transport of Al and Si as inorganic colloidal sols.</p>	<p>Leached elements with suspended clay particles.</p>	<p>Incorporated (Rim), transformed and redistributed materials (Rtdrm)</p>
<p><b>Erosion</b> (Burwell and Kramer, 1983) (Hjelmfelt et al., 1986) (Gonzalez-Hidalgo et al., 2012)</p>	<p>Losing and transforming energy and matter due to the effect of raindrops, runoff, wind, gravity, and other soil forming processes. Within this complex system, human impacts also cause changes to the soil, including negative inputs that are generating hazardous outputs including soil erosion.</p>	<p>Different volumes of soil loss</p>	<p>Transformed and redistributed materials (Rtdrm)</p>

Table 3. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<p><b>Decalcification</b> (Van Breemen et al., 1983) (Van Breemen and Protz, 1988) (Van Den Berg and Loch, 2000)</p>	<p>Two main causes for decalcification of the top layer of hydric soils are oxidation of iron sulphides under aerobic conditions and increased CO<sub>2</sub> pressure in the soil during waterlogging. Decalcification is further enhanced by, for example, nitrogen transformations, atmospheric acidic deposition and, in the case of vegetation removal, cation uptake excess by vegetation.</p>	Calcium carbonate removal	Transformed and redistributed materials (Rtdrm)
<p><b>Calcification</b> (Jaillard et al., 1991) (McConnaughey, 1994)(McConnaughey and Whelan, 1996)</p>	<p>Bicarbonate is the most abundant carbon source in alkaline waters, but is inaccessible without a source of protons, diffusion from ambient waters can supply protons, but the photosynthetic organism is then bathed in an alkaline, CO<sub>2</sub>-depleted micro-environment, which inhibits photosynthesis. By discharging the protons from calcification into their boundary layers, calcareous plants and symbioses can maintain or even elevate CO<sub>2</sub> concentrations despite photosynthetic CO<sub>2</sub> uptake.</p>	Massive calcium carbonate accumulation	Transformed and redistributed materials (Rtdrm)
<p><b>Salinization</b> (Gedroiz, 1912)(Funakawa et al., 2000) (Singh, 2015)</p>	<p>In the first stage, Solonchaks (Saline soils) are formed from non-salt affected soils by a process called salinization, characterized by the accumulation of salts more soluble than gypsum in the soil profile (mainly chlorides and sulfates of sodium, magnesium, calcium and potassium) and a consequent increase in mono- and divalent cations in the exchange complex.</p>	Soluble salts (sulfates and chlorides of calcium, magnesium, sodium and potassium) accumulation.	Incorporated (Rim), and redistributed materials (Rtdrm)

Table 4. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<b>Desalinization</b> (Van Der Molen, 1955) (Pen'kovskii, 1976) (Rao and Leeds-Harrison, 1991)	<p>Soil salt leaching plays an important role in soil desalinization and soil improvement. Desalinization through leaching as an effect of ponding water in irrigated cropping has been reported.</p>	Soluble salts removal.	Redistributed materials (Rtdrm)
<b>Solodization</b> (Gedroiz, 1912) (Summer et al., 1998) (Sparks, 2003)	<p>Originate by the leaching of most of the soluble salts and/or the precipitation of Ca<sup>2+</sup> and Mg<sup>2+</sup> minerals, with a relative increase in exchangeable Na<sup>+</sup> and common occurrence of sodium carbonates. This process is generally responsible for an important increase in the soil pH, generally higher than 8.5, mainly because of the liberation of hydroxyls to the solution by both sodium hydrolysis and the dissolution of sodium carbonates.</p>	Increase in exchangeable Na <sup>+</sup> and common occurrence of sodium carbonates	Incorporated (Rim), transformed and redistributed materials (Rtdrm)
<b>Solodization</b> (Gedroiz, 1925) (Kellog, 1934) (Miller and Pawluk, 1994)	<p>The continued leaching in the environment leads to a different process called solodization, responsible for the formation of a degraded Sodic soil (Soloth). Solodization is marked by a loss of sodium and other basic cations and an increase of H<sup>+</sup> in the exchange complex, first in the near-surface horizons and later in the whole profile. The soils formed in the initial stages of solodization are called Solodized Solonetz.</p>	Loss of sodium and other basic cations and an increase of H <sup>+</sup> in the exchange complex.	Redistributed materials (Rtdrm)

Table 5. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<p><b>Pedoturbation</b> (Wood and Johnson, 1978) (Johnson and Watson-Stegner, 1990) (Leigh, 2001)</p>	<p>Pedoturbation refers to the post-depositional disturbance of sedimentary deposits and soils either through mixing or exhumation. It is a global near surface phenomenon caused by numerous processes. Perhaps the most prevalent of these are disturbances by flora and fauna (bioturbation). This operates at a variety of scales ranging from the movement of individual grains to the creation of small-scale landforms.</p>	<p>Homogenization and disturbance of soils in varying degrees.</p>	<p>Redistributed materials (Rtdrm)</p>
<p><b>Laterization</b> (Pedro and Melfi, 1983) (Lal et al., 1989) (Li and Chen, 1994)</p>	<p>Process which, at its extreme, involves intense weathering (resulting in a breakdown of all minerals except quartz) and intense leaching of the soil. The iron and aluminum in lateritic material has traditionally been considered to be the result of residual accumulation from the original parent material. A portion of the material may have been transported vertically or laterally.</p>	<p>Iron accumulation. Soluble salts and silica removal.</p>	<p>Inherited materials (Ricm), transformed and redistributed (Rtdrm)</p>
<p><b>Decomposition</b> (Bingeman et al., 1953) (Wu et al., 1993) (Johnston et al., 2009)</p>	<p>Is the breakdown of complex organic substances into simpler molecules or ions by physical, chemical and/or biological processes. Decomposition of SOM (soil organic matter) releases mineral nutrients thereby making them available for plant growth.</p>	<p>The breakdown of minerals and organic materials.</p>	<p>Transformed materials (Rtdrm)</p>

Table 6. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<b>Synthesis</b> (Lapeyrie, 1988) (Arnold, 1983) (Baath, 1994)	<p>The formation of new particles of mineral and organic species</p>	<p>Particles of mineral and organic species.</p>	<p>Transformed materials (Rtdrm)</p>
<b>Melanization</b> (Soil Survey Staff, 1998) (Bockheim and Gennadiyev, 2000) (Almeida-Paes et al., 2009)	<p>Some soils are characterized by the accumulation of well-humified organic matter within the upper mineral soil. Where soils subject to melanization are base enriched, the humus accumulation is reflective of a mollic epipedon Mollisols; where bases are depleted, the soils have an umbric epipedon. Additional soils showing melanization include umbric great groups of Alfisols and Ultisols and humic great groups of Inceptisols.</p>	<p>Well-humified organic matter accumulation.</p>	<p>Incorporated (Rim), transformed and redistributed materials (Rtdrm)</p>
<b>Leucinization</b> (Wilde, 1958) (Hole and Nielsen, 1968) (Arnold, 1983)	<p>Destroy and remove dark humus, leaving mineral grains uncoated so that they impact a light color to the horizon. Leucinization has bleached sand and silt grains in the A1 horizon, in most of the A2 horizons in Planosols (Argiabolls) and on surfaces of grainy gray coatings on ped surfaces in the B horizons.</p>	<p>Destroy and remove dark humus, leaving mineral grains uncoated.</p>	<p>Redistributed (Rtdrm), and incorporated materials (Rim)</p>
<b>Littering</b> (Arnold, 1983) (Jansson and Berg, 1985) (Melillo et al., 1989)	<p>The accumulation on the mineral soil surface of organic litter and associated humus to a depth of less than 30 cm.</p>	<p>Accumulation of organic litter and associated humus</p>	<p>Incorporated materials (Rim)</p>

Table 7. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<p><b>Gleization</b> (Bouma, 1983) (Blume and Schlichting, 1985) (Bockheim and Gennadiyev, 2000)</p>	<p>Refers to the presence of aquatic conditions often evidenced by reductimorphic or redoximorphic features such as mottles, gleying, etc. The effect of reduction and oxidation processes has focused on iron and manganese compounds since these result in visible morphological features that have been used for predicting soil-moisture regimes. Gleization occurs in Gleysols and in some Plinthosols and Planosols.</p>	<p>The reduction of iron under anaerobic soil conditions.</p>	<p>Transformed and redistributed materials (Rtdrm)</p>
<p><b>Paludization</b> (Buol et al., 1989) (Bockheim and Gennadiyev, 2000) (Craft, 2000)</p>	<p>Accumulation of organic matter on the landscape usually in marshy areas to the deep &gt; 40 cm. Most soils featuring paludization are in the Histosol order or soil group, but soils containing histic materials &lt; 40 cm occur in the Gelisol and Inceptisol orders.</p>	<p>Organic matter accumulates in wetland soils</p>	<p>Incorporated materials (Rim)</p>
<p><b>Humification</b> (Johnson and Cole, 1980) (Zech et al., 1997) (Hartemink, 2006)</p>	<p>Transformation of macromorphologically identifiable resources into amorphous humic compounds.</p>	<p>Transformation of organic material into humus</p>	<p>Transformed materials (Rtdrm)</p>
<p><b>Ripening</b> (Pons and Zonneveld, 1965) (Pons and Van Der Molen, 1973) (Bockheim and Gennadiyev, 2000)</p>	<p>Ripening is a sub-process of paludization and refers to chemical, physical and biological changes following drainage and aeration of organic materials.</p>	<p>Organic soils with chemical, physical and biological</p>	<p>Transformed materials (Rtdrm)</p>

Table 8. Main weathering processes in the formation of soils and regoliths based on Arnold (1983) and sedimentary genetic soil materials proposal.

Process	Description	Materials	Fundamental materials of the geologic classification
<p><b>Mineralization</b> (Ladd et al., 1977) (Wieder and Lang, 1982) (Zech et al., 1997)</p>	<p>Transformation of organically bound elements (C, N, S, P) into inorganic compounds (<math>\text{CO}_2</math>, <math>\text{CH}_4</math>, <math>\text{NH}_4^+</math>, <math>\text{NO}_3^-</math>, <math>\text{SO}_4^{2-}</math>, <math>\text{HPO}_4^{2-}</math>).</p>	<p>Transformation of organically bound elements into inorganic compounds.</p>	<p>Transformed materials (Rtdrm)</p>
<p><b>Ferrugination</b> (Duchaufour, 1982) (Singh, 1995) (Singh et al., 1998)</p>	<p>Ferrugination phase is characterised by more neoformed 1:1 clays than 2:1 clays, exchange capacity between 16–25 mEq/100 g clay, silt:clay ratio &gt; 0.2, moderate clay illuviation, and incomplete weathering of feldspars and micas. Two subphases (ferruginous soils and ferrisols) are distinguished on the basis of the absence/presence of a distinct horizon with large amounts of red, dehydrated ferric iron. Ferrugination took place under overall well drained conditions.</p>	<p>Release of iron from primary minerals and the dispersion of particles of iron oxide in increasing amounts with progressive oxidation or hydration.</p>	<p>Transformed and redistributed materials (Rtdrm)</p>
<p><b>Chelation</b> (Schatz et al., 1954) (Lehman, 1963) (Schatz, 1963)</p>	<p>Form of chemical weathering that is a particular way that ions and molecules bind metal ions. Chelation has contributed much to agriculture by enhancing plant growth and has already entered the field of animal nutrition. Chelation is important in biochemical weathering of rocks and minerals, pedogenesis, microbiological associations available soil nutrients mycorrhizal associations plant root secretions and soil fertility.</p>	<p>Ions and molecules bind metal ions. Metals replace hydrogen ions.</p>	<p>Transformed materials (Rtdrm)</p>

#### **4. Theoretical proposal**

The study of regolith is receiving growing multidisciplinary attention inasmuch as it has many linkages with aspects that are important for the sustainability of life on Earth (Scott and Pain 2008), life is sustained by this delicate skin of the planet, which is receiving mounting and well-deserved attention (Brantley et al., 2007). Numerous systems with detailed classification of regoliths or soil are in existence: e.g., Birkeland (1999), Soil Survey Staff (1999), Eswaran et al. (2003), Kew and Gilkes (2006), Jahn et al. (2006), Geological Survey of Western Australia (2013), based on variety of complex criteria, such as material type and properties, e.g. the amount of contained organic material, presence of clay layers, and presence of oxic (iron-rich) horizons or reductive (iron-rich) horizons; or depositional characteristics, landform morphology and formational processes. The Unified Soil Classification System (USCS) has three major classification groups: (1) coarse-grained soils (e.g. sands and gravels); (2) fine-grained soils (e.g. silts and clays); and (3) highly organic soils (referred to as "peat"). Moderately organic soils are considered subdivisions of silts and clays, and are distinguished from inorganic soils (Casagrande 1948, 1952). Natural systems approaches to soil classification, such as the French Soil Reference System (Référentiel pédologique français) are based on presumed soil genesis (Baize and Girard, 2008).

##### **4.1 General Genetic regolith classification based on the three types of genetic materials**

Following in part Millot (1964) "clay minerals in a sedimentary basin can be neoformed, inherited or transformed", here are used these concepts for all kinds of regolith materials, therefore "regolith materials and structures" has three kinds of genetic materials (see tables 9, 10, 11): (a)

inherited-conserved materials and structures from original parent rock or deposit, (b) transformed, deteriorated and redistributed materials and, (c) incorporated materials.

#### **4.1.1 Inherited-conserved materials and structures from original parent rock.**

Those rocks or isolated biogenic or inorganic materials inherited and conserved from parent rocks or deposits materials released by weathering partial alteration destruction of parent rocks whatever sedimentary, igneous or metamorphic. They are resistant materials like rock fragments, amber, kerogen materials, and isolated minerals like quartz, zircon, ilmenite, among others, materials named pseudo particles, that look like particles but they aren't because they don't have any transportation (table 9).

**4.1.2 Transformed, deteriorated and redistributed materials.** Those materials formed by TDR process of original materials, those materials formed inside the soil by transformation, deterioration or redistribution process of original materials whatever inherited-conserved or incorporated (table 10).

**4.1.3 Incorporated materials.** Those biogenic or abiogenic materials incorporated into the regolith by any (a) clastic deposition or (b) chemical precipitation accumulation, or authigenic process, or by (c) biogenic productivity and activity (table 11).

The intensity of material transformation to form the soil or regoliths depends on deposition rates of sediments, deflation rates of materials, time exposition to weathering condition and specific climatic conditions (humidity and temperature mainly), the last two conditions are expressed in the figure 1 (time and climate) to show their relationship with inherited, incorporated and transformed materials and the transformations intensity of these materials. Applied terms for specific classification of regolith deposits according to the

transformation-deterioration and redistributed of the original materials presented in figure 1 (e.g., Mt mic, Ht si, etc.) and explained in table 12.

*Table 9. Proposal of Inherited-conserved materials according to their genetic condition point of view.*

<b>Inherited-conserved materials (Icprm) from parent rock</b>	
<p><b>Inherited and conserved pseudoparticles (Icpp):</b></p> <p>Solid preserved materials release by weathering partial alteration-destruction of parent rock:</p> <p>Resistant materials (rock, ambar, kerogen fragments and isolated minerals like quartz, zircon among others), materials named pseudo silt, sand and gravel, that look like particles but without any transportation.</p>	<p>Rock fragments pseudoparticles release by weathering alteration of surrounded materials of igneous (plutonic, hypabyssal, volcanic, among others), metamorphic (quartzite, marble, hornfels, schist, phyllite, slate, gneiss, cataclastic, among others), or sedimentary (regolith, clastic, biogenic, chemical or diagenetic).</p> <p>“Crystals” pseudoparticles (quartz, zircon, ilmenite, etc...) inherited-conserved from igneous or metamorphic rocks.</p> <p>Biogenic materials (Icbm): biogenic production inherited and conserved from sedimentary rocks (corporal bioliths, bioconstruction, etc..).</p> <p>Chemicals precipitation accumulation materials (Icchpam): chemical formation-accumulation materials inherited and conserved from sedimentary rocks (gypsum crystals, abiogenic oolites, etc...).</p> <p>Diagenetic materials (Icdm): diagenetic modification-transformation materials inherited and conserved from sedimentary rocks (hematitic ooids, calcareous, concretions, etc...).</p>
<p><b>Inherited and conserved particles (Icp):</b> gravel, sand and mud particles inherited and conserved from clastic sedimentary rocks.</p>	

*Table 10. Proposal of Transformed-deteriorated and redistributed materials according to their genetic condition point of view.*

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**Transformed-deteriorated and redistributed materials (Tdrm)**

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Weathering argillaceous materials (Jwam): layer-clay aluminosilicates minerals (e.g. kaolinite, among others) formed by transformed-deteriorated weathering process of labile materials (e.g. feldspar, pyroxenes etc), materials that look like clay particles but aren't, they are pseudoparticles.

Desiccation-contraction materials and structures (Jdcms), that include desiccation peloids, mud shrinkage cracks, and crack systems with polygonal pattern by the growth of dolomite and/or evaporite minerals (e.g. Assereto and Kendall, 1971; Bellamy, 1977).

Scoured materials and structures (Jsms) caused by swiftly moving water, can scoop out scour holes or irregular erosion surface.

Ice wedging and/or frost and freezing fissuring materials and structures (Jiwffms), those induced by regolith freezing, (e.g. Moore, 1914; Udden, 1918; Dylík and Macerleved, 1967; Benedict, 1979).

Redistributed materials and structures (Rdms): materials formed by redistribution of layer-clay aluminosilicates minerals (e.g. kaolinite), and coated or flocculated clay aggregates, isolated or structural clay, and fine silt bridging material between grains and clay layers (Kew and Gilkes, 2006).

Bioredistributed materials and structures (Brdms): inorganic materials and biological remains mixing, redistributed and deteriorate by biological activity, that include remobilization and reorientation of material.

Soft deformation and remobilization materials and structures (Jsdrms): deformation, injection and remobilization structures formed in sedimentary deposits by seismic activity (Bohra et al, 2014), or gravity, or fluidification-liquefaction: load casts, tee-shear (ice-push), flame, load, diapiric sand-mud structures, pseudonodule (Macar, 1948), ball-and-pillow structure (Smith, 1961) and relatives.

Dissolution and dissolution-collapse materials and structures (Jddcms): obliteration of unstable materials and consequently formation of dissolution structures like, poral and cavities, stylolites and/or collapse pseudobreccias (collapse breccias of Friedman, 1997).

Ion remobilization and segregation materials and structures (Jirms): intrastratal dissolution of unstable materials, with remobilization, segregation and precipitation of materials to form nodules, concretions and relatives.

Neomorphism materials and structures (Mms): any kind of mineral that is transformed by chemical recrystallization or mineral inversion or replacement of original materials.

Mixed juvenile biological and weathering materials and structures (Mxjwms): any material formed by a mixed biological-weathering process, e.g, microbial-desiccation-weathering materials and structures.

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*Table 11. Proposal of Incorporated materials according to their genetic condition point of view.*


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<b>Incorporated materials (Im)</b>
<p>Particles (ip): isolated deposition of gravel, sand and mud particles transported by gravity, water or wind; mud materials include clay bond aggregates formed in aerosol, water, cloud and snow, e.g. trololites and relatives.</p>
<p>Authigenic materials (iam): any kind of new mineral precipitation that is form or grown inside the regolith deposits, include cementation and relatives.</p>
<p>“Leaked materials” (ilm) or younger materials piped down into the deposits through cavities (burrows or fissures) (Kidwell et al., 1986), and infilling particulate materials (mud-sand-gravel) fine or coarse grained inside of the empty natural space (poral or biological cavities).</p>
<p>Juvenile biogenic materials (ijbm): biogenic production formed directly or accumulated (corporal biomineralized materials: shells, bones, pollen, spores among others; corporal tissues and organs; biodepositional materials (biogenic excretion or exudation); and, materials formed by organism’s activities: bioconstructions, and biofoodcaches materials and structures; bioerosion structures; biotools, biominerals, and biodetritus materials; coated microbial-chemical materials or structures.</p>
<p>Juvenile natural liquids and gases materials (ijnlgm): that include “atmospheric water and gas” in their natural state.</p>

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#### **4.2 Classification and naming of regolith deposits and soil (Rd).**

Regolith deposits are the external lithospheric overburden coverage-mantle of weathering altered and unconsolidated materials that forms in the earth atmosphere interface, as well with the interface of earth and fresh or marine water, where low deposition rates of sediments are present, and exposition time to weathering condition are large enough to transform original materials into new ones.

There are four parameters for the classification of regolith or soil deposits in the sedimentological and geological point of view: (1) genetic conditions, (2) structural conditions, (3) textural categories, and (4) compositional characteristic.

**4.2.1 Genetic conditions.** According to the original parental material that are formed weathering altered or transformed into soil, there are two kinds of regoliths: *Parental rock regoliths* (Prr), those coverage-mantle deposits formed directly “in situ” by weathering alteration of preexisting rock; and *Parental deposit regoliths* (Pdr), those coverage-mantle deposits formed by weathering alteration of recently formed, or deposited, or accumulated sedimentary deposits.

**4.2.2 Structural conditions.** Transformation-deterioration and redistribution intensity of the original materials and incorporated materials quantity in the specific soil horizon increases gradually towards the surface of the soil profile, by the contrary the percentage of inherited-conserved materials decreases gradually towards the surface of the soil profile, therefore a relationship between kind of materials, intensity of transformation and specific horizon of the soil profile are important in their classification: (1) *Horizon totally transformed* where original inherited and/or incorporated materials were totally transformed, (2) *Horizon heavily transformed*, with slightly original incorporated and/or slightly inherited-conserved parent materials that are still conserved (3) *Horizon moderately transformed*, with slightly to moderately incorporated and/or slightly to moderately inherited-conserved parent materials are still conserved (4) *Horizon heavily or moderately incorporated and slightly transformed*, (5) *Horizon heavily and moderately inherited-conserved and slightly transformed*, and (6) *Parent deposit or rock unaltered*.

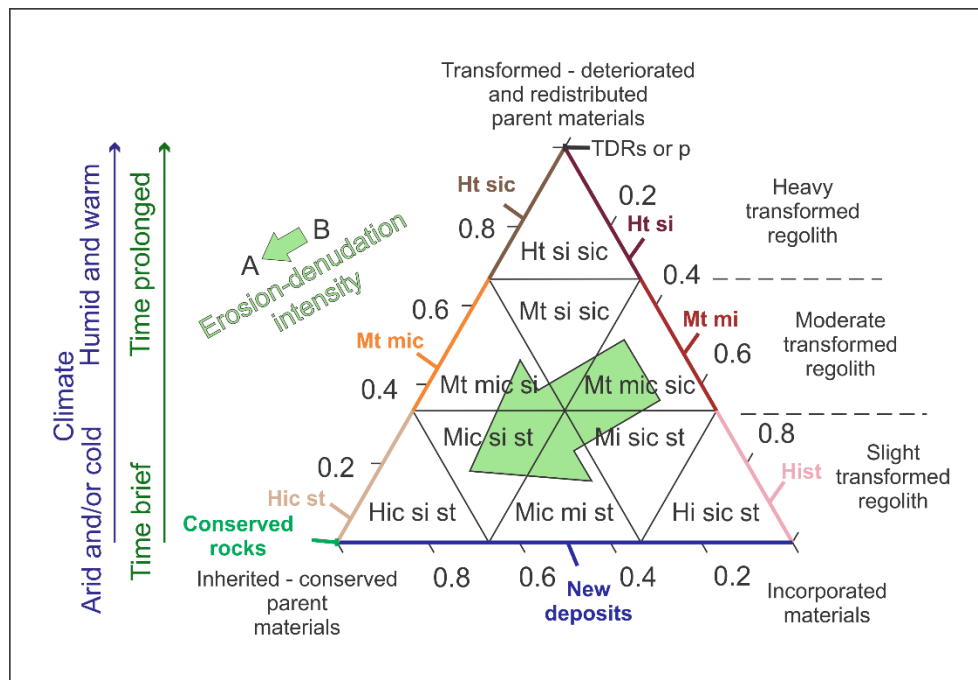


Figure 1. Proposal of General classification of regoliths deposits based on inherited and conserved parental materials (Icm), incorporated materials (Im), and transformed-deteriorated-redistributed materials (Tdrm). Transformation intensity: Heavy (H), moderately (M) and slightly (S). Green arrow show denudation erosion intensity, A strong denudation and B slight denudation.

**4.2.3 Textural categories.** The regolith size textural categories are gravel, sand, silt or clay size, particularly here Wentworth grain size chart from USGS Open-File Report 2006-1195 was used for the following materials: particles and pseudo particles. Specific for the authigenic and neoformed sedimentary crystals materials (table 13) it's necessary to actualize the "sedimentary crystal size", materials formed by chemically precipitated minerals either as products of regolith formation, chemical precipitation-accumulation or diagenesis (pore-filling cement, or as recrystallization and replacement). Regolith, chemical or diagenetic sedimentary crystal size (table 13) based on Folk's (1959, 1974) proposition for authigenic constituents, mega and microcrystals classification (Boggs, 2009), and nanocrystals material crystals having at least one dimension smaller than 100 nanometers (Fahlman, 2007).

Table 12. Proposal of Terms applied for specific classification of parent regolith deposits, according to the transformation-deterioration and redistributed of the original materials (figure 1).

Generic genetic classification	Specific genetic classification
Totally transformed parent regolith deposits ( <b>Ttrld</b> ).	Where original inherited materials was totally transformed-deteriorated and/or redistributed.
Heavily transformed parent regolith deposits( <b>Htrld</b> ).	<b>Ht si</b> - Heavily transformed regolith deposits with slightly incorporated materials.
	<b>Ht sicsl</b> - Heavily transformed regolith deposits with slightly original inherited and incorporated materials.
	<b>Ht sic</b> - Heavily transformed regolith deposits with slightly inherited-conserved parent rocks materials that are still conserved.
	<b>Mt mi</b> - Moderately transformed regolith deposits with moderately incorporated materials.
Moderately transformed parent regolith deposits ( <b>Mtrld</b> ).	<b>Mt mi sic</b> - Moderately transformed regolith deposits with moderately incorporated and slightly inherited-conserved parent rock materials.
	<b>Mt sic si</b> - Moderately transformed regolith deposits with slightly inherited-conserved parent rock and slightly incorporated materials
	<b>Mt mic si</b> - Moderately transformed regolith deposits with moderately inherited-conserved parent rock and slightly incorporated.
	<b>Mt mic</b> - Moderately transformed regolith deposits with moderately inherited-conserved parent rock materials.
	<b>Hi st</b> - Heavily incorporated regolith deposits slightly transformed.
Heavily and moderately incorporated.	<b>Hi sic st</b> - Heavily incorporated regolith deposits slightly inherited-conserved slightly transformed parent rock material.
	<b>Mi sic st</b> - Moderately incorporated regolith deposits with slightly inherited-conserved parent rock materials, slightly transformed.
Slightly transformed parent regolith deposits.	<b>Mic-mi st</b> - Moderately inherited-conserved moderately incorporated regolith deposits, slightly transformed.
	<b>Mic si st</b> - Moderately inherited-conserved regolith deposits, with slightly incorporated materials that are still conserved, slightly transformed.
Heavily and moderately inherited-conserved.	<b>Hic si st</b> - heavily inherited-conserved with slightly incorporated materials that are still conserved regolith deposits, slightly transformed.
	<b>Hic st</b> - heavily inherited-conserved materials regolith deposits, slightly transformed.

Table 13. Regolith, chemical or diagenetic sedimentary crystal size. Modified from Folk (1959, 1974) and Boggs (2009).

Sedimentary crystals size: chemical or diagenetic		
4 mm	Megacrystals megaspars megaquartz	Extremely coarsely crystals
1 mm		Very coarsely crystals
0.25 mm - 150 $\mu\text{m}$		Coarsely crystals
0.062 mm - 62 $\mu\text{m}$		Medium crystals
0.016 mm - 16 $\mu\text{m}$		Finely crystals
0.0005 mm - 0.5 $\mu\text{m}$	Microcrystals microspars microquartz	Very finely crystals
0.0001 mm - 0.1 $\mu\text{m}$		Ultrafine crystals
Nanocrystals		

Note: \* Millimeters (mm), microns ( $\mu\text{m}$ ), nanometers (nm).

**4.2.4 Compositional characteristic.** There are different component materials in the formation of soil and regoliths, many of them are very common in the other sedimentary deposits and rocks, the most important are the following: Quartz, feldspar, mica group (biotite, muscovite,...) they are in soils forming: particles, pseudo particles, and authigenic materials; Carbonates (calcite, aragonite, dolomite) they are in the soil forming: biogenic, bioclastic, sedimentary crystals, weathering alteration (microcrystalline), and authigenic materials; amorphous silica (opaline,...) they are in soils forming: biogenic, bioclastic, sedimentary crystals, weathering alteration (microcrystalline), and authigenic materials; phosphate materials (apatite, fluorapatite) they are in soils forming: biogenic, bioclastic, authigenic (francolite, collophanite) materials; iron oxide hydroxide materials (goethite, limonite, ferrihydrite), manganese oxides (lithiophorite, hollandite, and birnessite), argillaceous materials (kaolinite, montmorillonite-smectite, illite, sericite and chlorite), calcium sulphate (gypsum), and ferrous carbonate (siderite) they are in soils forming: particles, pseudoparticles, weathering alteration (microcrystalline), and authigenic materials; Organic compounds (coal, kerogen, wax, paraffin...etc.) they are in soils

forming: biogenic, bioclastic, particles, pseudoparticles, weathering alteration, and diagenetic materials.

Flow diagram proposal for establish the general classification of regolith deposits based on the four fundamental parameters genetic conditions, structural conditions, textural categories, and compositional characteristic, step by step (figure 2).

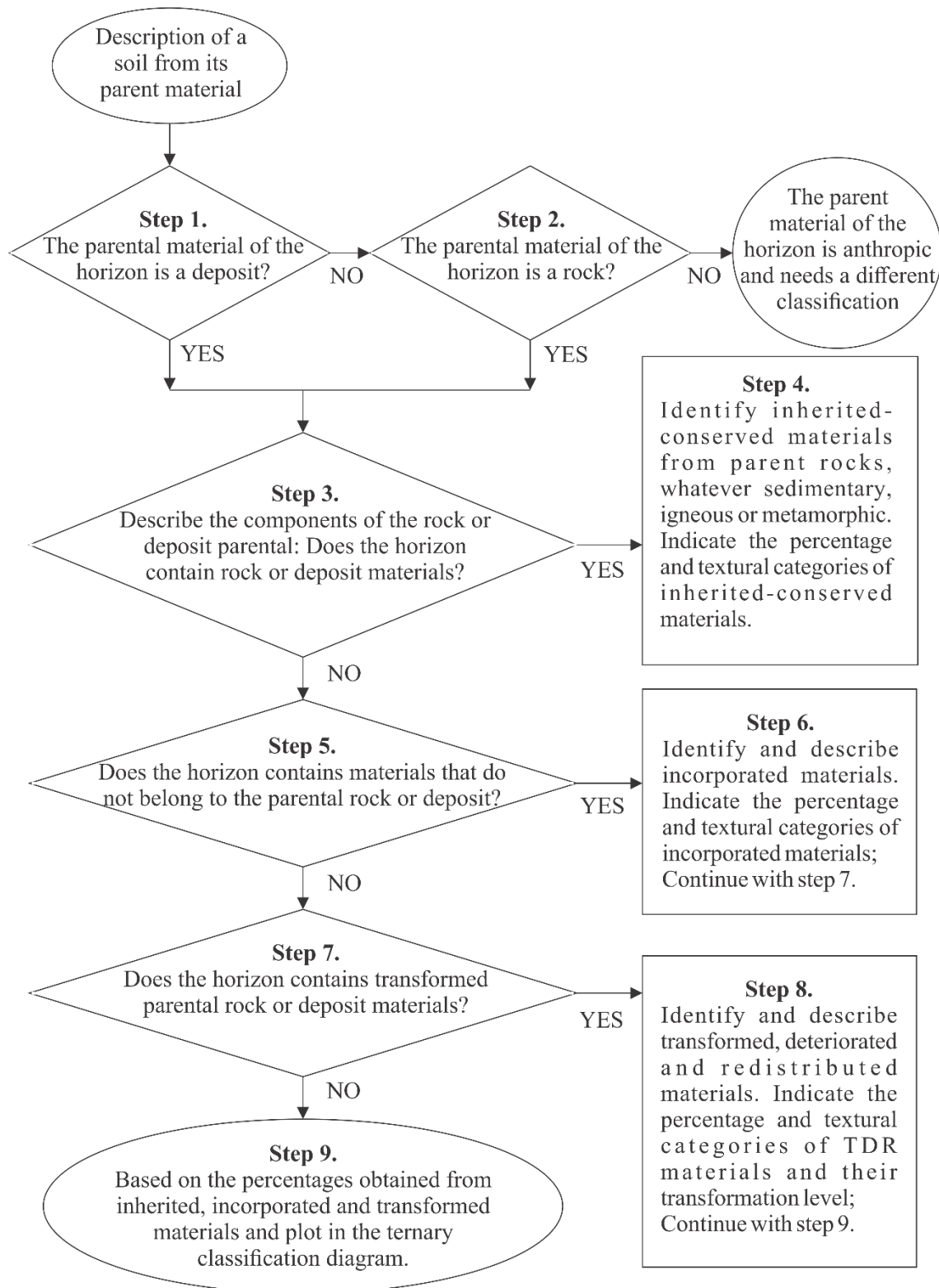


Figure 2. Flow diagram proposal of general classification of regolith deposits based on the four parameters: genetic conditions, structural conditions, textural categories, and compositional characteristic.

## 5. Results

The five field selected areas that allowed the study of recent soil cuts with different lithologic characteristics of the parental rock (sandstones, calcareous, granites, gneiss rocks and recent sedimentary deposits) are described below.

### 5.1 Soil developed on quartz sandstones lithology.

1,6m outcrop soil on “El Duende” cascade - “La Purnia” secondary road, coordinates X: 1°11'15.90, 048m, Y:1°25'23.70, 546m, y Z:1656 m.a.s.l. (figure 3B and 3D), the soil is developed on tabular feldspathic quartz sandstone intercalation with some silty claystone (25 to 30cm thickness), subhorizontal (<10°) to horizontal strata from upper section of “Los Santos” Formation. The soil profile is integrated by O horizon (topsoil) 10cm thickness with land use of pastures (2.3.1) according with CORINE land cover (CLC) (2010) and seven more horizons (figure 6).

**5.1.1 Geomorphology and climate.** This sampling place corresponds geomorphologically to the upper part of a structural plateau with sub horizontal to horizontal strata (dips smaller than 5°), the geomorphological slope is smooth (inclination from 0 to 4°) according to the slope map generated from a Digital Model of Elevation DEM, the range of heights varies between 1623 to 1718m (figures 3 and 4). It has SW slope direction (figure 4. G) and simple slope complexity (figure 4. H and 4. F), the slope segment relative position is on upper third of slope (figure 4. G) with linear and flat slope shape (figure 4. G) and well drained natural soil drainage (water is removed from the soil readily but not rapidly, see soil moisture average content 7.1w% in figure 6), the dominant land cover at the site is 2. Agricultural areas 2.3. Pastures, 2.3.1. Pastures (see figure 4. E) according with CORINE land cover (CLC) (2010) and the dominant kind of erosion is water (removal by running water) according with Schoeneberger et al., (2012).

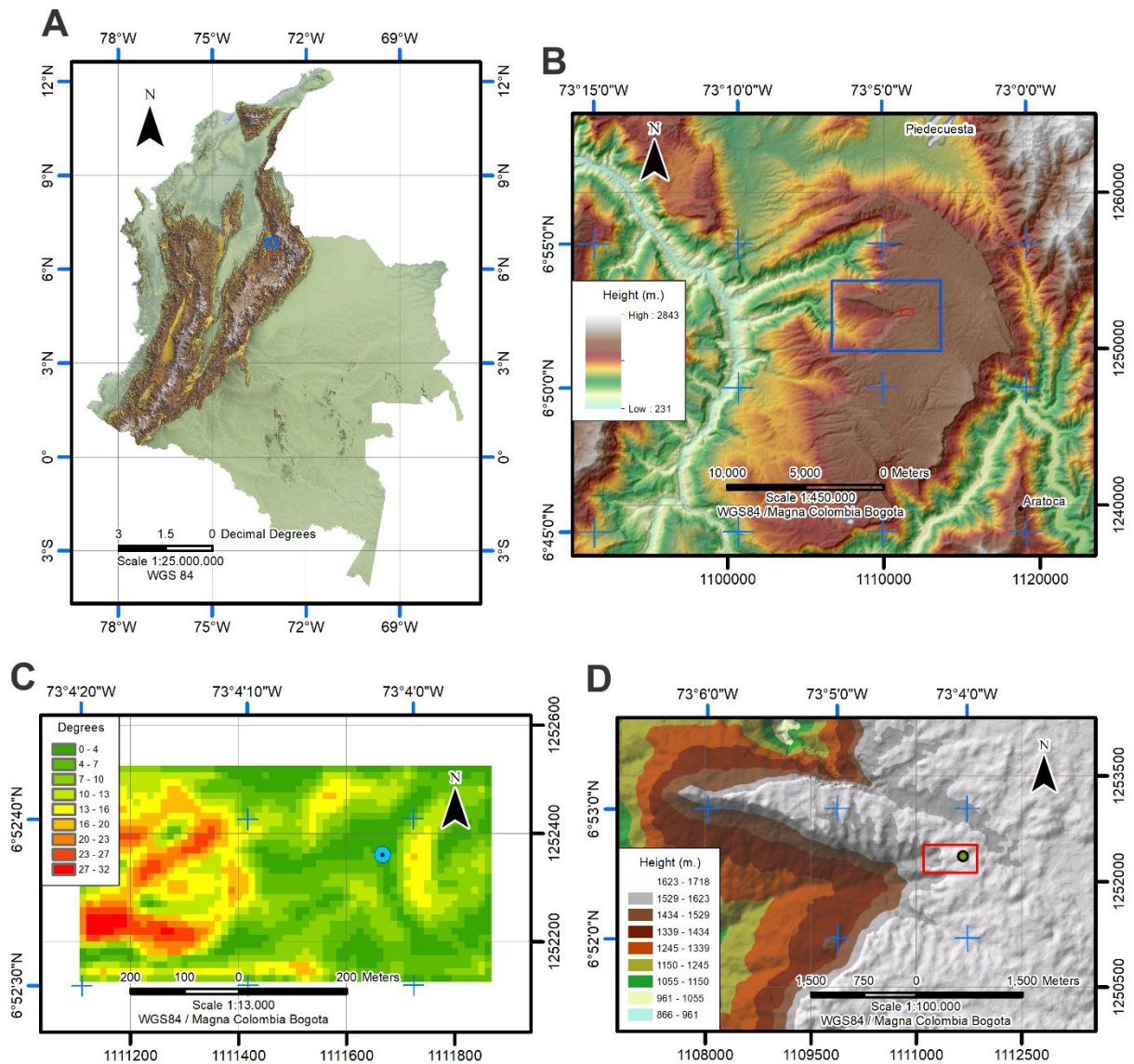
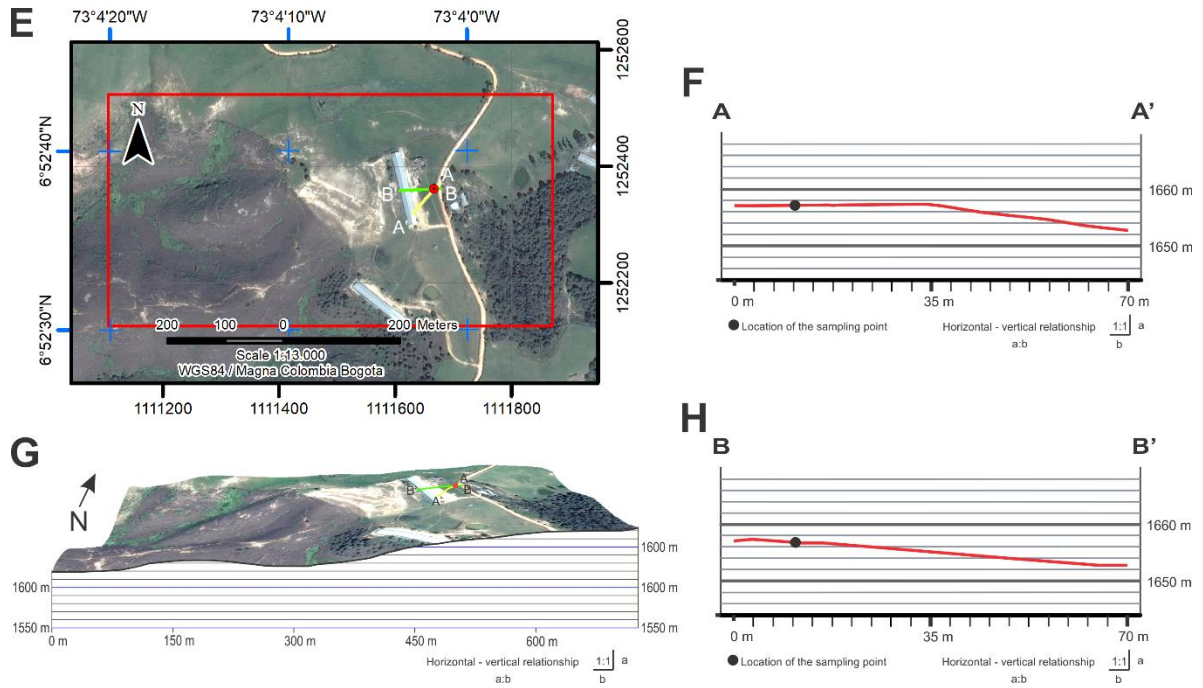


Figure 3. Localization of soil developed on Quartz sandstone lithology study place outcrop. A. - Colombian orographic map with site location (blue circle). B. - "Los Santos" geological plateau orography with site location (red circle). C. - Slope map of the local area with location site (blue circle). D. - Local height map with location site (black circle).



*Figure 4.* Specific localization of soil developed on Quartz sandstone lithology study place outcrop. E. - Satellite image of local area with localization of topographic profile A-A' and B-B'. F. - Topographic profile A-A'. G. - Three dimensional (3D) surface topography of local area. H. - Topographic profile B-B'.

The average annual rainfall is 1350mm. December, January, February, June and July are the driest months, the rainy season spans from March until May and from August until November. In the dry season months of the beginning of the year, it rains about 4 to 8 days/month; in the months with greater rainfall it rains around 12 to 16 days/month, and in the dry season months of mid-year, it can rain from 8 to 12 days/month with a maximum rainfall of 100 mm in 24 hours. The relative humidity of the air is greater than 80% in average and in times of rains reaches values greater than 85%.

The multi-annual average temperature that ranges from 20 to 22°C, the average temperature is 21°C, at midday the average maximum temperature ranges from 24 to 28°C, in the early morning the minimum temperature is between 12 and 18°C. The average hours of sunshine are between 4 and 5 hours a day in the rainy season months and for the dry season sunshine registers between 4 and 6 hours a day. The average monthly wind speed at 10m height maintains values between 3 and

4m/s in February and between 2 and 3m/s during the rest of the year, the average monthly evaporation values are between 120 and 150mm in the months of January and March, and values of 90 to 120mm during the rest of the year (figure 5).



Figure 5. Climatic variables (temperature, rainfall, sunshine, evaporation, wind speed) for soil developed on Quartz sandstone lithology sampling place, extrapolated from the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) Interactive Atlas.

Based on the climate classification Caldas–Lang and with the information about precipitation, temperature and altitude, this station corresponds to a semi-humid temperate climate (Tsh), (Table 14).

*Table 14. Use of extrapolated information to obtain climatic classification lang – caldas*

Annual average temperature (° C). Multiannual average since 1981 to 2010; based on IDEAM data.	Average annual rainfall (mm), multiyear average since 1981 to 2010; Based on IDEAM data.	Lang Factor (P/T)	Classification Lang	Height above sea level (m)	Classification Caldas	Climate classification Caldas -Lang
22	1350	61	semi-humid [sh] (61 - 100)	1656	Temperate[T] (1001 m - 2000 m) & (24°>T≥17.5°)	Temperate semi-humid [Tsh]

**5.1.2 Descriptions for soil developed on quartz sandstone lithology.** The soil is integrated by the following horizons (figure 6).

**5.1.2.1 Quartz Sandstone sampling place, 1st horizon field description:** Total horizon thickness of 20cm, the cross-sectional shape of the contact between 1st and 2nd horizons is planar with few or no irregularities (smooth), dry soil color is 5YR 5/3 (reddish brown) and moist soil color is 5YR 4/3 (reddish brown), the horizon has soil matrix with Fe/Mn nodules that can be removed as discrete units from soil, excavation difficulty is low because the excavation by tile spade requires arm pressure only. The quantity of roots no carbonized is 7% and they extend across 150cm of deep, roots and pores size is fine to medium (1 to 4mm), roots location is in the soil matrix and cracks. Quantity of pores is 12% and the form of pores is tubular, irregular like non-connected cavities and laminar like horizontal and vertical cracks. The average number of vertical and sub planar cracks, per meter, is 4% and there are reversible crust-related cracks (figure 6).

*5.1.2.1.1 Description based on sieve samples without clay materials, sample 1 from 1st horizon:* Very fine to medium sand-size Qtz particles, slightly granule-size, with some incorporated sand-size carbonized plant fragments and silt-size sericitic pseudo-matrix. Very fine to medium sand-size Qtz transparent-hyaline particles with sub-angular to sub-roundness, some roundness, elongated and low sphericity (62%). Some sand-size carbonized plants fragment (3%). Coarse sand to granule-size bacterial agglutinate soil blades-shape pseudo-particles with silt-size angular qtz, no spherical and carbonized plants fragment (3%). Silt-size sericitic matrix pseudo-matrix (32%). The 1st horizon characteristics are presented on table 15.

*Table 15.* Specific genetic materials in 1st horizon of soil profile developed on Quartz sandstones lithology

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium sand-size slightly granule-size qtz particles	50%
<b>Incorporated</b>	Coarse sand to granule-size agglutinate soil blades-shape pseudo-particles (3%)	23%
	TOC (3.02%)	
	Sand-size plant fragments (2%), roots, pores and water (17%)	
<b>TDR</b>	Argillaceous matrix and iron oxides cement	25%
	<b>Total</b>	<b>100%</b>

*5.1.2.2 Quartz Sandstone sampling place, 2nd horizon field description:* Total horizon thickness of 14 cm. The cross-sectional shape of the contact between 2nd and 3rd horizons is wavy (width of undulation is more than depth), dry soil color is 5YR 6/6 (reddish yellow) and moist soil color is 5YR 5/6 (yellowish red), the horizon has soil matrix with iron-manganese nodules and the gradation between nodules and matrix is sharp, so color changes abruptly in <0.1mm between the cemented bodies and the soil matrix. Nodules size is fine to medium (0.4 to 4mm) with ovoid and irregular shape. Excavation difficulty is high because excavation by tile spade is difficult but easily

done by pick using over-the-head swing. The quantity of roots no carbonized is 5% and their location is matted around iron-manganese nodules, roots size is very fine (<1mm). Quantity of pores is between 12 - 15% and the shape of pores are tubular, interstitial, cylindrical and elongated voids. The average number of cracks, per meter, is 3%, they are vertical, sub planar and there are reversible crust-related cracks (figure 6)

*5.1.2.2.1 Description based on sieve samples without clay materials, sample 2 from 2nd horizon:* Very fine to medium sand-size Qtz particles and granule to coarse pebbles-size ferruginous oxides nodules pseudo-particles. Very fine to medium sand-size monocrystals some polycrystalline Qtz (transparent-polished) particles (35 to 49%) sub-angular to sub-roundness some roundness and elongated. Granule to coarse pebbles-size ferruginous oxides nodules pseudo-particles (44%) and silt size sericitic pseudo-matrix (21%). The 2nd horizon characteristics are presented on table 16.

*Table 16.* Specific genetic materials in 2nd horizon of soil profile developed on Quartz sandstones lithology

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium qtz sand-size particles	34%
<b>Incorporated</b>	Granule to coarse pebbles-size ferruginous oxides ovoid shape nodules (30%)	48%
	TOC (2.02%)	
	Roots, pores and water (16%)	
<b>TDR</b>	Argillaceous matrix and iron oxides cement	18%
	<b>Total</b>	<b>100%</b>

*5.1.2.3 Quartz Sandstone sampling place, 3rd horizon field description:* Total horizon thickness of 20cm. The cross-sectional shape of the contact between 3rd and 4th horizons is

irregular (depth of undulation is more than width), dry matrix soil color is 5YR 7/8 (reddish yellow), with mottled structures color of 5YR 5/8 (yellowish red) and some iron-manganese nodules color of 10R 4/8 (red); Moist soil color is 5YR6/8 (reddish yellow), with mottled structures color of 5YR 4/6 (yellowish red), and some iron-manganese nodules color of 10R 3/4 (dark red). The gradation between mottles and matrix is sharp and the change of color is abrupt. Mottles size is medium to very coarse (4 to 24mm) and nodules size is fine (<2mm), mottles shape is reticulate and irregular, and the dominant nodules shape is ovoid and irregular. Excavation difficulty is moderate because excavation by tile spade requires impact energy or foot pressure; arm pressure is insufficient. The quantity of roots no carbonized is 3% and their location is in cracks, roots size is medium (4mm). Quantity of pores is 5% and the shape of pores is interstitial (voids between sand grains or rock frags). The average number of vertical and sub planar cracks, per meter, is 2% and there are reversible crust-related cracks (figure 6). The 3th horizon characteristics are presented on table 17.

*Table 17. Specific genetic materials in 3th horizon of soil profile developed on Quartz sandstones lithology.*

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Fine to medium sand lightly silty qtz particles	51%
<b>Incorporated</b>	Ferruginous or manganese oxides on mottle structure (5%)	30%
	Granule to coarse pebbles-size ferruginous oxides ovoid shape nodules (7%)	
	TOC (1.09%)	
	Roots, pores and water (17%)	
<b>TDR</b>	Argillaceous matrix and iron oxides cement	19%
	<b>Total</b>	<b>100%</b>

**5.1.2.4 Quartz Sandstone sampling place, 4th horizon field description:** Total horizon thickness of 30cm. The cross-sectional shape of the contact between 4th and 5th horizons is

smooth, dry soil color is GLEY1 8/N (white) with mottled structures color of 10R 7/8 (light red) and 10R 5/8 (red); moist soil color is GLEY1 8/1 10Y (light greenish gray) with mottled structures color of 10R 5/8 (red) and 10R 4/8 (red). The gradation between mottles and matrix is sharp and the change of color is abrupt. Mottles size is very coarse to extremely coarse (20 to 200mm) and their shape is reticulate and irregular. Excavation difficulty is high because excavation by tile spade is difficult but easily done by pick using over-the-head swing. The quantity of roots no carbonized is 3% and their location is in cracks, roots size is medium (4mm). Quantity of pores is 3% and the shape of pores is interstitial. The average number of cracks, per meter, is 2%, they are vertical, sub planar and there are reversible crust-related cracks and irreversible crust-related cracks (figure 6). The 4th horizon characteristics are presented on table 18.

*Table 18. Specific genetic materials in 4th horizon of soil profile developed on Quartz sandstones lithology.*

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Fine to medium qtz sand	53%
<b>Incorporated</b>	Ferruginous or manganese oxides on mottle structure (5%)	9,35%
	TOC (0.347%)	
	Roots, pores and water (12%)	
<b>TDR</b>	Argillaceous matrix and iron oxides cement	29,65%
	<b>Total</b>	<b>100%</b>

**5.1.2.5 Quartz Sandstone sampling place, 5th horizon field description:** Total horizon thickness of 19 cm. The cross-sectional shape of the contact between 5th and 6th horizons is smooth, dry soil color is GLEY1 8/N (white) with mottled structures color of 10R 7/8 (light red) and 10R 5/8 (red); moist soil color is GLEY1 8/1 10Y (light greenish gray) with mottled structures color of 10R 5/8 (red) and 10R 4/8 (red). The gradation between mottles and matrix is sharp and the change of color is abrupt. Mottles size is very coarse to extremely coarse (20 to 200mm) and

their shape is reticulate and irregular. Excavation difficulty is high and the quantity of roots no carbonized is 3%, their location is in cracks, roots size is medium (4mm). Quantity of pores is 3% and the shape of pores is interstitial. The 5th horizon characteristics are presented on table 19.

*Table 19. Specific genetic materials in 5th horizon of soil profile developed on Quartz sandstones lithology.*

Genetic general material	Specific material	Percentage
Inherited-conserved	Fine to medium sand fsp (5%)	55%
	Fine to medium sand qtz (5%)	
Incorporated	Ferruginous or manganese oxides on mottle structure (7%)	12%
	TOC (0.209%)	
	Pores and water (10%)	
TDR	Argillaceous materials and iron oxides cement	28%
	<b>Total</b>	<b>100%</b>

**5.1.2.6 Quartz Sandstone sampling place, 6th horizon field description:** Total horizon thickness of 7cm. The cross-sectional shape of the contact between 6th and 7th horizons is smooth, dry soil color is: GLEY1 8/1 10Y (light greenish gray) and moist soil color is: GLEY1 7/1 5GY (light greenish gray). The horizon corresponds to muddy material with fractures of up to 3cm. The 6th horizon characteristics are presented on table 20.

*Table 20. Specific genetic materials in 6th horizon of soil profile developed on Quartz sandstones lithology.*

Genetic general material	Specific material	Percentage
Inherited	Argillaceous claystone (Illite) (65.714%)	70,614%
	Very fine qtz sand (4.9%)	
Incorporated	TOC (0.386%)	0,386%
	Water (11.21)	
TDR	Argillaceous claystone (Kaolinite)	18%
	<b>Total</b>	<b>100%</b>

**5.1.2.7 Quartz Sandstone sampling place, 7th Horizon field description:** *Hic si st*, with mottled structure, >16cm thickness, 10R 5/8 (red) dry soil color, thickness (>20cm), *I-C materials*: slightly feldspathic moderately altered (5%), and fine to medium sand quartz (undulant some straight extinction with corrosion) with sub-roundness to sub-angular shape and low sphericity (71%), silt size zircon (1%): *TDR materials*: argillaceous to ferruginous matrix (8%) (See table 25). The 7th horizon characteristics are presented on table 21.

*Table 21.* Specific genetic materials in 7th horizon of soil profile developed on Quartz sandstones lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Fine to medium sand fsp (8%)	80%
	Fine to medium sand qtz (72%)	
<b>Incorporated</b>	Ferruginous or manganese oxides on mottle structure (7%)	12%
	Pores (5%)	
<b>TDR</b>	Argillaceous matrix and iron oxides cement	8%
	<b>Total</b>	<b>100%</b>

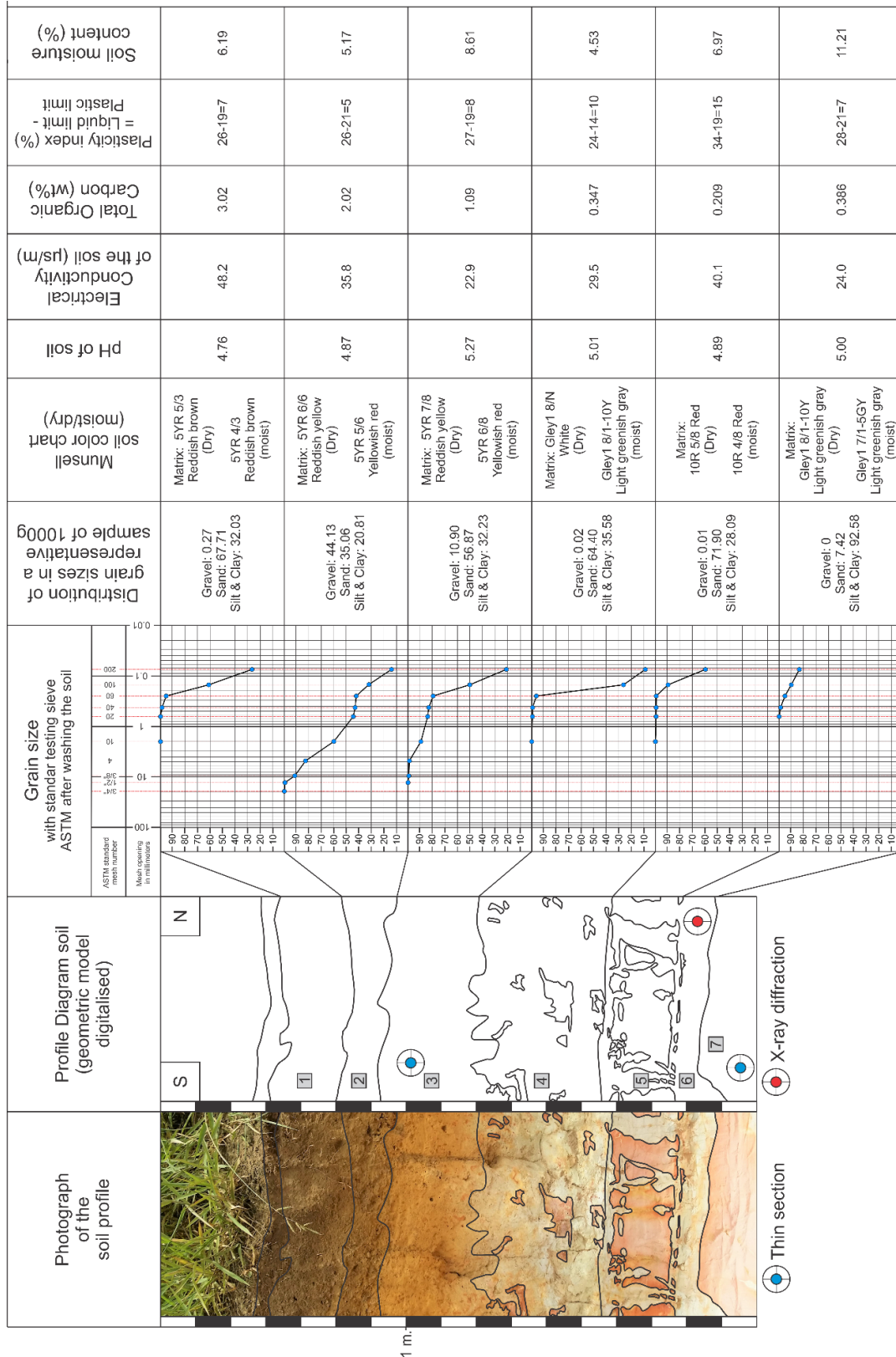


Figure 6. Soil profile developed on Quartz sandstone lithology sampling place with grain size distribution of materials, and physical and chemical properties.

### 5.1.3 Petrography for soil developed on quartz sandstone (7th and 3rd horizon).

*Thin section sample number 7 (7th horizon), with 5x objective and 10X ocular. Slightly feldspathic quartz fine to medium sandstone with sub-roundness to sub-angular shape and low sphericity, clayey to ferruginous matrix, with mottled structure. Quartz fine to medium size (55%) sub-roundness to sub-angular shape with corrosion and low sphericity, and undulant some straight extinction. Fine to medium size altered feldspar (5%), silt size zircon (1%), clayey to ferruginous matrix (39%) and bacterial strong mottled structure. Moderately conserved feldspar allows to establish that original rock parental material is a slightly feldspathic quartz sandstone (figure 7).*

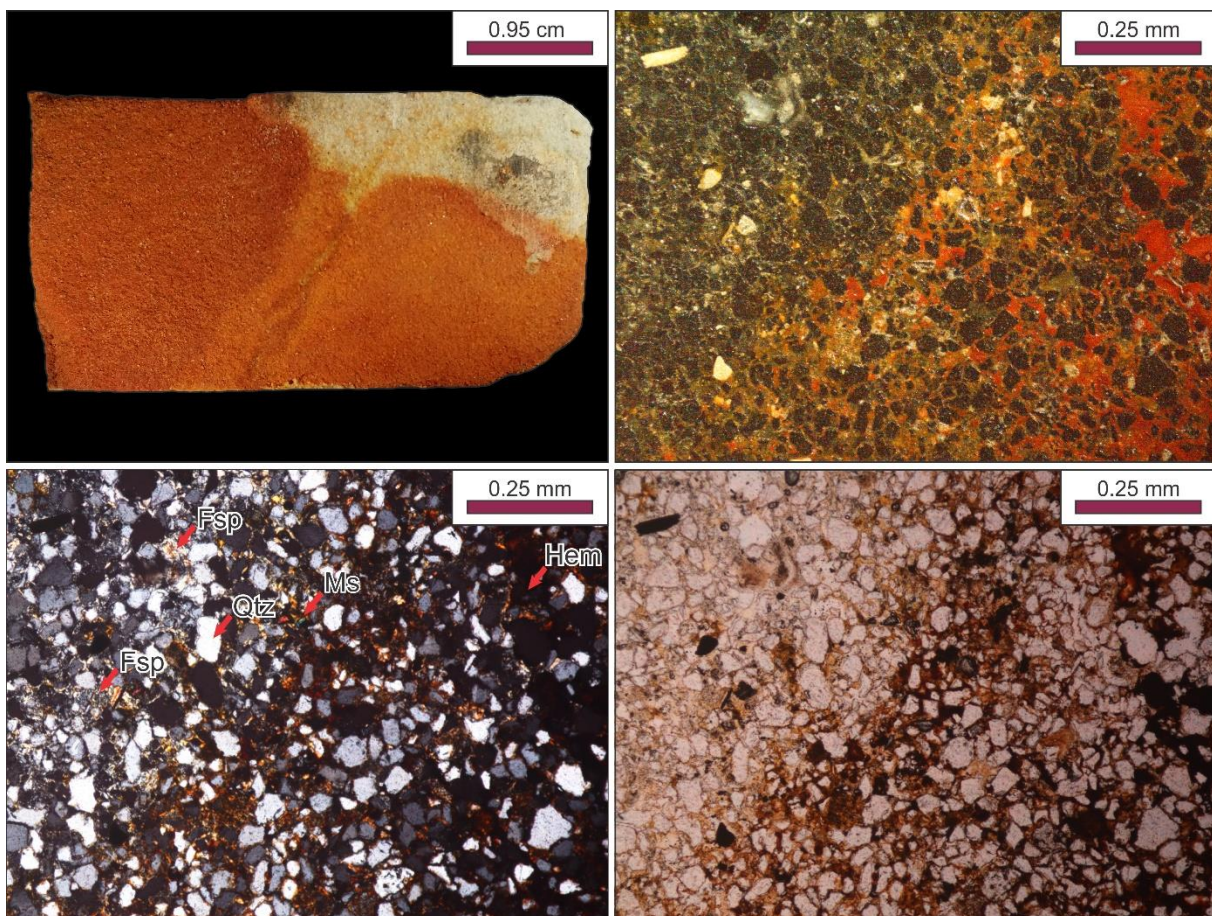
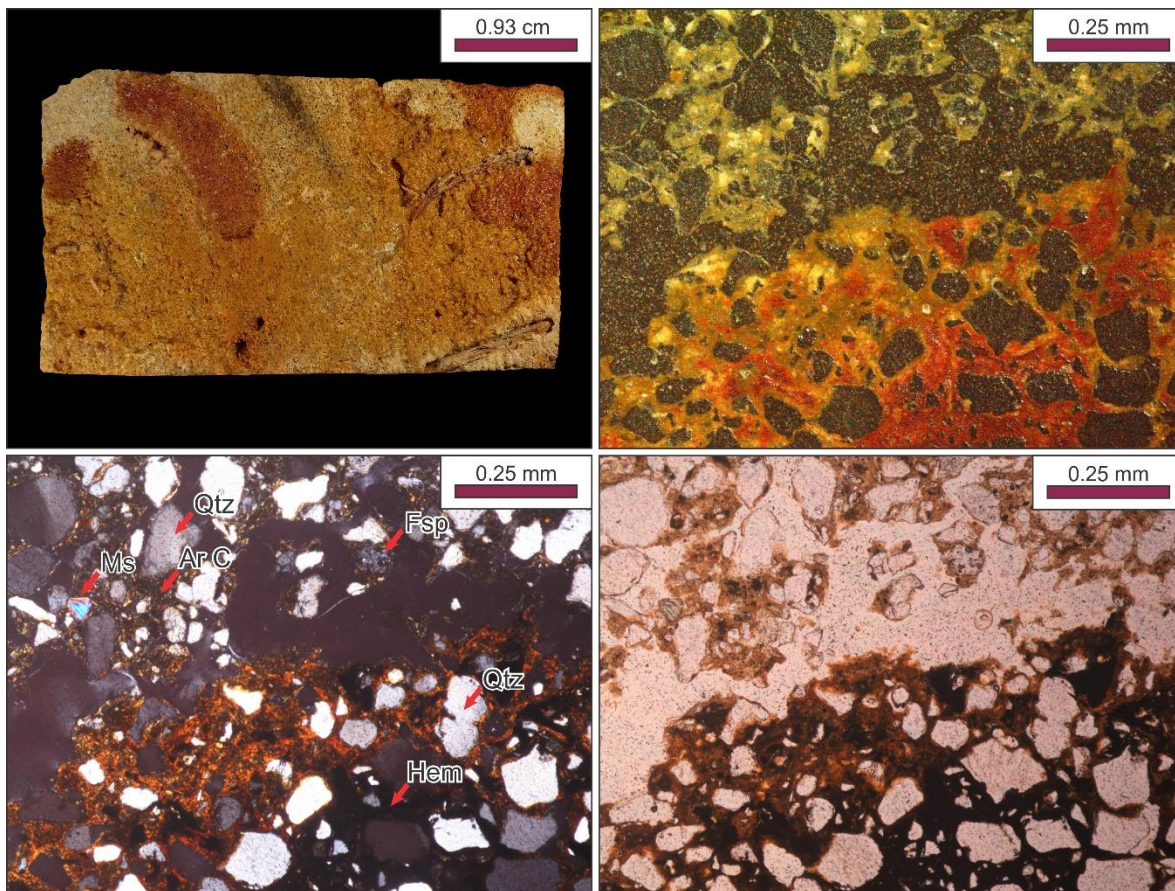


Figure 7. Fine quartz sandstone with argillaceous matrix and iron oxides cement. Thin section photography, with 5x objective and 10x ocular, sample number 7, soil profile 7th horizon of soil developed on Quartz sandstone lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL).

*Thin section sample number 3 (3rd horizon), with 5x objective and 10X ocular. Fine to medium sand lightly silty with sericitic matrix outside of the mottle structure and replaced with ferruginous or manganese oxides on mottle structure. Monocrystalline quartz floating (35%) medium silt to medium sand (0.027 to 0.40mm) with more abundant fine sand particles (0.17mm), sub-roundness to sub-angular, elongated and low sphericity, with undulant and straight extinction (~17.5%), external borders of particles have corrosion. Original rocks were very fine sand to silt sericitic matrix, and bacterial mottle structure area matrix was totally replaced by ferruginous or manganese oxides (figure 8).*



*Figure 8. Medium to fine quartz sandstone with argillaceous matrix and iron oxides cement. Iron nodule part on bottom right of the photography (0,6 to 3,7 cm nodules size). Thin section photography, with 5x objective and 10x ocular, sample number 3, soil profile 3rd nodular horizon of soil developed on Quartz sandstone lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL).*

#### 5.1.4 Clay fraction soil composition determination on quartz sandstone.

The sample analyzed shows the d spacing for the {001} plane measured in 10 (untreated sample) for the minerals in their natural state, the value after treating the minerals in a solution of Ethylene Glycol was no change and the mineral heated to 550°C shows the d spacing value with little change evidencing the presence of Illite. Besides, the sample analyzed shows the d spacing for the {001} plane measured in 7,1 (untreated sample) for the minerals in their natural state, the value after treating the minerals in a solution of Ethylene Glycol was no change and the mineral heated to 550°C shows d spacing value destroyed evidencing the presence of Kaolinite.

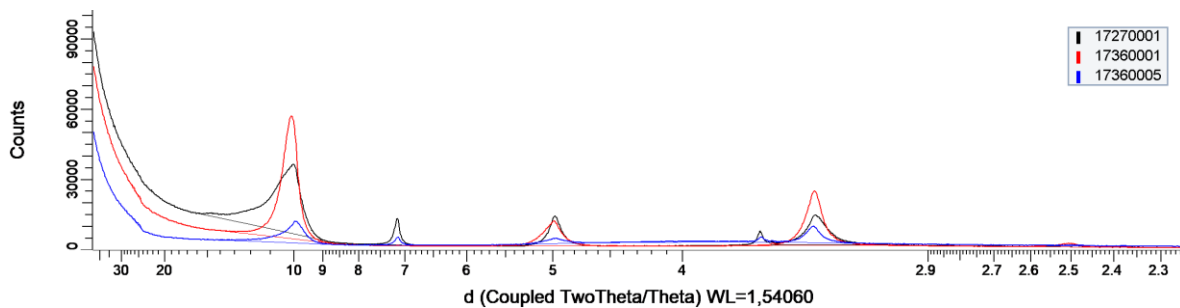


Figure 9. X-Ray Diffractogram for Clay fraction soil determination on Quartz sandstone lithology sample. Black line represents the undisturbed sample, the red one represents the sample at 550 degrees Celsius and the blue one represents the sample with Ethylene Glycol.

#### 5.1.5 Genetic material distribution of soil profile developed on feldspatic quartz sandstone lithology.

Soil profile developed on feldspatic quartz sandstone lithology show a soil slight TDR (argillaceous materials and iron oxides cement) moderately inherited-conserved (very fine to medium sand size slightly granule-size qtz) slight to moderately incorporated materials (coarse sand to granule-size agglutinate soil blades-shape pseudo-particles, sand-size plant fragments, roots and pores with TOC 3.02 to 0.386) (1st to 5th horizon) and Heavily inherited-conserved slight incorporated (6th to 7th horizon) (see figure 10)

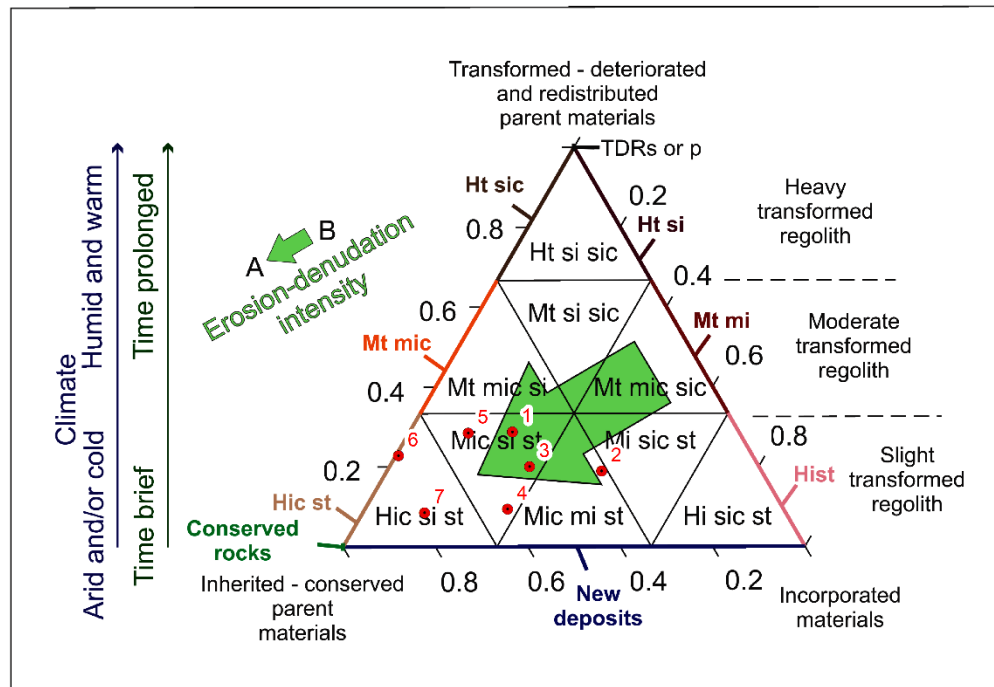


Figure 10 Implementation of the classification with the seven soil horizons developed in the lithology of Qtz sandstone, include relation with the tree fundamentals factors that control the formation of soils: time, climate and denudation.

## 5.2 Soil developed on gneiss lithology.

4m soil outcrop on “los Cauchos-Bella Vista” secondary road, coordinates X: 1°10'7837, 896m, Y: 1°27'0679, 241m, y Z: 1222m.a.s.l. (figure 11.B and 11.D), developed on biotitic feldspathic quartz gneiss from Bucaramanga gneiss. The soil profile is integrated by O horizon (topsoil) with a land cover of Transitional woodland-shrub (3.2.4.) according with CORINE land cover (CLC) (2010) and four more horizons (figure 14).

**5.2.1 Geomorphology and climate.** This sampling place corresponds geomorphologically with triangular facets, with abrupt surface and inclination of 30 to 34° of the geomorphological slope according to the map of slopes generated from a Digital Model of Elevation DEM, the range of heights ranges from 1130 to 1292. (See figures 11 and 12). It has SW slope direction (figure 12. G) and complex slope (figure 12. H and 12. F), the slope segment relative position is on lower

third of slope (figure 12. G and 12. D) with linear and convex slope shape (figure 12. G) and somewhat poorly drained natural soil drainage (see soil moisture content 8.4w% in figure 14), the dominant land cover at the site is 3. Forest and semi natural areas, 3.2. Scrub and/or herbaceous vegetation associations, 3.2.4. Transitional woodland-shrub (see figure 12. E) according with CORINE land cover (CLC) (2010) and the dominant kind of erosion is water with big channels according with Schoeneberger et al., (2012).

The average annual rainfall is 1450mm. December, January and February are the driest months, the rainy season spans from March until November, with May and October being the months of the highest proportion. In the dry season months of the beginning of the year, it rains about 4 to 8 days/month; in the months with greater rainfall it rains around 16 to 20 days/month with a maximum rainfall of 125mm in 24 hours. The relative humidity of the air is greater than 80% in average and in times of rains reaches values greater than 85%.

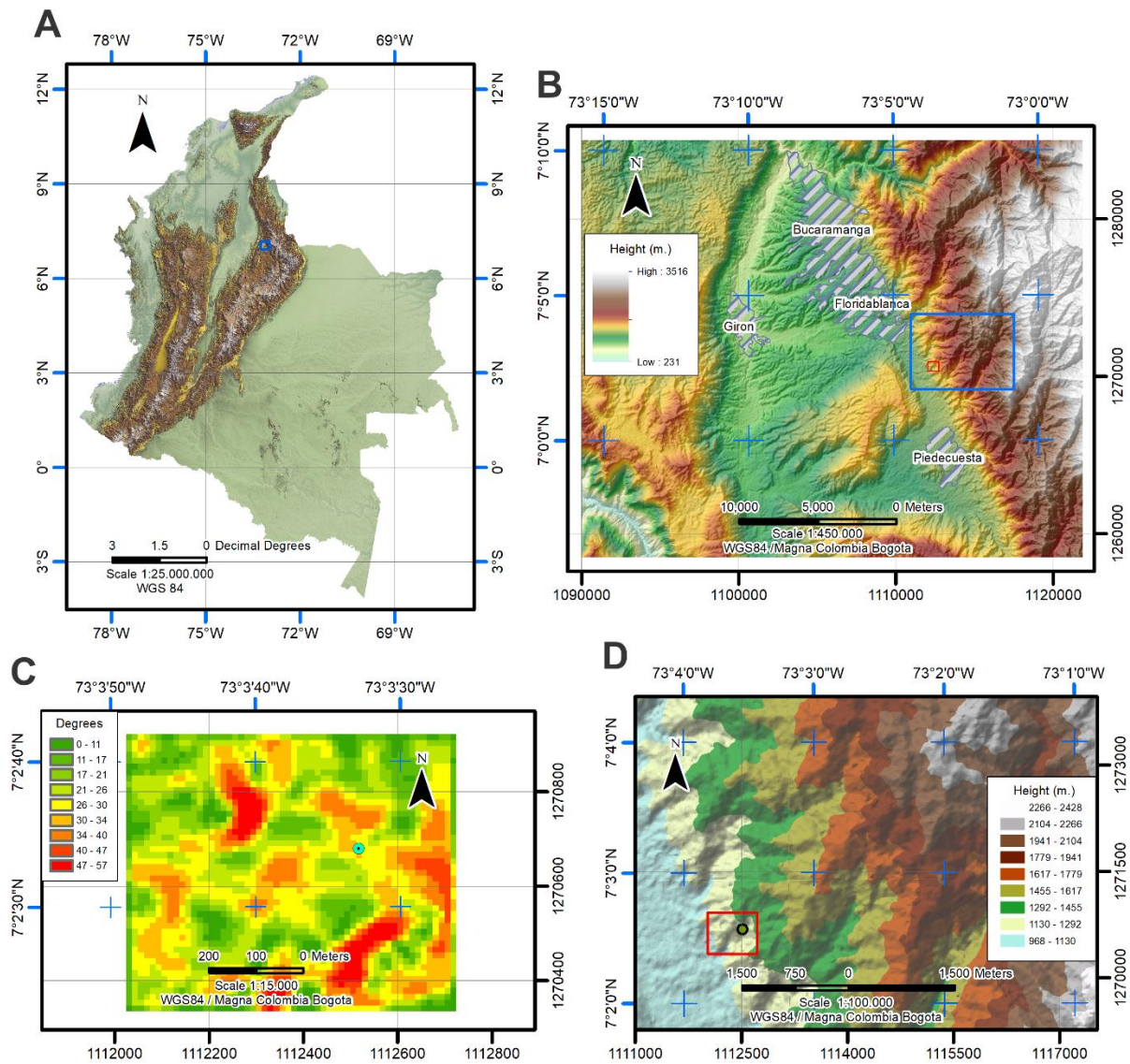


Figure 11. Localization of soil developed on Gneiss lithology study place outcrop. A. - Colombian orographic map with site location (blue circle). B. - Local orography with site location (red circle). C. - Slope map of the local area with location site (blue circle). D. - Local height map with location site (black circle).

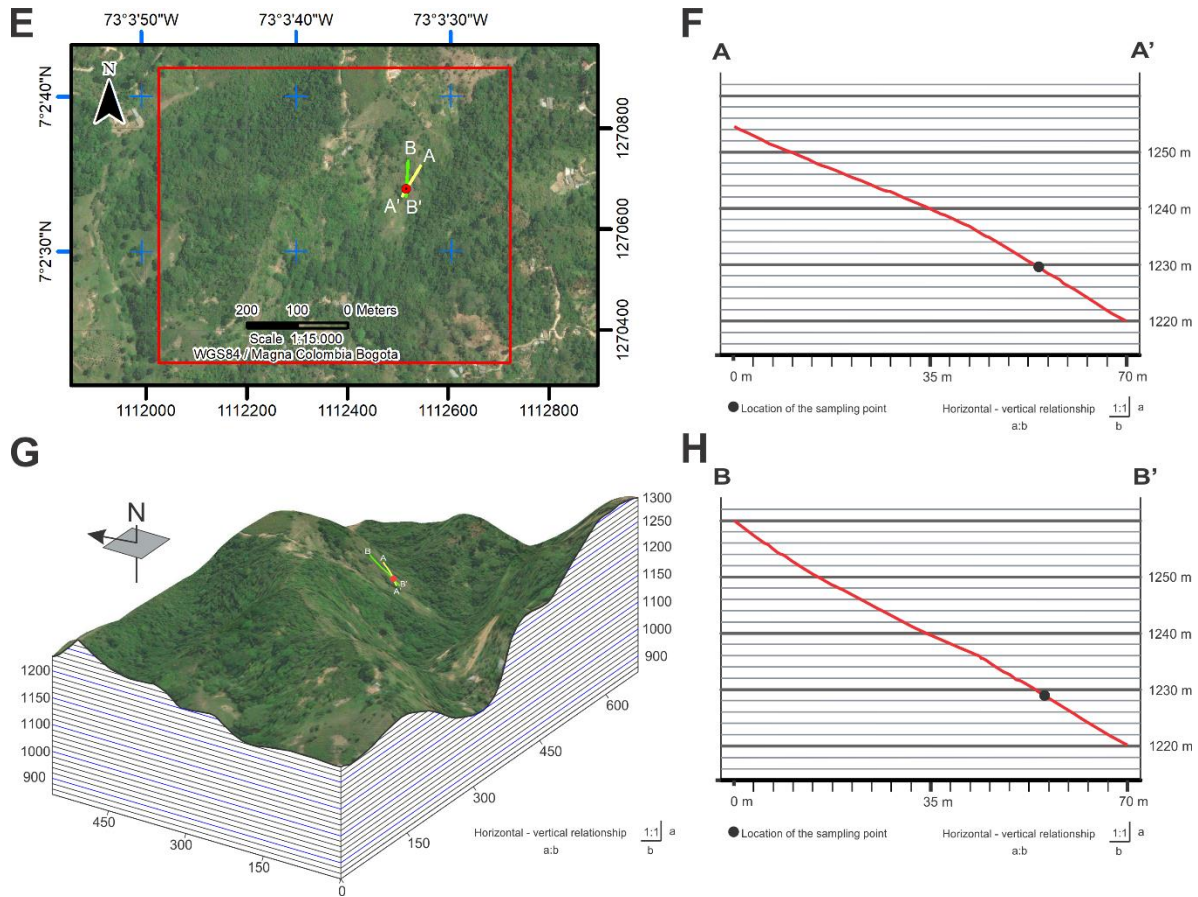


Figure 12. Specific localization of soil developed on Gneiss lithology study place outcrop. E. - Satellite image of local area with localization of topographic profile A-A' and B-B'. F. - Topographic profile A-A'. G. - Three dimensional (3D) surface topography of local area. H. - Topographic profile B-B'.

The multi-annual average temperature that ranges from 16 to 20°C, the average temperature is 18°C, at midday the average maximum temperature ranges from 20 to 24°C, in the early morning the minimum temperature is between 8 and 12°C. The average hours of sunshine are between 3 to 4 hours a day in the rainy season months and for the dry season sunshine registers between 4 and 6 hours a day. The average monthly wind speed at 10m height maintains values between 3 and 4m/s in the months of December, January, February and March and between 2 and 3m/s during the rest of the year, the average monthly evaporation registers values between 120 to 150mm in the months of January and March, and values of 90 to 120mm during the rest of the year (figure 13).



Figure 13. Climatic variables (temperature, rainfall, sunshine, evaporation, wind speed) for soil developed on Gneiss lithology sampling place, extrapolated from IDEAM Interactive Atlas.

Based on the climate classification Caldas–Lang and with the information about precipitation, temperature and altitude, this station corresponds to a semi-humid temperate climate (Tsh), (Table 15).

*Table 22.* Use of extrapolated information to obtain climatic classification lang – caldas

Annual average temperature (° C). Multiannual average since 1981 to 2010; based on IDEAM data.	Average annual rainfall (mm), multiyear average since 1981 to 2010; Based on IDEAM data.	Lang Factor (P/T)	Classification Lang	Height above sea level (m)	Classification Caldas	Climate classification Caldas -Lang
18	1450	81	semi-humid [sh] (61 - 100)	1222	Temperate[T] (1001 m - 2000 m) & (24°>T≥17.5°)	Temperate semi-humid [Tsh]

**5.2.2 Descriptions for soil developed on gneiss lithology.** The soil is integrated by the following horizons (see figure 14).

**5.2.2.1 Gneiss sampling place, 1st horizon field description:** Total horizon thickness varies from 6 to 16cm. The cross-sectional shape of the contact between 1st and 2nd horizons is wavy, dry soil matrix color is 5Y4/1 (dark gray), with 7.5YR9.5/1 (white), 10YR8/4 (very pale brown) and 5GY3/2 (very dark gray olive) clasts; moist soil matrix color is 5Y 2.5/1 (black), with 10YR 7/6 (yellow), 7Y 2.5/1 (black), 10YR 9/1 (white) clasts, the gradation between rock fragments and matrix is sharp, so color changes abruptly in <0.1mm between the fragments and the soil matrix. The dominant form of the rock fragments is elongated and the relative roundness is angular. Excavation difficulty is moderate, the quantity of roots no carbonized is 3% and their location is matted around rock fragments, roots size is very fine to coarse (<1 to 10mm). Quantity of pores is 15% and the dominant shape of pores is tubular 2%, branching voids 8%, cylindrical 3% and interstitial 2%. The average number of cracks, per meter, is 3%, they are the result of desiccation and there are reversible crust-related cracks.

*5.2.2.1.1 Description based on sieve samples without clay materials, sample 8 from 1st horizon:* Very fine to medium sand-size biotite and muscovite, Qtz transparent-hialine and amphibole with very angular-shape (13%). Coarse sand to coarse pebbles-size gneisses and polycrystalline qtz RF, monocrystalline transparent very angular-shape qtz (58%), carbonized plant fragments (1%). Silt-size monocrystalline Qtz transparent and phyllosilicates angular (28%). The 1st horizon characteristics are presented on table 23.

*Table 23.* Specific genetic materials in 1st horizon of soil profile developed on Gneiss lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Fine to medium sand biotite, muscovite, amphibole and qtz (9%)	57,864%
	Coarse sand to coarse pebbles size RF (Gneiss and polycrystalline qtz (51%)	
<b>Incorporated</b>	TOC (2,136%)	17,136%
	Root (3%)	
	Pores and water (12%)	
<b>TDR</b>	Silty matrix and some iron oxides cement	25%
	<b>Total</b>	<b>100%</b>

*5.2.2.2 Gneiss sampling place, 2nd horizon field description:* Total horizon thickness varies from 5 to 41cm. The cross-sectional shape of the contact between 2nd and 3rd horizons is irregular, dry soil matrix color is 5Y4/2 (olive gray), with 2.5Y 2/9 (very pale yellow) and 5Y 3/2 (dark olive gray) clasts, and moist soil matrix color is 5Y 3/1 (very dark gray), with 5Y 2.5/2 (black) and 2.5Y 8/2 (pale yellow) clasts, the gradation between rock fragments and matrix is sharp and the change of color is abrupt. The dominant form of the rock fragments is spherical, elongated and the relative roundness is angular. Excavation difficulty is low in matrix but is high in rock fragments, the quantity of roots no carbonized is 5%, they extend across 2nd horizon to 3rd horizon with 570mm of deep and their location is matted around rock fragments, roots size is fine (1 to

<2mm). Quantity of pores is 15% and the dominant shape of pores is irregular and interstitial. The average number of cracks, per meter, is 8%, they are the result of desiccation and there are reversible crust-related cracks. The 2nd horizon characteristics are presented on table 24.

Table 24. Specific genetic materials in 2nd horizon of soil profile developed on Gneiss lithology.

Genetic general material	Specific material	Percentage
Inherited-conserved	Very fine to very coarse sand RF pseudoparticles (13%)	77,165%
	Granule sand to coarse pebbles size RF (Gneiss and polycrystalline qtz pseudoparticles (66%))	
Incorporated	TOC (1,835%)	10,835%
	Root (3%)	
	Pores and water (6%)	
TDR	Argillaceous materials	12%
	<b>Total</b>	<b>100%</b>

**5.2.2.3 Gneiss sampling place, 3rd horizon field description:** Total horizon thickness varies from 16 to 27cm, very fractured and weathered parental rock. The topography of the contact between 3rd and 4th (rock) horizons is wavy, dry soil color is 2.5Y 6/4 (light yellowish brown) and moist soil color is 2.5Y 6/6 (olive yellow), the excavation difficulty is low in weathered rock but is high in quartz fragments, the quantity of root is 1% and their size is medium (2 to < 5mm). Pores are interstitial and the average number of cracks per meter is 5%, there are reversible crust-related cracks. The 3th horizon characteristics are presented on table 25.

Table 25. Specific genetic materials in 3th horizon of soil profile developed on Gneiss lithology.

Genetic general material	Specific material	Percentage
Inherited-conserved	Very fine to very coarse sand (51%)	58,62%
	Granule to coarse pebbles size RF (Gneiss and polycrystalline qtz) (8%)	
Incorporated	TOC (0,38%)	11,38%
	Root (3%)	
	Pores and water (8%)	
TDR	Argillaceous materials (Montmorillonite (26%) and Kaolinite (4%))	30%
	<b>Total</b>	<b>100%</b>

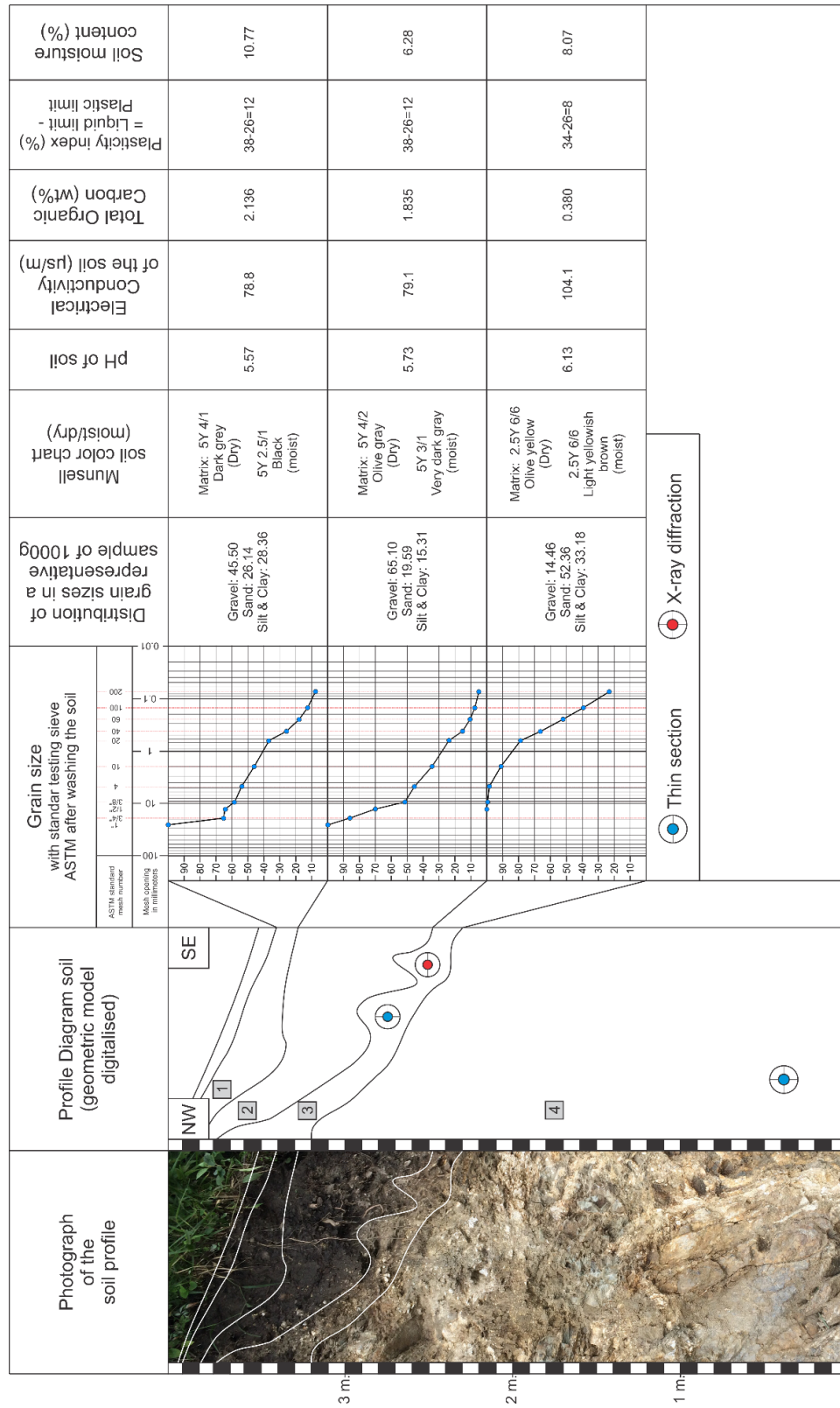
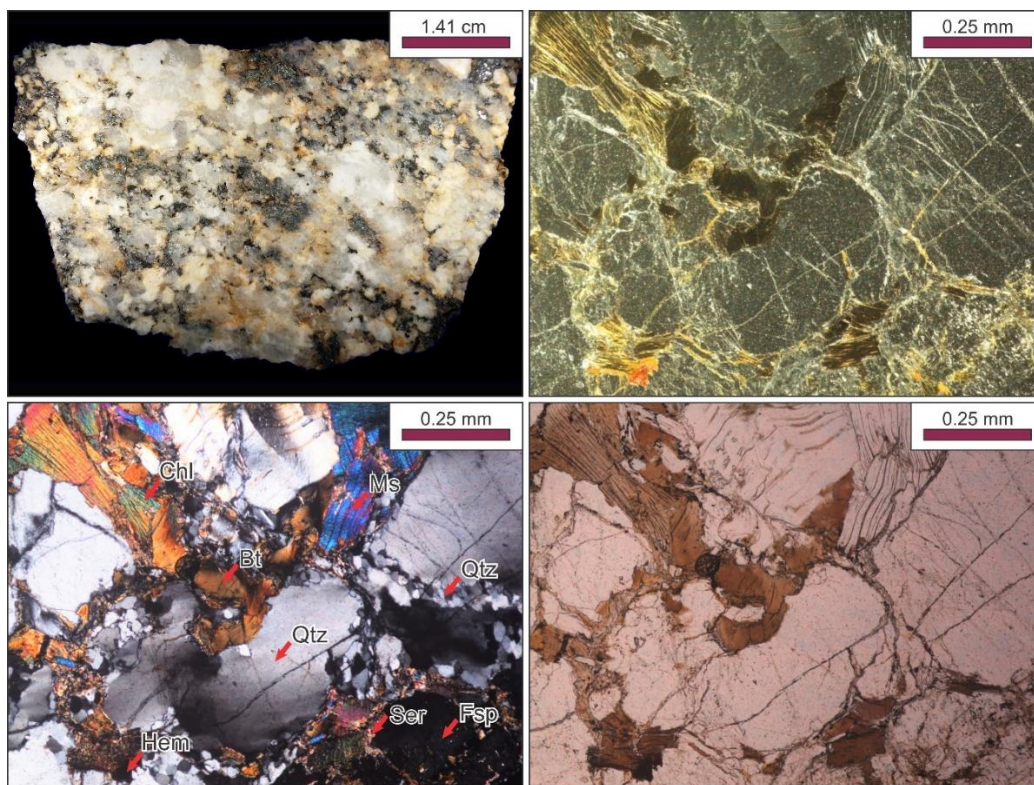


Figure 14. Soil profile developed on Gneiss lithology sampling place with grain size distribution of materials, and physical and chemical properties.

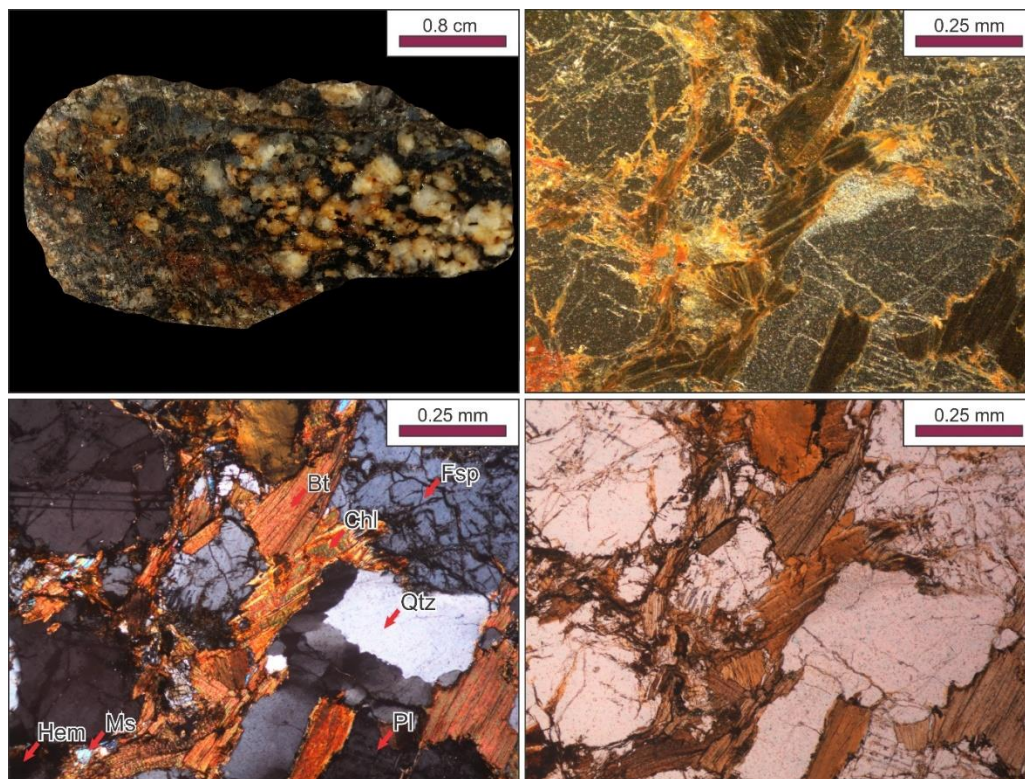
### 5.2.3 Petrography for soil developed on gneiss (4th (rock) and 3rd horizon).

*Thin section sample number 11 (4th horizon- Gneiss rock), with 5x objective and 10X ocular.* The mineralogical composition consists of high contents of anhedral quartz of fine to medium size 45%, potassium feldspar in medium size crystals with crystal twinning 20%, biotite in pale green to brown sheets slightly chloritized 15%, plagioclase in medium-sized crystals with polysynthetic twinning 14% and muscovite with slight folding 6%. The main minerals of alteration are chlorite and sericite, recrystallization of quartz with mortar texture and deformation in recrystallized quartz, a slight folding in some chloritized biotite and low sericitization of feldspar and plagioclase. The mineral assemblage consists of quartz + potassium feldspar + plagioclase + biotite (figure 15).



*Figure 15.* Biotite feldspathic -quartz gneiss. Thin section photography, with 5x objective and 10x ocular, sample number 11 of soil profile 4th horizon of soil developed on Gneiss lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ms: Muscovite, Fsp: Feldspar, Qtz: Quartz, Hem: Hematite, Chl: Chlorite, Bt: Biotite.

*Thin section sample number 10 (3rd horizon):* With 5x objective and 10X ocular. The mineralogical composition of the thin section consists of fine-to-medium-sized anhedral quartz, potassium feldspar altered in medium-sized crystals, biotite in brown sheets (some completely chloritized), plagioclase altered in medium-sized crystals with polysynthetic twinning and Muscovite. The main altering minerals are chlorite and sericite, high oxidation is observed in some minerals and there is high sericitization of feldspar and plagioclase (figure 16).



*Figure 16.* Feldspathic-biotite-quartz gneiss. Thin section photography, with 5x objective and 10x ocular, sample number 10 of soil profile 3rd horizon of soil developed on Gneiss lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ms: Muscovite, Fsp: Feldspar, Qtz: Quartz, Hem: Hematite, Chl: Chlorite, Bt: Biotite, Pl: Plagioclase.

#### 5.2.4 Clay fraction soil composition determination on gneiss.

The sample analyzed shows the d spacing for the {001} plane measured in 15, 02 (untreated sample) for the minerals in their natural state, the Ethylene Glycol value after treating the minerals in a solution of Ethylene Glycol (the principal ingredient in anti-freeze) was d spacing in 16,9 and

the mineral heated to 550°C shows the d spacing value in 9,9 evidencing the presence of Montmorillonite. Besides, the sample analyzed shows the d spacing for the {001} plane measured in 7,1 (untreated sample) for the minerals in their natural state, and the mineral heated to 550°C shows the d spacing value destroyed evidencing the presence of Kaolinite. (figure 17).

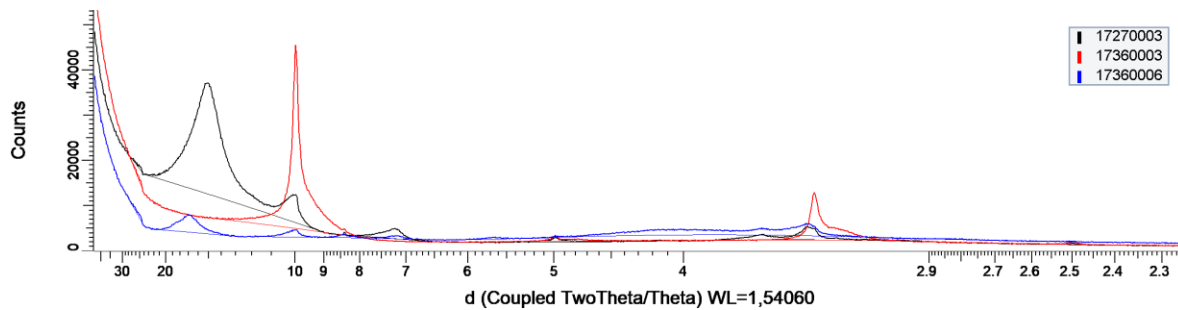


Figure 17. X-Ray Diffractogram for Clay fraction soil determination on Gneiss lithology sample. Black line represents the undisturbed sample, the red one represents the sample at 550 degrees Celsius and the blue one represents the sample with Ethylene Glycol.

### 5.2.5 Genetic material distribution of soil profile developed on biotitic feldspathic quartz gneiss lithology.

Soil profile developed on biotitic feldspathic quartz gneiss lithology show a soil slight TDR (Argillaceous materials (Montmorillonite and Kaolinite) and iron oxides in form of hematite) moderately to highly inherited-conserved materials (Granule sand to coarse pebbles size RF (Gneiss, polycrystalline qtz pseudoparticles) and Very fine to very coarse sand) slight incorporated materials (sand-size plant fragments, roots and pores with TOC 2.136 to 0.38) (1st to 3th horizon) (see figure 18)

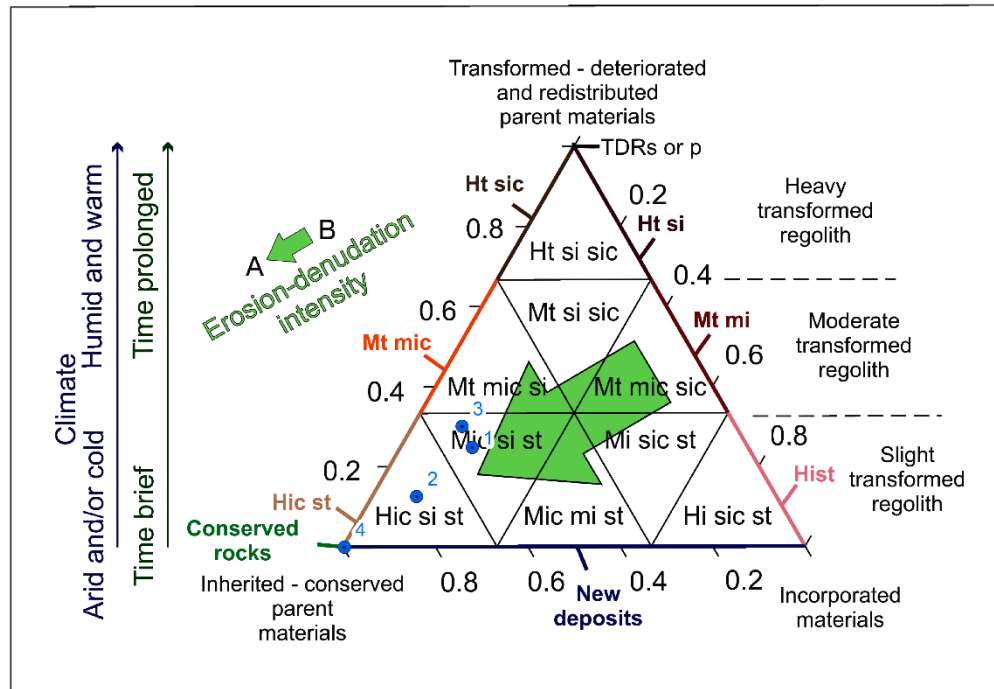


Figure 18. Implementation of the classification with the seven soil horizons developed in the lithology of gneiss, include relation with the tree fundamentals factors that control the formation of soils: time, climate and denudation.

### 5.3 Soil formed by weathering alteration of fluvio-torrential deposits.

2,5m soil outcrop at main road Bucaramanga- Floridablanca, coordinates X: 1'107837, 896m, Y: 1'273482, 054m, and Z: 870m.a.s.l. (17.B and 17.D), on fluvio-torrential terrace deposits. The soil profile is integrated by O horizon (topsoil) with land cover of green urban areas (1.4.1.) according with CORINE land cover (CLC) (2010) and five more horizons (figure 22).

**5.3.1 Geomorphology and climate.** This sampling place is a torrential fluvial deposit whose morphological expression is an eroded alluvial fan. With slope of 4 to 6° of the geomorphological slope according to the map of slopes generated from a Digital Model of Elevation DEM, the range of heights is from 871 to 944 (see figures 19 and 20). It has SE slope direction (figure 20. G) and simple slope complexity (figure 20. H and 20. F), the slope segment

relative position is on lower third of slope (figure 20. G) with linear and flat slope shape (figure 20. G) and somewhat poorly drained natural soil drainage (see soil moisture content 8.8w% in figure 22), the dominant land cover at the site is 1. artificial surfaces, 1.4. Artificial, non-agricultural vegetated areas, 1.4.1. green urban areas (See figure 20. E) according with CORINE land cover (CLC) (2010) and the dominant kind of erosion is water according with Schoeneberger et al., (2012).

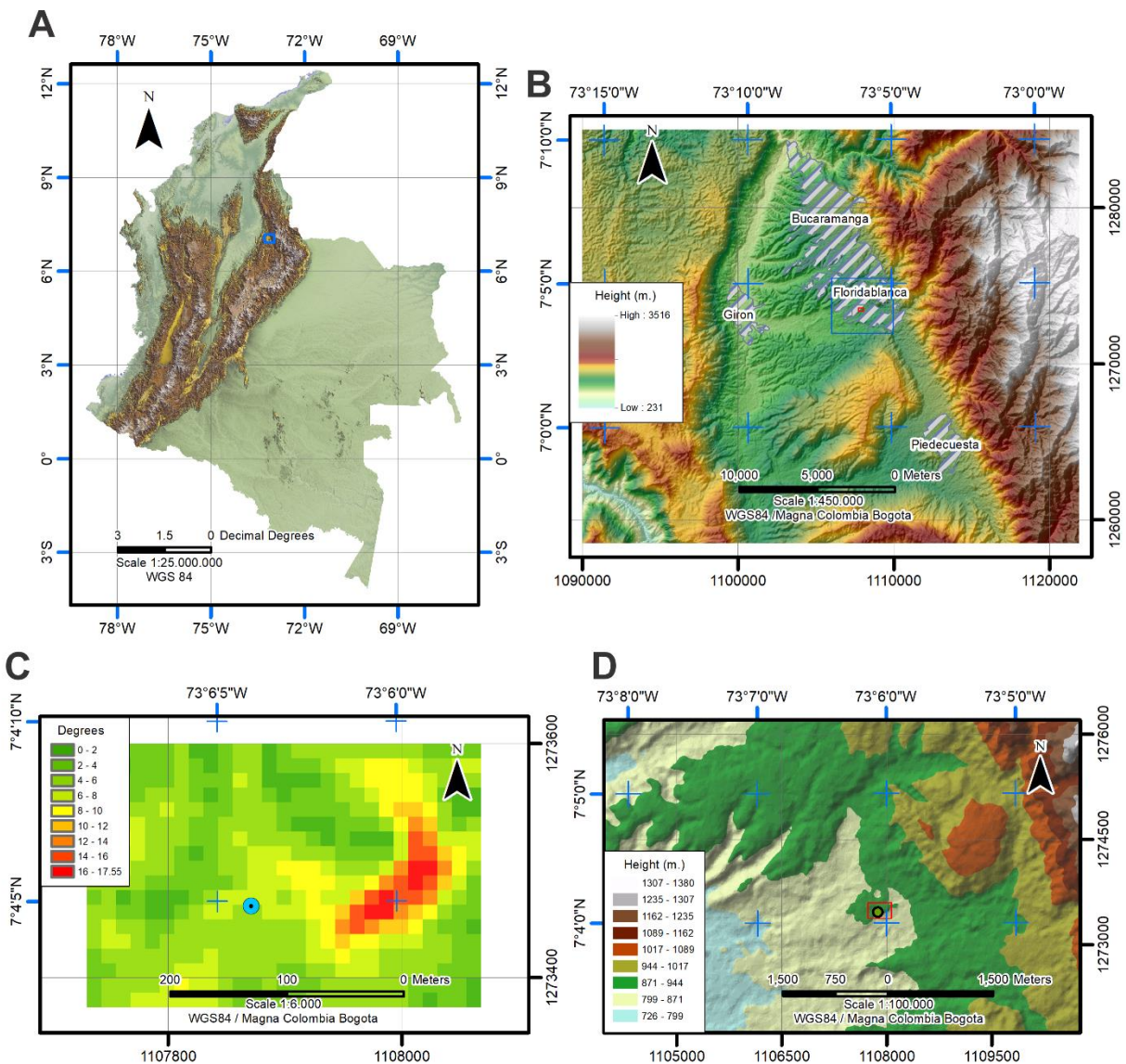


Figure 19. Localization of soil developed on Holocene fluvio-torrential deposits lithology study place outcrop. A. - Colombian orographic map with site location (blue circle). B. - Local orography with site location (red circle). C. - Slope map of the local area with location site (blue circle). D. - Local height map with location site (black circle).

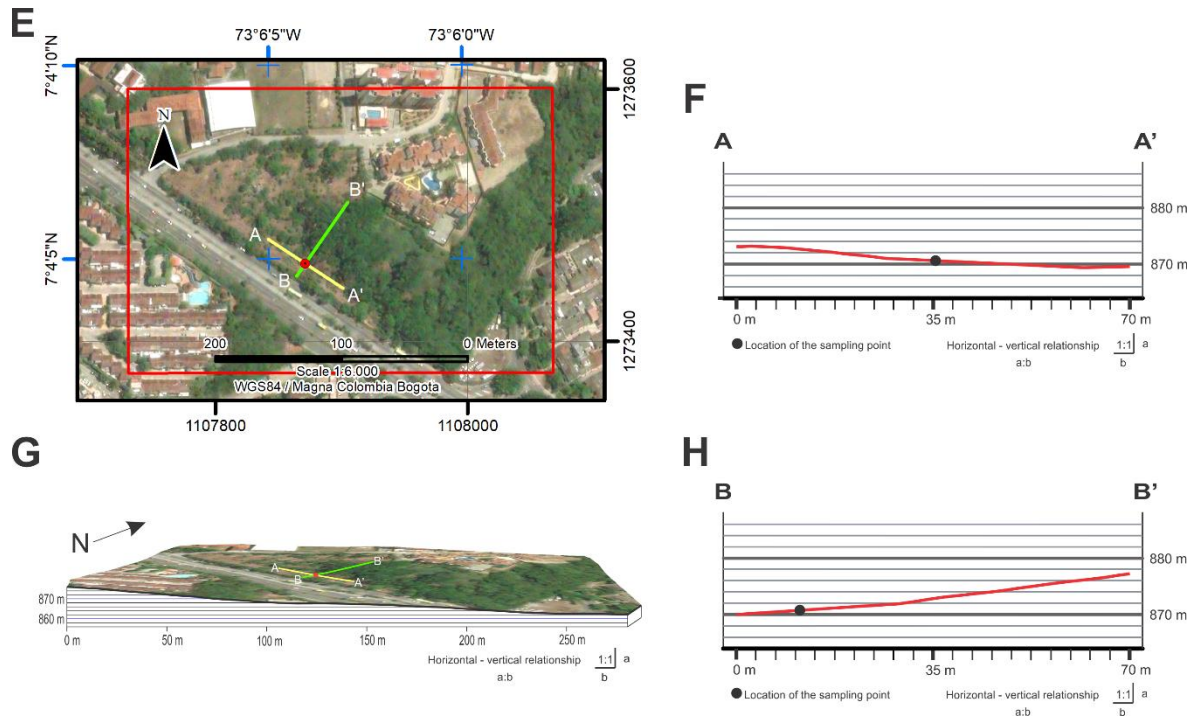


Figure 20. Specific localization of soil developed on Holocene fluvio-torrential deposits lithology study place outcrop. E. - Satellite image of local area with localization of topographic profile A-A' and B-B'. F. - Topographic profile A-A'. G. - Three-dimensional (3D) surface topography of local area. H. - Topographic profile B-B'.

The average annual rainfall is 1450mm. December, January and February are the driest months, rainy season spans from March until November, with May and October being the months of the highest proportion. In the dry season months of the beginning of the year, it rains about 4 to 8 days/month; in the months with greater rainfall it rains around 16 to 20 days/month with a maximum rainfall of 125mm in 24 hours. The relative humidity of the air is greater than 80% in average and in times of rains reaches values greater than 85%.

The multi-annual average temperature that ranges from 22 to 24°C, the average temperature is 22°C, at midday the average maximum temperature ranges from 26 to 28°C, in the

early morning the minimum temperature is between 18 and 20°C in the months of May and June, and the rest of the year ranges between 16 and 18°C. The average hours of sunshine are between 3 and 4 hours a day in the months of February, April, May, June and October, for the months of January, March and November sunshine registers between 4 and 5 hours a day and for the months of July, August, September and December, sunshine registers between 5 and 6 hours a day. The average monthly wind speed at 10m height maintains values between 2 and 3m/s throughout the year and the average monthly evaporation values between 120 and 150mm in the months of January and March, and values of 90 to 120mm during the rest of the year figure 21).

Based on the climate classification Caldas–Lang and with the information about precipitation, temperature and altitude, this station corresponds to a semi-humid warm climate (CsH), (Table 26).

*Table 26.* Use of extrapolated information to obtain climatic classification lang – caldas

Annual average temperature (° C). Multiannual average since 1981 to 2010; based on IDEAM data.	Average annual rainfall (mm), multiyear average since 1981 to 2010; Based on IDEAM data.	Lang Factor (P/T)	Classification Lang	Height above sea level (m)	Classification Caldas	Climate classification Caldas -Lang
24	1450	60	semi-arid [sa] (41 - 60)	870	Warm [C] (0m - 1000m) & ( T ≥ 24° )	Warm semi-arid [Csa]

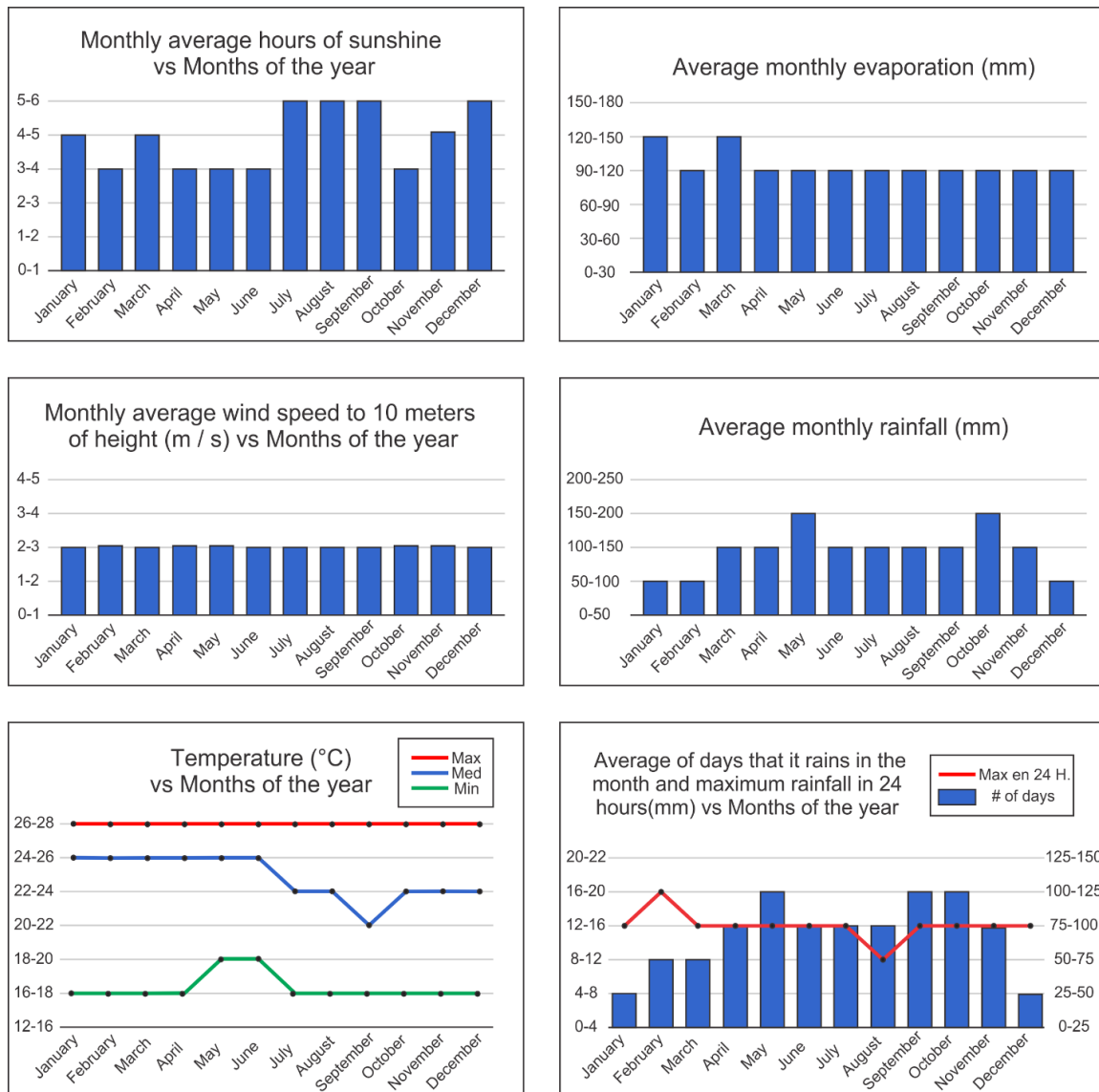


Figure 21. Deposit sampling place climatic variables: temperature, rainfall, sunshine, evaporation, wind speed, extrapolated from IDEAM Interactive Atlas.

**5.3.2 Descriptions for soil developed on deposit.** The soil is integrated by the following horizons (see figure 22).

**5.3.2.1 Parental deposit sampling place, 1st horizon field description:** Total horizon thickness varies from 15 to 28cm, the cross-sectional shape of the contact between 1st and 2nd horizons is wavy, dry soil color is 7.5 YR 4/4 (brown) and moist soil color is 7.5 YR 3/3 (dark brown), the horizon has just matrix and excavation difficulty is low. The quantity of roots no

carbonized is 6%, their size is fine to very coarse (1 to 16mm) and they extend across the five horizons with 2000mm of deep, roots location is throughout the horizon. Quantity of pores is 10% and the dominant form of pores are tubular, branching voids and interstitial. The average number of cracks, per meter, is 2% and there are irreversible crust-related cracks.

*5.3.2.1.1 Description based on sieve samples without clay materials, sample 12 from 1st horizon:* Very fine to medium sand-size monocryztalline qtz hyaline angular (29%). Coarse sand to medium pebbles-size polycrystalline qtz, metamorphic and lidite with benthic foraminifera RF, and monocrystalline qtz very angular (19%), and medium sand to medium pebbles-size carbonized plant fragments and root plant fragments and bacterial agglutinate soil blades-shape pseudo-particles with silt-size angular qtz, no spherical and carbonized plants fragment (5%). Silt-size monocrystalline Qtz hyaline angular and carbonized plant fragments (47%). The 1st horizon characteristics are presented on table 27.

*Table 27.* Specific genetic materials in 1st horizon of soil profile developed on Holocene fluvio-torrential deposits.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium sand qtz (26%)	39,545%
	Coarse sand to medium pebbles-size polycrystalline qtz, metamorphic and some lidite with benthic foraminifera RF (16%)	
<b>Incorporated</b>	Medium sand to medium pebbles-size plant fragments and root plant fragments (1%)	18,455%
	Medium sand to medium pebbles-size agglutinate soil blades-shape materials (2%)	
	TOC (2,455%)	
	Roots no carbonized (3%)	
	Pores and water (10%)	
<b>TDR</b>	Argillaceous materials	42%
	<b>Total</b>	<b>100%</b>

**5.3.2.2 Parental deposit sampling place, 2nd horizon field description:** Total horizon thickness varies from 56 to 87cm, the cross-sectional shape of the contact between 2nd and 3rd horizons is wavy, dry soil color is 7.5YR5/6 (strong brown) and moist soil color is 7.5YR4/4 (brown), the gradation between rock fragments and matrix is sharp and the color change is abrupt. The rock fragments are irregular and angular, the fragments size is from 6 to 10mm diameter (medium gravel). Excavation difficulty is low, the quantity of roots no carbonized is 3% and their location is matted around rock fragments, roots size is coarse (7mm). Quantity of pores is 10% and the dominant shape of pores is tubular and interstitial. The average number of cracks, per meter, is 2% and there are reversible crust-related cracks. The 2nd horizon characteristics are presented on table 28.

*Table 28.* Specific genetic materials in 2nd horizon of soil profile developed on Holocene fluvio-torrential deposits.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to very coarse sand qtz (38,821%)	39,821%
	Granule to coarse pebbles-size RF (1%)	
<b>Incorporated</b>	TOC (1,179)	11,179%
	Roots no carbonized (7%)	
	Pores and water (8%)	
<b>TDR</b>	Argillaceous materials	44%
	<b>Total</b>	<b>100%</b>

**5.3.2.3 Parental deposit sampling place, 3rd horizon field description:** Total horizon thickness varies from 12 to 32 cm, the cross-sectional shape of the contact between 3rd and 4th horizons is irregular, dry soil color is 10YR7/6 (yellow) and moist soil color is 10YR6/6 (brownish yellow), the gradation between rock fragments and matrix is sharp, so color changes abruptly in <0.1mm between the fragments and the soil matrix. The rock fragments are angular and the size is 6mm diameter (medium gravel). Excavation difficulty is low, the quantity of roots no carbonized is 2% and their location is matted around rock fragments, roots size is coarse (1 to < 2mm).

Quantity of pores is 9% and the dominant shape of pores is tubular and interstitial. There are some cracks with a different and dark material fill. The 3th horizon characteristics are presented on table 29.

*Table 29.* Specific genetic materials in 3th horizon of soil profile developed on Holocene fluvio-torrential deposits.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to very coarse sand qtz (46%)	47,302%
	Argillaceous materials (Illite 4%)	
	Granule to coarse pebbles-size metamorphic and pegmatite RF (1%)	
<b>Incorporated</b>	TOC (0,698%)	9,698%
	Roots no carbonized (1%)	
	Pores and water (9%)	
<b>TDR</b>	Argillaceous materials (Kaolinite)	43%
	<b>Total</b>	<b>100%</b>

**5.3.2.4 Parental deposit sampling place, 4th horizon field description:** Total horizon thickness varies from 17 to 42 cm. The cross-sectional shape of the contact between 4th and 5th horizons is smooth, dry soil color is 10YR6/6 (brownish yellow) and moist soil color is 10YR5/6 (yellowish brown), the gradation between rock fragments and matrix is sharp and the color change is abrupt. The rock fragments are angular and the size is 100mm diameter (cobbles). Excavation difficulty is low, the quantity of roots no carbonized is 1% and their location is in cracks, roots size is very fine (<1mm). Quantity of pores is 7% and the dominant shape of pores is tubular and interstitial. There are trans-horizon cracks which are deep, vertical cracks that extend across more than one horizon and extend to the surface. The 4th horizon characteristics are presented on table 30.

*Table 30.* Specific genetic materials in 4th horizon of soil profile developed on Holocene fluvio-torrential deposits.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Coarse to very coarse sand fsp (altered) and qtz (39,62%)	43,62%
	Granule to coarse pebbles-size metamorphic RF (4%)	
<b>Incorporated</b>	TOC (0,38%)	14,38%
	Roots no carbonized tubular shape (6%)	
	Pores and water (8%)	
<b>TDR</b>	Argillaceous materials	42%
	<b>Total</b>	<b>100%</b>

**5.3.2.5 Parental deposit sampling place, 5th horizon field description:** Total horizon thickness of 34cm. This is a different parental deposit, the cross-sectional shape of the contact between 4th and 5th horizons is smooth, dry soil color is 10 YR 8/3 (very pale brown) and 10 YR 6/1 gray and moist soil color is 10 YR 7/6 (yellow) and 10 YR 5/1 (gray), the gradation between rock fragments and matrix is diffuse, so color changes in  $\geq 2$ mm between the fragment and the soil matrix. The rock fragments are irregular and angular, the size is 150mm diameter (cobbles). Excavation difficulty is low, the quantity of roots no carbonized is 1% and their location is in cracks, roots size is very fine (<1mm). Quantity of pores is 5% and the dominant shape of pores is branching voids and interstitial. There are some cracks with a different and dark material fill. The 5th horizon characteristics are presented on table 31.

*Table 31.* Specific genetic materials in 5th horizon of soil profile developed on Holocene fluvio-torrential deposits.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Fine to coarse sand qtz (53,803%)	54,803%
	Granule to coarse pebbles-size metamorphic RF (1%)	
<b>Incorporated</b>	TOC (0,197%)	10,197%
	Roots no carbonized (1%)	
	Pores and water (9%)	
<b>TDR</b>	Argillaceous materials	35%
	<b>Total</b>	<b>100%</b>

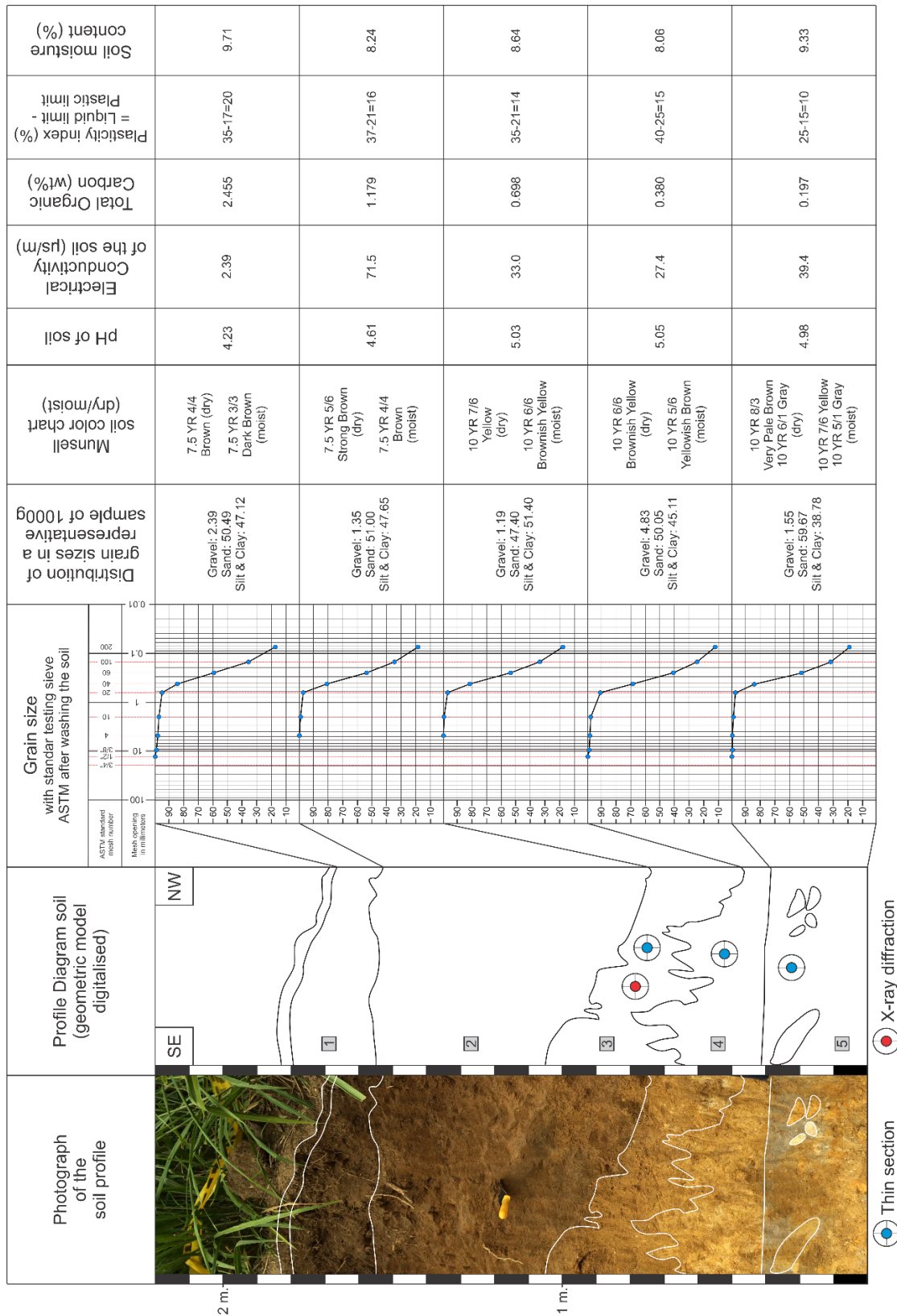


Figure 22. Soil profile developed on Holocene fluvio-torrential deposits lithology sampling place with grain size distribution of materials, and physical and chemical properties.

**5.3.3 Petrography for soil developed on deposit (5th, 4th and 3rd horizon).** *Thin section sample number 16 (5th horizon), with 5x objective and 10X ocular.* Feldspathic lithic quartz fine to coarse sandstone with clay matrix and cement. Monocrystalline quartz metamorphic, a lot of angular Carlsbad and polysynthetic twinning. Metamorphic polycrystalline quartz, clastic (figure 23).

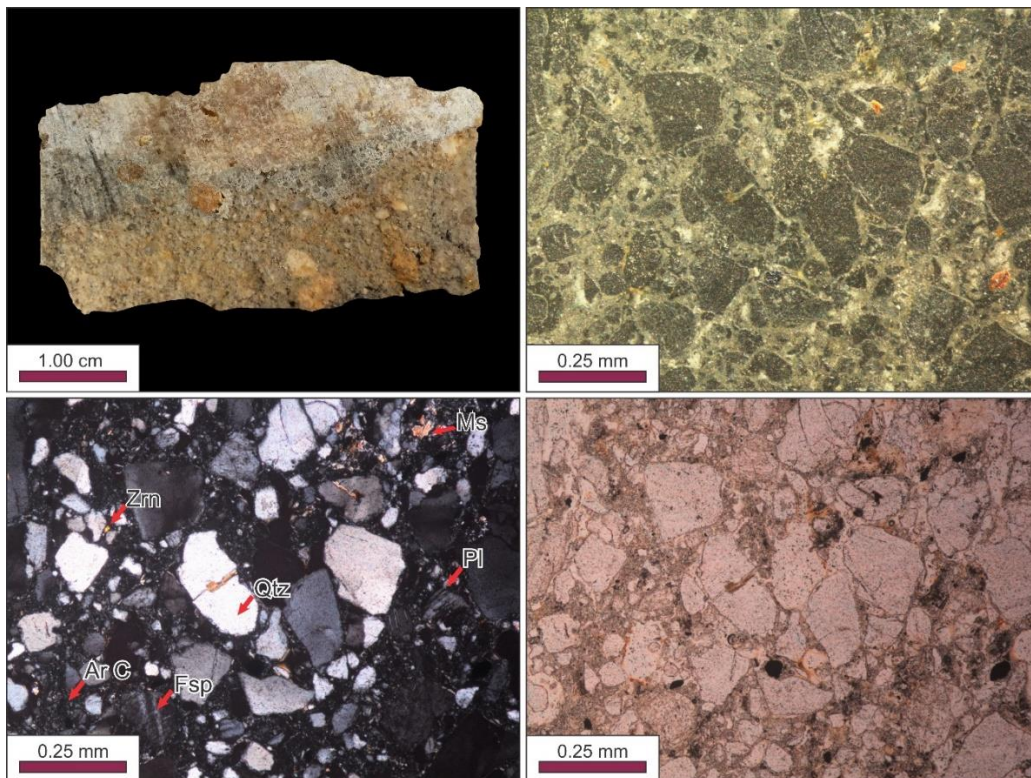
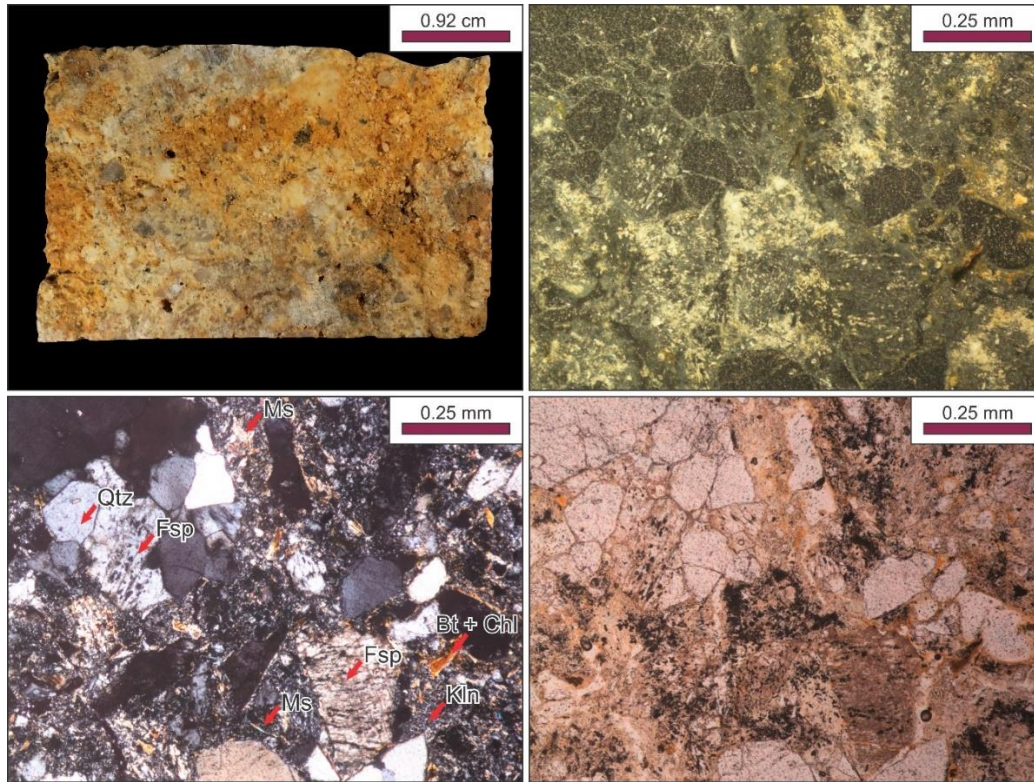


Figure 23. Slightly argillaceous claystone and very coarse sandstone lithic feldspathic quartz. Thin section photography, with 5x objective and 10x ocular, sample number 16 of soil profile 5th horizon of soil developed on Holocene fluvio-torrential deposits. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ms: Muscovite, Fsp: Feldspar, Qtz: Quartz, Ar C: Argillaceous clay, Pl: Plagioclase, Zm: Zircon.

*Thin section sample number 15 (4th horizon), with 5x objective and 10X ocular.* Slight lithic feldspathic quartz coarse to very coarse sand with slight clay matrix and cement. Monocrystalline quartz very angular with undulant to straight extinction. Lithic fraction altered metamorphic FR and metamorphic polycrystalline quartz coarse to very coarse (0.82 to 1.7 mm) sub-angular to sub-roundness with quartz with undulant extinction and fractured. Altered feldspar

middle sand (0.5 mm), iron oxides materials coarse sand (0.6 mm), clastic muscovite (0.6 mm).  
Monocrystalline quartz metamorphic and igneous provenance (figure 24).



*Figure 24.* Slightly argillaceous claystone and very coarse sandstone quartz feldspathic rock fragments. Thin section photography, with 5x objective and 10x ocular, sample number 15 of soil profile 4th horizon of soil developed on Holocene fluvio-torrential deposits. Top right photograph with reflected monochromatic light and polarization analyzer. Bottom left photograph with cross polarized light (XPL). Bottom right photograph with plain polarized light (PPL). Ms: Muscovite, Fsp: Feldspar, Qtz: Quartz, Kln: kaolinite, Bt: Biotite, Chl: Chlorite.

*Thin section sample number 14 (3rd horizon), with 5x objective and 10X ocular.* Slight lithic feldspathic quartz fine, very fine, lightly very coarse sand to granular with clay matrix and cement (48%). Very angular quartz with undulant to straight extinction, some with surface corrosion. Some moderately altered feldspar very fine sand (0.08 mm) with very angular shape. Metamorphic FR (polycrystalline quartz with undulant extinction) very coarse sand to granule (1.2 a 2.2 mm) with good roundness and pegmatite FR (muscovite and quartz) coarse sand (0.74 mm) mainly angular, some clastic muscovite (<1%) fine sand (0.2 mm), and with a few iron oxides.

Clay matrix and cement (clay recrystallization). Monocrystalline quartz metamorphic and igneous provenance (figure 25).

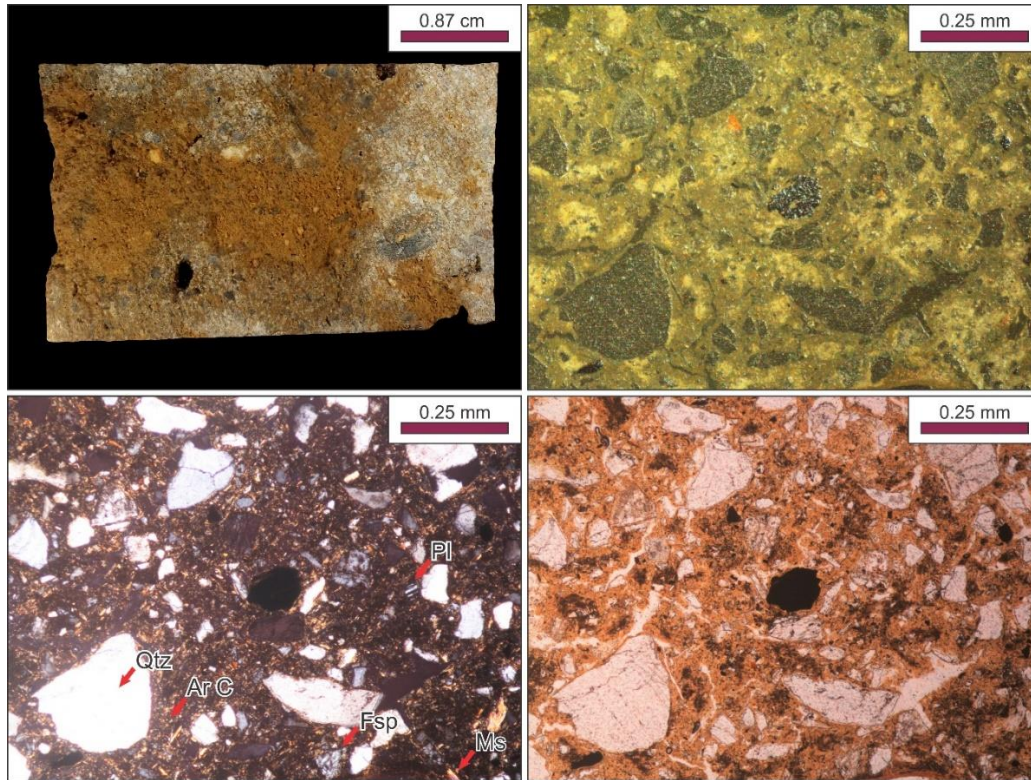


Figure 25. Feldspathic lithic quartz coarse sand to silty argillaceous claystone. Thin section photography, with 5x objective and 10x ocular, sample number 14 of soil profile 3rd horizon of soil developed on Holocene fluvio-torrential deposits. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ms: Muscovite, Fsp: Feldspar, Qtz: Quartz, Ar C: Argillaceous clay, Pl: Plagioclase.

#### 5.3.4 Clay fraction soil composition determination on deposit.

The sample analyzed shows the d spacing for the {001} plane measured in 7,1 (untreated sample) for the minerals in their natural state and the mineral heated to 550°C shows the d spacing value destroyed evidencing the presence of Kaolinite. Besides, the sample analyzed shows the d spacing for the {001} plane measured in 9,9 (untreated sample) for the minerals in their natural state and after the effect of the mineral heated to 550°C the d spacing value is little change evidencing the presence of Illite. (figure 26)

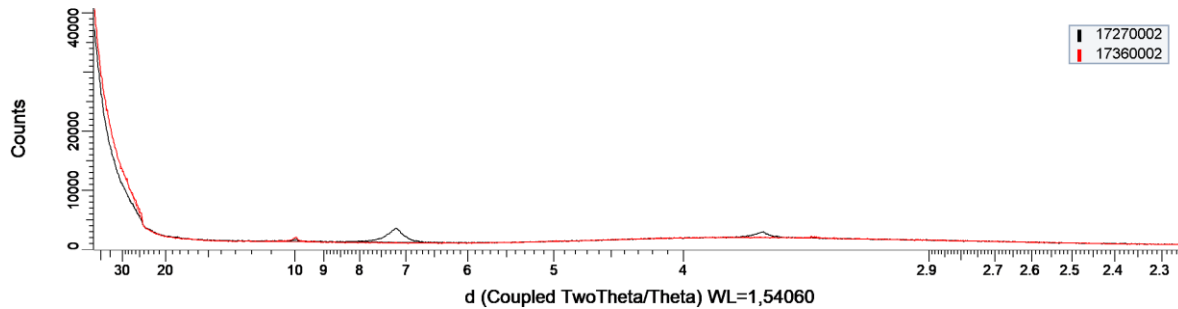


Figure 26 X-Ray Diffractogram for Clay fraction soil determination on Holocene fluvio-torrential deposit sample. Black line represents the undisturbed sample, the red one represents the sample at 550 degrees Celsius.

### 5.3.5 Genetic material distribution of soil profile developed on fluvio-torrential terrace deposits.

Soil profile developed on fluvio-torrential terrace deposits a soil moderately TDR (Argillaceous materials (Kaolinite)) moderately inherited-conserved materials (Granule to coarse pebbles-size metamorphic RF, Coarse to very coarse sand fsp (altered) and qtz, Coarse sand to medium pebbles-size polycrystalline qtz, metamorphic and some lidite with benthic foraminifera RF, Argillaceous materials (Illite) and ) slight incorporated materials (Medium sand to medium pebbles-size plant fragments and root plant fragments, Medium sand to medium pebbles-size agglutinate soil blades-shape materials with TOC 2.455 to 0.197) (1st to 5th horizon) (see figure 27)

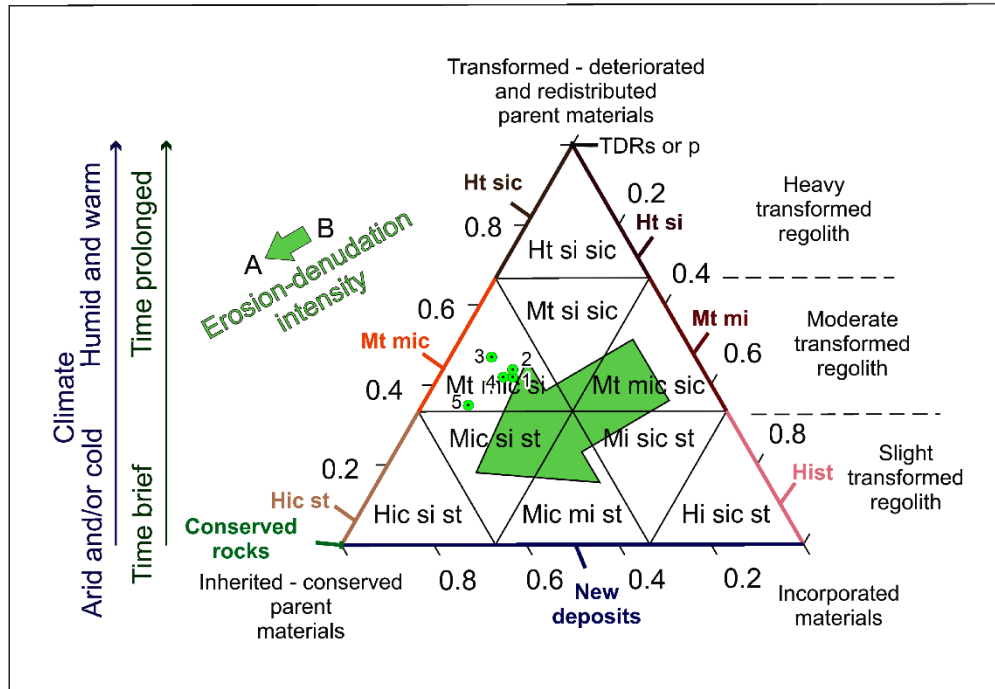


Figure 27. Implementation of the classification with the five soil horizons developed in the lithology of Holocene fluvio-torrenial deposits, include relation with the tree fundamentals factors that control the formation of soils: time, climate and denudation.

### 5.4 Soil developed on Limestone lithology.

3m outcrop at Los Santos-Gypsum mine district secondary road, 500 m W of Los Santos Town on limestone informal extraction site. Coordinates: X: 1'106029, 63m, Y: 1'239622, 27m, Z: 1308m.a.s.l. (figure 28. B and 28. D), the soil profile is integrated by O horizon (topsoil) with a land cover Natural grasslands (3.2.1.) according with CORINE land cover (CLC) (2010) and three more horizons (figure 30).

**5.4.1 Geomorphology and climate.** This sampling place corresponds geomorphologically with the top of a structural plateau with inclination of the slope between 14 and 17° according to the slope map generated from a Digital Model of DEM Elevation, the range of heights is from 1278 to 1407 (See figures 28 and 29). It has NE slope direction (figure 29. G) and simple slope complexity (figure 29. H and 29. F), the slope segment relative position is on lower third of slope

(figure 29. G) with linear and concavity slope shape (figure 29. G) and well drained natural soil drainage (water is removed from the soil readily but not rapidly) (see soil moisture content 6w% in figure 30), the dominant land cover at the site is 3. Forest and semi natural areas, 3.2. Scrub and/or herbaceous vegetation associations, 3.2.1. Natural grasslands (See figure 29. E) according with CORINE land cover (CLC) (2010) and the dominant kind of erosion is water according with Schoeneberger et al., (2012).

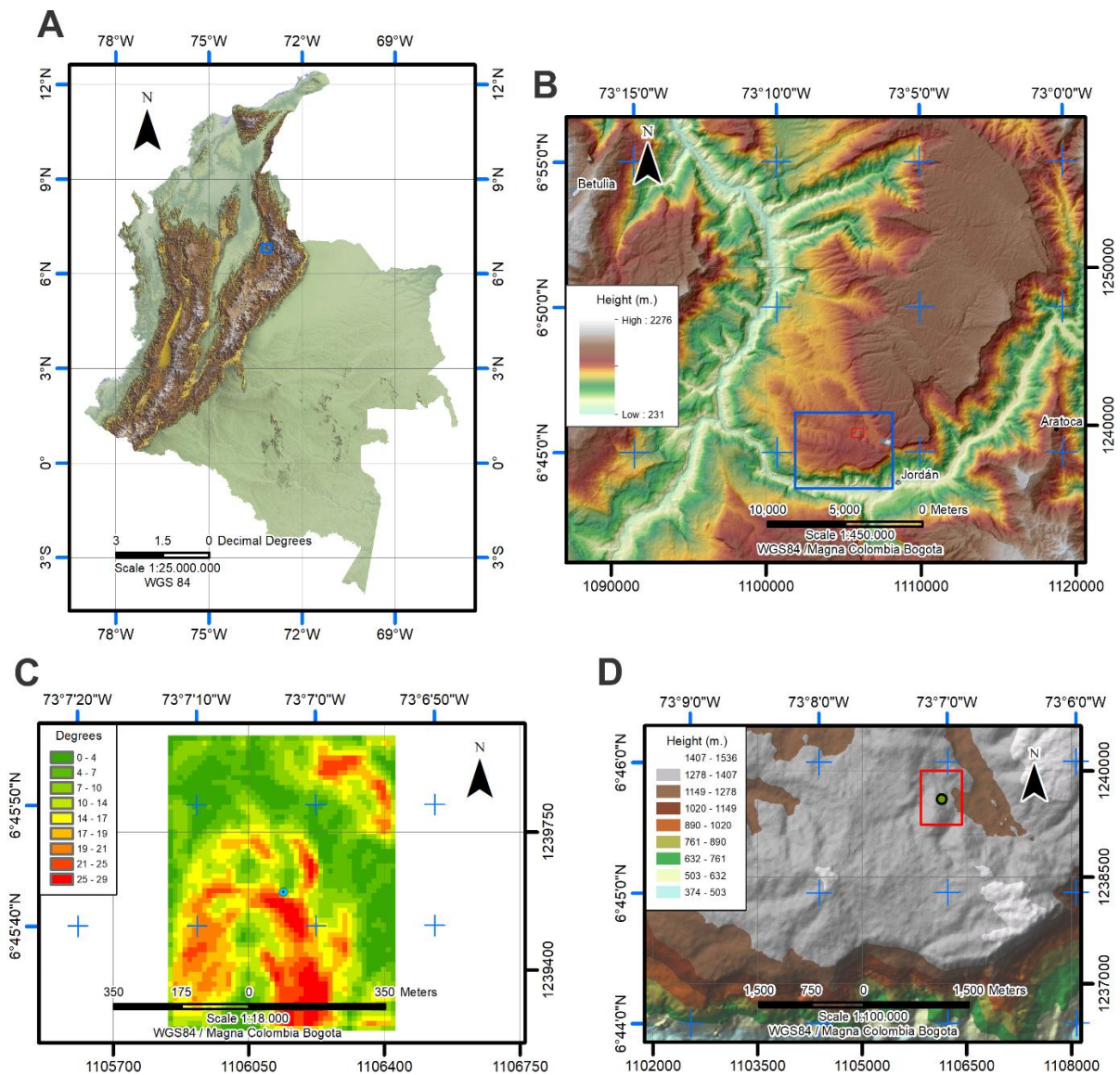


Figure 28. Localization of limestone lithology study place outcrop. A. - Colombian orographic map with site location (blue circle). B. - Local orography with site location (red circle). C. - Slope map of the local area with location site (blue circle). D. - Local height map with location site (black circle).

The average annual rainfall is 1050mm. December, January, February, March, June, July and August are the driest months, rainy seasons spans from April until May and from September until December. In the dry season months of the beginning of the year, it rains about 4 to 8 days / month; in the months with greater rainfall it rains about 8 to 16 days/month, and in the dry season months of mid-year, it can rain from 8 to 12 days/month with a maximum rainfall of 100 mm in 24 hours. The relative humidity of the air is greater than 75% in average and in times of rains reaches values greater than 80%.

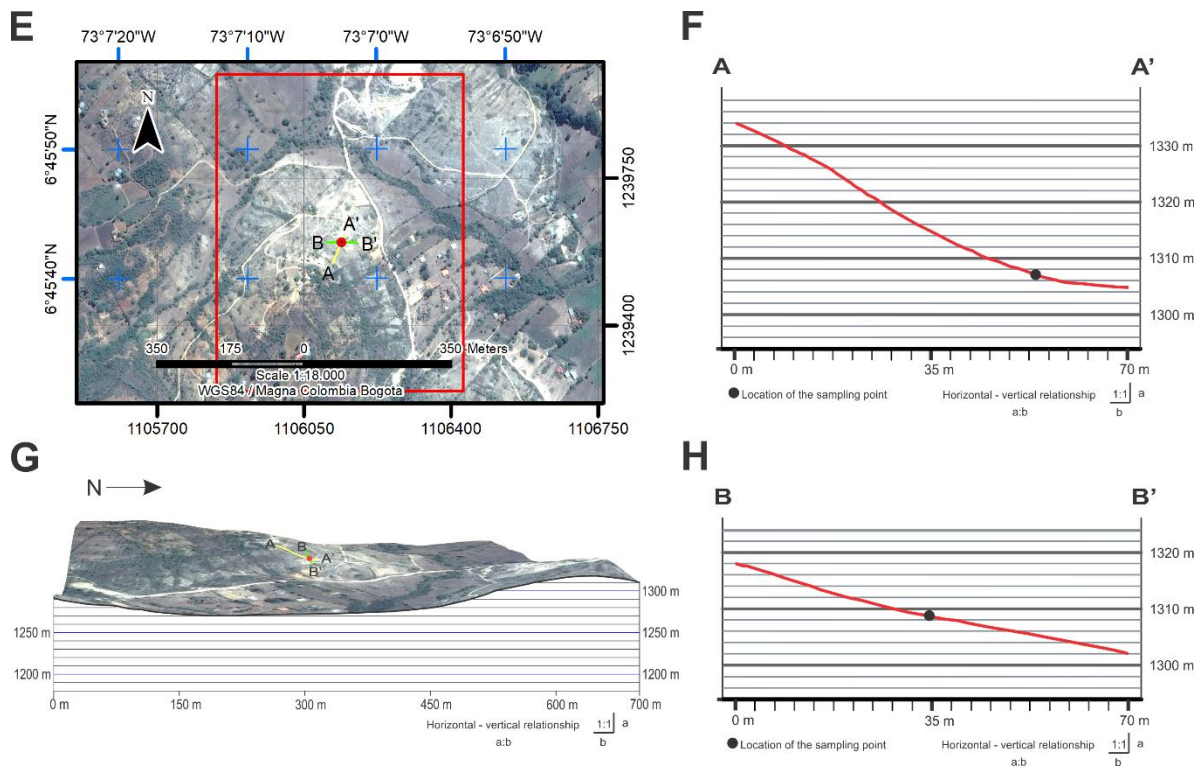


Figure 29. Specific localization of limestone lithology study place outcrop. E. - Satellital image of local area with localization of topographic profile A-A' and B-B'. F. - Topographic profile A-A'. G. - Three dimensional (3D) surface topography of local area. H. - Topographic profile B-B'.

The multi-annual average temperature that ranges from 20 to 22°C, the average temperature is 21°C, at midday the average maximum temperature ranges from 24 to 28°C, in the early morning the minimum temperature ranges from 12 to 18°C. The average hours of sunshine are between 4 and 5 hours a day in the rainy season months and for the dry season months sunshine registers between 5 and 6 hours a day. The average monthly wind speed at 10m height maintains values between 2 and 3m/s throughout the year and the average monthly evaporation values between 120 and 150mm in the months of January and March, and values of 90 to 120mm during the rest of the year (figure 30).



Figure 30. Climatic variables (temperature, rainfall, sunshine, evaporation, wind speed) for soil developed on Limestone lithology sampling place, extrapolated from IDEAM Interactive Atlas.

Based on the climate classification Caldas–Lang and with the information about precipitation, temperature and altitude, this station corresponds to a semi-arid temperate climate (Tsa), (Table 17).

*Table 32.* Use of extrapolated information to obtain climatic classification lang – caldas

Annual average temperature (° C). Multiannual average since 1981 to 2010; based on IDEAM data.	Average annual rainfall (mm), multiyear average since 1981 to 2010; Based on IDEAM data.	Lang Factor (P/T)	Classification Lang	Height above sea level (m)	Classification Caldas	Climate classification Caldas -Lang
21	1050	50	semi-arid [sa] (41 - 60)	1308	Temperate[T] (1001 m - 2000 m) & (24°>T≥17.5°)	Temperate semi-arid [Tsa]

**5.4.2 Descriptions for soil developed on limestone lithology.** The soil is integrated by the following horizons (see figure 31).

**5.4.2.1 Limestone sampling place, 1st horizon field description:** The cross-sectional shape of the contact between 1st and 2nd horizons is wavy (Width of undulation is bigger than depth), dry matrix soil color is 10YR4/2 (dark grayish brown), and clast color is 10YR8/1 (pale orange yellow), moist matrix soil color is 10YR3/2 (very dark grayish brown), and clast color is 10YR8/2 (very pale brown), the gradation between feature and matrix is sharp, so color changes abruptly in <0.1mm between the feature and the soil matrix. The dominant shape of the rock fragments in this horizon is elongated, the relative roundness is angular. Excavation difficulty is low because the excavation by tile spade requires arm pressure only, the quantity of roots no carbonized is between 5 to 7% and they extend across 1st to 2nd horizons with 800mm of deep, roots and pores size are very fine to medium (<1 to 3mm), roots location is matted around rock fragments in the dark grayish brown matrix but they are not in cracks. Quantity of pores is >20% and the dominant form of pores is tubular, cylindrical, elongated, branching voids; e.g., empty root channels, interstitial and irregular like nonconnected cavities. There are reversible crust-related cracks.

*5.4.2.1.1 Description based on sieve samples without clay materials, sample 17 from 1st horizon:* Very fine to coarse pebbles-size caliche fragment (23%). Coarse sand to medium pebbles-size bacterial agglutinate soil blades-shape pseudo-particles with silt-size angular qtz, no spherical and carbonized plants fragment (19%). Inherited and transformed very fine to medium sand-size monocrystals transparent sub-angular elonged qtz (15%). Incorporate-transformed very fine to medium sand-size carbonized root and plant fragments (3%). Inherited-transformed very fine crystals-size of calcium carbonate pseudo-matriz (40%). There are two pulmonate gastropods medium and coarse sand-size one trocospiral and other near planispiral. Very fine sand-size to coarse pebbles-size caliches fragments are formed by very fine crystals-size of calcium carbonate. The 1st horizon characteristics are presented on table 33.

*Table 33.* Specific genetic materials in 1st horizon of soil profile developed on limestone lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium-size sand qtz particles (15%)	35,56%
	Granule to fine cobble-size altered limestone RF pseudoparticles (20,56%)	
<b>Incorporated</b>	Coarse sand to medium pebbles-size bacterial agglutinate soil blades-shape pseudo-particles (6,56%)	27%
	TOC (3,44%)	
	Iron oxide (4%)	
	Roots no carbonized (3%)	
	Pores and water (10%)	
<b>TDR</b>	Microcrystals-size of calcium carbonate (27%)	34%
	Argillaceous materials (7%)	
	<b>Total</b>	<b>100%</b>

*5.4.2.2 Limestone sampling place, 2nd horizon field description:* Weathered parental rock, the cross-sectional shape of the contact between 2nd and 3rd (rock) horizons is wavy, dry soil color is 2.5Y9.5/1 (white) and moist soil color is 2.5Y8/2 (pale yellow), the horizon has just matrix and excavation difficulty is high because excavation by tile spade is difficult but easily

done by pick using over-the-head swing. The quantity of roots no carbonized is 3%, their location is throughout the horizon and their size is very fine to medium (<1 to 3mm). Quantity of pores is 5% and the dominant form of pores is tubular, branching voids and interstitial. There are trans-horizon cracks and irreversible crust-related cracks. The 2nd horizon characteristics are presented on table 34.

*Table 34.* Specific genetic materials in 2nd horizon of soil profile developed on limestone lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium-size sand qtz (15%)	30%
	Medium crystal calcite (15%)	
<b>Incorporated</b>	Iron oxide (10%)	24%
	Roots no carbonized (2%)	
	Pores and water (12%)	
<b>TDR</b>	Microcrystals-size of calcium carbonate (39%)	46%
	Argillaceous materials (7%)	
	<b>Total</b>	<b>100%</b>

*Table35.* Specific genetic materials in 3th horizon of soil profile developed on limestone lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to medium-size sand qtz (15%)	30%
	Medium crystal calcite (15%)	
<b>Incorporated</b>	Iron oxide (10%)	22%
	Pores and water (12%)	
<b>TDR</b>	Microcrystals-size of calcium carbonate (41%)	48%
	Argillaceous materials (7%)	
	<b>Total</b>	<b>100%</b>



**5.4.3 Petrography for soil developed on limestone rock.** *Thin section sample number 19 (3rd horizon- Limestone rock), with 5x objective and 10X ocular.* Crystalline limestone with very fine to fine quartz sandy-size and calcareous and oxide cements, intercalation of tiny laminated algal stromatolite micro-crystalline calcium carbonate with some very fine to coarse silt-size quartz and echinoderm spicule and bivalve fragment, planktonic foraminifera. Crystalline calcium carbonate mosaic, framework materials and cement (50%), very fine to fine sand-size floating quartz (30%) sub-angular to roundness with slightly elongated and low sphericity, border quartz grain corroded by calcium carbonate, ferruginous oxide (10%), very fine sand-size clastic muscovite (1%) well roundness and elongated, dissolution and intraparticle porosity (9%) (figure 32). It is observed that the very fine to fine sand Qtz particles formed locally groups of three to seven particles with punctual contact between them.

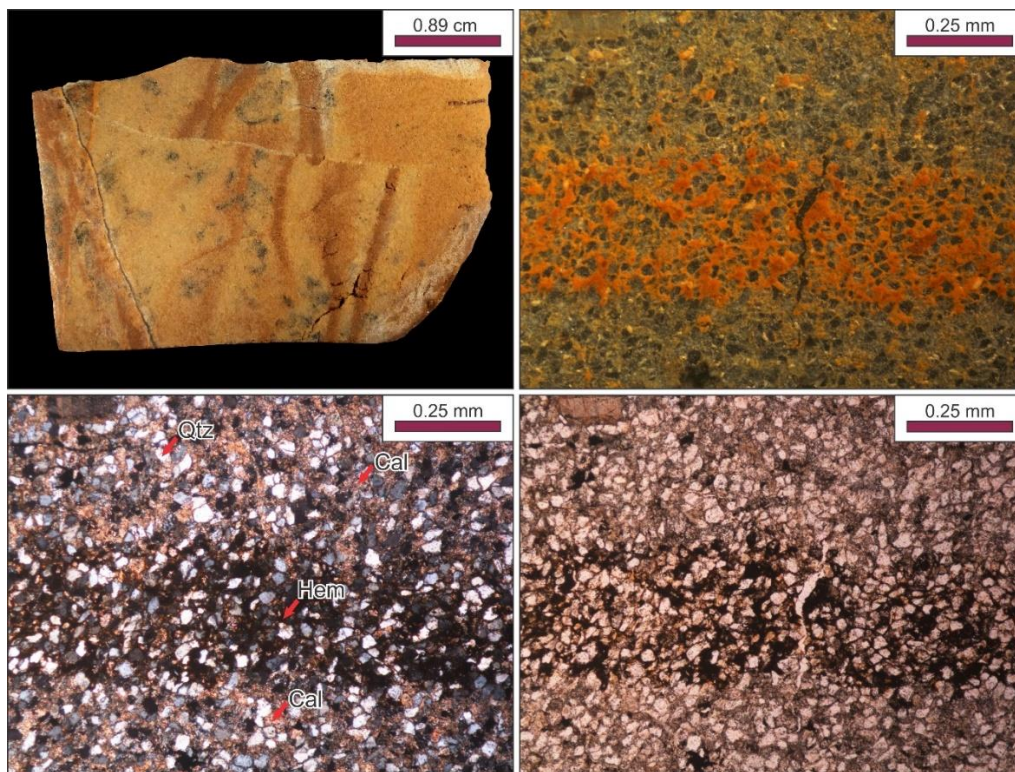


Figure 32. Crystalline limestone with very fine to fine quartz sandy-size and calcareous and oxide cements. Thin section photography, with 5x objective and 10x ocular, sample number 19, soil profile 3rd horizon of soil developed on limestone lithology. Top right photography with reflected monochromatic light and polarization

analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Qtz: Quartz, Cal: Calcite, Hem: Hematite.

#### 5.4.4 Clay fraction soil composition determination on limestone.

The sample analyzed shows the d spacing for the {001} plane measured in 18, 53 (untreated sample) for the minerals in their natural state, and the mineral heated to 120°C shows the d spacing value in 10 evidencing that the clay was saturated in water and after heating the water evaporated, the space between the layers of the clay decreased and the value of d spacing decreased allowing the registration of the Montmorillonite. (figure 33)

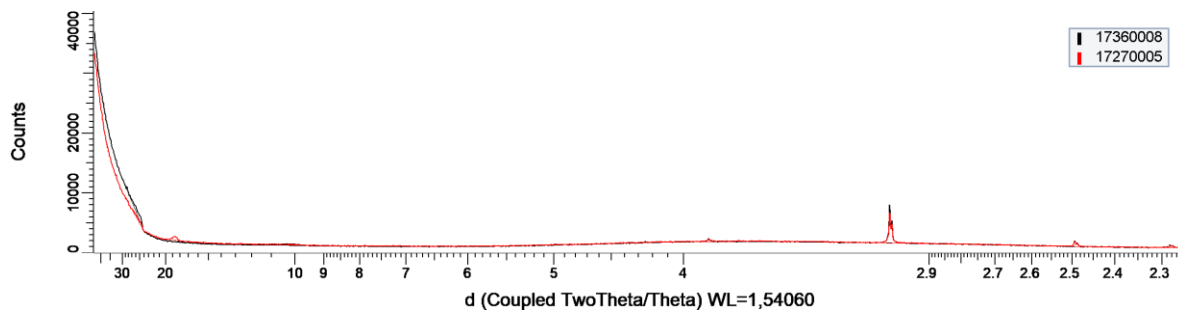


Figure 33 X-Ray Diffractogram Clay fraction soil determination on Limestone lithology sample. Black line represents the undisturbed sample, the red one represents the sample at 120 degrees Celsius .

#### 5.4.5 Genetic material distribution of soil profile developed on limestone lithology.

Soil profile developed on limestone a soil moderately TDR (Microcrystals-size of calcium carbonate and Argillaceous materials (montmorillonite)) moderately inherited-conserved materials (Granule to fine cobble-size altered limestone RF pseudoparticles, Very fine to medium-size sand qtz and Medium crystal calcite) slight incorporated materials (Iron oxidem, Coarse sand to medium pebbles-size bacterial agglutinate soil blades-shape pseudo-particles, Roots no carbonized, TOC of 3.44 just in the 1st horizon) (1st to 3th horizon) (see figure 34)

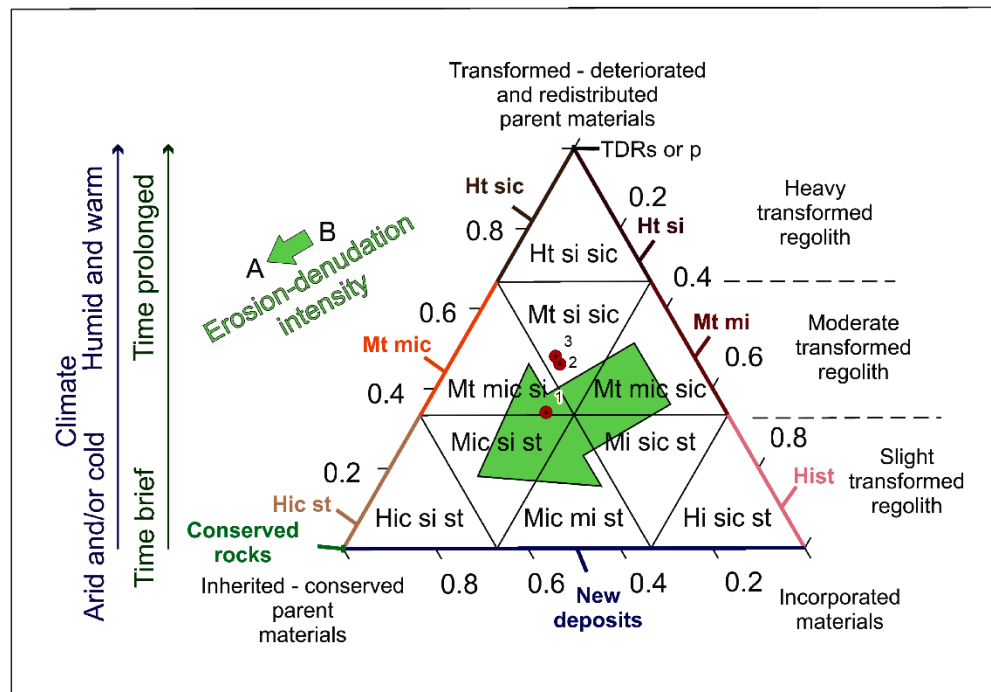


Figure 34. Implementation of the classification with the seven soil horizons developed in the lithology of limestone, include relation with the tree fundamentals factors that control the formation of soils: time, climate and denudation

### 5.5 Soil developed on granite lithology.

3m granite outcrop 3,5 km south east of Piedecuesta, on secondary road abandoned 1 km west deviation from El Chivo restaurant (Piedecuesta to San Gil principal road 2km south east of Piedecuesta town) to Piedecuesta-Los Santos secondary road. Soil developed over altered granite. Coordinates: X: 1'116201, 127m, Y: 1'259151, 544m, Z: 1157m.a.s.l. (32. B and 32. D), the soil profile is integrated by O horizon (topsoil) with a land use of Transitional Woodland-shrub (3.2.4.) according with CORINE land cover (CLC) (2010) and four more horizons (figure 38).

**5.5.1 Geomorphology and climate.** This sampling corresponds with an abrupt geomorphological slope with convex top terminations and inclination of 29° to 33° according to the slope map generated from a Digital Elevation Model DEM, the range of heights is from 1055

to 1194 (see figures 35 and 36). It has NW slope direction (figure 36. G) and simple slope complexity (figure 36. H and 36. F), the slope segment relative position is on lower third of slope (figure 36. G), slope shape is linear and convex (figure 36. G) and somewhat poorly drained natural soil drainage (see soil moisture content 9.4w% in figure 34), the dominant land cover at the site is 3. Forest and semi natural areas, 3.2. Scrub and/or herbaceous vegetation associations, 3.2.4. Transitional Woodland-shrub (see figure 36. E) according with CORINE land cover (CLC) (2010) and the dominant kind of erosion is water with channels according with Schoeneberger et al., (2012).

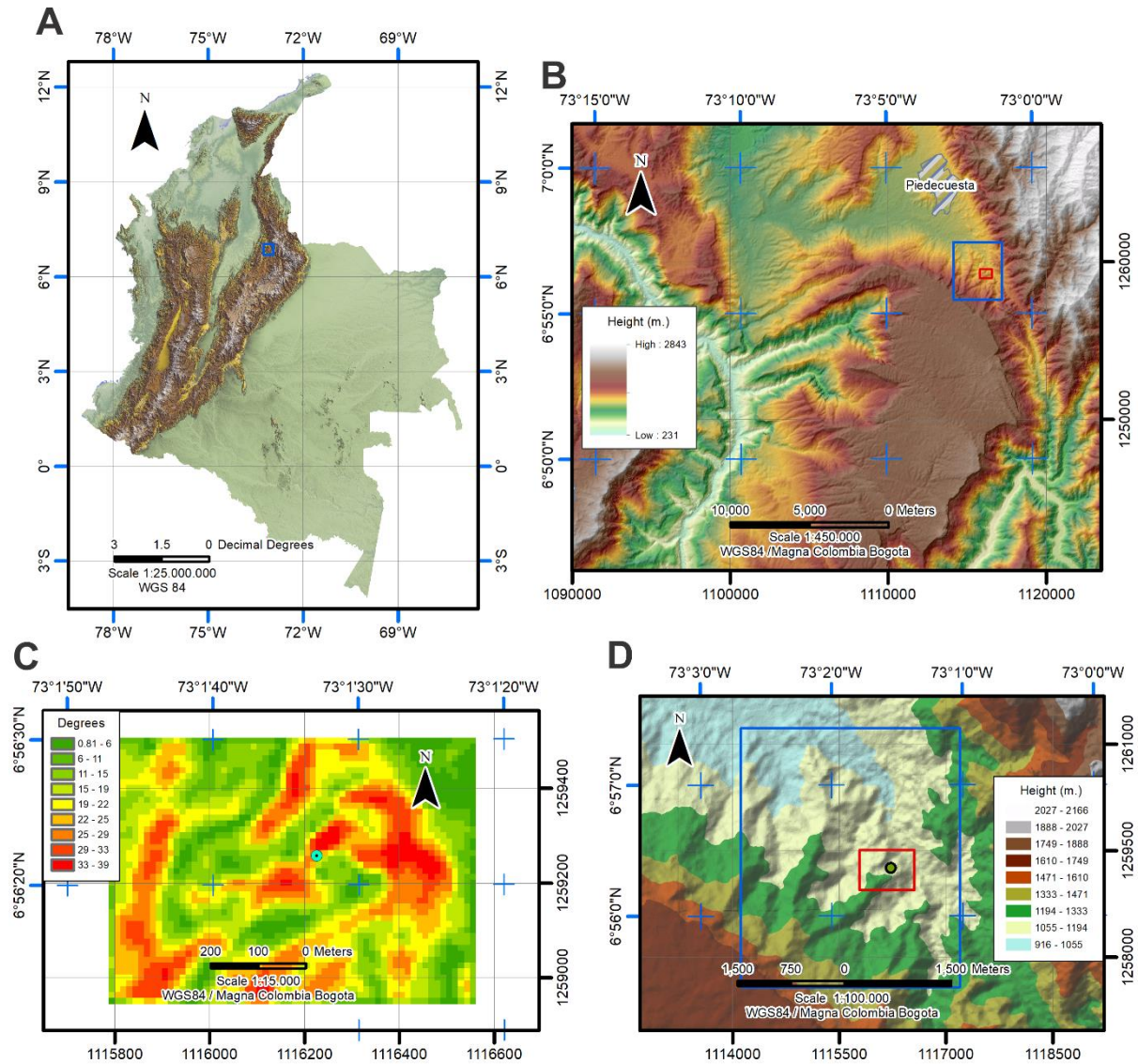


Figure 35. Localization of soil developed on Granite lithology study place outcrop. A. - Colombian orographic map with site location (blue circle). B. - "Los Santos" geological plateau orography with site location (red circle). C. - Slope map of the local area with location site (blue circle). D. - Local height map with location site (black circle).

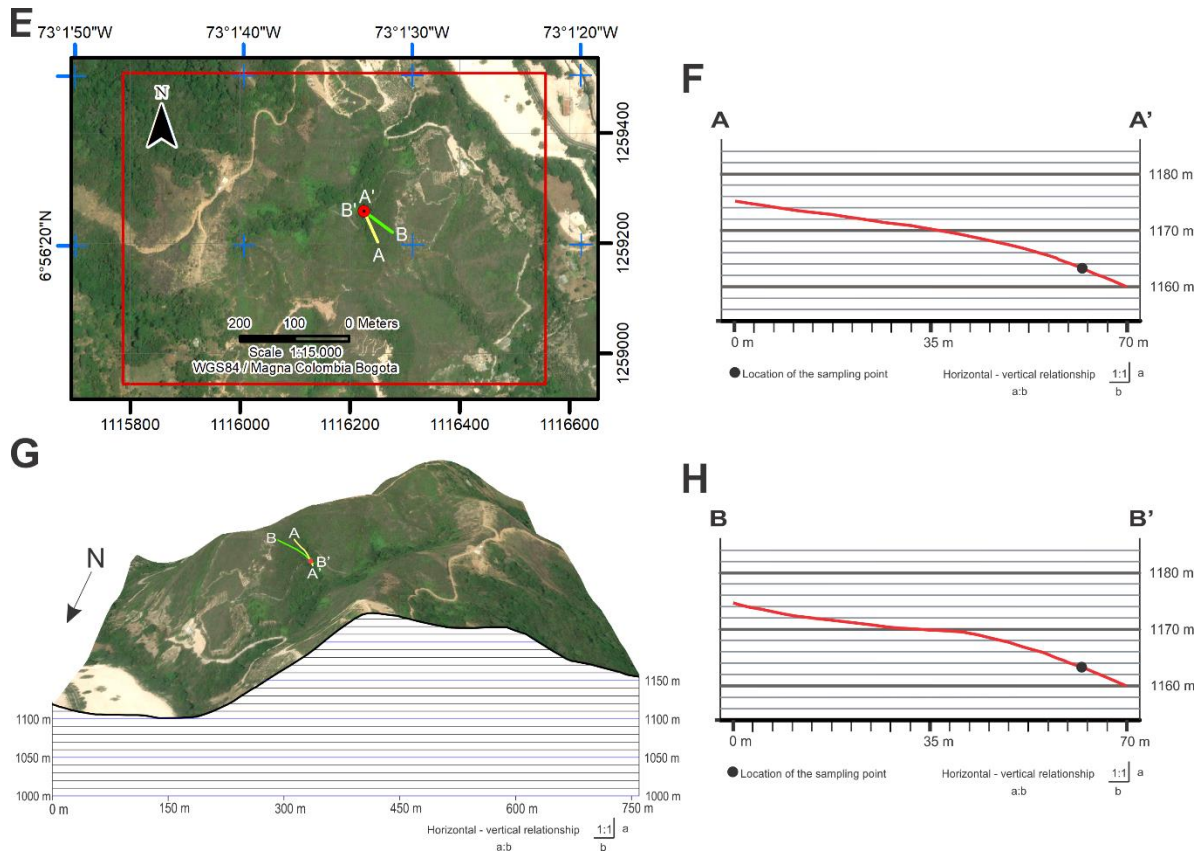


Figure 36. Specific localization of soil developed on Granite lithology study place outcrop. E. - Satellite image of local area with localization of topographic profile A-A' and B-B'. F. - Topographic profile A-A'. G. - Three dimensional (3D) surface topography of local area. H. - Topographic profile B-B'.

The average annual rainfall is 1500mm. December, January and February are the driest months, the rainy season spans from March until November, with May, September and October being the months with the highest proportion. In the dry season months of the beginning of the year, it rains about 4 to 8 days/month; in the months with greater rainfall it rains around 16 to 20 days/month with a maximum rainfall of 125mm in 24 hours. The relative humidity of the air is greater than 80% in average and in times of rains reaches values greater than 85%.

The multi-annual average temperature that ranges from 16 to 20°C, the average temperature is 18°C, at midday the average maximum temperature ranges from 20 to 24°C, in the

early morning the minimum temperature is between 12 and 16°C. The average hours of sunshine are between 4 to 5 hours a day in the rainy season months and for the dry season sunshine registers between 4 and 6 hours a day. The average monthly wind speed at 10m height maintains values between 3 and 4m/s in the months of December, January, February and March and between 2 and 3m/s during the rest of the year, the average monthly evaporation registers values between 120 to 150mm in the months of January and March, and values of 90 to 120mm during the rest of the year (figure 37).

Based on the climate classification Caldas–Lang and with the information about precipitation, temperature and altitude, this station corresponds to a semi-humid temperate climate (Tsh), (Table 18).

*Table 36.* Use of extrapolated information to obtain climatic classification lang – caldas

Annual average temperature (° C). Multiannual average since 1981 to 2010; based on IDEAM data.	Average annual rainfall (mm), multiyear average since 1981 to 2010; Based on IDEAM data.	Lang Factor (P/T)	Classification Lang	Height above sea level (m)	Classification Caldas	Climate classification Caldas -Lang
18	1500	83	semi-humid [sh] (61 - 100)	1157	Temperate[T] (1001 m - 2000 m) & (24°>T≥17.5°)	Temperate semi-humid [Tsh]

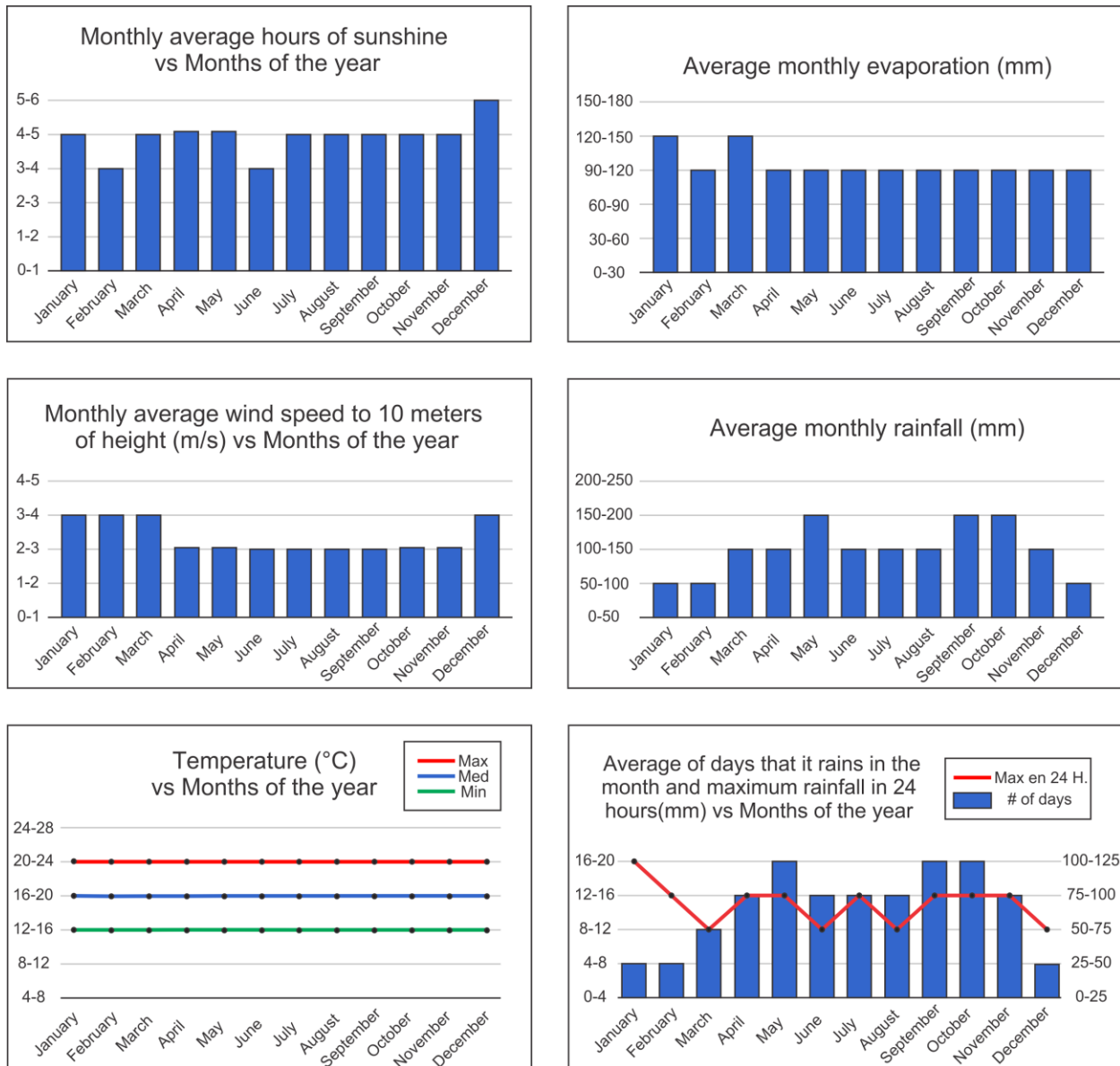


Figure 37. Climatic variables (temperature, rainfall, sunshine, evaporation, wind speed) for soil developed on Granite lithology sampling place, extrapolated from IDEAM Interactive Atlas.

**5.5.2 Descriptions for soil developed on granite lithology.** The soil is integrated by the following horizons (see figure 38).

**5.5.2.1 Granite sampling place, 1st horizon field description:** Total horizon thickness from 4 to 11cm. The cross-sectional shape of the contact between 1st and 2nd horizons is wavy,

dry matrix soil color is 5YR4/3 (reddish brown), with clast color of 7.5R8/3 (light pink), and moist matrix soil color is 5YR3/2 (dark reddish brown) with clast color of 10R7/6 (light red), the gradation between rock fragments and matrix is sharp, so color changes abruptly in <0.1mm between the fragments and the soil matrix. The dominant shape of the rock fragments is elongated, the relative roundness is angular and the fragments size is from 15 to 27mm diameter (medium gravel to coarse gravel). Excavation difficulty is moderate because excavation by tile spade requires impact energy or foot pressure, human arm pressure is insufficient. The quantity of roots no carbonized is 2% and their location is matted around rock fragments and in cracks, roots size is very fine to medium (<1 to 5mm). Quantity of pores is 15% and the dominant shape of pores is tubular, branching voids and interstitial. The average number of cracks, per meter, is 3%, they are the result of desiccation and there are reversible crust-related cracks.

*5.5.2.1.1 Description based on sieve samples without clay materials, sample 20 from 1st horizon: Very coarse sand to coarse pebbles-size sienogranite Rock Fragments very angular (56%). Very fine to coarse sand-size hyaline qtz, white dull feldspar and sienogranite Rock fragments very angular (15%). Silt-size qtz hyaline, white dull feldspar and muscovite very angular (24%). Silt to coarse sand-size carbonized plant fragment and some translucent tiny roots (5%). The 1st horizon characteristics are presented on table 37.*

*Table 37. Specific genetic materials in 1st horizon of soil profile developed on Granite lithology.*

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to coarse sand-size qtz, dull fsp and light altered granite RF (26%)	65%
	Granule to very coarse pebble-size light altered granite RF (39%)	
<b>Incorporated</b>	Roots no carbonized (5%)	14%
	Pores and water (9%)	
<b>TDR</b>	Argillaceous materials	21%
	<b>Total</b>	<b>100%</b>

**5.5.2.2 Granite sampling place, 2nd horizon field description:** Total horizon thickness varies from 5 to 11cm. The cross-sectional shape of the contact between 2nd and 3rd horizons is wavy, dry matrix soil color is 2.5YR8/3 (pink), with clast color of 7.5R8/3 (light pink), and moist matrix soil color is 2.5YR6/4 (light reddish brown), with clast color of 10R7/6 (light red), the gradation between rock fragments and matrix is sharp and the change of color is abrupt. The relative roundness of fragments is angular and the size is from 12 to 25mm diameter (medium gravel to coarse gravel). Excavation difficulty is low in matrix but is high in rock fragments. The quantity of roots no carbonized is 2%, they extend across 3rd horizon to 4th (rock) horizon with 500mm of deep and their location is matted around rock fragments and in cracks, roots size diameter is medium (5mm). Quantity of pores is 10% and the dominant shape of pores is interstitial and tubular. The average number of cracks, per meter, is 2% and there are reversible crust-related cracks. The 2nd horizon characteristics are presented on table 38.

*Table 38.* Specific genetic materials in 2nd horizon of soil profile developed on granite lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to coarse sand-size qtz, dull fsp and light altered granite RF (25%)	64%
	Granule to very coarse pebble-size light altered granite RF (39%)	
<b>Incorporated</b>	Roots no carbonized (2%)	13%
	Pores and water (11%)	
<b>TDR</b>	Argillaceous materials	23%
	<b>Total</b>	<b>100%</b>

**5.5.2.3 Granite sampling place, 3rd horizon field description:** Total horizon thickness varies from 7 to 21cm. Weathered parental rock, the cross-sectional shape of the contact between 3rd and 4th (rock) horizons is smooth, dry soil color is 5YR7/4 (pink) and moist soil color is 5YR6/4 (light reddish brown). Excavation difficulty is high. The quantity of roots no carbonized

is 1% and their location is throughout the horizon, roots size is fine (1 to <2mm). Quantity of pores is 12% and the dominant shape of pores is interstitial 7%, tubular 1% and branching voids 4%. The average number of cracks, per meter, is 4% and there are irreversible crust-related cracks. The 3th horizon characteristics are presented on table 39.

*Table 39.* Specific genetic materials in 3th horizon of soil profile developed on granite lithology.

<b>Genetic general material</b>	<b>Specific material</b>	<b>Percentage</b>
<b>Inherited-conserved</b>	Very fine to coarse sand-size qtz, dull fsp and light altered granite RF (31%)	77%
	Granule to coarse pebble-size light altered granite RF (37%)	
	Illite (9%)	
<b>Incorporated</b>	Roots no carbonized (1%)	9%
	Pores and water (8%)	
<b>TDR</b>	Argillaceous materials (Kaolinite) (14%)	14%
	<b>Total</b>	<b>100%</b>

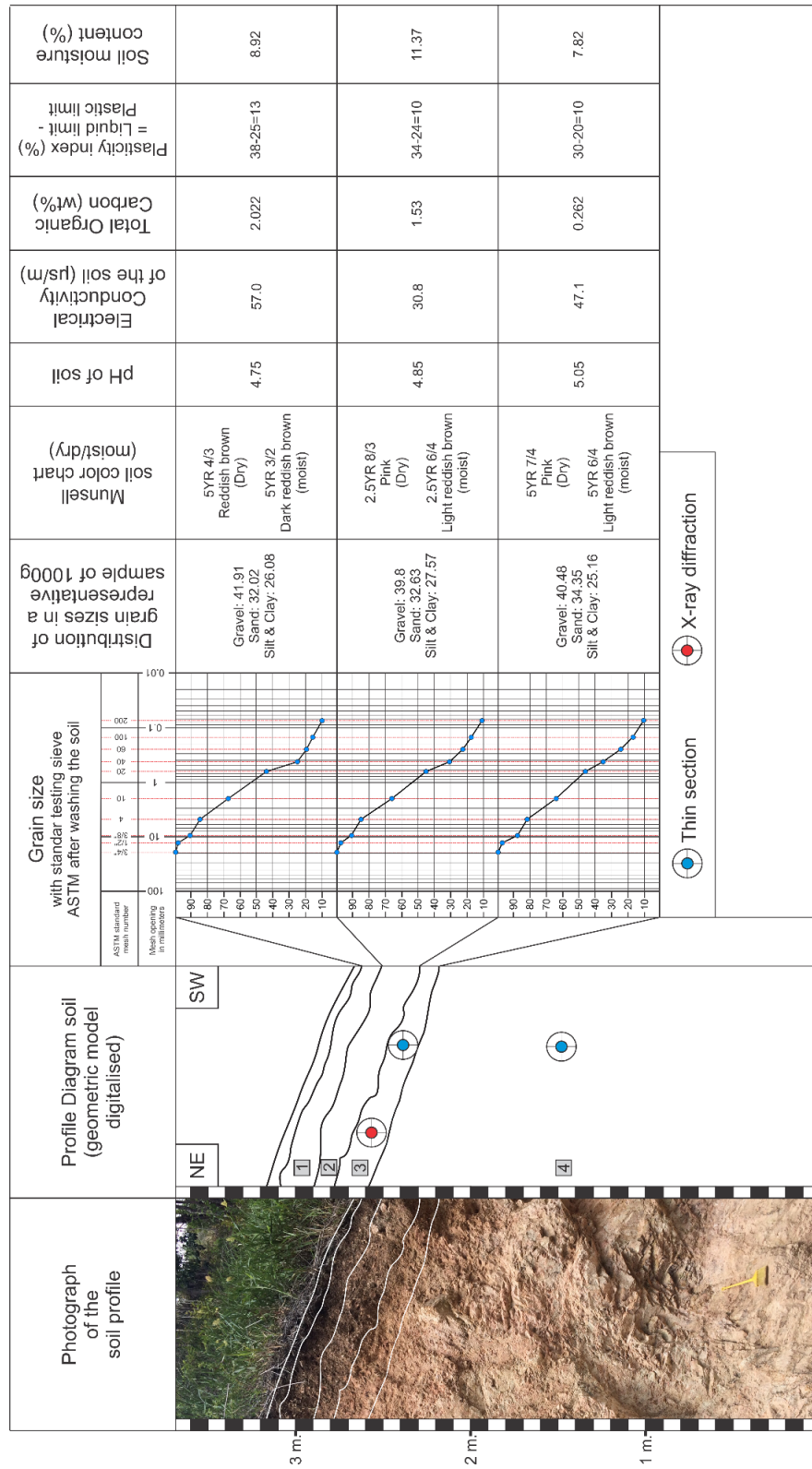
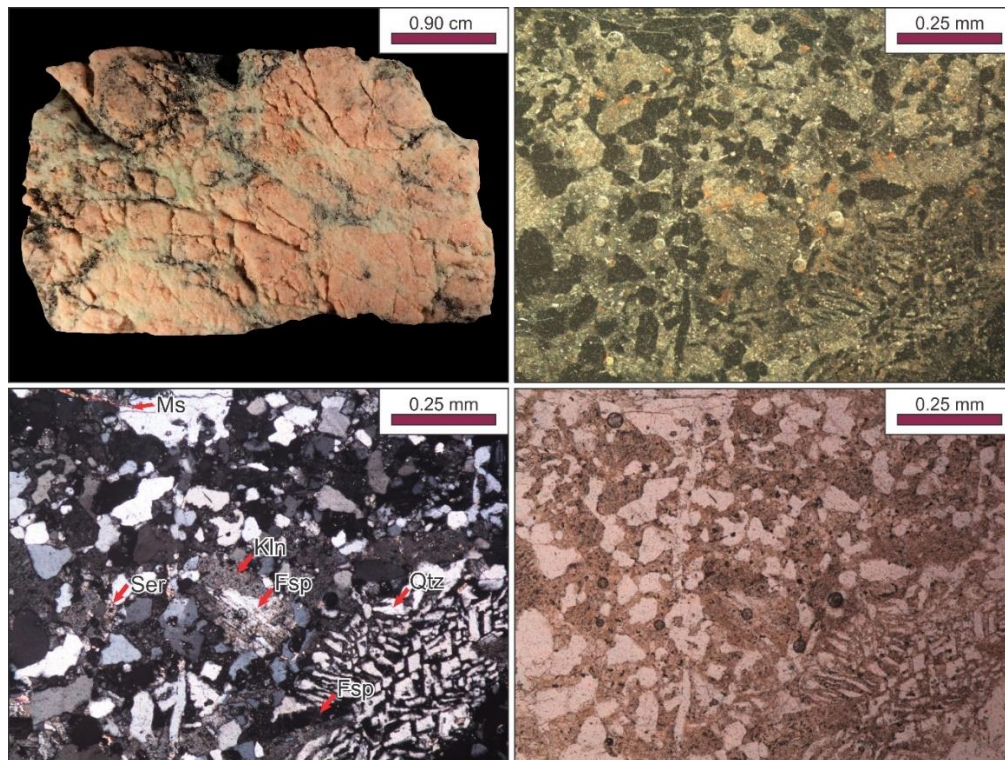


Figure 38 Soil profile developed on Granite lithology sampling place with grain size distribution of materials, and physical and chemical properties.

**5.5.3 Petrography for soil developed on granite (rock and 3rd horizon).** *Thin section sample number 23 (4th horizon- Granite rock), with 5x objective and 10X ocular.* Sienogranite; Mainly quartz, potassium feldspar anhedral crystals 2.3 mm size, some altered to sericite, plagioclase with polysynthetic twinning and some muscovite. Anhedral to euhedral crystals and inequigranular hypidiomorphic phaneritic texture. It is observed quartz with potassium feldspathic crystalline inter-growing or micrographic texture.

Point-counting result (300 measuring), potassium feldspathic (46.1%), quartz (32.6%), plagioclase (19.4%), muscovite (1.2%) and altered minerals (sericite) (<0.7%). Volume Q, A, P determination use potassium feldspathic (46.99%), quartz (33.23%), plagioclase (19.77%), it allows classifying the rock as sienogranite according to Streckeisen (1976) triangle plutonic igneous rock classification (figure 39).



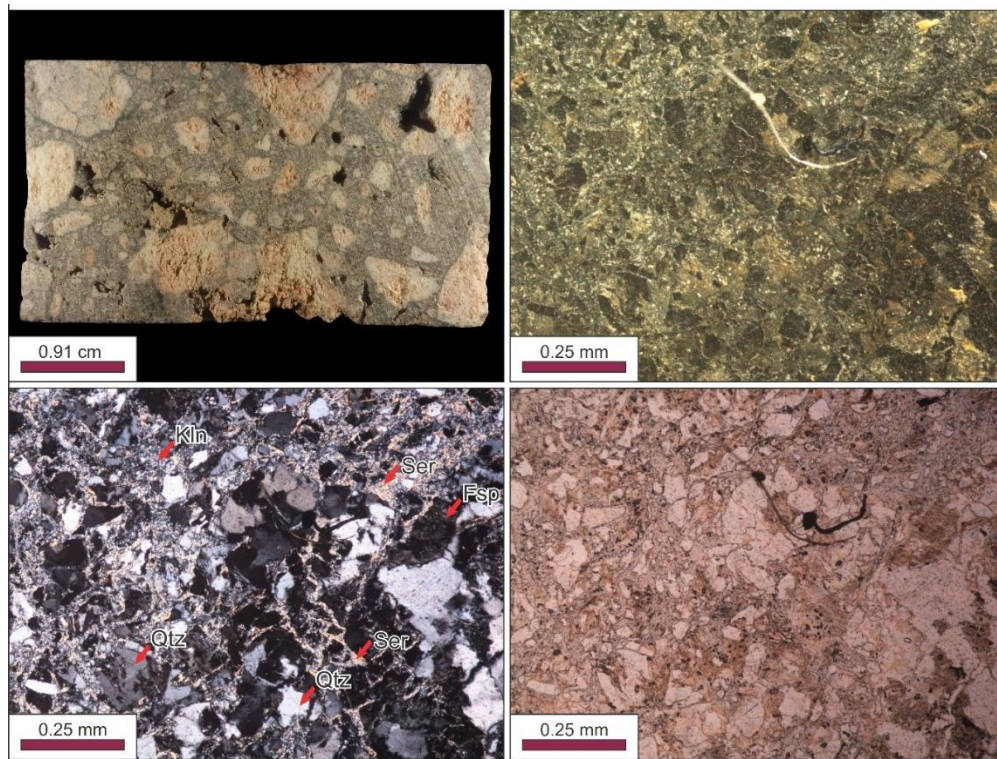
*Figure 39.* Sienogranite, mainly quartz, potassium feldspathic anhedral crystals, some altered to sericite, plagioclase with polysynthetic twinning and some muscovite. Thin section photography, with 5x objective

and 10x ocular, sample number 23, soil profile 4th horizon of soil developed on Quartz sandstone lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ms: Muscovite, Ser: sericite, Fsp: Feldspar, Kln: kaolinite, Qtz: Quartz.

*Thin section sample number 22 (3rd horizon), with 5x objective and 10X ocular.*

Sienogranite; mainly quartz, heavy altered plagioclase and altered potassium feldspar, muscovite and sericite (alteration product of plagioclase and potassium feldspar materials).

Inequigranular hypidiomorphic phaneritic texture, anhedral shape of crystals, some euhedrals. It is observed quartz with potassium feldspathic crystalline inter-growing or micrographic texture (figure 40).



*Figure 40. Sienogranite, mainly quartz, heavy altered plagioclase and altered potassium feldspar, muscovite and sericite (alteration product of plagioclase and potassium feldspar materials). Thin section photography, with 5x objective and 10x ocular, sample number 22, soil profile 3rd horizon of soil developed on Quartz sandstone lithology. Top right photography with reflected monochromatic light and polarization analyzer. Bottom left photography with cross polarized light (XPL). Bottom right photography with plain polarized light (PPL). Ser: sericite, Fsp: Feldspar, Kln: kaolinite, Qtz: Quartz.*

#### 5.5.4 Clay fraction soil composition determination on limestone.

The sample analyzed shows the d spacing for the {001} plane measured in 7,1 (untreated sample) for the minerals in their natural state, the value after treating the minerals in a solution of Ethylene Glycol was no change and the mineral heated to 550°C shows the d spacing value destroyed evidencing the presence of Kaolinite. Besides, the sample analyzed shows the d spacing for the {001} plane measured in 9,9 (untreated sample) for the minerals in their natural state, the value after treating the minerals in a solution of Ethylene Glycol was no change and the mineral heated to 550°C shows the d spacing value with little change evidencing the presence of Illite. (figure 41).

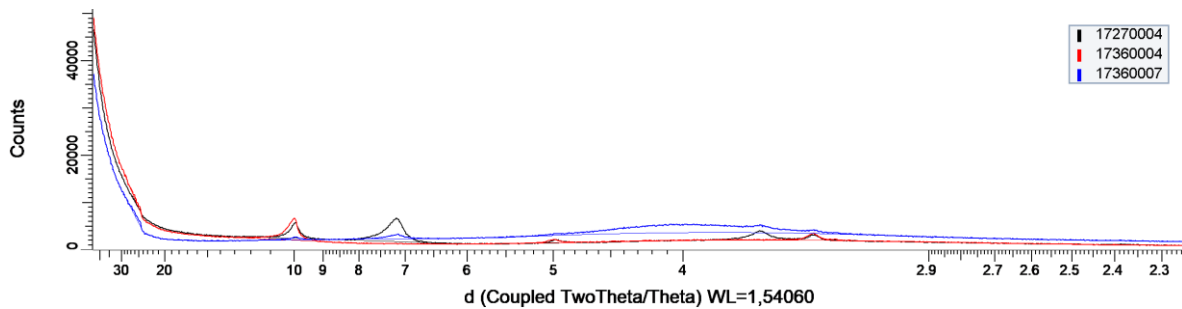


Figure 41 X-Ray Diffractogram for Clay fraction soil determination on Granite lithology sample. Black line represents the undisturbed sample, the red one represents the sample at 550 degrees Celsius and the blue one represents the sample with Ethylene Glycol.

#### 5.5.5 Genetic material distribution of soil profile developed on sienogranite lithology.

Soil profile developed on sienogranite a soil slightly TDR (Argillaceous materials (Kaolinite)) moderately to highly inherited-conserved materials (Granule to coarse pebble-size light altered granite RF, very fine to coarse sand-size qtz, dull fsp and light altered granite RF and Illite) slight incorporated materials (Roots no carbonized, TOC of 2 to 0.262 and water) (1st to 3th horizon) (see figure 42)

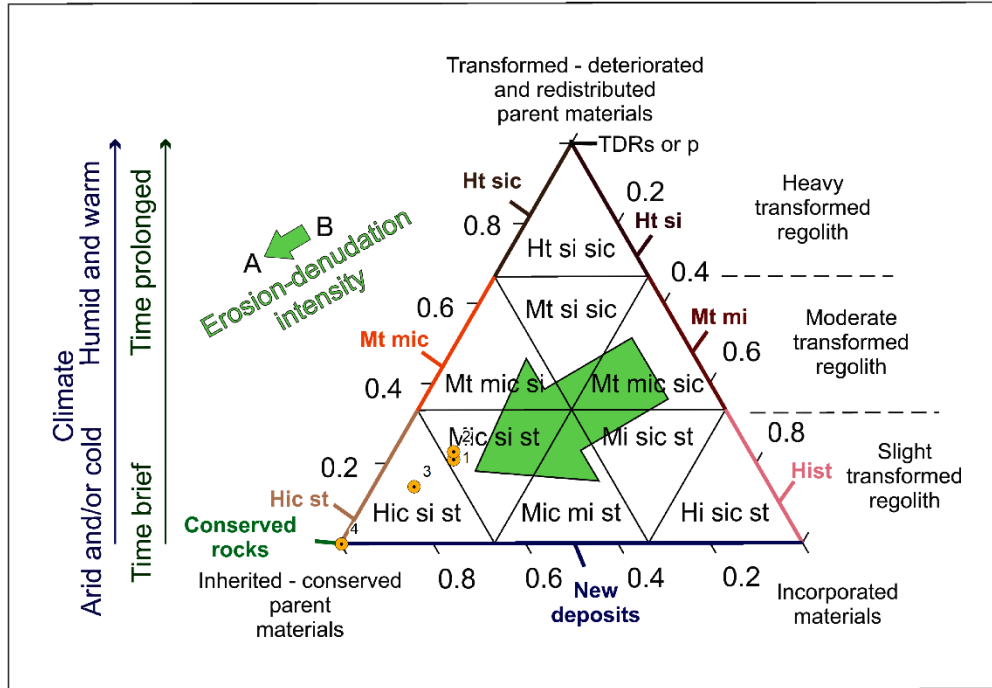


Figure 42. Implementation of the classification with the seven soil horizons developed in the lithology of sienogranite, include relation with the tree fundamentals factors that control the formation of soils: time, climate and denudation.

### 6. Conclusions

- 1) The presence of montmorillonite on soil profile developed in limestone could be explain because calcite is insoluble in alkaline solutions having pH greater than 9, in such alkaline solutions silica dissolves (Friedman and Sanders, 1978) and the average pH measured of this soil could generate amorphous silica and it could be transformed to montmorillonite according to Friedman and Sanders (1978)
  
- 2) According to the classification of expansive soils based on the plastic index proposed by Chen (1988) and the relationship established between the volume change potential and the type of clay proposed by Holtz & Kovacs (1981), the soil profile developed on quartz sandstone presents potential of low swelling related to the presence of kaolinite; and the soil

profiles developed on fluvial torrential deposit, gneiss and granite lithology have medium swelling potential related to the presence of Illite, which corresponds to the results obtained in the analysis of x-ray diffraction for determination of clays fraction.

3) The results obtained by mechanical analysis showed that the profile of soil developed on a fluvial torrential deposit presents the highest plasticity with an plasticity index (IP) of 15% and the least plasticity is presented in the soil developed on sandstone with an IP of 8,6%. This indicates that the soil developed on a deposit will have greater deformation capacity, without showing any cracking before a mechanical effort, than the profiles of soil developed on rock.

4) Presence of Illite (69%) on soil profile developed on feldspathic quartz sandstone states the inherited of them from deeply buried shales, and the presence of Kaolinite (23%) states the genesis of them by weathering soil alteration or TDR material from feldspar materials under tropical and equatorial climatic conditions on smooth or plain topography.

5) Present of Nodule beds in 2nd horizon soil profile developed on feldspathic quartz sandstone replacing of matrix materials by iron-magnesium oxide with conservation of original very fine to medium quartz sand materials, states that soil waters from overlying marsh transporting ferrous materials interacts with underlying well-oxygenated water of siliceous aquifer leads to oxidation of the ferrous materials to form iron oxide precipitation.

6) According to the results obtained in chemical analysis (pH and conductivity) and taking into account that pH information is divided into three categories, acid for  $\text{pH} < 5$ , neutral for pH between 5 and 8, and alkaline pH for  $\text{pH} > 8$ ; soil developed on feldspathic quartz sandstone is acid, soil developed on gneiss is neutral, soil developed on limestone is alkaline,

soil developed on deposit is acid, and soil developed on granite is acid; and all of them are very strongly saline.

7) The main processes that affect the proportion relationship that occurs between inherited, transformed and incorporated materials in the soil profile were listed.

8) The different incorporated, transformed and inherited materials were specified.

9) A ternary diagram was proposed for the geological classification of modern soils with their respective nomenclature, based on the content of parent materials, incorporated materials and transformed materials.

10) Five model examples were made characterizing the parental rock in four cases comprising soils developed on a feldspathic quartz sandstone, a sienogranite, a biotite feldspathic quartz gneiss and a limestone, as well as a soil profile developed on a torrential fluvial deposit. The relationship between the developed soil and the parent material corresponding to the different lithologies located in different climate regimes was determined.

### **Recommendations**

1) The development and improvement of this new proposal, will help to highlight the roll that lithology has in the soil formation process, which in turn will improve the understanding of how modern soils evolve in diagenesis processes in the step to their conversion into paleosols.

2) This proposal would help to improve the description of the UGS currently used by the Colombian geological service and frequently evaluated for the realization of territorial

planning plans, differentiating which products in the soil profile are related to the rock and its alterations with all that be alien to this. Information of great importance to determine what is the cause of a particular problem and how to attack it more assertively

3)The next step is to implement this classification at the geoform level and propose a methodology for its use in the cartography of soils and superficial geological units.

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