



UNIVERSIDAD REGIONAL AMAZÓNICA IKIAM
FACULTAD DE CIENCIAS DE LA TIERRA Y AGUA
CARRERA DE GEOCIENCIAS

**EVALUACIÓN CUANTITATIVA DE LA GEODIVERSIDAD EN
LA AMAZONÍA ECUATORIANA, PROVINCIA DE NAPO:
ESTUDIO DE CASO GEOPARQUE NAPO SUMACO**

Proyecto de investigación previo a la obtención del título de:

INGENIERA EN GEOCIENCIAS

AUTORA
DAYANA LIZBETH VERA JARAMILLO

Napo – Ecuador

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AUTORA: DAYANA LIZBETH VERA JARAMILLO

TUTOR: MSc. MARCO VINICIO SIMBAÑA TASIGUANO

CO-TUTOR: PhD. OSWALDO JOSÉ GUZMÁN GUTIÉRREZ

Napo – Ecuador

2022

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Marco Vinicio Simbaña Tasiguano
C.I: 1717760399



Oswaldo José Guzmán Gutiérrez
C.I:1759458613

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Dedico este trabajo de investigación, a mis padres y hermanas por todo el apoyo que me han brindado para que pueda culminar con esta etapa de mi vida. A mis docentes por haberme guiado durante todo este camino. A mis amigos y todas las personas que me motivaron y contribuyeron de alguna manera para que pueda llegar a este punto de mi carrera. También dedico este trabajo a todas las personas que conforman el Geoparque Napo Sumaco y a todos quienes estudian la geodiversidad.

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RESUMEN

La geodiversidad es el equivalente abiótico de la biodiversidad que puede ser explotado desde tres campos principales como son el científico, educativo y turístico. En los dieciséis geositos del Geoparque Napo Sumaco, se realizó una evaluación cuantitativa de la geodiversidad utilizando la metodología propuesta por Brilha. En este trabajo, se llevó a cabo recolección de datos en campo de los geositos Shunku Rumi y Cantera Pungarayacu, donde se realizó por primera vez un croquis geológico y una columna estratigráfica. Dentro de los principales hallazgos de la evaluación cuantitativa, se encontró que el geosito Volcán Sumaco, y el geosito Laguna y mirador Guagua Sumaco tienen un alto valor científico. Asimismo, el geosito Cantera Pungarayacu tiene un alto potencial de uso educativo y el geosito Librerías de Puerto Misahualli tiene un alto potencial de uso turístico. En cuanto a la evaluación de riesgo a degradación, los geositos Cantera Pungarayacu y Río Hollín tienen un riesgo a degradación alto y moderado respectivamente. Los catorce geositos restantes muestran un bajo riesgo a degradación, debido a que no hay actividades que causen degradación. Además, son protegidos y cuidados por las personas de las comunidades y los guías locales. Finalmente, este trabajo muestra la necesidad de realizar más investigaciones científicas, mejorar las condiciones de seguridad, promocionar los geositos y desarrollar material didáctico.

Palabras clave Geodiversidad, Geoparque, Evaluación de geodiversidad, Amazonía ecuatoriana

ABSTRACT

Geodiversity is considered the abiotic equivalent of biodiversity and can be exploited in three main fields such as scientific, educational, and tourism. In the sixteen geosites of Napo Sumaco Geopark, a quantitative assessment of geodiversity was carried out using the methodology proposed by Brilha. In this work, field data collection was carried out in the Shunku Rumi and Pungarayacu Quarry geosites, where a geological sketch and stratigraphic columns were made for the first time. In what concerns the quantitative assessment, it was found that the Sumaco Volcano geosite and Guagua Sumaco Lagoon, and Outlook geosite have a high scientific value. Likewise, the Pungarayacu Quarry geosite has a high potential for educational use and the Puerto Misahualli's Bookcase geosite has a high potential tourist use. In terms of degradation risk assessment, the geosites Pungarayacu Quarry and Hollin River have a high and moderate degradation risk, respectively. The remaining fourteen geosites show a low risk of degradation because there are no activities that cause degradation and they are protected by the people of communities and local guides. Finally, this work shows the need for more research scientific, improve the security conditions, promotion of the geosites, and development of didactic material.

Keywords Geodiversity, Geopark, Geodiversity assessment, Ecuadorian amazon

QUANTITATIVE ASSESSMENT OF GEODIVERSITY IN ECUADORIAN AMAZON, NAPO PROVINCE: CASE STUDY NAPO SUMACO GEOPARK

Dayana Vera^{1,2} · Marco Simbaña^{1,2} · Oswaldo Guzmán^{1,3}

- ¹ Geociencias, Facultad de Ciencias de la Tierra y Agua, Universidad Regional Amazónica Ikiám, Tena, Ecuador
- ² Geoparque Napo Sumaco, Tena, Ecuador
- ³ Grupo de Ciencias de la Tierra y Clima, Universidad Regional Amazónica Ikiám, Muyuna, Ecuador

Introduction

Geodiversity is considered the abiotic equivalent of biodiversity (Gray 2008). It has been defined by Nieto (2001) as “the number and variety of structures (sedimentary, tectonic, geomorphological, hydrogeological and petrological) and geologic materials (rocks, minerals, fossils, and soils) that form the natural physical substrate of a region”. Gray (2004) considers geodiversity as “the natural range (diversity) of geological (rocks, minerals, fossils) geomorphological (landform, processes) and soil features. It includes their assemblages, relationships, properties, interpretations, and systems”. Serrano and Ruiz-Flaño (2007) add hydrologic and topographic elements and systems produced by natural and anthropogenic processes.

Geodiversity can be exploited from three main fields such as scientific, educational, and tourist, where Geoparks have infrastructure used for its adequate exploitation and conservation (Ruban 2017). Geoparks are geographically defined places (Brilha 2009) that are used as tools for the conservation of geologically important territories and the development of local communities in a sustainable way (Sánchez-Cortez and Simbaña-Tasiguano 2018).

Geodiversity provides a variety of benefits that allow economic development and the well-being of people (Gordon et al. 2012; Kubalíková 2020). It offers knowledge,

materials for construction, sources of inspiration for the artist, and resources for therapeutic, recreational, educational, and tourist activities (Gordon et al. 2012). Therefore, knowledge of geodiversity distribution is important to implement sustainable resources and recognize high priority conservation zones (Kaskela and Kotilainen 2017). Several methodologies have been developed to assess geodiversity using qualitative (Gordon et al. 2012; Gray et al. 2013; Hjort et al. 2015), quantitative (Ruban 2010; Manosso and de Nóbrega 2016; Dias et al. 2021), and qualitative-quantitative methods (Neches 2016; Poch et al. 2019; Zakharovskiy and Németh 2021). Quantitative methods are based on various parameters and indicators used to calculate the elements of geodiversity in the area; qualitative methods are descriptive and use expert knowledge and experience (Zwoliński et al. 2018).

Geodiversity assessments in Ecuador are few and these have focused on the Sierra and Costa regions (Carrión Mero et al. 2018; Carrión-Mero et al. 2020a, b; Herrera-Franco et al. 2020a, b; Morante-Carballo et al. 2020; Carrión-mero et al. 2021), while in the Ecuadorian Amazon, this type of analysis has not yet been developed. Therefore, the aim of this paper is to quantitatively assess the geodiversity of the sites of interest in Napo Sumaco Geopark.

For the evaluation of geodiversity in the territory of the Napo Sumaco Geopark, the methodology proposed by Brilha (2016) was applied to 16 geosites. Brilha is one of the leading international specialists in geoparks. He has extensive experience in research and education related to geoheritage worldwide and has been a member of several advisory groups on geoparks for UNESCO and other associations. This methodology has been developed through the compilation of the best published proposals and the author's experience (Brilha 2016).

This methodology allows to identify the scientific value, potential tourist use, potential educational use and degradation risk of the geosites. For this purpose, several criteria are scored from 0 to 4 and then a weighted sum of the criteria is made. Each potential is evaluated separately because the geosites must have specific characteristics. For example, a geosite with touristic potential must demonstrate its use as tourist attraction (Brilha 2016). Therefore, this study shows that the geosites of Napo Sumaco Geopark have a scientific value that varies between high, moderate, and low. Likewise, the

geosites have a potential tourist and educational use that ranges from high to moderate. And finally, two geosites present a high and moderate degradation risk.

Napo Sumaco Geopark: A Territorial Description

Napo Sumaco Geopark (NSG) is located in the Napo province, in Tena and Archidona cantons, with an area of approximately 1.780 km² and 68.000 inhabitants (Sanchez-cortez et al. 2022). There are 16 sites interest denominated geosites by Napo Sumaco Geopark (Fig. 1) and most of these geosites have Kichwa names. They are Sumaco Volcano, Guagua Sumaco Lagoon and Outlook, Hollin Waterfall, Pungarayacu Quarry, Virgen de Guacamayos Outlook, Los Guacamayos Granite and the Gringos's Stone, Ñachi Yacu River Grand Canyon, Chiuta Hill, Waysa Yacu and the Jatun Yacu River, Napo River Labyrinths, Puerto Misahualli's Bookcase, Hollin River, Churo, Karst Relief composed of 34 caves, Cotundo Petroglyphs and Shunku Rumi.

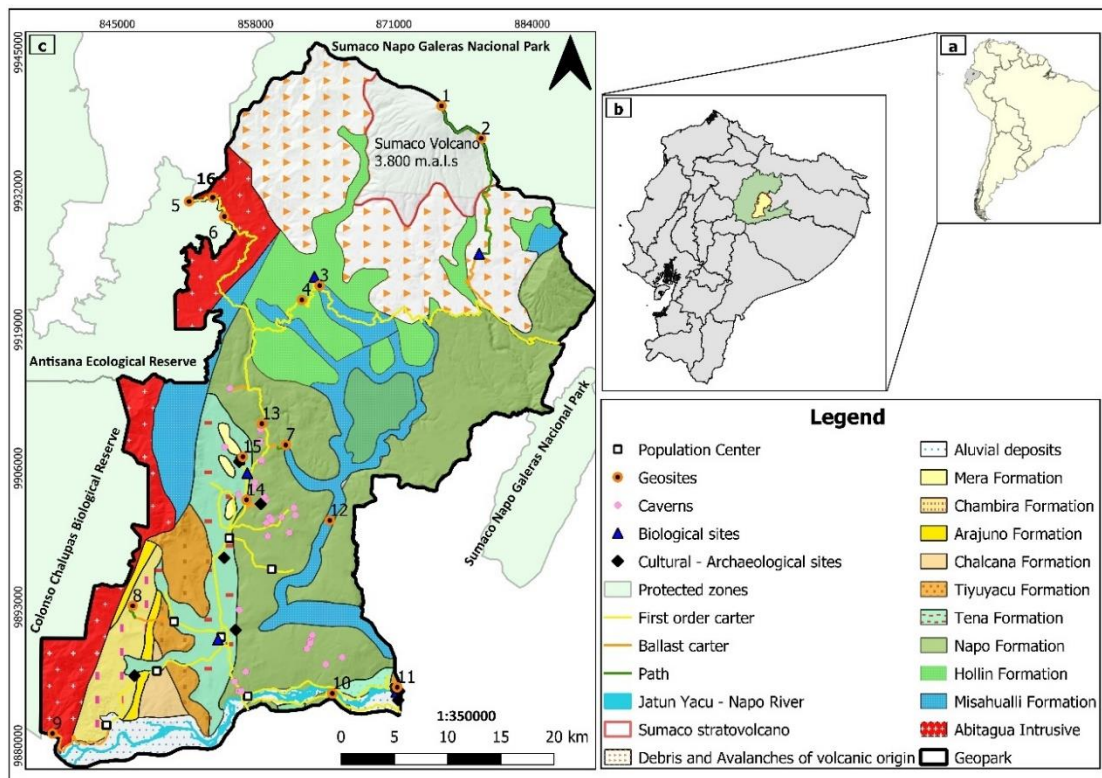


Fig. 1 a Location of Ecuador in South America. b Location of Napo Sumaco Geopark in Napo province. c Geological map with the location of geosites.

Realized by: Vera, Dayana, 2022.

From a geologic point of view, in the north of Geopark lies part of the Napo uplift, this positive structure has 70 km wide and 150 km long (Balseca et al. 1993). In the northwest, there are outcrops of Jurassic granitic intrusive and to the east, there are massifs of volcanic rocks and compacted sediments presumed to be 176 million years old and 110 to 25 million years old, respectively (Sanchez-cortez et al. 2022). There are also a variety of karst landscapes formed by the erosion of limestone of the Napo Formation (Sanchez-cortez et al. 2022). In addition, Cretaceous (Hollin, Napo, and Tena) (Rivadeneira and Almeida 2014) and Cenozoic (Tiyuyacu, Arajuno, and Chalcana) geological formations are found in this territory (Christophoul et al. 2014).

The Hollin Formation (Albian, Aptian) outcrops mainly in sectors of the Napo Uplift, has a thickness of 80 m to 240 m and it is composed of white quartz sandstones and fractures (Baldock 1982; Brookfield et al. 2009). The Napo Formation (Lower Albian to Senonian) has thicknesses between 200 m to 700 m, composed of black shales, gray to black limestones, and calcareous sandstones. The Tena Formation (Maastrichtian) has a thickness of 1000 m to less than 300 m consists of shales with sandstone intercalations and few conglomerates, also has a smaller proportion of marls and arenaceous limestones (Baldock 1982).

Likewise, the Tiyuyacu Formation (Upper Paleocene-Eocene) has a thickness of 100 m to 250 m, composed of basal conglomerates and sandstones intercalated with red, greenish, and gray shales. The Arajuno Formation (Upper Miocene) has a thickness of more than 1000 meters, composed mainly of sandstones, conglomerates intercalated with bentonite clays, and reddish clay. And the Chalcana Formation (Upper Oligocene – Middle Miocene) composed of claystones and siltstones interbedded with thin lenses of fine to medium sandstones (Baldock 1982; Christophoul et al. 2014).

Moreover, this territory is surrounded by some protected areas such as Antisana Ecological Reserve, Sumaco Napo Galeras National Park, Colonso Chalupas Biological Reserve, and Biosphere Reserve. In addition, GSN is culturally rich. It is inhabited by 68.000 people; they identify themselves as Amazonian Kichwa. These Kichwa people associate geological elements with their beliefs, myths, and legends (Valarezo 2002; Sanchez-cortez et al. 2022). For example, shamans, through their traditional knowledge and spiritual practices can access the beings that inhabit caves. Likewise, they mention

though their oral histories that the caves were a refuge for Amazonian warriors (Sanchez-cortez et al. 2022). The people of this territory also have ancestral knowledge, such as Kichwa Midwives Association of Alto Napo (AMUPAKIN) (Bernis et al. 2017b). They use diets with native foods and cultivate medicinal plants to treat illnesses and reproductive health issues (Bernis et al. 2017a).

Methods

Quantitative assessment was applied using the methodology proposed by Brilha (2016). This assessment method focuses on the evaluation of the scientific value (SV), potential educational use (PEU), potential tourist use (PTU), and degradation risk (DR). The evaluation of SV focuses on seven criteria: representativity, key locality, scientific knowledge, integrity, geological diversity, rarity and use limitations. Each criterion had indicators that were scored with 0, 1, 2, or 4 points. The evaluation of PEU and PTU is based on ten common criteria: vulnerability, accessibility, use limitations, safety, logistics, density of population, association with other values, scenery, uniqueness, and observation conditions. In addition, PTU also includes three criteria: interpretative potential, economic level, and proximity of recreational areas. And PEU also evaluates two additional criteria: didactic potential and geological diversity. On the other hand, the degradation risk is focused on five criteria: deterioration of geological elements, proximity to areas/ activities with potential to cause degradation, legal protection, accessibility, and density of population. All criteria were scored from 0 to 4 points. Finally, SV, DR, PEU, and PTU are obtained by the weighted sum of each criterion (table 1) and are classified according to table 2.

For a better application of the evaluation methodology to the socioeconomic context of the NSG, the following adaptation will be made: i) In the safety criterion for potential educational and touristic use, the following were considered: distance to emergency centers, safety facilities, and the accompaniment of guides prepared to act in case of emergency. From our perspective, these indicators are more important to preserve the safety of visitors and students because access to several geosites is through trails that do not allow the entry of vehicles and do not have mobile coverage.

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Table 1 Weights for the criteria used for assessment of Scientific Value, Potential Touristic Use, potential Educational Use, and Degradation Risk

Potential Educational Use		Potential Touristic Use		Scientific value	
Criteria	Weight (%)	Criteria	Weight (%)	Criteria	Weight (%)
Vulnerability	10	Vulnerability	10	Representativeness	30
Accessibility	10	Accessibility	10	Key Locality	20
Use limitations	5	Use limitations	5	Scientific Knowledge	5
Safety	10	Safety	10	Integrity	15
Logistics	5	Logistics	5	Geological diversity	5
Density of population	5	Density of population	5	Rarity	15
Association with other values	5	Association with other values	5	Use limitations	10
Scenery	5	Scenery	15	Degradation Risk	
Uniqueness	5	Uniqueness	10	Criteria	Weight (%)
Observation conditions	10	Observation conditions	5	Deterioration of geological elements	35
Didactic potential	20	Interpretative potential	10	Proximity to areas/activities with potential to cause degradation	20
Geological diversity	10	Economic level	5	Legal protection	20
		Proximity of recreational areas	5	Accessibility	15
				Density of population	10

Adapted from Brilha, 2016, 130.

Table 2 Classification of scientific value, potential tourist use, potential educational use and degradation risk

Total Weighted	Value, Potential use and Risk
< 200	Low
201 - 300	Moderate
301- 400	High

Adapted from Brilha, 2016, 131.

For the quantification 16 geosites were evaluated. The information used was collected by the NSG researchers' team and by us during the fieldwork, literature review (scientific articles, books, tourist packages, national surveys and school curricula) and through direct conversations with five geosite owners and local community leaders. During the fieldwork, a new site was identified, so we proceeded to obtain information from the geosite denominated Shunku Rumi. Likewise, a stratigraphic column was made in the Pungarayacu Quarry geosite. Both geosites were studied in detail in this work. This allowed to complete the available information (Pungarayacu Quarry) or to obtain for the first-time information from one of the geosites (Shunku Rumi). Additionally, it was possible to evaluate the ease of applying the methodology with previously published data and with the data obtained in the present work. Likewise, geosite karstic relief is composed of 34 inventoried caverns, distributed in the territory of NSG. In this work only two caverns were evaluated (Usayaku and Jumandy caverns), which were selected according to: i) their location, one to the north and the other to the south, ii) their length, one large and the other small. This allowed us to evaluate the effectiveness of the evaluation method in caverns with different characteristics.

This work also included the macroscopic and microscopic petrographic analysis of rock samples from the Shunku Rumi geosite carried out at the Geosciences laboratory of the Universidad Regional Amazónica Ikiam. A geological sketch was made with a drone image and the information obtained from the analysis (Fig. 2). The lithology used was modified from U.S. Geological Survey (USGS) (2006). Likewise, a sedimentological study was carried out in the field at the Pungarayacu Quarry, which allowed the elaboration of a stratigraphic column (Fig. 3). The lithology and symbology used were adapted from Nichols (2009) and Tucker (2003). In both cases, the Inkscape 1.1 software was used and the lithology codes (RGB) are available on the USGS website (<https://mrdata.usgs.gov/catalog/lithclass-color.php>).

Results

A new geosite called Shunku Rumi was studied. It corresponds to a rocky outcrop associated with the Abitagua batholith (Jurassic), the Rb-Sr dating shows an age of 162 Ma (Drobe et al. 2013). It is an outcrop approximately 200 m wide, where intrusive rocks are found. The left section consists of monzogranites intruded by dikes of diorite composition (Fig. 2). While the right section is composed of granodiorites intruded by

diorite and granodiorite dykes. It can be observed that the intrusion processes have not been homogeneous because the outcrop has been intruded by bodies of different compositions. Likewise, these rocks present minerals such as quartz, feldspars, plagioclase, biotite, calcite, epidote, and chlorite.

Pungarayacu Quarry geosite is an open-pit mining structure. For the first time, a detailed stratigraphic column 46 m thick was made and divides into three sections for ease of study. However, the sections were continuous, except between sections II and III, because the conditions of the outcrop did not allow obtaining a continuous section. Fig. 3 shows the summarized stratigraphic column and to obtain the complete column, see Appendix 1. Section I shows the contact between the Misahualli and Hollin formations, and it is composed of hydrocarbon impregnated sandstone and a siltstone layer. Section II is composed of predominantly massive sandstone and some hydrocarbon impregnated layers. Section III are sandstones intercalated with siltstones; the sandstones are impregnated with hydrocarbons. In addition, sections I and III show organic matter, carbon, and sedimentary structures such as ripples, parallel lamination, cross stratification, and flaser bedding.

On the other hand, in this work, a quantitative evaluation of the scientific value, degradation risk, potential educational use, and potential tourist use in the 16 geosites of the Napo Sumaco Geopark was carried out. Therefore, Table 3 shows the geosites name, locations and characteristics. Also, the scores for each criterion of the evaluation can be seen in Table 4 and Figure 4 shows the total values of SV, PEU, PTU and DR for each geosite.

According to Figure 4a the Sumaco Volcano and Guagua Sumaco Lagoon and Outlook geosites have a score higher than 301 points, therefore, they have a high scientific value. Likewise, the Jumandy Caverns, Shunku Rumi, Pungarayacu Quarry, Cotundo Petroglyphs, Churo, Ñachi Yacu River Grand Canyon, Chiuta Hill, Waysa Yacu, and the Jatun Yacu River and Hollin Waterfall geosites have a moderate scientific value with 201 to 300 points. And the Usayaku Caverns, Napo River Labyrinths, Puerto Misahualli's Bookcase, Hollin River, Los Guacamayos Granite and the Gringos's Stone and Virgen de Guacamayos Outlook geosites have low scientific value with scores below 200 points. In addition, Figure 4b shows that the Puerto Misahualli's Bookcase geosite has a high potential touristic use with a score of 305 points, while the other fifteen geosites have

moderate potential touristic use with scores ranging from 210 to 300 points. Likewise, Figure 4c shows that the fifteen geosites evaluated have moderate potential educational use with scores between 205 to 285 points and Pungarayacu Quarry has a high potential with 330 points. Finally, Figure 4d shows that the Pungarayacu Quarry geosite has a high degradation risk, Hollin River geosite has a moderate risk and the other fourteen geosites have a low risk of degradation.

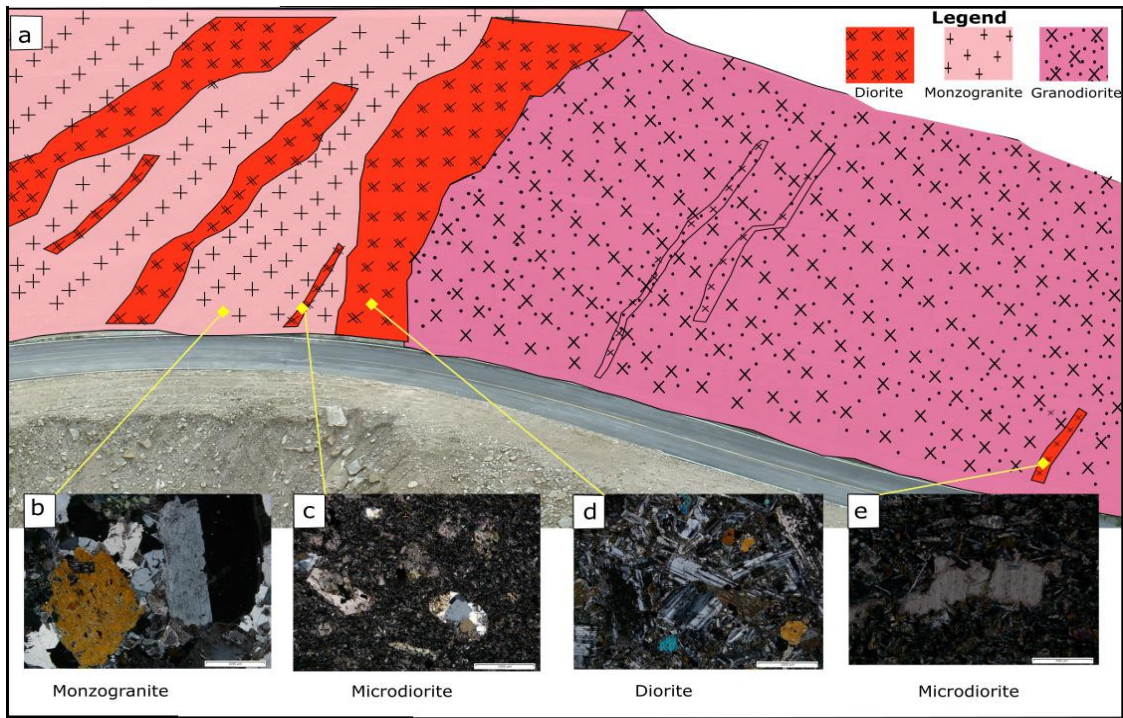


Fig. 2 a Geological sketch of Shunku Rumi geosite. b Petrographic image of monzogranitic rock. c, d, and e are petrographic images of a dike of diorite composition.

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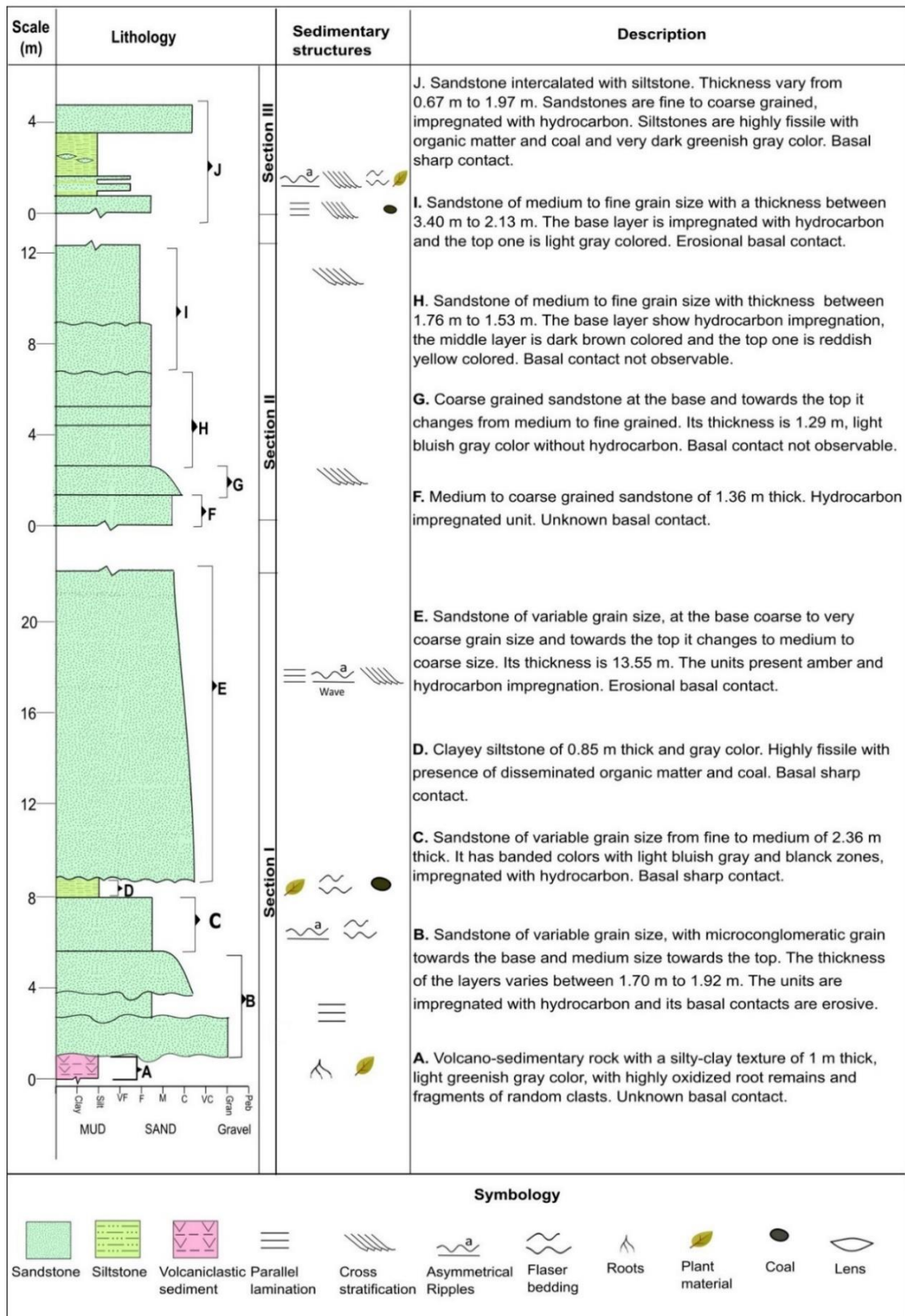


Fig. 3 Generalized stratigraphic column of Pungarayacu Quarry geosite.

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Table 3 Geological characterization of 16 geosites identified in Napo Sumaco Geopark

Code	Geosites	Coordinates	Geological features
G1	Sumaco Volcano	77° 37' W 0° 32' S	Symmetrical cone Stratovolcano, potentially active, with unique geochemical characteristics in the country. It has rocks such as phonolites, basanites, and tephrites and its lavas have phenocrysts of haüyne, leucite, augite and plagioclase (Fig. 5a).
G2	Guagua Sumaco Lagoon and Outlook	77° 35' W 0° 34' S	Crater in a volcanic cone with a lagoon, located in the middle of the Amazon jungle. It has volcano sediments from Sumaco volcano.
G3	Hollín Waterfall	77° 43' W 0° 41' S	It's an imposing waterfall of approximately 20 meters high. It shows different outcrops of geological formations, volcanic deposits and textures (Fi. 5b).
G4	Pungarayacu Quarry	77° 44' W 0° 42' S	It's an open-pit mining structure; it has different rocks, sedimentary structures, amber, and hydrocarbon (Fig. 5c).
G5	Virgen de Guacamayos Outlook	77° 50' W 0° 37' S	This Outlook allows us to observe the sub-Andean landscape of the Napo province and interpret the formation of the Cosanga river Valley.
G6	Los Guacamayos Granite and the Gringo's Stone.	77° 48' W 0° 38' S	It's an outcrop associated with the Abitagua batholith, presents a diversity of rocks and minerals and fracture families that make it an ideal site for geostructural and geomechanical analysis.
G7	Ñachi Yacu River Grand Canyon	77° 45' W 0° 49' S	The site is a canyon approximately 10 meters high formed by the chemical and physical erosion of the rock massif. Grand Canyon shows erosive processes and sedimentary structures.
G8	Chiuta Hill	77° 53' W 0° 57' S	It's a plateau of 150 m high, 250 m wide, and 450 m long. It is composed of siliciclastic sedimentary rocks (Fig. 5d)
G9	Waysa Yacu and the Jatun Yacu River	77° 57' W 1° 4' S	It's a morphology formed by the outcropping of the Abitagua batholith and the crystalline water from Colonso Chalupas Reserve. It shows mechanical weathering processes (Fig. 5e).
G10	Napo River Labyrinths	77° 43' W 1° 2' S	Lapies field covering 4 hectares, formed by chemical erosion and collapse of caverns. The site presents black limestones with fossils (Fig. 5f).
G11	Puerto Misahualli's Bookcase	77° 39' W 1° 2' S	This site has the appearance of books placed on a bookcase due to the inclined arrangement of the rocks
G12	Hollin River	77° 45' W 0° 56' S	It is a 10 km long river that originates in the Guacamayos mountain range and the Sumaco Volcano, and crosses outcrops of the Misahualli, Hollin and Napo geological formations.
G13	Churo	77° 46' W 0° 48' S	It's a rock labyrinth covering 2 hectares formed by the collapse of caverns, its outcrops between 13 to 53 m high. It also has karstic forms typical of endokarst and an abundance of ammonites
G14.1 G14.2	Usayaku Caverns Jumandy Caverns	77° 47' W 0° 46' S 77° 47' W 0° 52' S	Usayaku is a cavern with partially flooded galleries. It has stalagmites, stalactites and lava flows. Jumandy caverns have wide galleries and a permanent river. It has speleothems with abstract figure shapes such as a giant cauliflower (Fig. 5g).
G15	Cotundo Petroglyphs	77° 47' W 0° 50' S	Petroglyphs engrave on giant granitic rocks associated with the Abitagua batholith and Misahualli formation, located on a trail that ends in a doline associated with the Napo formation (Fig. 5h)
G16	Shunku Rumi	77° 49' W 0° 37' S	It's an intrusive outcrop with different rocks and minerals. It shows the intrusion of dykes and is an ideal site for structural analysis (Fig. 5i).

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Table 4 score of each criterion for the quantitative assessment of 16 geosites of Napo Sumaco Geopark.

Assessment of scientific value, degradation risk, potential educational and tourist use	Geosites*																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14.1	G14.2	G15	G16
Representativeness	4	4	2	4	1	2	4	4	4	2	1	1	4	2	4	4	4
Key location	2	1	1	1	0	1	0	0	0	0	0	0	1	0	2	0	0
Scientific knowledge	4	4	0	4	0	0	0	0	0	0	0	0	0	0	4	0	0
Integrity	4	4	4	1	4	4	2	4	4	4	4	4	4	4	4	2	4
Geological diversity (SV)	2	2	1	2	0	0	0	0	0	0	0	0	2	1	1	2	1
Rarity	4	4	4	4	4	2	4	4	4	2	4	4	2	1	1	4	4
Use limitations (SV)	2	2	2	4	2	2	2	2	2	2	4	4	2	2	2	1	2
Vulnerability	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	4	4
Accessibility	0	0	4	4	4	3	0	0	2	4	4	2	3	3	3	3	3
Use limitations (PEU and PTU)	2	2	2	4	4	2	2	2	2	2	4	4	2	2	2	2	2
Safety	3	3	2	2	3	2	2	2	3	3	4	2	3	2	2	4	2
Logistics	2	2	3	3	4	3	4	4	4	4	4	4	4	3	4	4	4
Population density	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Association with other values	2	1	1	2	4	4	3	3	2	3	1	2	3	2	4	4	2
Scenery	2	2	2	1	1	1	4	1	4	1	4	1	2	2	4	1	0
Uniqueness	3	1	1	3	1	1	2	1	3	2	1	1	2	1	1	1	3
Observation conditions	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Interpretative potential	4	3	4	3	2	2	2	3	3	2	2	2	3	3	3	3	2
Economic Level	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Proximity of recreational areas	4	4	2	3	0	0	4	4	4	3	4	4	4	3	4	4	0
Didactic potential	4	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1
Geological diversity (PEU)	4	3	3	4	1	3	3	2	2	2	2	2	4	3	3	2	4
Deterioration of geological elements	0	0	0	4	0	0	3	0	0	1	0	3	0	0	0	0	0
Proximity to areas/ activities with potential to cause degradation	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4	0	0
Legal Protection	1	1	3	2	2	1	3	3	3	3	4	4	3	3	3	1	1

***G1:** Sumaco Volcano/ **G2:** Guagua Sumaco Lagoon and Outlook/ **G3:** Hollin Waterfall/ **G4:** Pungarayacu Quarry/ **G5:** Virgen de Guacamayos Outlook / **G6:** Los Guacamayos Granite and the Gringos's Stone/ **G7:** Ñachi Yacu River Grand Canyon/ **G8:** Chiuta Hill/ **G9:** Waysa Yacu and the Jatun Yacu River/ **G10:** Napo River Labyrinths/ **G11:** Puerto Misahualli's Bookcase/ **G12:** Hollin River/ **G13:** Churo/ **G14.1:** Usayaku Caverns/ **G14.2:** Jumandy Caverns/ **G15:** Cotundo Petroglyphs/ **G16:** Shunku Rumi.

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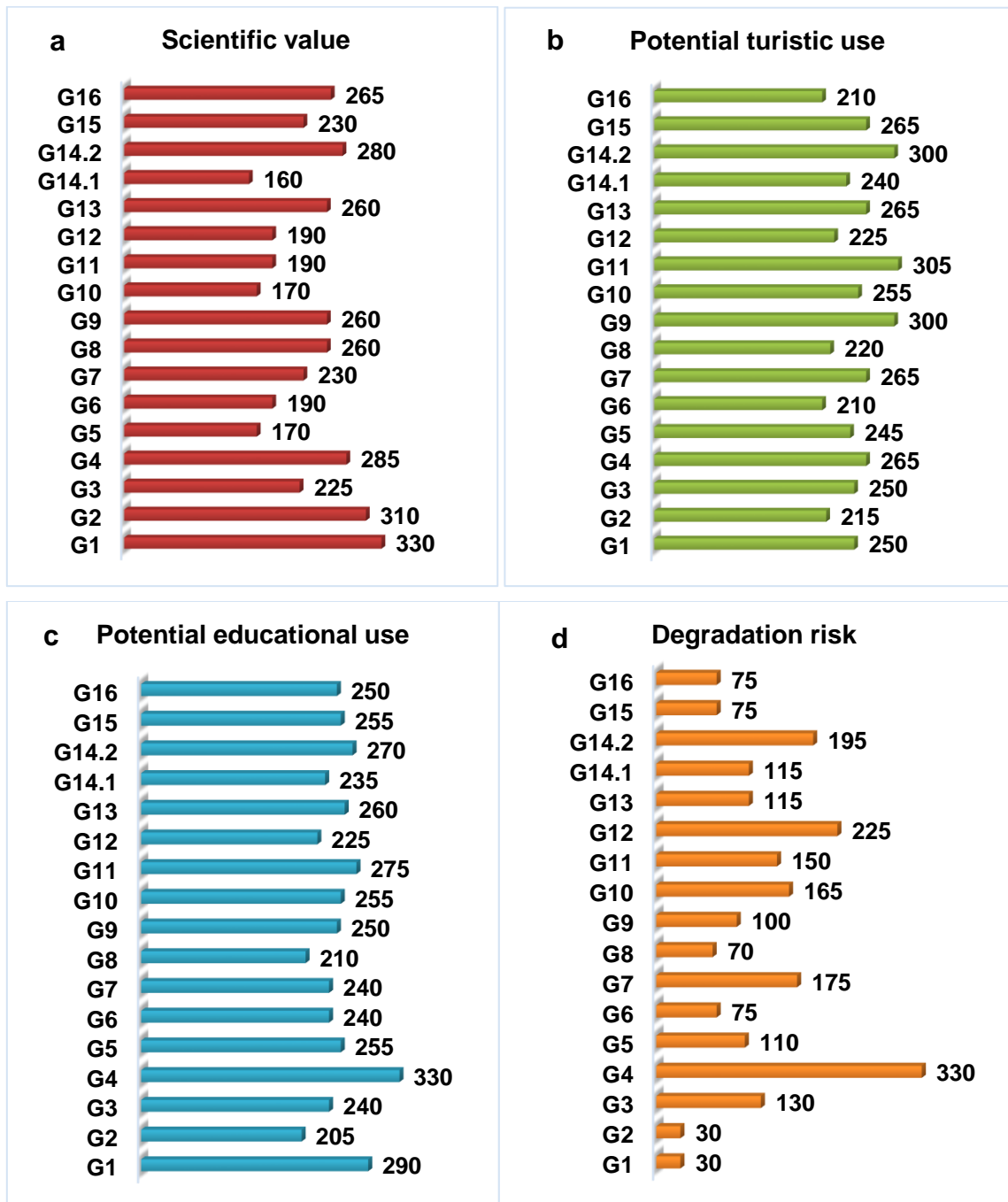


Fig. 4 Final assessment quantitative. **a** Scientific value. **b** Potential tourist use. **c** Potential educational use. **d** Degradation risk of each site of interest in Napo Sumaco Geopark.
Realized by: Vera, Dayana, 2022

Discussion

Shunku Rumi is a Kichwa name that means Shunku = Heart and Rumi = Stone. This name is due to the fact that, according to the macroscopic and microscopic observations



Fig. 5 Geosites images. **a** G1, **b** G3, **c** G4, **d** G8, **e** G9, **f** G10, **g** G14.2, **h** G15 and **i** G16.

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made on the rocks exposed in this geosite, it is proposed that these rocks were formed as in a magmatic chamber that outcrops on the surface and the local people associate it as the heart of the earth that is formed by rock. According to its characteristics, this outcrop can be used to understand magmatic processes and igneous body intrusions in a magmatic chamber. This geosite has a moderate scientific value because it has 235 points. The geosite is the only and best example of this type in the NSG and the geological elements are well preserved. However, this site is a recent slope (2020) built anthropically to solve problems on the road, therefore its final score was moderate because it is not recognized as a type locality, there are no articles in scientific journals about this site and it is located in the Biosphere Reserve and the boundary between Sumaco Napo Galeras National Park and Antisana National Park, so some permits for fieldwork and sampling must be obtained. In what concerns potential, Shunku Rumi has geological diversity (rocks, minerals, dikes and fracture families), this type of outcrops of Abitagua Batholith intruded by dykes is rare in the country. Likewise, there are restaurants and hotels within 15 km, there are no obstacles that make difficult the observation of geological elements and it is located a few meters from the paved road. However, there are no security facilities or mobile coverage, the site is not yet used as a tourist attraction and there are geological elements that are not taught at the primary and secondary education levels (Ministerio de Educación del Ecuador 2019).

Pungarayacu Quarry Geosite is a 2.6 ha open-pit mining structure that is in an active state and extracts asphalt material. Its name has a kichwa meaning Pungara= tar and Yacu= river. This quarry is inside of the Pungarayacu Field which has the largest accumulation of crude oil in the Oriente Basin with 4 billion barrels (Rivadeneira and Baby 2014). According to Rivadeneira and Almeida (2014), as well as observed in this work, this geosite shows sandstones associated with the Hollín Formation deposited on volcano sedimentary rocks of Misahualli Formation. The Hollín Formation is the main reservoir of the Oriente Basin Petroleum System, it is divided into two sections. The lower section of Hollin formation is composed of sandstones deposited in interbedded fluvial environments and the Upper section is formed by quartz sandstones with marine-littoral depositional environments (Rivadeneira and Almeida 2014). On the other hand, the quantitative assessment indicates that this geosite has a moderate scientific value. This is because despite being a site of scientific (recent research projects have started to be developed in national universities (Cadena et al. 2018)) and economic importance, it is

only used by national science and it has preservation problems. In addition, the geosite has a moderate potential tourist use because it does not have all security measures, the population density is less than 100 inhabits/km², the family income is lower than the national average, there are ecological values but no cultural value, and the geosite is occasionally used as a tourist site at the local level. In terms of potential educational use, it has a high potential with 330 points. This is because it is easily accessible, has no use limitations, there are no obstacles that make difficult the observation of geological elements, there are restaurants and hotels a 43 km away, it has a diversity of geological elements (rocks, minerals, sedimentary structures, amber) and it has geological features that can be taught at all educational levels and cannot be destroyed by students. However, it has a high risk of degradation because there is a possibility of deterioration of all geological elements because it is an active mining structure and is less than 100 m from a paved road.

In general, geosites of the Napo Sumaco Geopark are characterized by moderate scientific value. Two geosites have a high scientific value, nine geosites have a moderate value (225 to 285 points) and six geosites have a low value (160 to 190 points). Sumaco Volcano and Guagua Sumaco Lagoon and Outlook geosites have a high scientific value with scores of 330 and 310 points respectively. This result was obtained because these geosites are used by national and international science, have scientific publications (Bourdon et al. 2003; Garrison et al. 2018; Salgado et al. 2021) and their geological characteristics are uncommon in the country. While other fourteen geosites have moderate and low value because these geosites are not yet recognized as key localities and their detailed studies are just beginning (Cadena et al. 2018; Salgado et al. 2021; Sanchez-cortez et al. 2022). Scientific knowledge is also a limiting criterion because it only considers publications in scientific journals and participation in international events. However, it does not take into account monographs and theses (Tavares et al. 2020). Brilha (2016) mentions that the lack of scientific publications does not indicate that the geosites have no scientific value, perhaps they have been recently discovered (Shunku Rumi case, discovered in 2020), are located in a place with few research groups (just one university is located in the NSG place) or are not dedicated to geological studies.

The assessment also shows that one geosite has a high potential tourist use and the other fifteen have a moderate potential. Puerto Misahuallí's Bookcase geosite has a score of 305 points, this is because the geosite is located in Los Monos beach, which is

a known tourist destination in the province, it is easily accessible, has no limitations of use and it is not present obstacles that make difficult the observation and it is located few kilometers from restaurants and hotels. The remaining fifteen geosites present moderate potential use because several of them are accessible through trails, have use limitations (entrance and guide fees), are located in rural areas, which means less than 100 inhabitants/km² (Prefectura de Napo 2020) and the household income is lower than the national average (INEC 2012). Most of the geosites are located in areas without cell phone coverage, so the scoring took into consideration the fact that tourist will always be accompanied by guides trained in first aid and wilderness rescue and the nearest health center. Likewise, this work identifies that some criteria (e.g., household income and inhabitants/km²) have an impact on the final evaluation obtained by the geosites. They obtained the lowest score in these criteria (1 point) because they are located in rural areas, however, most of the geosites are recognized as tourist attractions by the Ministry of Tourism (MINTUR 2004) and have a national and local tourist demand (Prefectura de Napo 2020).

In what concerns potential educational use, one geosite has a high potential educational use (Pungarayacu Quarry) and the other fifteen geosites have a moderate potential use. Despite the fact that most of the geological elements are not vulnerable, have trained guides and are proximity to health centers, there are no obstacles that make difficult the observation, have several elements of geodiversity, and the limitations of use are surmountable except the Cotundo Petroglyph geosite, which is cultural heritage of Ecuador and does not allow obtaining samples. Fifteen geosites have a score of potential use moderate due to the fact that in Ecuador the primary and secondary education levels do not have topics related to geology in their educational curriculum, the topics that could be found are rock cycle, volcanology, and associated risk (Ministerio de Educación del Ecuador 2019). Therefore, most geosites had a low score in this criterion, its weighting is 20%. Studies indicate that in some countries geological aspects are taught in conjunction with other disciplines, for example in the natural sciences; in other cases, geology is eliminated from secondary education or is absent from university access exams (Fermeli et al. 2015). Similarly, the population density is 10.66 inhabitants/km² (Prefectura de Napo 2020) and some geosites present common geological characteristics in the country. Likewise, in the case of Pungarayacu Quarry, it has a high potential educational use, quarries allow to learn about the history of the earth, they show outcrops that are not possible to observe in other places, they allow us to directly observe

rocks, sedimentary structures, fossils and exploitation methods (Gajek et al. 2019). Therefore, the use of geosite with educational potential is important because students can observe and experiment with materials not found in the classroom (Berrocal-Casero et al. 2018).

An important factor that should be considered for both tourists and students is safety, it is recommended to improve the signage of the trails, install safety measures or barriers to protect people from falling (Huber and Iakovleva 2021). It was also identified that geosites are mostly used as tourist destinations at the local level. Therefore, better promotion of these sites should be carried out. Similarly, it is recommended to develop and promote outdoor events or tours where a historical recreation or culture of the geosites is also performed, this could attract local and national population (Huber and Iakovleva 2021). Regarding the educational potential also realize didactic material such as pamphlets, guide books and path cards, implement didactic trails for students and develop interpretation points or museums, where unusual geological elements are exhibited and can be used for teaching and demonstration (Gajek et al. 2019; Huber and Iakovleva 2021). In the case of NSG, it started with the divulgation of topics related to earth sciences and the environment to primary and secondary school students in the Napo province, using attractive didactic material such as infant games and multimedia elements (Simbaña Tasiguano et al. 2020). Likewise, together with different institutions, local guides have been trained in the exploration and characterization of caves (Sanchez-cortez et al. 2022).

On other hand, the results of the degradation risk assessment show that the Pungarayacu Quarry geosite has a high risk because it is an operation mining structure. However, it has moderate scientific value, potential tourist use, and potential educational use; therefore, conservation and management measures should be implemented, since continued exploitation could destroy all the geological elements of interest. The Hollin River geosite also shows a moderate risk of degradation due to the presence of mining in sectors of this site. The other fourteen geosites show a low risk, in the case of the Jumandy Caverns, it has 195 points due to the presence of livestock farming in the area. And Ñachi Yacu River Grand Canyon geosite has 175 points because vandalism was observed on the rock wall of the site. In general, the geosites are a low risk of degradation because there are in protected areas and each site is always visited with guides, who inform visitors of the measures they should take to avoid damaging the geosites.

Finally, in this study, it was found that Brilha's methodology should be adapted to the context of each geopark because several criteria cannot always be applied due to the location of geosites (rural areas) or that they have not yet been studied in detail and this influences the final scoring of the geosite potential. Additionally, it was identified that in sites that have not yet studied in detail (in the case of the NSG geosites) it is easier to apply the evaluation when the researcher obtained the information for each geosite compared to using information previously obtained by other researchers.

Conclusion

Quantitative assessment shows in general that Napo Sumaco Geopark geosites have moderate scientific value, potential educational use and potential tourist use. The geosites Sumaco Volcano and Guagua Sumaco lagoon and Outlook have a high scientific value and have a low degradation risk. Puerto Misahualli's Bookcase geosite has a high potential educational use and a low risk of degradation. In the case of potential educational use, the Pungarayacu Quarry has a high potential, however, it has a high risk of degradation because it is an active mining structure. In addition, the Hollin River geosite has a moderate risk of degradation because there is mining in this site. The other geosites show a low risk of degradation because they are cared for and protected for the people of the communities and local guides. In addition, this work shows the need for more research studies in the geosites because there are few sites with scientific publications. Similarly, it is necessary to improve the security conditions, promotion of the geosites, and development of didactic material. This work also shows that Brilha methodology needs to be adapted to the context of geoparks because some criteria are not applicable or the scores reached are not representative.

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Appendix 1

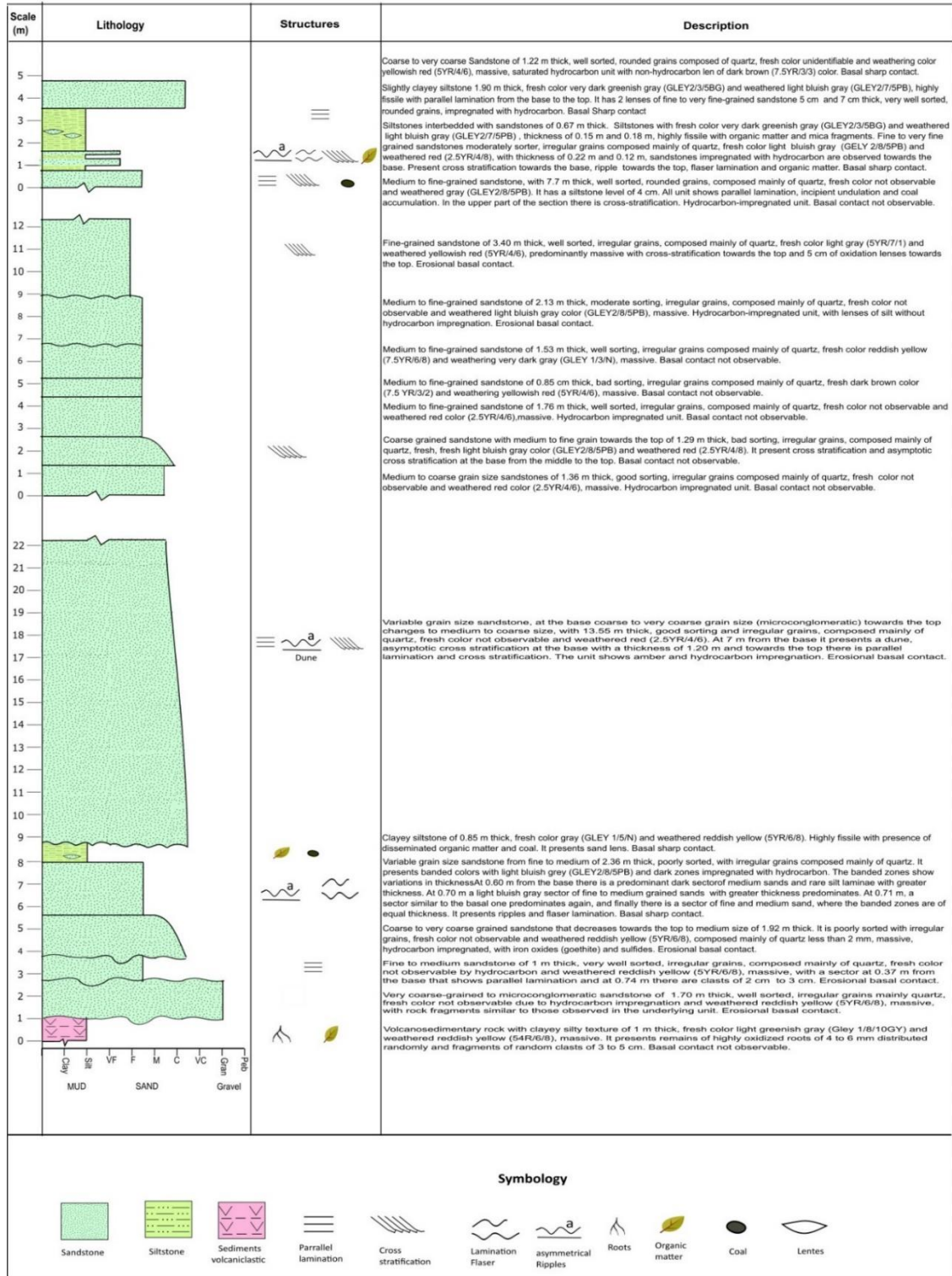


Fig. 6 Detailed stratigraphic column of Pungarayacu Quarry geosite. **Realized by:** Vera, Dayana, 2022.