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RESEARCH ARTICLE

Geomorphological Characterization from the Geographical Perspective of theYunganza Zone Limón Indanza, Ecuador

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ABSTRACT

The geomorphological characterization of different areas of the Yunganza parish belonging tothe Limón Indanza canton in the state of Ecuador, analysed the economic potential it representsin terms of the growth of the country's mining sector. In order to achieve this goal, geographicinformation was collected, obtaining a baseline reference of the area of influence, where geological conditions were evaluated, which allowed the delivery of the geomorphological profile of the area. Results were obtained from a delimitation of the study sector with its respective location map, slope and flow calculation tables of the existing streams, as well as maps of structural alignments of the sector of interest, with a definition of the geomorphologyof three zones of the Yunganza sector with a geomechanical description based on limestone and andesitic rocks. Being conclusive, the composition of the edges of the geomorphological profiles based on igneous, metamorphic and sedimentary rocks originating from the Cordillera Real, with rock massifs of class II and IV, suggesting a possible geomorphological potential ofthe sector for the development of different mining projects.

1. INTRODUCTION

The representative geography of General Leónidas Plaza Gutiérrez of the parish of Yunganza is located in the southeast of Ecuadorian territory, and is the cantonal capital of the canton of Limón Indanza, which belongs to the province of Morona Santiago; it is bordered to the northand east by Santiago de Méndez, to the south by San Juan Bosco and to the west by Azuay. (Baldock, 1982).

Characterised by an altitude ranging between 1040 and 1400 metres above sea level, it has a humid and temperate climate with temperature variations between 18 and 22 degrees Celsius.(Reinozo & Piña, 2022). Geological studies are developed through a process that includes the identification of geological units, their main and secondary structures, as well as the evaluationof the quality of the materials (Pasato & Cuesta, 2019). (Pasato & Cuesta, 2019a)..

The geographic-structural analysis of the region was based on the collection of bibliographic data followed by its validation in the field (Coronel, 2015). (Coronel, 2015)These data allowed understanding the lithology, structures and lineaments, which, combined with other susceptibility parameters, made it possible to identify the causes of instability in the study area(Pasato & Cuesta, 2019b). (Pasato & Cuesta, 2019b)..

A topographic map, as a comprehensive graphic document, provides a subjective interpretationof the geomorphological landscape, which should be easily referenced in the field and include detailed representations of landforms, processes of origin, evolution of landforms and degree of dynamic equilibrium (Fraustro, 1998). (Fraustro, 1998). The scale of the map should be appropriate to the relief texture and the specific purpose of the representation, following methodologies or rules of thumb whenever possible (Peña, 1997). (Peña, 1997). These studies enable the creation of geophysical maps, natural risk assessment and mining projects at national, regional, provincial and local levels.(Rivera & Cuesta, 2023)Similarly, geophysical surveys play a fundamental role in the generation of basic information necessary for policy formulation and decision making in the socio-economic development of the country. (Peña, 1997).

The graphic representation of the stratigraphy of the sector is achieved through a rock column, highlighting the oldest layers at the bottom and the most recent at the top. The resistance to weathering is represented on the horizontal axis, and from a petrological perspective, the materials are classified into two groups: rocks and soils (Abramson et al., 1996)..

Complex geomorphological profiles provide data on the relief and the intensity of endogenousand exogenous processes; these profiles are interpreted using geomorphological indicators and are reflected in thematic landscape analysis maps, there are two types of profiles, longitudinal and transversal, whose main objective is to harmonise the relief elements in relation to endogenous (tectonic) and extrinsic (erosive) factors. (Núñez et al., 2023a)..

The RMR index has been used to evaluate rock mass characteristics. Bieniawski (1989) has established a direct relationship between RMR and the modulus of deformation of the rock mass. In addition, the RMR value is used as a method to estimate the *m* and *s* factors of the Hoek-Brown failure criterion, with specific equations provided together with the GSI value that assesses the strength of the rock mass. (Hoek & Brown, 1988).

These studies and profiles have been carried out in the project, which is located in the southeastof Ecuador, in a valley between the Cutucú Mountains to the east and the Royal Mountains tothe west. Providing relevant information for the geomorphological understanding of the sector,due to the fact that it is a very rich site for the lithological occurrence and at the same time a sector of great economic interest for the mining sector of the canton. (Limón Indanza PDOT Technical Team, 2020).

2. MATERIALS AND METHODS

For the field methodology he used various materials such as topographic maps, geologist's compass, GPS, geologist's hammer, 10x and 20x magnifying glasses, flexometer, camera, pencil and protractor (Coronel, 2015). (Coronel, 2015). For the final output of the document, alaptop computer, an HP plotter, an Epson L4160 printer and different softwares were used together with a varied database that gave way to the creation of maps and didactic graphics presented in this research. (López & Cuesta, 2023).

2.1 Geomorphological map of Ecuador

A geological map of Méndez at a scale of 1:3466743 is used as a reference, providing essential information for generalised geological investigations. Once the location is defined, a preliminary study is carried out to select a precise route within a strip of several kilometres wide. Criteria such as topography and achieving a specific road slope were considered, requiring the excavation of ditches and the construction of embankments. (Tricart, 1979).

2.2 Study area

Bibliographic information on the study area is collected, including geological mapping,topographic maps at scales that allow the area of interest to be identified, and aerial photographs or vertical orthophotos at various scales (Coronel, 2015).. Finally, with data taken in-situ, the flows and slopes of existing streams are calculated using the floatation method, which links thearea of the aquifer section with the flow rate. These are included in irrigation canals and pipes,allowing approximate flow measurements.

2.3 Structural alignments

An important part of the fieldwork involves the mapping of rock-soil contacts on slopes, distinguishing healthy rocks from decompressed or altered rocks. Lithological and structural data were used to define the geology of the area.

The collection of these data also covers structural characteristics and general properties such as colour, composition, mineralogy, texture (size, shape, arrangement of rock elements) and structure (macroscopic characteristics of the rock units), as well as the thickness of the rock units and the number of beds (in metres). Similarly, the correlation of different lithological units with other known lithological units is carried out, naming them according to their magnitude and location in time as groups, formations or members of various lithological units. This process culminates in the elaboration of the local stratigraphic order or column.

Finally, and thanks to the definition of structural geology as the branch of geology in charge ofthe study of the structural characteristics of the rock masses that form the earth's crust, their geographical distribution, geological period and the causes that generated them; they are also identified, described and graphically represented in maps and geological sections. (Montaño, 2021). Given the lack of vegetation in some areas of the study area (soil and slopes), the data collection is carried out at equal intervals of 20 or 25 m.

In addition, data previously identified from aerial and satellite photographs are compiled to obtain structural and lithological information on both sides of the structure, showing all lines on the surface of rivers and springs (Cuesta et al., 2023). (Cuesta et al., 2023).. Faults were identified by their type, strike, dip and the characteristics of the material in the fault zone. Knowing the extent of the fault and its relative age in relation to different rock units so the fracture systems were determined the distance between them, direction and dip, type of infill.

2.4 Geomorphology of the Yungantza zone

In-situ, the levels corresponding to the most important topographic events, stratigraphiccolumns and rocks forming the main structures were identified. Areas of geological interest were taken into account, including road cuts and natural outcrops. Three of the main geomorphological zones of the study sector were detailed as being of primary importance.

2.5 Geomorphological profiles

GIS software is used to trace the complex geomorphological profiles of the sub-basins with theaim of analysing the morphometric parameters obtained from the mapping and to establish relationships between endogenous and extrinsic processes of the relief (Núñez et al., 2023b).. As part of the geological study, the relief and its topographic characteristics are also identifiedand described, with emphasis on slopes and their variations.

2.6 Geomechanical description

Rock classification systems are essential for empirical mine planning. The use of such systemscan be implicit or explicit and have traditionally been used to group areas with similar geomechanical properties, provide stability performance guidelines and select appropriate supports. In recent years, classification systems have been widely used in combination with analytical and numerical tools (Alvarado, 2022). (Alvarado, 2022). Therefore, in addition andafter completion of the geological survey, the discovered rock units are correlated with outcropmechanical RMR analysis of Bieniawski (1989)a small geomechanical sketch that can serve asa basis for determining the unstable zones in the study area (Pasato & Cuesta, 2019). (Pasato & Cuesta, 2019a)..

3. RESULTS

3.1 Geomorphological map of Ecuador

In the eastern region, two morphological zones can be identified that extend from the foothillsof the Cordillera Real to the Cutucú and El Cóndor mountains, encompassing the Upano and Zamora river basins. The Upano River forms a rectangular valley with steep vertical slopes, culminating in a canyon surrounded by rocks of the Mesas and Upano Formation, products ofthe eruption of the Sangay volcano.

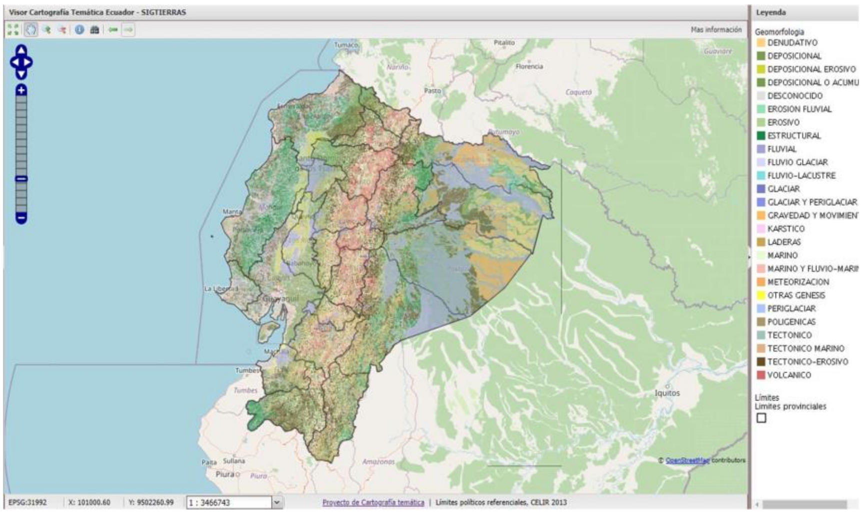

Figure 1: Geomorphological Map of Ecuador

Source: Ministry of Agriculture, Livestock, Aquaculture and Fisheries. (SIGTIERRAS,2024)

To the south, this area includes the Yunganza Valley, with the river flowing through a graben-like geological structure towards the foothills of the Plan de Milagro. The region encompassesthe Limón area, characterised by strong tectonism and a mixture of geological formations; Baldock (1982) defines this area as the Limón Group, which includes the Hollín and Napo formations. Similarly, Coronel (2015) describes this complex as Champs de Limón, which includes rocks from the Jurassic to the Tertiary (Chapisa, Hollín, Napo and Mesa); in a southerly direction, it encompasses the Indanza Valley up to the Calaglas buttresses, continuingtowards the Guarakiza and Cuchumburza passes with their rock formations. The eastern boundary of this region corresponds to the Zamora River (Coronel, 2015)..

In the project area, morphological aspects indicate that the metamorphic rocks of the mountainrange generate deep valleys with vertical incisions, strongly controlled by the structure. Thesevalleys are narrow and can host numerous waterfalls. The rocks of the Santiago Formation giverise to vertical valleys with waterfalls and cascades, especially at the mouths of tributaries.

3.2 Study area

The study area covers 300 hectares in the municipality of Yunganza, belonging to the provinceof Limón Indanza under the jurisdiction of Morona-Santiago (Figure #2). The UTM coordinates PSAD 56 Coordinate System, in the geographical area 17, Vertex 1 (792000,9684000), Vertex 2 (792000, 9682500), Vertex 3 (794000, 9682500), Vertex 4 (794000, 9684000)

Figure 2: Location Map

Source: Own elaboration

The Pupumasa and Delgado rivers, tributaries of the Yunganza river, originate in the southeastern part of the study area. The calculation of the flows and slopes of the streams are shown in Table #1 and #2 below:

Table 1: Calculation of flow of existing streams

Quebrada	Flow Velocity (m/s)	Section area (cm)^2	Fiction coefficient	Flow rate (l/s)
Flowers	1.67	400	0.8	533.33
Córdova	2.00	156	0.8	156.00
Gabychula	1.43	360	0.8	565.71
Jhoselyn	1.67	400	0.8	533.33
Girl	2.00	351	0.8	523.64
Delgado	0.43	520	0.8	360.53
Pupumasa	1.11	1560	0.8	1386.67
Cumtza	2.00	41000	0.8	67200.00
Yungantza	1.43	210000	0.8	240000.00

Source: Own elaboration

Table 2: Calculation of slopes of existing creeks

Quebrada	Length of watercourse (m)	Pending(%)
Córdova	365	23.29
Jhoselyn	888	17.45
Delgado	877	25.88
Pupumasa	1210	16.86
Cumtza	1328	3.84
Yungantza	2016	2.10

Source: Own elaboration

3.3 Structural alignments

The following image shows the structural alignments in trend with the local crack called Yunganza.

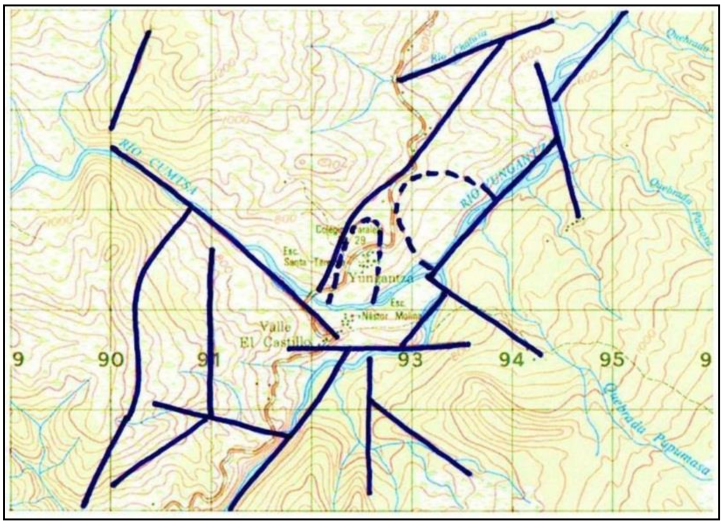

Figure 3: Structural Alignments

Source: Own elaboration

This image shows the general trend of the local rift (Yunganza rift). The regional trend in its northeastern part is cut by the northwest and east-west faults, and local strike changes due to microtectonic effects can be observed.

In the same way, in figure #4 we can visualise a smoother and higher quality line in terms of the behaviour of the rivers in the studied area.

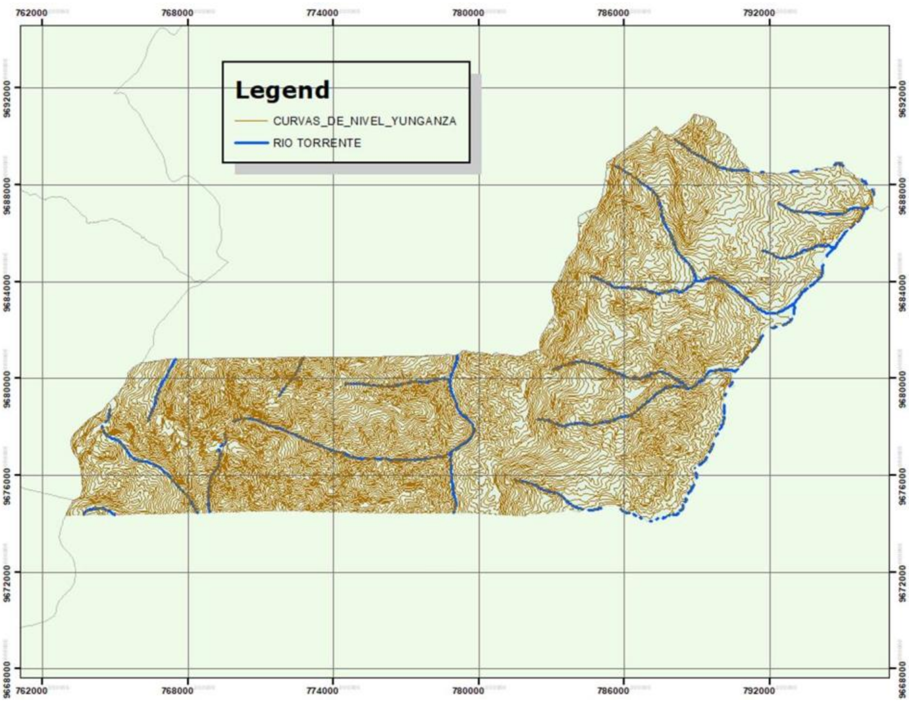

Figure 4: Smoothed structural alignments of the sector

Source: Own elaboration

3.4 Geomorphology of the Yunganza area

The Yungantza region is located in the plains on the left bank of the *Cumtza* River, at an elevation of 585 metres above sea level. To the south, at an altitude of 840 metres above sea level, the Yungantza

River appears as a narrow valley surrounded by misahualli volcanic rockformations. The andesite, with a marked verticality, forms valleys of approximately 10 metreswide, although at some points the depth of the valley is less than 6 metres, with the river flowingin a north-westerly direction at about 55 degrees. Subsequently, the river forms a 30-metre wide valley in a N30E direction and, as it leaves the area to the northeast, it widens to form a 40 to 50-metre wide valley. (Coronel, 2015).. The slope of the Yungantza river is 3.95%, located at the southern entrance at 595 metres above sea level and at the northern exit of the site.

The *Cumtza* river flows south of the area, forming a semicircle that changes its course from northwest to southeast and then southwest, creating a wide valley delimited by a sub-horizontal valley on the right bank and a semi-horizontal one on the left. Through the rocks of the mesa, it presents a steep slope of up to 3 metres in height with a 4.37% slope from 673 metres, locatedat the western entrance of the area at 615 metres altitude, confluent with the Yunganza river (Cuesta et al., 20). (Cuesta et al., 2023).

Table 3: Geomorphological units

Geoform	Genesis	Lithology	Relief	Drainage	Remarks
Flattened	Fluvial lacustrine deposit	Conglomerate polymetric tableformation	Sub-horizontal flattening < 10°.	Parallel	River beaches
			Sloping		
			Flattened > 10°		
		Conglomerate	Sloping > 10°		
Hillside					Paleo sliding
	Landslides	polymetric table	Sloping	Parallel	
deposit					zone
		formation	Flattened > 10°		
			Sloping > 10°		
			Sloping		
			Vertical cuts >		
			70° Vertical cuts		
			> 70° Vertical		
Steep	Effect of	All	cuts > 70°	Parallel	Present in fault
	geological faults		Vertical cuts >		zones
			70° Vertical cuts > 70° Vertical cuts > 70		
	Lithological peculiarities	Training table			Natural land cuts

Hill relief	Morphological rejuvenation	Igneous rocks, Chapiza formation	Smooth Wavy between 30° and 60	Dendritic to Parallel	Study area extremities

Source: Own elaboration

DISCUSSIONS

The geomorphological units and subdivisions are of different morphological and morphometric contrasts that associate various materials or structural arrangements with individual topographical characteristics described in table #3. Based on these, the Yungantza sector is characterised by three well-defined geomorphological zones, which are described as follows (Coronel, 2015).

3.4.1 First geomorphological zone

This first area is located to the left of the Cumtza river, encompassing the land mass territory, presenting a slope with four visible steps in the north-south section and belonging to the rocky formation domain. With a gradient of 640 metres above sea level at the highest point of the Cumtza River, at 800 metres above sea level, the maximum slope reaches 18%. The morphology shows a slope in areas of the paleo-collapse with a tendency to dip, creating an extensive staircase followed by a gentle slope of approximately 15°, reflecting the general direction of the landslides in the direction of the Cumtza River.

3.4.2 Second geomorphological zone

Located on the right bank of the Cumtza River and on the left bank of the Yunganza River, thisarea is a sub-horizontal relief with a gradient of 593 metres above sea level. At 675 metres above sea level, it has a 6% slope, and corresponds to the Mesa formation rock field, originatingfrom modern colluvial deposits.

Figure 5: Cumtza River, left bank, rocks of the Mesa Fm

Source: Own elaboration

Figure 6: View of the Yunganza river valley

Source: Own elaboration

This geoform is present on the plateau above the road where the Technical University of Yungantza is located, resting on the rocks of the mesa formation, affected by ground movements.

3.4.3 The third geomorphological zone

Located in the southern and eastern regions, this area exhibits steep slopes and vertical incisions, especially notable in the Misahuallí volcano. These features originate from tectonicmovements linked to faults present in the geological activity of the region.

Figure 7: Tectonic scarps in andesites

Source: Own elaboration

Figure 8: ***Engraved characteristics of the Yungantza riverbed***

Source: Own elaboration

3.5 Geomorphological profiles

In order to define and conceptualise the geomorphological characteristics of this region, three geomorphological profiles were established:

First hand, the topographic profile "A-A" which starts at coordinates 9'684.000N, 782.650E and ends at 9'662.500N, 793.500E, provides a detailed analysis of the topographic layout in thecentral zone dominated by the mesa formation.

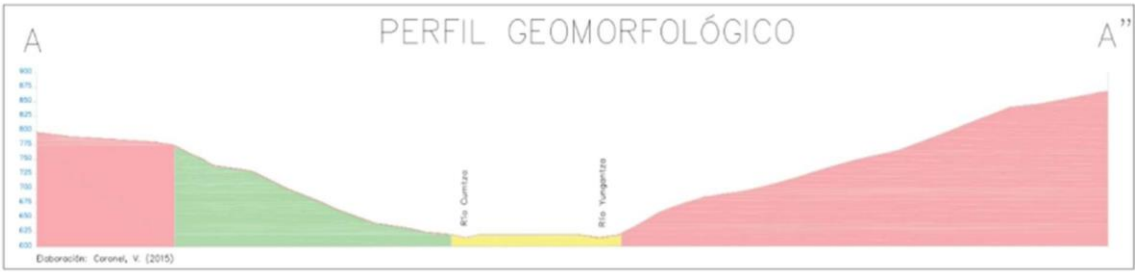

Figure 9: Geomorphological Profile A-A"

Source: Own elaboration

Continuing with the geomorphological profile "B-B", which starts at 9'693.950N, 792.650E and extends to 9'682.540N, 792.600E, crossing the Mesa Formation zone to the northwest of the area affected by the Yungantza landslide, illustrating the geomorphological relationships of this phenomenon.

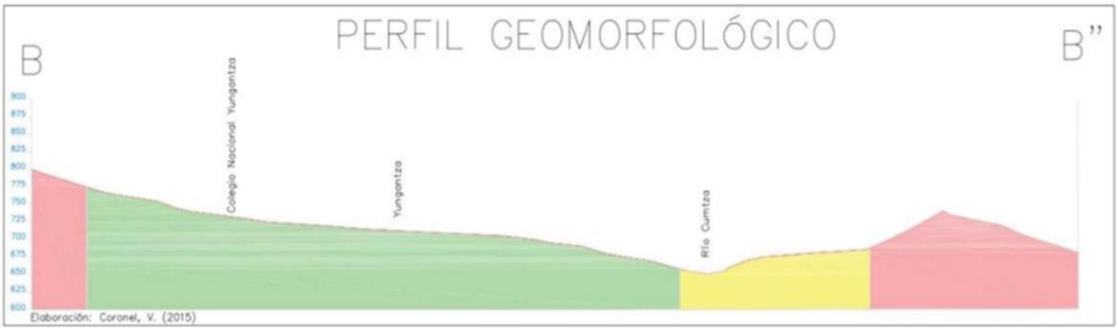

Figure 10: Geomorphological Profile B-B"

Source: Own elaboration

Finally, the Troncal Amazónica defines the C-C topographic profile that runs from 9'683.620N, 792.000E to the eastern edge, revealing a north-south slope formed by a significant landslide towards the Cumtza river. This profile describes the relationship between landslides and rock formation in the region.

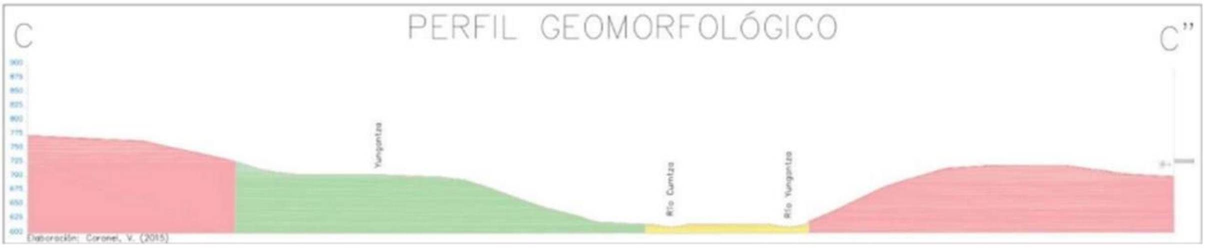

Figure 11: Geomorphological Profile C-C"

Source: Own elaboration

3.6 Geomechanical description

Finally, an evaluation of the physical and mechanical properties of soils and rocks has been generated to determine their strength. Two field sheets were carried out, one for each outcrop according to Bieniawski's classification which assigns classes from I to V, being I high qualityrocks and V low quality rocks. (Bieniawski, 1989).

The rock classes are defined in a range from I to V, with class I being considered very good rocks and class V very poor rocks. The results of the RMR classification for the main rock massifs in the study area are shown below.

3.6.1 Andesite

The first result of this field analysis is the presence of this andesitic rock mass as a pseudo- layer with low simple compressive strength, with RQD is less than 25%, the discontinuity distance is less than 80 mm and water droplets are produced. The strike and dip directions of the discontinuities are good, the length of the discontinuities is less than 1 m, the spacing is between 0.1 and 1 mm and these discontinuities are thick, unfilled and moderately weathered. Class IV rocks are determined by superimposing these measurements.

3.6.2 Limestone

On the other hand, the sector also exhibits remarkable simple compressive strength properties associated with limestones as assessed by field indices. For this rock massif, the RQD index isbetween 50% and 75%, and the spacing of discontinuities varies from 0.6 to 2 metres, the rockis in a wet state, the strike and dip orientation of the discontinuities is favourable, with a lengthof discontinuities persisting less than 1 metre and an open spacing of 0.1 to 1 mm; these discontinuities are rough, have a hard fill of more than 5 mm and undergo slight weathering. Tabulation of the measured values determined a rock massif classified as class III.

4. CONCLUSIONS

Different documents and representative information such as the geomorphological map of Ecuador have been reviewed and have provided initial representative information as a baselinefor this study. Some outstanding morphological aspects are the metamorphic rocks of the mountain range, which generate deep valleys with vertical incisions, strongly controlled by thestructure. These valleys are narrow and can host numerous waterfalls. The predominant geological structure in the area is the Real fault, which connects the sedimentary rocks of the Amazon basin with the metamorphic rocks of the Andean Cordillera. Its general direction is north-south, with an elevation of approximately 500 metres.

Thanks to the analysis of the flow and slopes of the streams, it has been possible to define thatin the study sector we have the Cumtza river as a tributary on the left bank of the Yungantza river, which flows in a west-east direction from the western limit of the area to the town of Valle del Castillo, where it changes its course towards the southwest-northeast. The upper partof the river forms a narrow valley upstream of the Amazon Highway Bridge. Below the bridge,a wide, flat valley with a gentle slope towards the east is formed, showing clear differences inthe formation of the edges. The right bank represents a typical alluvial terrace, while the left bank exhibits a slope of approximately 10 degrees to the south, with rocks of the Mesa Formation affected by soil movements, ending in a small dike at the base of the river.

In the same way, a clear trend of structural alignments in the sector is concluded, framing towards the west of the Yungantza River, where it is presented as a reverse fault, causing the elevation of the western block in relation to the eastern one. Associated with this fault and as aconsequence of distension faults, a variety of normal and reverse faults are observed, generating the dislocation of blocks. Images of structural alignments reveal the general trend of the local rift (Yunganza rift). In its northeastern part, the regional trend is interrupted by northwest and east-west faults, with local changes due to microtectonics.

It has also been defined that the main morphological feature not considered in the morphological evolution of the region is the influence of the ice age, evidenced by areas of moraines, U-shaped valleys and the remains of a flattened area. This generates geomorphological profiles with a predominant form on the right bank of the Cumtza River upto the mouth of the Yunganza River, composed of sediments of glacial origin with rounded edges to squares of approximately one metre, randomly arranged in the landscape. The composition of the rim includes igneous, metamorphic and sedimentary rocks originating fromthe Cordillera Real. The presence of steep areas is associated with two geological phenomena,mainly the formation of cliffs is attributed to the action of geological faults, which generate variations in the vertical displacement of the rock masses, giving rise to andesitic cliffs, such as those observed near the bridge over the Yunganza.

It has been possible to define that the main rock massifs exposed in the area are mainly composed of andesitic rocks and limestone; rock massifs that, once evaluated according to the RMR characterisation system of Bieniawski, obtained a qualification of poor and medium quality respectively. On the one hand, the Andesite obtained a class IV designation, which is known as bad rock and has an average useful life of 10 hours on a 2.5 m high slope; while thelimestone had a class III classification, which describes it as regular rock, so this type of rock exhibits an average stability of one week on a 5 m high slope.

Finally, and thanks to the superposition of favourable results of the different geological analyses carried out, the sector within the parish of Yunganza, being mainly composed of andesitic rock and limestone, has the geomorphological potential to be feasible for the possibledevelopment of a project for the exploitation of non-renewable natural resources such as those developed in the mining industry.

The main recommendation for the study carried out is to carry out topographic monitoring of the area in order to clarify any uncertainty about the presence or absence of movements that could affect and generate significant variation of the results in this document; if this is the case,it is suggested to carry out these processes by means of topographic triangulation, using as a reference point one that guarantees stability. Without ruling out the confirmation of each of the results and conclusions presented here, through the use of new technologies and/or tests discovered.

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