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Article

Innovative Approaches to Geoscientific Outreach in the Napo Sumaco Aspiring UNESCO Global Geopark, Ecuadorian Amazon Region

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Abstract: The Napo Sumaco Aspiring UNESCO Global Geopark (NSAUGG) in Ecuador represents a genuine variety of geological, cultural, and natural heritage, which aims to promote sustainable development through geotourism. This study describes the significance of NSAUGG, emphasizing its geological diversity which includes a variety of geosites, and focusing on three recently annexed geosites: the Wawa Sumaco Quarry, Puka Urku, and the Pucuno River, where geological analyses, including petrographic and mineralogical assessments, were conducted. To enhance community engagement and educational outreach, a multi-platform mobile application, "SumAppGeo", was developed using ArcGIS and Flutterflow. This application serves as an interactive tool for visitors and local communities, providing detailed geological information, interactive maps, and educational content. The findings reveal the presence of significant geological features, such as haüyne-bearing alkaline rocks, which indicate specific volcanic activity in this region and are an element of geodiversity, validating the Wawa Sumaco Quarry, Puka Urku, and the Pucuno River as geosites. The implementation of SumAppGeo aims to foster a deeper understanding of the region's geodiversity while promoting responsible tourism practices. This initiative not only supports the recognition of NSAUGG as part of the UNESCO Global Geoparks Network but also contributes to the socio-economic development of local communities through sustainable tourism practices.

Keywords: geoparks; geodiversity; geomatics; GIS; geological heritage; geotourism; guides

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1. Introduction

A UNESCO Global Geopark is a geographically defined area with well-delineated boundaries that contain geological sites of international significance. These sites are used to develop research, education, and tourism with the objective of implementing sustainable development and conservation by local communities [1]. The establishment of a geopark is intended to encompass world-class geological heritage while also exploring, developing, and highlighting the relationships between geological heritage and various aspects of a region's natural and cultural heritage [2]. The ABC concept—which encompasses the relationships between abiotic, biotic, and cultural components within geopark heritage—provides a framework that facilitates a holistic understanding of the area [3].

Moreover, areas of geological interest and significance have been identified and designated as geosites, encompassing a range of geological, geomorphological, and paleontological features [4]. These include minerals, rocks, soils, fossils, and landforms which constitute valuable natural resources deserving conservation and proper management as part of the geological heritage [5] of a territory. Geological heritage represents a significant component of both natural and cultural heritage, offering society a wide array of essential services that are crucial for its socioeconomic advancement [6].

The economic development of rural areas rich in geological resources is significantly influenced by the integration of geotourism and geoparks [7]. Geotourism, characterized by its emphasis on landscape and geological features and dedication to environmental innovation, thrives in regions that possess significant geological heritage [8]. This development depends upon geological heritage, science transfer, and educational initiatives as essential instruments for integrating local communities into geopark initiatives [9].

Geodiversity, defined as the natural diversity encompassing geological elements such as rocks, minerals, and fossils, as well as geomorphological features such as landforms, topography, and physical processes, also includes soil and hydrological features and their assemblages, structures, systems, and contributions to landscapes [10,11]. Geodiversity is regarded as the foundational framework of Earth, evolving gradually since its emergence, and is a fundamental component of the planet's ecosystem, sustaining life on the planet [12]. The analysis and utilization of geodiversity aims to foster sustainable development in geotourism by enhancing territories for potential tourists, thereby increasing destinations and promoting the territory [9].

Geoparks represent an innovative approach to the protection of natural and geological heritage, serving as network sites for the dissemination and popularization of Earth knowledge. They facilitate the transfer of geo-knowledge from professional to public audiences through geotourism, while additionally fostering the appreciation and understanding of cultural heritage by integrating knowledge derived from natural, human, and social sciences within the context of geological heritage [13].

The pursuit of sustainable territorial development necessitates concentrated efforts on three principal fronts: the advancement of education, the intensification of pertinent applied research, and the dissemination of new knowledge. This strategy fosters opportunities by cultivating a sense of belonging and identification with the potential of a territory, encompassing its diverse heritages, including geological, natural, historical, cultural, and intercultural elements [14]. In this context, multidisciplinary scientific research on geological heritage and geodiversity has been conducted. Geodiversity research has focused on assessing the Earth's scientific diversity and exploring the connections among biodiversity, ecological factors, and human activities. Additionally, geological heritage evaluation has emphasized the geological characteristics of an area, placing geosites within their broader spatio-temporal contexts. This approach is designed to highlight the scientific significance of these geosites, enhance their geological heritage value, and establish a foundation for effective geosite management and geoconservation [15] for geotourism development.

Geoparks play a focal role in sustainable tourism development through geotourism activities. These activities stimulate the local economy and community, which is crucial for the long-term viability of the geopark. Emphasizing all elements within the geopark is essential for development, as it significantly impacts the preservation of geological heritage and cultural values. The integration of new technology applications, such as social media, smartphone apps, augmented reality (AR), and virtual tours, serves as an additional tool for promoting the multifaceted role of a geopark. The aforementioned technologies serve to illustrate the multifunctional role of the geopark and provide information (images, videos, and texts) about points of interest [2].

The abiotic, biotic, and cultural interconnections (ABC concept) represent a promising interpretive approach for the popularization of Earth heritage through geotourism [3]. Under this consideration, and considering the integration of geodiversity and geological heritage with cultural and natural heritage, among others, that exists in the Ecuadorian Amazon, the Napo Sumaco Aspiring UNESCO Global Geopark (NSAUGG) territory is highlighted. This geopark has been working and building for just over nine years, with sustained collaboration among multiple territorial stakeholders such as communities, local decision-makers, and members of academia [16].

However, nowadays, one of the problems that is faced by society is the limited understanding of the geological environment [17]. Many people, especially teenagers, are even unaware of the existence of this discipline as a professional career. Also, in the last decade, enrolment in geology courses has seen a decline [18]. All of this contributes to the fact that tourism, potentially related to geology, is frequently underestimated or ignored. Furthermore, the information available on geological topics is often scattered, disorganized or, in many cases, incomplete. This limits its usefulness to both tour guides and visitors interested in better understanding the geological heritage of specific areas such as geoparks.

In this context, it is essential to develop tools that allow the systematization and complementation of existing information by integrating new data obtained in the field. These tools must be presented in an accessible, attractive, and understandable way, facilitating their use by tour guides, visitors, and the local community. Likewise, to foster a greater understanding and appreciation of geology and geodiversity, it is essential that these tools are freely accessible, intuitive, and designed to capture the interest of people without prior training in geology. This will allow even non-specialized users to understand geological concepts, delivered in a clear, fast, and entertaining way, thus promoting greater interest in this discipline and its relevance in sustainable tourism.

For this reason, a teaching–learning process has been proposed, through the implementation of geoeducation to promote the sustainable development of geotourism. This process requires a multidisciplinary investigative approach into the geodiversity of the NSAUGG geosites, followed by the dissemination of the acquired geological knowledge through various physical and virtual means. The knowledge transfer is intended to reach a broad demographic within the territory, including children, adolescents, and adults [17,18].

The promotion of geological research and the dissemination of knowledge about the NSAUGG territory are key actions for the sustainable development of geotourism and the conservation of geological heritage. In this way, this study presents geological research on the three geosites recently added to the official list of geoparks, with the aim of advancing scientific knowledge and for the promotion of geotourism. The creation of a multi-platform application is proposed using software such as Flutterflow, ArcGIS Experience Builder, and ArcGIS Online. This application, which compiles pre-existing information about geological sites within NSAUGG and integrates new geological data obtained through this research, will provide interactive maps, detailed geosite descriptions, routes, and recommendations for tour guides, visitors, and the local community.

2. Geological and Socioeconomic Setting

Ecuador lies at the convergence of active tectonic plates, including the Nazca Plate, the Pacific Plate, and the South American Plate. The subduction of the Nazca Plate beneath the South American Plate has created a complex tectonic setting, resulting in notable seismic and volcanic activity [19,20]. This tectonic activity has divided Ecuador into distinct geological zones, with NSAUGG located in the retro-arc foreland basin known as the Oriente Basin [21,22]. This region is also characterized by the Napo Uplift, an elongated dome (antiformal culmination) formed by juxtapositions of imbricated thrust slices, strike-slip faults, and flexures related to a deep megathrust system exhibiting weak shortening and vertical displacement, where the Cretaceous and Tertiary sediments of the Oriente Basin appear [23,24].

The sub-Andean zone is characterized by mountain ranges. Formed by the geological active belt, these ranges represent the transition between the Andes Mountains and the Amazonian plain. The elevations and depressions in this setting result from the interaction between the Nazca and South American tectonic plates [25].

This geological context has given rise to various formations. such as the Pumbuiza formation, a black-and-grey shale formation formed in a marine environment; the Macuma formation, characterized by limestone and dolostone intercalated with black-greenish shale and sandstone; the Santiago formation, constituting organic marine sediments and volcano sediments: the Sacha formation, a continental environment formation composed of siltstone and claystone with some presence of limestone and dolostone; the Chapiza formation and the Misahuallí formation, which are known for sediments and volcanic sediment accumulations [26]; the Hollín formation, characterized by sandstone and shale of fluvial and deltaic origin; and the Napo formation, known for marine limestone and shale deposits.

The Amazon basin is characterized by the influence of erosion and the deposition of extensive Quaternary and Tertiary sediments, transported and deposited by the rivers draining the Andes [27]. The interaction between the tectonic processes of the sub-Andean region and the sedimentary processes of the basin has resulted in a dynamic and constantly evolving landscape.

Additionally, NSAUUG encompasses considerable geological diversity [28–30] and is associated with volcanic and sedimentary rocks from the Misahuallí formation, among other specific geological formations of the Oriente Basin. The elements of geodiversity within NSAUGG can be grouped into several categories: (a) volcanic rocks associated with the geodynamic setting (intraplate subduction) that have contributed to the formation of the Andes Mountains, (b) detrital sedimentary rocks related to deposits of ancient river and lake beds, and (c) specific geomorphological–geological formations such as caves, canyons, and rock formations that have evolved into karst reliefs through chemical dissolution processes, creating magnificent landscapes.

This diverse geological setting not only underpins NSAUGG's rich geodiversity, but also offers an array of geological features that are crucial for scientific research, education, and sustainable geotourism. By understanding and leveraging these geological characteristics, NSAUGG can effectively promote the conservation of geological heritage and foster socioeconomic development through geotourism. This approach aligns with the broader goals of UNESCO Global Geoparks of integrating geological heritage with cultural and natural heritage, thereby contributing to sustainable development and community engagement.

2.1. Geosites of NSAUGG

The NSAUGG territory encompasses approximately 1780 square kilometers and is situated in the sub-Andean region of Ecuador within the upper Amazon basin of South America. It boasts a geological history of approximately 170 million years [17]. The selection and study of the geological geosites (G) within NSAUGG are based on a holistic and strategic analysis of the territory, conducted collaboratively by its inhabitants and users of geodiverse spaces [16,17]. This analysis involves members of the communities, including both mestizo and native peoples, as well as geoeducators and students engaged in geological research and the development of the geopark territory in the Ecuadorian Amazon [18].

In 2019, 15 geological geosites were submitted for the acceptance process of NSAUGG as a UNESCO Global Geopark. Subsequently, through a geodiversity analysis process, the incorporation of an additional geosite was proposed [17]. In the present study, geological information from three more geosites, G17, G18, and G19, has been collected and analyzed, bringing the total number of geological geosites within the geopark (Figure 1) to 19. This comprehensive approach to geosite selection and analysis not only underscores the region's rich geodiversity but also highlights the collaborative efforts of local communities and researchers in promoting sustainable development and educational opportunities through the NSAUGG initiative.

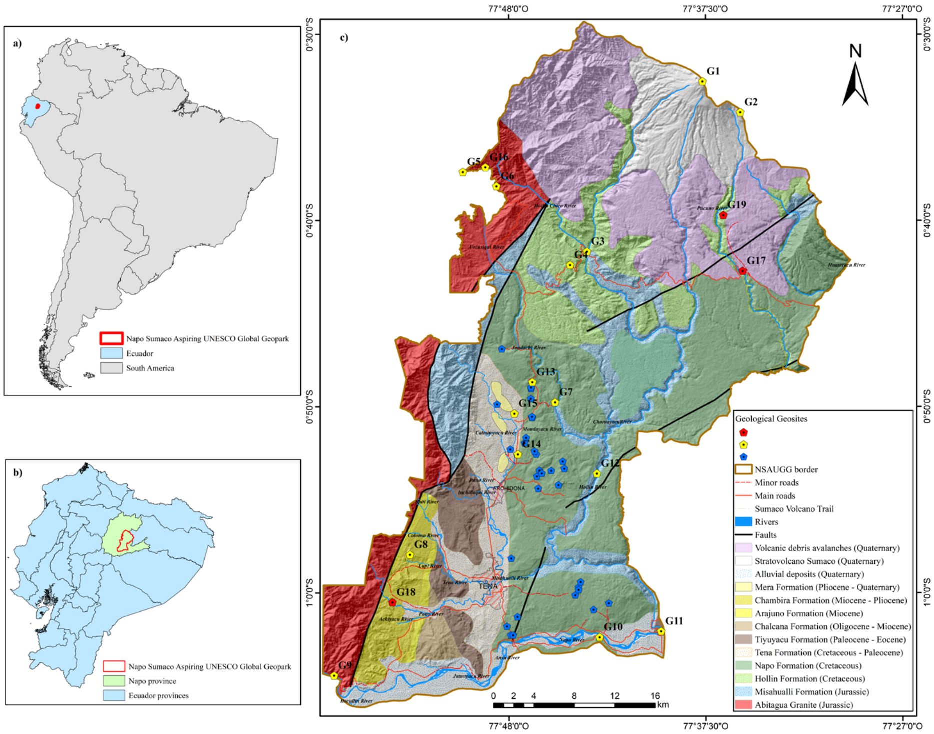


Figure 1. Location map of Napo Sumaco Aspiring UNESCO Global Geopark area.

The geosites can be classified at a macro level according to the type of rock, which is predominantly igneous and sedimentary, as shown in Table 1.

Table 1. NSAUGG's geological geosites, modified from [30].

Code	Geosite	Rock Type	Geological Formation	Ages	Location
G1	Sumaco Volcano	Igneous	Sumaco volcanic deposits	Pleistocene	77°37′ W 0°32′ S
G2	Guagua Sumaco Lagoon and Outlook	Igneous	Sumaco volcanic deposits	Pleistocene	77°35′ W 0°34′ S
G3	Hollín Waterfall	Igneous	Misahuallí	Jurassic	77°43′ W 0°41′ S
G4	Pungarayacu Quarry	Sedimentary Igneous	Hollín	Cretaceous	77°44′ W 0°42′ S
G5	Virgen de Guacamayos Outlook	Igneous	Superficial deposits	Jurassic	77°50′ W 0°37′ S

Table 1. *Cont.*

Code	Geosite	Rock Type	Geological Formation	Ages	Location
G6	Los Guacamayos Granite and the Gringo's Stone	Igneous	Abitagua granite	Jurassic	77°48′ W 0°38′ S
G7	Ñachi Yacu River Grand Canyon	Sedimentary	Hollín-Napo	Cretaceous	77°45′ W 0°49′ S
G8	Chiuta Hill	Sedimentary	Tiyuyacu	Paleocene–Eocene	77°53′ W 0°57′ S
G9	Waysa Yacu and the Jatun Yacu River	Igneous	Abitagua granite	Jurassic	77°57′ W 1°4′ S
G10	Napo River Labyrinths	Sedimentary	Napo	Cretaceous	77°43′ W 1°2′ S
G11	Puerto Misahuallí's Bookcase	Sedimentary	Alluvial deposits	Eocene	77°39′ W 1°2′ S
G12	Hollín River	Sedimentary Igneous	Hollín-Napo	Cretaceous	77°45′ W 0°56′ S
G13	Churo	Sedimentary	Napo	Cretaceous	77°46′ W 0°48′ S
G14	Karst Relief (34 caverns)	Sedimentary	Napo	Cretaceous	77°47′ W 0°52′ S
G15	Cotundo Petroglyphs	Igneous	Superficial deposits	Holocene	77°47′ W 0°50′ S
G16	Shunku Rumi	Igneous	Abitagua Granite	Jurassic	77°49′ W 0°37′ S
G17	Wawa Sumaco Quarry	Igneous	Sumaco Volcanic Deposits	Pleistocene	77°35′ W 0°42′ S
G18	Puka Urku	Sedimentary	Tiyuyacu	Paleocene–Eocene	77°54′ W 1°00′ S
G19	Pucuno River	Sedimentary Igneous	Sumaco volcanic deposits Hollín Abitagua Granite	Cenozoic	77°36′ W 0°39′ S

2.2. Socioeconomic Background

The NSAUGG territory is situated within the cantons of Tena and Archidona in the province of Napo, Ecuador. It encompasses 13% of the total provincial area, with most of this area dedicated to productive activities. According to the 2022 Ecuador census, the population of the geopark is 95,107 inhabitants, with 60% residing in rural areas, 51% being women, and 76% identifying as part of an indigenous group [31]. The geopark is home to approximately 70 rural communities, most of which have Amazonian Kichwa ancestry [17].

The economy of the NSAUGG region is dominated by primary extractive activities, which are primarily concentrated in rural areas. These activities include agriculture, livestock, fishing, forestry, and artisanal mining. In urban areas, the economically active population is mainly engaged in services and commerce [32,33]. The cantons of Tena and Archidona are considered potential tourist destinations due to their natural and cultural diversity, with archaeological sites and natural landscapes serving as main attractions [34]. In this context, a provincial tourism development plan has been developed and implemented, highlighting the NSAUGG geosites to promote geotourism in the Amazon. This plan aligns with other forms of tourism to ensure the conservation of the natural and productive resources of the territory [35].

3. Materials and Methods

To conduct this study, an integrated methodology was developed, encompassing four stages: (1) Data collection, which included an analysis of previous knowledge and the planning that was carried out at the start of the geopark's creation. This information was used to identify new places and will also be uploaded to the app developed during this research. (2) Fieldwork, during which samples were taken for petrographic and XRD analysis to identify the types of rocks and minerals present in the geosites, some of which have applications in skincare. (3) Laboratory work, utilizing equipment available in Yachay Experimental Technology Research University (YETRU) laboratories, chosen for their accessibility and suitability for this research; and, finally, (4) the office work phase, involving data analysis, interpretation, and the development of a mobile application. This methodology is illustrated in Figure 2 and represents the most appropriate approach based on the study's objectives: performing a geological analysis of the proposed geosites and creating an app that serves both the community and park guides, while considering the resources provided by the university.

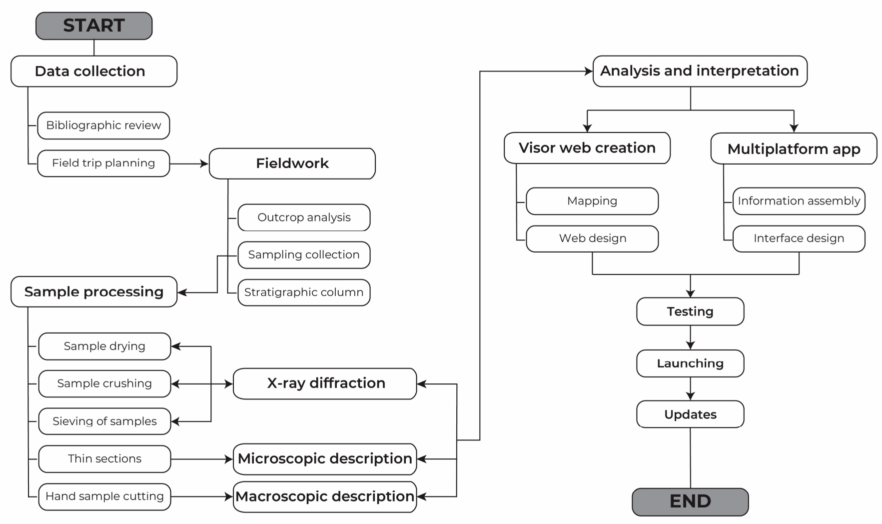


Figure 2. Workflow diagram for the implementation of this study.

3.1. Data Collection

The sample and data collection procedure involved a thorough bibliographic review, including articles, journals, books, maps, and reference works related to the study area. This encompassed general, geological, structural, mining, and tourist information, with key sources including technical reports from oil companies

3.2. Fieldwork

Fieldwork entailed planning field trips to essential geological geosites and related areas within NSAUGG, along with detailed geological surveys in the three newly listed geosites of the geopark, identified as G17, G18, and G19. These investigations aimed to address the existing information gaps, providing scientific data to support geoeducation and the educational and touristic dissemination of geological knowledge about these geosites. Data collection included sampling various lithologies for petrographic and XRD analysis, with ten representative samples obtained from each geosite; the number of samples taken from every site was established according to the surface of each zone. Seven of these samples were used to obtain thin sections and hand-sample cubes, and five of them were used for XRD mineralogical analysis to assess mineral percentages and mineral origin. Additionally, a sedimentological and stratigraphic study was conducted on three outcrops: Geosite G17, Geosite G18, and Geosite G19, located in the northwest and southeast of NSAUGG.

3.3. Laboratory Work

The methods and the equipment used in this research were selected primarily based on the facilities present at YETRU. The "Thin Sections, Magnetic Separator, and Heavy Minerals" laboratory and the "Materials Characterization" laboratory were employed for the processing of samples and subsequent petrographic and mineralogical analysis.

3.3.1. Thin Section Elaboration

The petrographic analysis involved the elaboration and analysis of thin sections; for this elaboration, a thin section preparation kit, of the brand SystemAbele and consisting of a precision rock-cutting machine and a Universal Grinding Machine, was used. This helped to identify the minerals present in the samples and then the rock.

3.3.2. XRD Analysis

For the XRD analysis, samples were crushed using an agate mortar and sieved to obtain five finely homogenized powder samples which were placed in a standard sample holder. The "Rigaku Miniflex X-ray" diffractometer was used to scan the samples, with a Cu (K-Alpha) radiation source, a tube voltage of 40 kV, and a tube current of 15 mA. Data acquisition was performed using a Theta/2Theta scanning axis with a step width of 0.005° and a scanning range of 10–100° at 2Theta. The scanning speed was set at 10°/min, and a D/tex detector Ultra2 was used in 1D scanning mode. X-ray diffraction patterns were obtained for mineral identification using the HighScore Plus 3.0 software. This equipment allows the identification of the percentages of minerals present in the samples. Identifying clay minerals is particularly important, as the mud is used by tourists and members of the community for skincare treatments.

3.4. Development of Data and Analytical Methods

3.4.1. Petrographic Analysis

The petrographic analysis involved the elaboration of thin sections to identify the mineral composition of a rock, observing structural features and interpreting environmental conditions during rock formation. Thin sections, with a thickness of 30 microns and mounted on a glass slide, were analyzed using a polarizing light microscope. A trinocular model iScope DC20000 with polarizing light was used to carry out the thin section analysis, identifying mineral composition and other important structures.

3.4.2. Multi-Platform App

The methodology for creating a multi-platform application integrating ArcGIS and Flutterflow tools begins with defining the project's requirements and objectives for the Napo Sumaco Geopark application. ArcGIS tools are utilized for website development due to their preferred interface and comprehensive functionality, supported by technical assistance for problem resolution [36]. Flutterflow was chosen for mobile app development, as it offers rapid and efficient application creation through its low-code development approach [37].

The process involved detailed project planning and timeline establishment. User interface prototyping was conducted using Flutterflow, ensuring a seamless integration with ArcGIS while prioritizing user experience. Concurrently, project configuration in Flutterflow and integration with ArcGIS were executed, enabling cohesive interaction between application logic and geospatial mapping components. For the web map creation, ArcGIS Online Map Viewer and ArcMap were employed. Geospatial data from NSAUGG, including base maps, layers, tables, images, and descriptions, were processed with ArcMap and uploaded to Map Viewer. The web application was developed using Experience Builder, encompassing design outline, visual elements, and interactive features.

For the mobile application, Flutterflow was utilized for its offline mode development capabilities. The base interface was designed using a visual editor, with low code implementation for layers and widgets. Geospatial data from Map Viewer were integrated with URL links as individual layers. The application's functionality, including navigation, data editing, and notifications, was configured, followed by continuous testing and bug fixing. The mobile application was compiled into an APK (Android Package) file for distribution exclusively on the Android operating system, with the beta version accessible only to geopark staff. Additionally, a QR code was created to promote the application, offering clear instructions to facilitate the process of download and installation for end users.

4. Results

A comprehensive analysis of the samples collected at the three geological geosites was carried out. This process included the collection of geological data and petrographic, mineralogical, structural, and sedimentary analysis. In addition, the mobile application developed with the ArcGIS software tools was evaluated in the field.

4.1. Geodiversity Knowledge

4.1.1. Wawa Sumaco Quarry Geosite (G17)

Wawa (from Kichwa into English Son) Sumaco Quarry Geosite is located 18.40 km away from the Sumaco Volcano Geosite (G1), and ~18 km from the Pungarayacu Quarry Geosite (G4) to the east. G17 is an outcrop with a semi-vertical slope excavated in the form of berms and banks (anthropogenic origin), 150 m wide and 30 m high. Its geological materials are used for pavement material in Napo Prefecture.

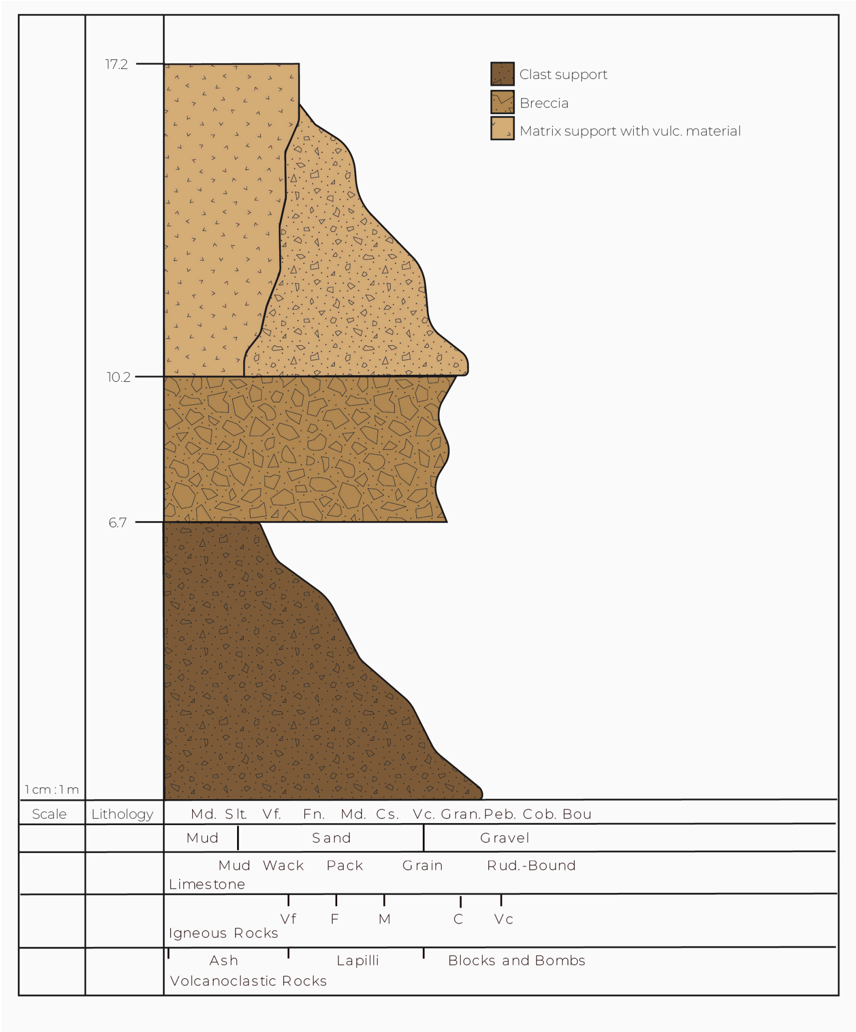
G17 is composed of two debris flow events associated with G1's volcanic activity, with three layers clearly capped. Haüyne is found in this zone; the presence of this feldspathoid is noted with younger rocks from the recent Sumaco Volcano eruption [38] (Figure 3). The deposit exhibits a heterogeneous composition, ranging from a fine-grained matrix to volcanic rocks of various sizes, ranging from centimeters to an average of one meter. The clasts are angular and show fractures indicating prior deformation or fracturing before their deposition.

(**a**) (**b**)

Figure 3. *Cont.*

(**c**)

(**d**)

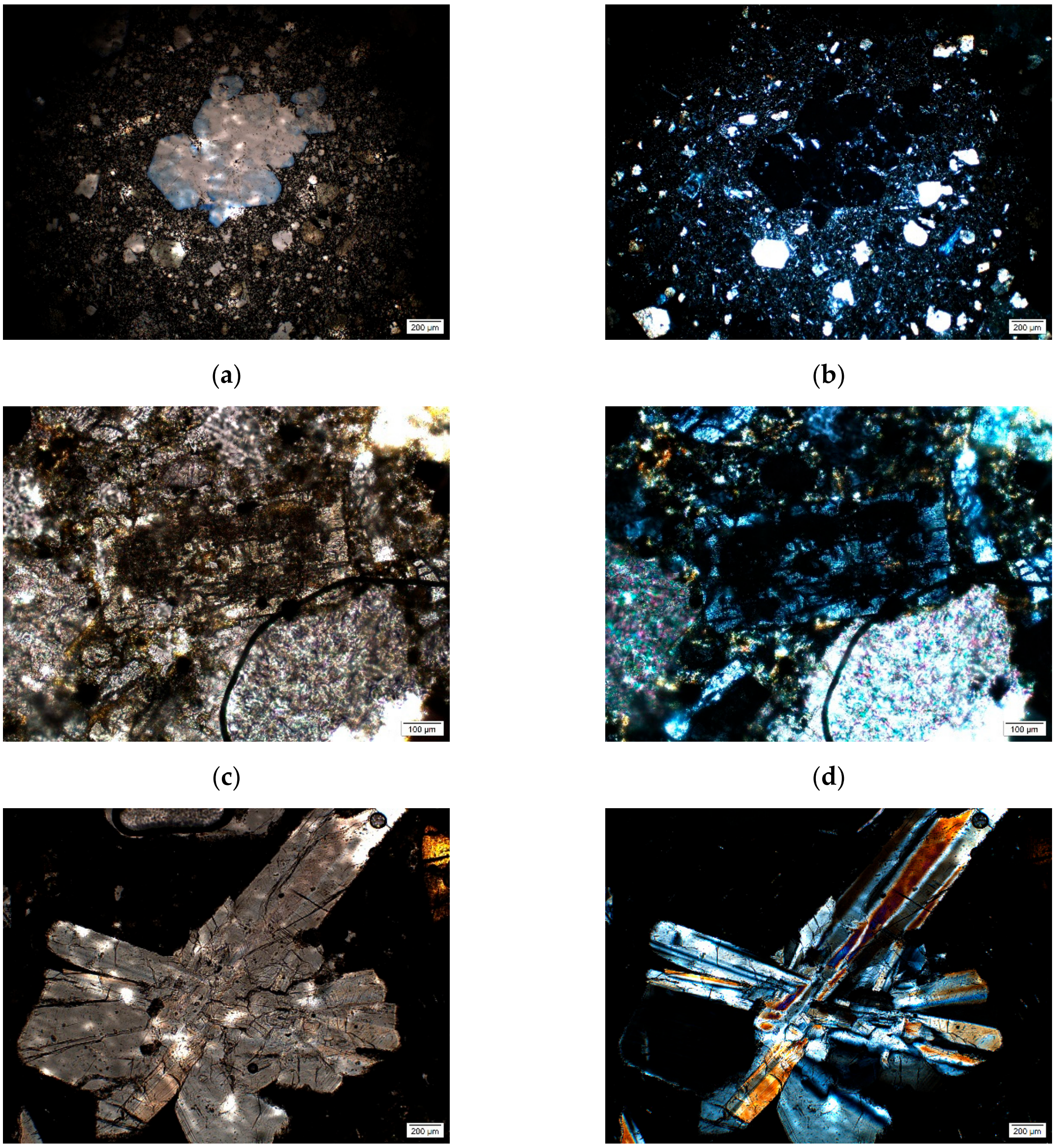


(**e**)

Figure 3. (**a**) Upper outcrop; (**b**) felsic rock; (**c**) debris flow (lahar) matrix supported with mafic rocks; (**d**) volcanic rock with pores; and (**e**) stratigraphic column of Wawa Sumaco Quarry.

Three samples were analyzed to develop the petrographic analysis. WS01 sample (Figure 4a,b) is classified as a phonolithic tephrite, characterized by phenocrysts of haüyne, plagioclase, pyroxenes, and opaque minerals, with haüyne crystals being euhedral to subhedral and present in significant proportions within a vesicular structure. WS02 sample

(Figure 4c,d) presents a weathered breccia consisting of potassium feldspars, plagioclases, amphiboles, opaque minerals, and sericite, with plagioclase crystals showing evidence of kaolinization, indicating association with older events of the Sumaco Volcano. WS03 sample (Figure 4e,f) is a light-gray tephrite with a vesicular porphyritic texture, and contains euhedral and subhedral crystals of plagioclase and amphiboles, with the presence of haüyne crystals suggesting a more recent volcanic event from the Sumaco Volcano.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 4. (**a**) Sample WS01, under plane-polarized light (PPL), showing inequigranular texture with haüyne presence; (**b**) sample WS01, under cross-polarized light (XPL); (**c**) sample WS02, under PPL, showing plagioclase (center) with kaolinization process and fragmented quartz (bottom-right); (**d**) sample WS02 under XPL; (**e**) sample WS03, under PPL, showing plagioclase presenting with an agglomerated texture and polysynthetic twining; and (**f**) sample WS03 under XPL.

The analysis results, the coordinates where the samples were taken from, and the rock classifications are summarized in Table 2.

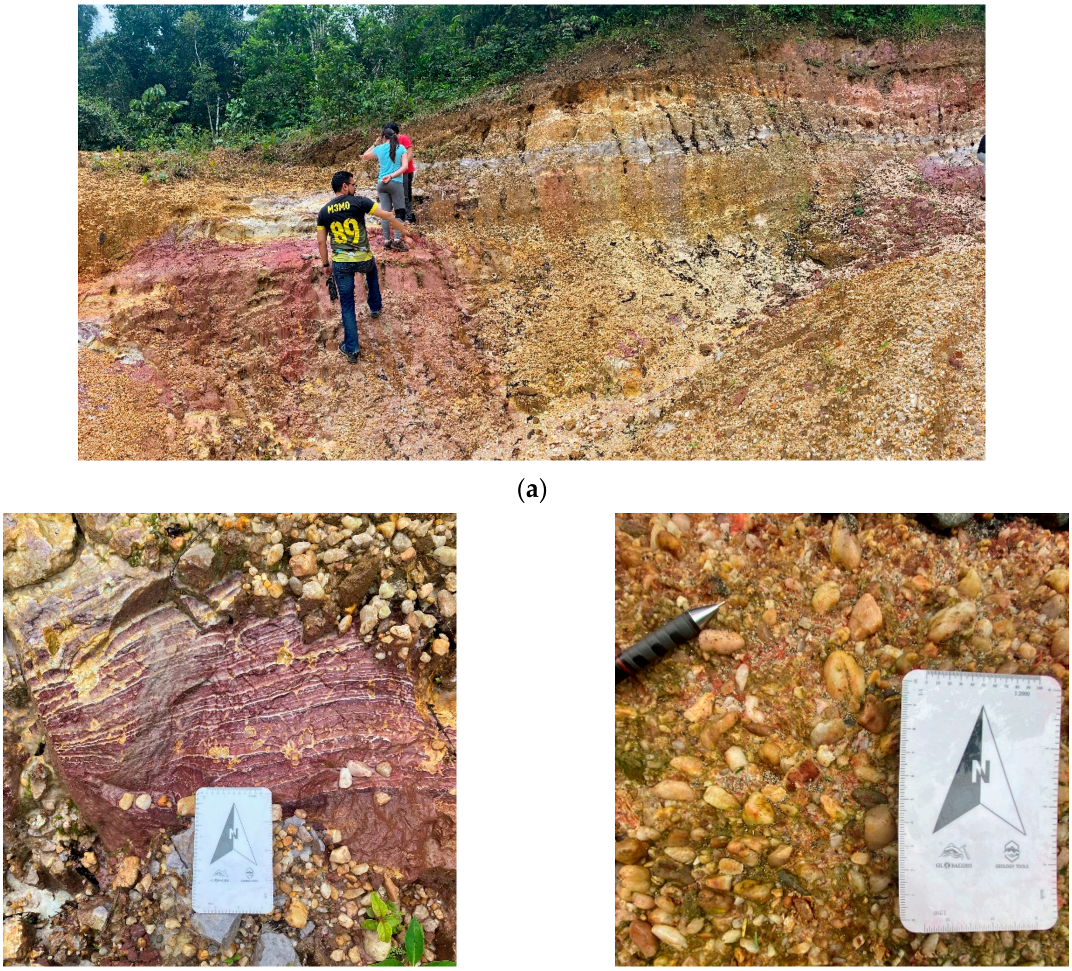
Table 2. Samples taken from Wawa Sumaco.

Geo Zone	X	Y	Code	Analysis	Rock Name
18M	201,501.00	9,921,188.00	WS01	Petrographic	Tephrite
18M	211,490.00	9,921,270.00	WS02	Petrographic	Weathered basaltic breccia
18M	211,472.00	9,921,284.00	WS03	Petrographic	Tephrite

4.1.2. Puka Urku Geosite (G18)

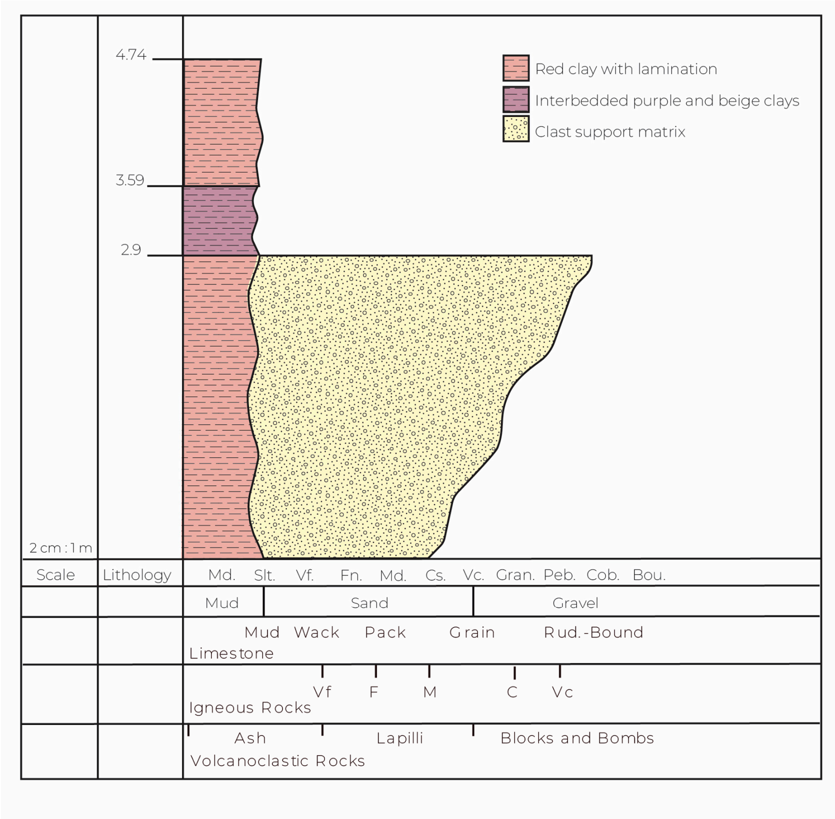
Puka Urku (from *Kichwa* into English: red mountain) is located southwest of the geopark, 5 km from the parish of Pano. It is very popular with tourists; the place is known as "the colored stone" and has clear water from the Pano River. The main outcrop presents a unique morphology and has a height of 25 m between intercalations of silt clay and quartz conglomerate layers varying between 50 cm and 2 m in height.

At a point 350 m to the NE of the "the colored stone", an accessible secondary outcrop for lithographic description, associated with G18, is located. In this section, clay layers, matured milky quartz, and the presence of a high-energy paleochannel have been identified (Figure 5).



(**a**) (**b**) (**c**)

Figure 5. *Cont.*



(**d**)

Figure 5. (**a**) Outcrop from which the stratigraphic column was constructed, where a paleochannel can be identified; (**b**) parallel and cross-stratification in the reddish clay; (**c**) milky quartz clasts of varying grain size from 1 mm to 3 cm; and (**d**) stratigraphic column of Puka Urku Geosite.

From G17, two samples were taken for XRD analysis. According to this analysis, XRD_PU01 shows crystalline phases of kaolinite (95.7%) and quartz (4.3%) whereas, in XRD_PU02, the identified crystalline phases are quartz (56.4%), kaolinite (42%), and montmorillonite (1.5%) (Table 3).

Table 3. Samples taken from Puka Urku.

Geo Zone	X	Y	Code	Analysis	Rock Name
18M	176,840.00	9,888,409.00	PU01	XRD	Kaolinite
18M	177,049.00	9,888,652.00	PU02	XRD	Quartz–Kaolinite

4.1.3. Pucuno River Geosite (G19)

This site is located approximately 2 km west of the Pacto Sumaco community, and to the south of G1 and G2 (13.5 and 10.4 km, respectively). In this site, deposits with volcanoclastic material were observed over intercalations of shale with fine-grained sandstone. Some of the volcanoclastic rocks exhibit weathering attributable to the tropical climatic conditions of the Amazon region (Figure 6).

To develop the petrographic analysis, four samples were studied with the following results: PR01 sample (Figure 7a,b) from Pacto Sumaco is a well-consolidated quartz sandstone with a sandy texture rich in quartz and minor opaque minerals indicating a continental alluvial–fluvial depositional environment. PR03 sample (Figure 7c,d), characterized by a porphyritic texture with microcrystals and phenocrysts of plagioclase, pyroxenes, amphiboles, and opaque minerals, is classified as a vesicular porphyritic andesite with a microcrystalline matrix. Similarly, PR04 (Figure 7e,f) displays a porphyritic and microcrystalline texture with vesicular structures, and abundant plagioclase, pyroxenes, amphiboles, haüyne, and opaque minerals. PR05 sample (Figure 7g,h), from an outcrop near the Pucuno River, shows a hypocrystalline texture with phenocrysts of plagioclase, pink potassium feldspars, and dark minerals, and is classified as a highly altered plutonic syenite.

Three samples were used in the XRD analysis, with the following results. In sample XRD_PR01, the identified crystalline phases are quartz (74.9%) and rutile (25.1%). XRD_PR02 is characterized as a quartz sandstone due to the identification of the crystalline phase as quartz (100%). Based on the XRD analysis, the crystalline phases identified in sample XRD_PR05 are orthoclase (80.9%), albite (16.4%), and quartz (2.7%), classifying this rock as a syenite. All analyses, with the coordinates of where the samples were taken from and their classification, are summarized in Table 4.

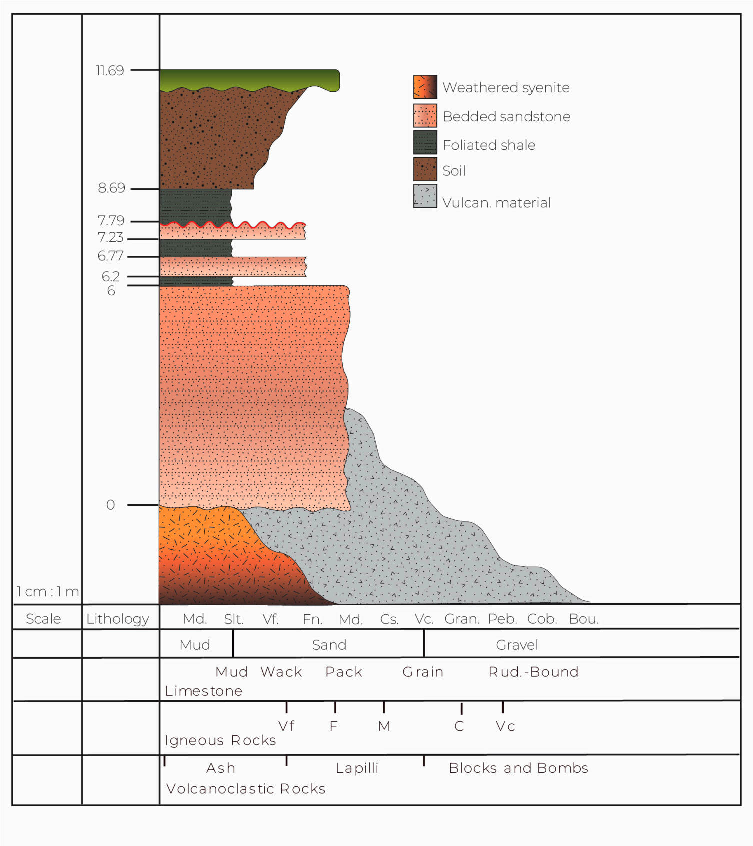
(**a**)

(**b**)

(**c**)

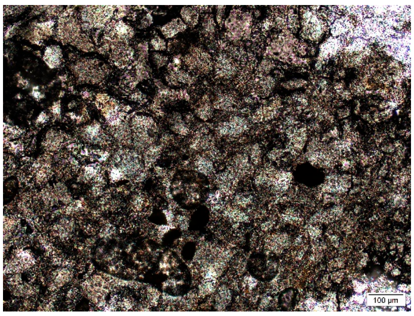
(**d**)

Figure 6. *Cont.*

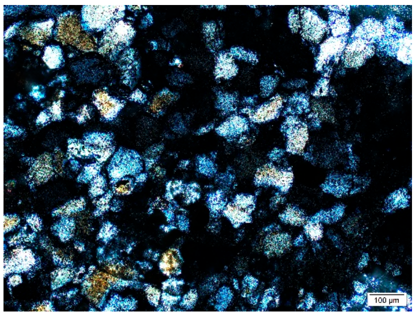


(**e**)

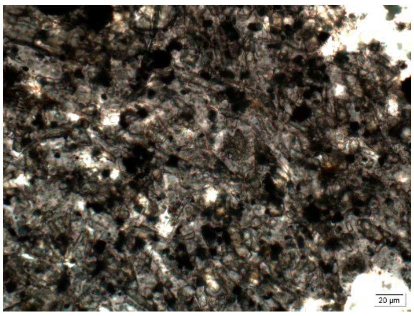
Figure 6. (**a**) Beige to reddish-beige sandstone sample; (**b**) laminated shale sample; (**c**) sandstone matrix with clasts from the pyroclastic deposit; (**d**) collected sample PR04; and (**e**) stratigraphic column of Pucuno River.



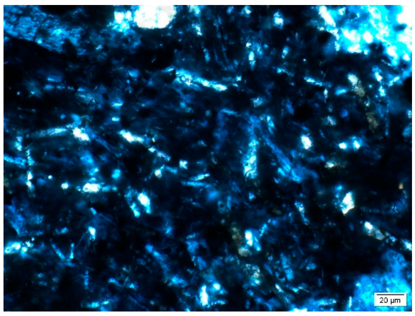
(**a**)



(**b**)

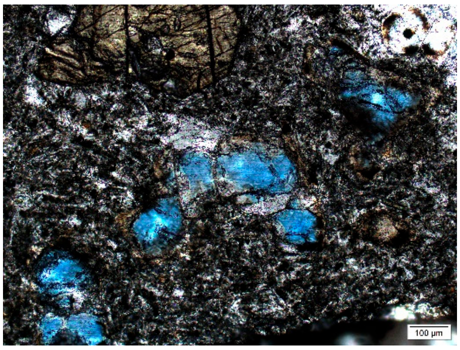


(**c**)

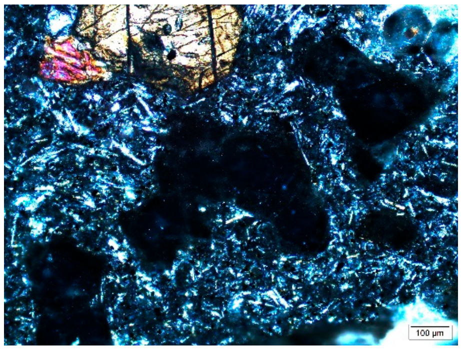


(**d**)

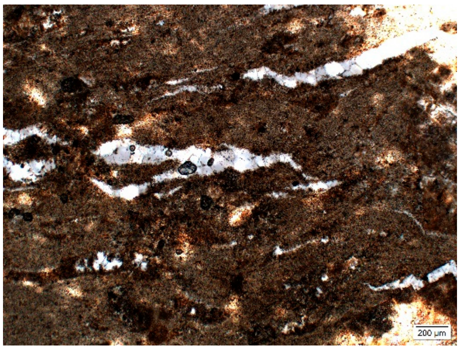
Figure 7. *Cont.*



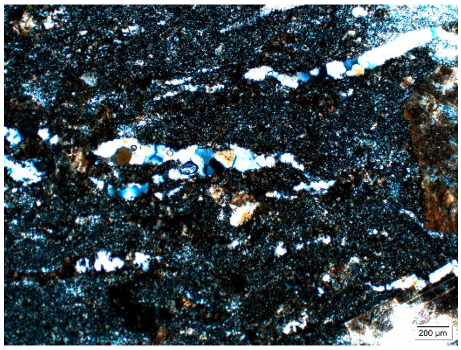
(**e**)



(**f**)



(**g**)



(**h**)

Figure 7. (**a**) PR01 sample seen under a microscope and PPL. It is possible to appreciate the monocrystalline sandy texture with rounded quartz; (**b**) Sample PR01 under XPL; (**c**) PR03 sample seen in the 40x objective microscope with PPL. Crystals can be observed in intersertal plagioclase texture; (**d**) PR03 under XPL; (**e**) PR04 feldspathoid conglomerate crystals. The matrix is composed of plagioclase, glass, and opaque minerals (10x objective microscope); (**f**) PR04 under XPL; (**g**) PR05 presenting a fluid matrix with plagioclase phenocrysts surrounded by oxide crowns; and (**h**) PR05 under XLP.

Table 4. Samples taken from Pucuno River.

Geo Zone	X	Y	Code	Analysis	Rock Name
18M	209,660.00	9,926,914.00	PR01	Petrographic and XRD	Quartz sandstone
18M	209,580.00	9,926,788.00	PR02	XRD	Quartz sandstone
18M	209,662.00	9,926,916.00	PR03	Petrographic	Andesite
18M	209,660.00	9,926,914.00	PR04	Petrographic	Tephrite
18M	209,048.00	9,927,081.00	PR05	Petrographic and XRD	Weathered syenite

4.2. SumAppGeo Multi-Platform Application Elaboration

After the completion of the geological analysis of the three main geosites and the organization of the data collected on NSAUGG, the SumAppGeo cross-platform application was developed. This application provides not only up-to-date information on the geosites, but also integrates specific geological data from throughout NSAUGG, with the aim of enriching the geological knowledge of the community and improving the skills of local tour guides. The name "SumAppGeo" was chosen as a reference to the Sumaco Volcano, integrating the concept of "SumApp", which sounds like Sumaco, and "Geo" for geology.

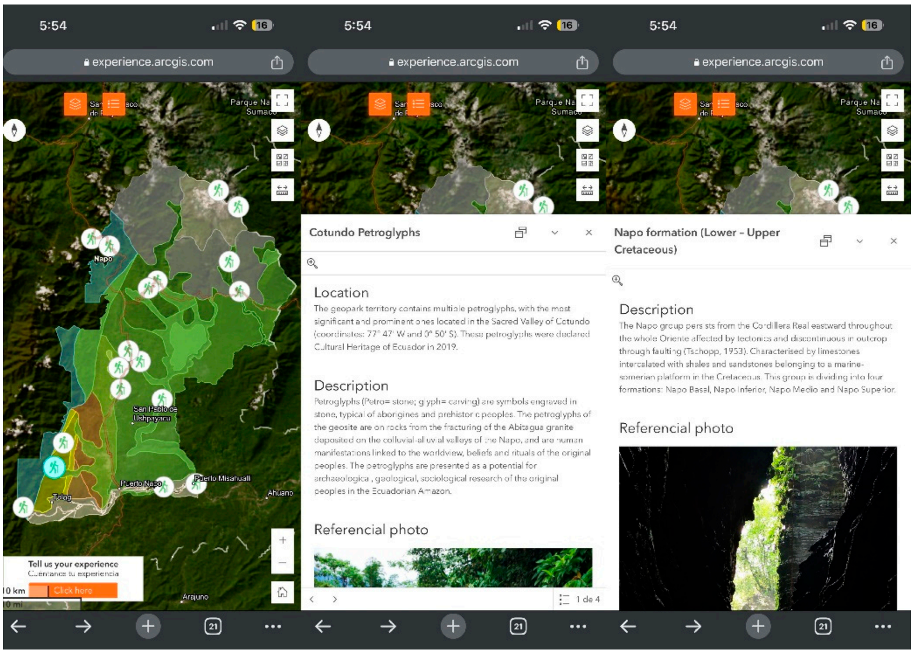
Mobile technology has proven to be a key tool for environmental and geological education, especially in conservation areas such as geoparks. As seen in the study by [39] on the UNESCO Global Geopark Ciletuh Palabuhanratu in Indonesia, the integration of GIS and mobile technologies can facilitate geographic interpretation and user experience, resulting in more interactive and dynamic access to spatial information. As in the case of Ciletuh, SumAppGeo provides interactive maps and guided tours that allow users to explore the geological and cultural diversity of NSAUGG.

The development of SumAppGeo was based on the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) [40], an approach frequently used in the design of learning systems. This methodology allowed the application to be tailored to the needs of both Napo Sumaco Geopark staff and local communities, promoting end-users' appropriation of geological knowledge. This process ensures that the application serves not only as a reference tool but also to enhance participation in conservation initiatives and promote sustainable tourism.

One of the most important aspects of SumAppGeo is the inclusion of educational content that engages both tourists and local communities. The authors of [41] suggest that the use of geospatial applications in education can significantly increase users' engagement with the material presented, allowing them to interact directly with the data in real-time. In this regard, SumAppGeo allows tour guides to access key geological and environmental information as they conduct tours, enhancing visitors' interpretation of sites.

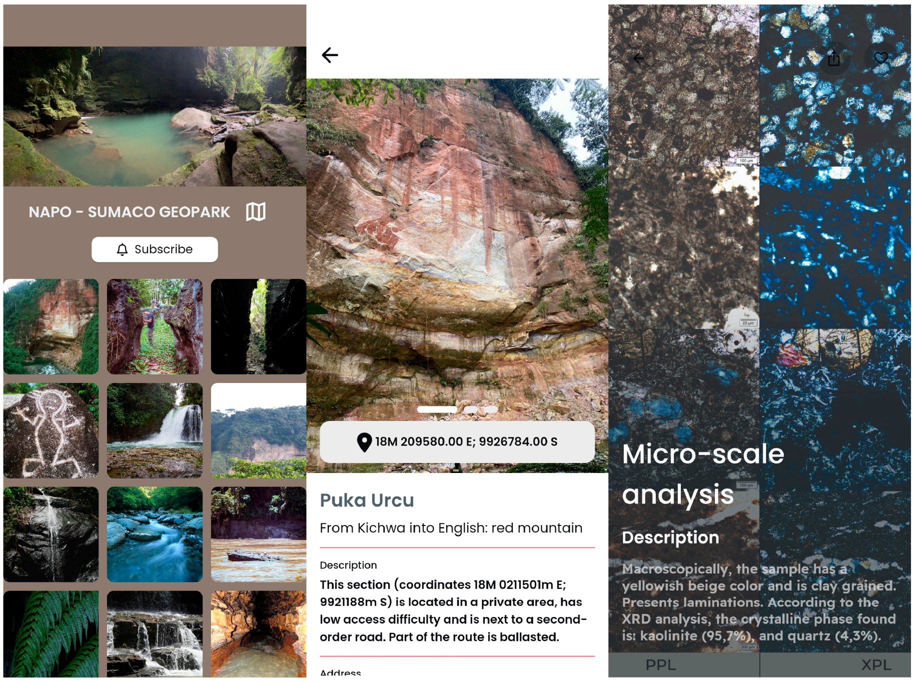
Ease of use is a key factor in end users' adoption of mobile technologies. According to [42], creating applications that provide geospatial data in a simple and accessible interface allows users to obtain valuable information without requiring advanced technical knowledge. SumAppGeo offers an intuitive interface with zoom options, GPS navigation, and detailed geosite descriptions, making it easy to use for both experts and the public.

The mobile version of SumAppGeo is designed specifically for Android devices (Figure 8), in APK format, which allows its distribution in areas with limited connectivity. In addition, it includes an interactive gallery showing images of geological sites and their evolution over time. This feature is similar to those of other applications, such as Collector for ArcGIS, mentioned by [41], which allow real-time field data collection and subsequent analysis.



(**a**)

Figure 8. *Cont.*



(**b**)

Figure 8. (**a**) Web application interface and (**b**) mobile application interface.

The final implementation of SumAppGeo will take approximately five months, during which time the collaboration with Napo Sumaco Geopark staff and local communities will be permanent. This participatory development process will ensure that the application adapts to the geopark's changing needs and incorporates suggestions and continuous improvements over time. According to [39], the success of mobile applications in complex geographic contexts relies heavily on collaboration with local communities, who provide valuable insights into land use and user needs.

A crucial aspect of the implementation of SumAppGeo is the continuous evaluation of its effectiveness. As pointed out by the authors of [42], the use of GIS systems allows not only the mapping and visualization of geological data but also the quantification of the social value of ecosystem services provided by geosites. SumAppGeo will include feedback tools that will allow users to report bugs, suggestions, and new functionalities, which will contribute to improving the application in the long term.

The SumAppGeo app is expected to play a key role in promoting geological tourism in the NSAUGG region. By providing access to detailed and easy-to-understand geological data, the app can transform the way visitors interact with the landscape. Furthermore, this educational tool can be used by geology students and professionals to conduct field research, following the model of geospatial data collection applications presented in [41]. A schematic of the application appearance can be seen in Figure 8.

5. Discussion

The different analytical techniques provide detailed insights into geodiversity features associated with the composition and structure of the deposits at geosites. The petrographic analyses revealed the mineralogical and textural characteristics of the samples, while the XRD analyses provided data on the composition of major minerals, accessory minerals, and clays. Structural studies identified deformation patterns and tectonic features in the reservoirs. Sedimentary analyses provided information on depositional processes and the sedimentary environment.

5.1. NSAUGG Geodiversity and Sociocultural Use

5.1.1. Wawa Sumaco Quarry (G17)

The two samples, WS01 and WS03, exhibit an alkaline mineral association, with minerals such as plagioclase, potassium feldspar, pyroxenes, amphiboles, biotite, and opaque minerals, and exhibit a vesicular structure and porphyritic texture. They have well-developed crystals, suggesting a very stable composition, and the presence of haüyne indicates that they belong to the group of more evolved rocks from the Sumaco Volcano [38,43].

Sample WS02 has a particular composition with basaltic clasts. It contains vesicles and is composed of potassium feldspars, plagioclases, amphiboles, opaque minerals, and sericite. The sample is highly altered due to weathering factors (water, wind, and time). The combination of these geodiverse elements provides evidence that an explosive volcanic phenomenon occurred, resulting in the mobilization of volcanic conduit fragments within this debris flow deposit.

The data suggest that two debris flow events have been recorded in this deposit (Table 5). One is associated with an older volcanic event, as evidenced by the mafic characteristics at the bottom of the outcrop. At the same time, the upper part is related to a more recent volcanic event, indicated by the presence of the mineral haüyne [43]. The study reveals a correlation between the Pucuno River (G18) samples and those from the northern part of G17.

Table 5. Summary of features of the SumAppGeo application.

Development Application	Software Compatibility		Requirements			Data Updating	Offline Mode
			Internet		Sw Version		
			Yes	No			
SumAppGeo by Flutterflow	Android		X		6.0 or later	Monthly	Test phase
	iOS		X		13 or later		Development phase
Experience Builder	Browsers	Chrome Firefox Safari	X		Not applicable	Every week	Development phase

Regarding research and the dissemination of scientific knowledge, the geodiversity of the G17 geosite provides an opportunity to promote geological understanding, including the study of volcanic phenomena and the risks associated with the Sumaco Volcano edifice (G1–G2). This outcrop is of particular significance to the study of igneous rocks and minerals, representing a valuable resource for both geoscientists and the public. Additionally, its status as an active open-pit quarry provides a unique opportunity to engage in discourse surrounding the utilization of geological resources and the implications of their extraction for society. Thus, an awareness of geology and environmental knowledge related to quarries in geotourism development is promoted [44,45] in NSAUGG.

5.1.2. Puka Urku (G18)

The G18 area is characterized by conglomerates (mostly milky quartz clasts) with a quartz clay/sandy matrix. A high-energy paleocurrent or channel (Figure 5c) related to the transport of gravel-sized clasts was observed. Paleocurrent measurement shows a NW-SE direction, and the current river direction shows two main directions, NW-SE and NS. The data suggest that its sediments are related to a braided fluvial system [46]. These results obtained from the different analyses carried out confirm that the G18 geosite outcrops the Tiyuyacu formation, characterized by quartz pebble conglomerates with a clayey matrix rich in quartz. This was corroborated in the samples analyzed. Its depositional environment, according to [47], is related to an alluvial piedmont fan system. Geological materials may be mainly associated with the erosive processes developed in the Abitagua granite (at the G6, G9, and G16 geosites).

Based on the findings of the X-ray analysis for G18, the diffractograms of samples PU1 and PU2 reveal kaolinite and quartz, and quartz, kaolinite, and montmorillonite, respectively. According to [48,49], kaolinite is the dominant mineral in residual kaolin and is commonly the result of the profound weathering of feldspathic rocks like pegmatite and granite. It is one of the only kaolin minerals that forms extensive deposits, and it is used for fine ceramic creations. Montmorillonite is formed from the weathering of soils, rocks, or volcanic ash. It belongs to a group of hydroxyl aluminosilicates, and it has absorbent properties that could be used for skincare products. This experiment provides a new insight into the relationship between geological knowledge, commerce, and tourism in this zone.

Refs. [49,50] mention that kaolinite, also known as kaolin, has a lot of industrial applications in addition to application in the ceramics industry. Industrial uses of kaolin include in the production of paper, paint, rubber, ceramics, plastic, and medicinal products, as well as its use as a catalyst for petroleum cracking, vehicle exhaust emission control systems, and as a base and pigment for cosmetics. In addition, kaolin is also used as an anti-cracking agent in the manufacture of fertilizer tablets, as a carrier for pesticides, in the production of white cement, and in the production of glass fiber.

According to the authors of [50], kaolin can be found in a variety of cosmetics, including eye shadows, blushers, face powders, mascara, and foundation. In addition, it can be included in a skincare routine due to its absorbent properties and the fact that it is a good source of minerals. Thanks to its neutral pH, important cosmetic companies use this mineral in cleansers and masks, mainly for oily skin, as it is an excellent exfoliant, absorbs excess oil, and attenuates pores, as well as having other important characteristics that facilitate the use of this clay.

The G18 geosite exhibits the presence of minor kaolin clay deposits, which have the potential to be exploited for commercial purposes on a modest scale. This could serve to enhance the economic viability of the geosite, which currently relies on tourism as its primary source of income.

5.1.3. Pucuno River (G19)

Interbedded sandstone and mudstone exhibit sedimentary structures that suggest a continental depositional environment ranging from fluvial to shallow marine. According to the authors of [51], the upper Hollín formation includes sandstone and mudstone with tidal structures, indicating a transition from fluvial to coastal environments with tidal influence and shallow marine platforms. Therefore, these interbedded sections could be related to the Hollín formation, specifically the upper Hollín formation.

The volcanoclastic material is located at UTM coordinates 18M 0209656m E; 9926822m S and is situated in a debris flow deposit within a paleo profile. This could have originated from the ascent of a large amount of magma in the volcanic edifice, a high-magnitude earthquake near the volcano, or the weakening of the volcano's structure [52].

The volcanoclastic samples (PR03 and PR04) show signs of weathering both in the matrix and in the rocks. They have a mineralogical composition that includes plagioclases, potassium feldspars, pyroxenes, amphiboles, and haüyne, and exhibit a vesicular structure and a porphyritic texture. These mineralogical characteristics are attributed to the unique alkaline composition of Sumaco Volcano, which contains mineral assemblages including haüyne and titanaugite [38,53]. The presence of haüyne is linked to high temperatures, low pressures, and a high oxygen concentration in the magma reservoir, which maintains a sufficient amount of SO_2 in the shallow magma to promote the formation of this feldspathoid, resulting in a low-viscosity magma [38]. Samples PR03 and PR04 are classified as andesite and tephrite foidite, respectively.

Sample PR05 was taken from UTM coordinates 18M 0209048m E; 9927081m S, next to the Pucuno River. This sample is classified as syenite; it belongs to an intrusive body with alkaline geochemistry, is rich in potassium, and has its origin in a continental rift with alkaline volcanism [54]. It may be related to the Chapiza/Yaupi/Misahuallí cycle (Triassic and/or lower Jurassic), or related to the intrusion of the Abitagua, Azafrán, and Rosa Florida batholiths [47].

The geodiverse elements present at geosite G19 render it a unique and significant site for illustrating the evolution of the Oriente Basin. At this geosite, the upper Cretaceous sandstone of the Hollín formation has been intruded into at a later stage by a syenite body, which may be associated with the Abitagua batholith. This was subsequently covered by volcano-sedimentary deposits from the Pleistocene Sumaco Volcano. Therefore, the east–west transect that traverses geosite G19 is an optimal setting for comprehensive geological inquiry, offering a valuable opportunity for the advancement of geotourism.

Geosites G17, G18, and G19 offer optimal conditions for promoting geotourism, allowing visitors to learn from NSAUGG guides about the abiotic, biotic, and cultural interactions present in the geopark. At geosite G18, for example, the traditional use of clays as face masks is part of the cultural knowledge transmitted during guided tours. At G17 and G19 geosites, the presence of the blue mineral haüyne, characteristic of the Sumaco Volcano, is explained, highlighting the geological and geochemical conditions responsible for its color, and highlighting the relationship between abiotic and cultural components [30]. Finally, at geosite G19, the trails used by local inhabitants allow the observation of lithological changes and plant diversity, illustrating the interaction between abiotic and biotic elements of the environment.

5.2. SumAppGeo Web and Mobile Application

The SumAppGeo application emerges as a revolutionary tool designed for the exploration and dissemination of knowledge about NSAUGG, providing its users with access to a vast geological and environmental database. Through the application, users can obtain detailed information about each geosite, with descriptions ranging from its geological origin to its scientific relevance. This information is key not only for tourists and students but also for researchers who wish to delve deeper into the scientific aspects of the region.

With access to detailed information on geological formations, geological ages, and other geospatial data positions, SumAppGeo is a key tool for promoting scientific and educational tourism in the region [55]. Like the approach implemented in the mobile application for the Ciletuh-Palabuhanratu Geopark in Indonesia, which employs mobile GIS technologies to provide navigation routes, digital maps, and interpretive information [39], SumAppGeo incorporates innovative components that allow users to better understand the natural environment of the geosites. However, unlike the Yehliu Geopark application in Taiwan, which focuses mainly on navigation and augmented reality (AR) functions [56], SumAppGeo stands out for its ability to integrate advanced geospatial analysis and provide specialized educational content.

Additionally, by building on methodologies such as those employed in the development of SolVES, an application designed to map and quantify the social values of ecosystem services [42], the functionalities of SumAppGeo could also be extended to assess the social impact of geosites on tourism and conservation. This ability to adapt GIS technologies to educational and scientific contexts reinforces the uniqueness of SumAppGeo compared to other existing proposals.

Compared to the aforementioned apps, SumAppGeo takes a more holistic approach by combining access to detailed geological information with navigation and educational interpretation functionalities. The app developed for the Ciletuh-Palabuhanratu Geopark [39] focuses mainly on providing guided routes and basic spatial data, while the Yehliu Geopark mobile guidance system [56] incorporates augmented reality technology to enhance the tourism experience. On the other hand, SolVES [42] excels in quantifying social and ecosystem values through the use of advanced spatial surveys and analysis, a feature that could be integrated into future versions of SumAppGeo to assess the social impact of geotourism on geosites. Unlike these apps, SumAppGeo not only offers a guided experience, but also promotes deep and meaningful learning through the inclusion of detailed scientific content, making it a unique tool in the field of science tourism and education.

SumAppGeo's interactive map is one of the most attractive features of the application. This map not only allows detailed exploration of geosites but also provides a clear visualization of routes and points of interest, optimizing the visitor experience. The importance of these functions is evident in studies such as [41], which demonstrates how the combination of GIS and mobile technology can increase user participation and engagement. In the case of NSAUGG, the map not only enhances the visual experience but also contributes to the interpretation and understanding of the geological value of the area.

The availability of SumAppGeo in two versions—one web and one mobile—ensures that the application can be used by a wide range of users, regardless of their preferred devices. This cross-platform approach, also adopted in other successful geopark projects [57], is key to ensuring the application's accessibility. Tourists who prefer to use their smartphones can access the APK version on Android, while those who prefer to work from a computer can use the web version (Table 5).

In addition, the design of the application considers the connectivity limitations of the region. In remote areas of NSAUGG, where internet connectivity is limited, the application allows the download of an offline version in APK format. This offline version is crucial, as it ensures that users still have access to information even without network connectivity. As observed in the case of the application developed for the Ciletuh-Palabuhanratu Geopark [39], offline functionality is vital to maintain the flow of information in places with low connectivity.

One of the aspects that make SumAppGeo stand out is that users can easily navigate through the different geosites using zoom and location-based search functions. These tools allow users to focus on specific areas of interest, quickly accessing relevant geological information. According to the authors of [42], customizability is essential in GIS-based applications, as it allows for more efficient interaction tailored to the user's needs.

The ability to click on geosites for detailed descriptions adds an additional level of interactivity. This feature allows users to quickly and easily access the information they need, optimizing their user experience. In addition, the application includes interactive widgets such as sliders and search engines that make navigation intuitive and efficient.

The development of SumAppGeo currently includes extensive testing with various user groups, including tour guides, tourists, and students. Both the web and mobile application versions are undergoing continuous testing to ensure system functionality, verify the accuracy of geospatial data, and enhance ease of use. User feedback plays a crucial role in refining the interface and improving the application's smoothness and effectiveness to ensure a successful final launch. According to the authors of [41], continuous evaluation of user experience is essential for fostering the adoption of new technologies.

One of the key results of these tests is the implementation of improvements based on user feedback. The possibility of adjusting aspects such as the speed of map loading or the visibility of certain geographical elements allows the user experience to be refined, ensuring that the application is not only functional, but also pleasant to use.

The use of QR codes is another innovation that stands out in SumAppGeo. These codes, strategically placed at points of interest in the geopark, allow visitors to scan with their mobile devices and immediately access detailed information about the geosites. This reduces the need to manually search for information and makes the user experience more efficient. The authors of [39] highlighted the importance of integrating innovative technologies such as QR codes to improve the accessibility of applications in remote areas.

The value of SumAppGeo is not limited to enhancing the tourism experience; it also facilitates the development of science tourism in NSAUGG. The app provides researchers with access to detailed geological data, georeferencing points of interest and tools to manage field information. The authors of [42] noted that the use of GIS applications for field data collection significantly improves the accuracy and efficiency of geospatial data management.

In addition, SumAppGeo will allow users to annotate and record their explorations in real time, which is useful for scientists and students conducting research in the field. This not only streamlines the research process but also encourages a higher level of participation and engagement with geospatial data.

The development and implementation of SumAppGeo has been carried out in close collaboration with the local NSAUGG communities. As observed in the case of the Ciletuh-Palabuhanratu Geopark, the active participation of local communities is essential to ensure that the application is tailored to the specific needs of the region. Collaboration with local people also ensures that the information provided in the application is accurate and relevant.

Local communities have also played an important role in testing and improving the application. By providing feedback on the functionality and usability of SumAppGeo, community members have contributed to its evolution, ensuring that the tool is useful for both inhabitants and visitors.

The SumAppGeo implementation plan is designed with a five-month timeline but is flexible to adapt to the specifics of NSAUGG. This flexibility is essential to ensure that any necessary adjustments to the schedule or activities are made without compromising the application's quality or effectiveness. Flexibility in project implementation is a recommended strategy to ensure that technology projects can respond to local specificities and changing conditions.

In addition to its educational and tourism functions, SumAppGeo has a direct impact on the conservation of NSAUGG's geological heritage. By providing an accessible tool that promotes knowledge and appreciation of local geodiversity, the application helps to raise community and visitor awareness of the importance of conserving these resources. Disseminating this type of knowledge is key to raising awareness of the need to protect geological heritage, which is aligned with the conservation principles set out by UNESCO.

SumAppGeo is continuously undergoing development and testing, and its functionality is expected to expand to include new features, such as advanced geospatial data analysis and the integration of additional information layers. Furthermore, future versions may incorporate capabilities for simulations and interactive geological modeling, providing users with an even richer and more educational experience.

Finally, at the territorial level, the creation of SumAppGeo not only facilitates the dissemination of geological knowledge about NSAUGG to the public but also supports the teaching and learning processes developed in the geopark. These processes are essentially aimed at local tourist guides and communities linked to community tourism centers, and thus promote geotourism as a tool for sustainable development and the appreciation of geological heritage [58].

6. Conclusions

The implementation of this research contributes to scientific development and the promotion of geotourism through the improvement of geological knowledge regarding the G17, G18, and G19 geological sites, and through the development of a mobile application aimed at integrating information on the geological diversity present in NSAUGG. To achieve this, two main tasks were carried out. The first involved carrying out analyses and interpretations to understand the geology of the study areas. The second task focused on the collection of information and its subsequent storage in the mobile SumAppGeo application. This contributes to the development of the research and supports the recognition of NSAUGG as part of the UNESCO Global Geoparks Network.

The results obtained in this research validate the Wawa Sumaco Quarry (G17), Puka Urku (G17), and the Pucuno River (G19) as geosites due to their potential geological content and geodiverse elements. These three recently studied geosites need to be assessed in terms of the difficulty of access and the risks present in the area. The creation of a risk management plan and the establishment of a safe and easily accessible route for tourists is therefore recommended. However, there is undoubtedly great potential for the teaching and learning of geological sciences related to the Napo and Tiyuyacu formations, avalanche deposits, volcanic rocks related to the Sumaco Volcano, and intrusive rocks related to Abitagua granite.

The information presented in this research represents a significant contribution to the geological field of NSAUGG. The geosites at the Pucuno River and the Wawa Sumaco Quarry offer a significant educational and touristic contribution due to the presence of alkaline rocks containing haüyne, a particular feature of the Sumaco Volcano with a unique composition compared to that found in other volcanoes in Ecuador. On the other hand, the Puka Urku Geosite also provides an educational contribution by allowing the study of the arrangement of sediments and sedimentary structures, which contributes to the interpretation of the Tiyuyacu formation. In addition, this site serves as a tourist attraction, thanks to the presence of an impressive sediment outcrop known colloquially as the "Piedra de Colores" and the crystalline water of the Pano River.

Furthermore, the SumAppGeo application was successfully developed using ArcGIS tools and the Flutterflow development application tool. It will be available both online as a web app using the Experience Builder platform and as an APK application, available on Android only. A version for iOS is in development. SumAppGeo provides a comprehensive visualization of NSAUGG, displaying various locations and detailed descriptions of each geosite, including the associated geological formations and ages. Users can access the necessary information tailored to their interests.

Since the development process is ongoing, a follow-up study focusing exclusively on the application's architecture, functionality, and impact would be highly valuable. For now, this work provides a general overview of the tools and approaches used in this stage of the project, highlighting their role in achieving the broader goals of geoscientific community outreach. As development progresses, further exploration of the application's technical details and insights into its evolution will be shared.

This research carried out at NSAUGG shows the crucial role of geological heritage as a driver of sustainable development in regions with high geodiversity. The results obtained will not only strengthen scientific knowledge and contribute to the effective management of geosites, but will also enhance geotourism as an integrating tool for the local economy and the cultural valorization of the territory. The proposed interactive application will be an innovative means of connecting communities, tourists, and local stakeholders with the geological richness of the geopark, fostering a deeper appreciation of the Earth's heritage and promoting sustainability through education, technology, and community participation.

The creation of our multi-platform application, "SumAppGeo", has been a significant achievement in promoting NSAUGG, and it responds to the requirements of the UNESCO evaluation carried out in November 2021. Finally, it offers visitors an interactive and educational experience, allowing them to explore and learn about the geodiversity of this beautiful region. The commitment to the continuous improvement of the application and the enhancement of the user experience in the geopark remains.

The addition of biological data could be considered, such as data regarding biodiversity, natural habitats, and endemic species present in the Napo Sumaco Geopark. This would enrich the available information and provide a more complete understanding of the relationship between geology and biology in the region. Furthermore, it would be beneficial to include tourist, gastronomic, and cultural information, to provide visitors with a more enriching and comprehensive experience during their visit to the Napo Sumaco Geopark.

It is important to conduct user testing to identify potential problems in the user experience and make improvements based on user recommendations prior to launching to the public. In addition, regular evaluations of the application should be carried out to obtain statistics on its use for the more effective and sustainable management of the geopark.

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