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Amethyst Deposits of the Los Catalanes Gemological District (Artigas Department): The First Uruguayan IUGS Geological Heritage Site

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Abstract

The recognition and valorization of geological heritage in Uruguay is an incipient and developing process. The International Union of Geological Sciences designated the deposits of amethysts of Los Catalanes Gemological District, in northern Uruguay, as one of the first 100 "Geological Heritage Sites" on October 22, 2022, in the Mineralogy category, the first in Uruguay. It is part of one of the most important continental flood volcanism episodes on Earth (end of Jurassic to Early Cretaceous). The Paraná igneous province, a dominant tholeiitic basaltic and scarce acidic province that extends into parts of Brazil, Paraguay, Argentina and Uruguay, contains amethyst and agate deposits of unique international significance because of frequent mega-geode concentration, enormous reserves, and gemstone quality of varied size and forms. Although quartz-filled geodic cavities are common in the southern Serra Geral Formation in Brazil (Ametista do Sul, Quaraí), the more intense purple amethysts in giant geode deposits are found in the Arapey Formation in the lower-middle basin of the Catalán Grande stream in Uruguay. This contributes to the empowerment and pride of the local population as well as raising awareness of the need for the conservation of part of this mineral resource. Further, there was a recent inventory assessment that contributed to the understanding of the real scientific value of this designation.

Keywords: Geological heritage, Inventory assessment, Paraná igneous province, Amethysts, Uruguay.

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Introduction

Since the Romans, and from its Latin root, the term patrimonium (heritage) has contained the notion of father and homeland, and with this duality, it has crossed many centuries. Heritage is what we inherited from our parents and ancestors and at the same time is everything that belongs to all of us, as a community (Goso et al 2016). Under this approach, heritage is made up of objects or non-material assets.

Cultural heritage can be defined as a construction that changes according to new criteria, purposes or circumstances of each social context and with diverse meanings, which vary according to the communities (Prats 2004). This social construction links interpretation, selection, historical and risk awareness about what is identified as heritage, and the community. The main changes in the evolution of heritage knowledge refer to the recognition, scale, spaces and plurality of representations, as well as to its use and conservation, within the framework of sustainability and citizen participation (Ariño 2009). This conceptual shift is reflected in the contents of agreements, recommendations and documents agreed by international organizations (e.g., UNESCO, ICOMOS, IUCN, ICCROM). An important milestone in terms of heritage conservation was the signing in 1972 of the World Heritage Convention, which created World Heritage Sites with the main objectives of nature conservation and the preservation of cultural assets.

As Wimbledon (1996) states, geologists have long been concerned with the apparent imbalance of natural features in the World Heritage list, and there has been a perception that globally significant geological sites, some of them defining outstanding stages in the organic and inorganic evolution of the Earth, have been overlooked. It is for this reason that an indicative list (GILGES, Global Indicative List of Geological Sites) was compiled in 1991, as a first attempt at an inventory to aid judgments on the selection of World Heritage sites, under the guidance of the International Geological Correlation Programme (IGCP), the International Union of Geological Sciences (IUGS) and the International Union for Conservation of Nature (IUCN).

In past decades, the conservation of geological heritage was based on the idea that certain geological features have an exceptional value in their own right and should therefore be protected and conserved. Therefore, outcrops or landscapes that present unique characteristics, either because of their singularity or their usefulness for establishing correlations, are fundamental for the scientific advancement and dissemination of geology (Carcavilla *et al.* 2007).

In the 1990s, the IUGS Global Geosites Working Group initiated the development of a database of geological sites of international relevance through the project "GEOSITES: A global comparative site inventory to enable prioritization for conservation" (Wimbledon *et al.* 2000). The project was supported by ProGEO, created in 1993 by the European Association for Conservation of Geological Heritage, until 2021, as well as by IUCN and UNESCO, but did not achieve the global acceptance initially expected the lack of widely accepted methodologies.

In recent years, there has been a growing interest in researching methods for geological heritage assessment around the world. For instance, ProGEO at the European level, and the Association of Iberoamerican Geological and Mining Surveys (ASGMI) in Latin America have proposed similar methodologies for the evaluation of geological heritage sites (ASGMI 2018). A method based on systematic survey and assessment was developed through the GEOSITES project and applied in several European countries (Wimbledon *et al.* 2000).

In 2020, the IUGS Executive Council restructured the new IUGS International Commission on Geological Heritage (IUGS-ICG). In 2021, the IUGS-ICG reformulated this much-needed initiative (Global Geosites project) in the context of the IGCP731 project: IUGS Geological Heritage sites (https://www.unesco.org/en/iggp/igcp-projects/731). This project is now a collaborative effort involving the UNESCO International Geosciences and Geoparks Programme (IGCP), geological surveys around the world, research institutions, as well as IUGS commissions and affiliated international organizations related to earth sciences. The IUGS-ICG provides a useful definition: “an IUGS Geological Heritage Site is a key place with extraordinary geological elements and/or processes of the highest scientific international relevance, used as a global reference, and/or with a substantial contribution to the development of geological sciences through history” (https://iugs-geoheritage.org/subcomission-on-sites/).

This new IUGS Global Geosites project opens a new opportunity, to accomplish a worldwide inventory of geological heritage of international relevance in a new context where UNESCO Global Geoparks can play an important role (https://www.unesco.org/en/iggp/igcp-projects/731). As IUGS-ICG states “The knowledge of Earth and its history is based on places and landscapes that have been described and studied since the beginning of the geological sciences. Some of these places have a special value. They are inspiring and extraordinary places that have contributed significantly to the development of Geological Sciences. They represent the memory of the Earth and are part of the natural heritage that we must in equal parts value, manage, use and conserve with determination” (https://iugs-geoheritage.org/subcomission-on-sites/).

The IUGS-ICG defined a series of main standard conditions: name of the geological heritage site; location; geological period of the main geological interest; typology (history of geosciences, stratigraphy and sedimentology, paleontology, igneous and metamorphic geology, volcanology, tectonics, mineralogy, geomorphology and active geological processes, and impact structures and extraterrestrial rocks); main arguments for the designation; and scientific research and tradition (https://iugs-geoheritage.org/subcomission-on-sites/).

According to the IUGS-ICG the main objectives are to:

(a) Establish global standards for the recognition of IUGS Geological Heritage Sites, Geo-collections and Heritage Stones;

(b) Compile and maintain an IUGS Geoheritage database for the global Earth Science community;

(c) Promote, disseminate and educate in Geoheritage through participation and organization of meetings and international conferences on Geoheritage;

The first objective of the IGCP – 731 IUGS GEOLOGICAL HERITAGE SITES (IUGS – UNESCO) was the creation of proper conditions of collaboration of more than 200 specialists from almost 40 nations and 10 international organizations, representing different disciplines of Earth Sciences, and promoting broad participation in the selection of the first 100 geosites. During the request, 181 candidate sites from 56 countries were proposed and evaluated by international experts from 34 countries. The result of this challenging and collaborative process is the list of the First 100 IUGS Geological Heritage Sites, distributed by regions: 34 in America, 28 in Europe, 23 in Asia-Pacific and the Middle East and 15 in Africa. In October 2022, during an official event in Zumaya (Basque Coast UNESCO Global Geopark) celebrating the 60th IUGS anniversary, was the public presentation of the first 100 IUGS Geological Heritage Sites, including the first Uruguayan

IUGS Geological Heritage Site (Goso & Faraone 2022), the Los Catalanes Gemological District represented by the abandoned Oliveira mine Geosite in Artigas Department (Fig. 1).

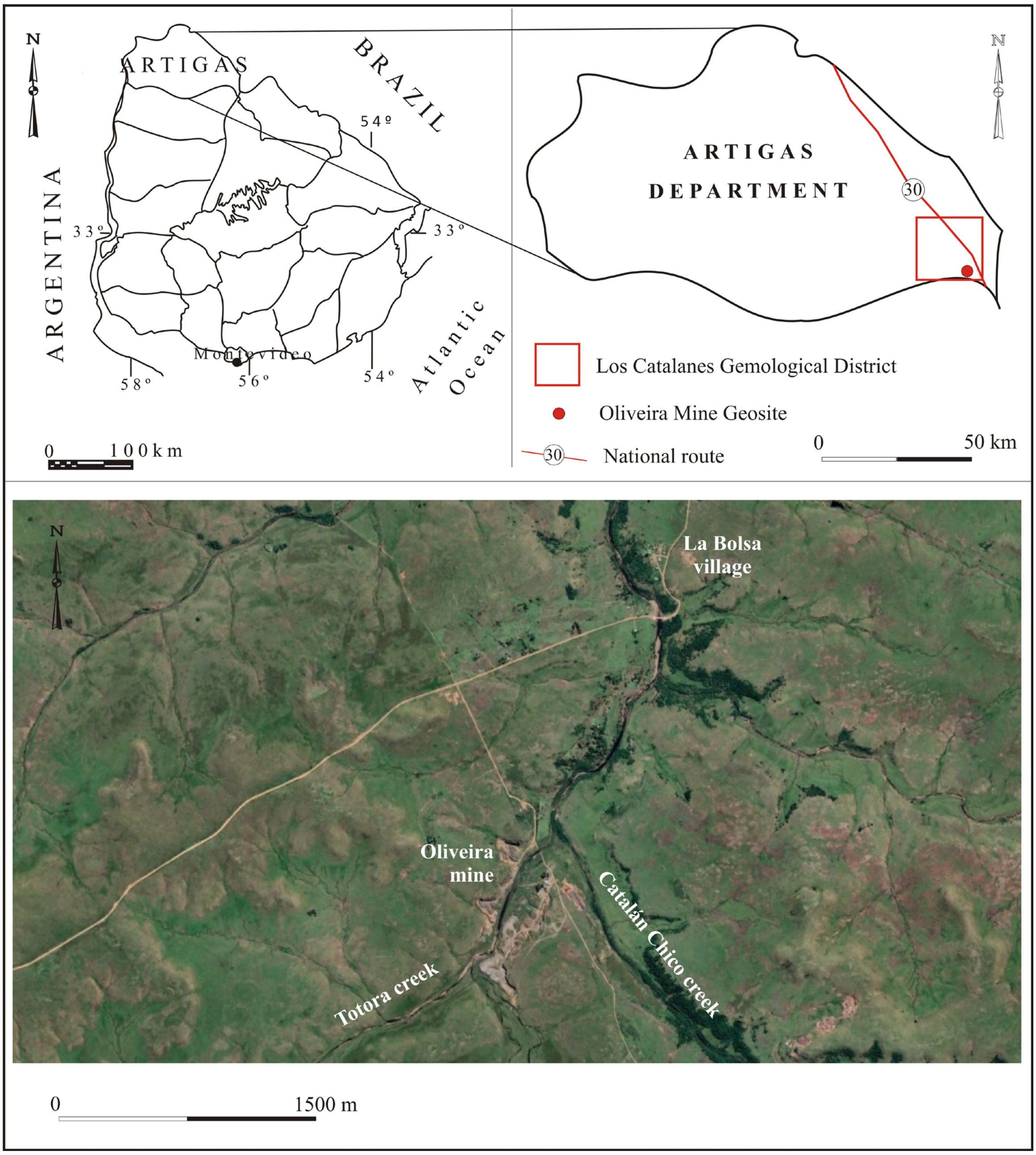

Figure 1. Localization map of Los Catalanes Geomological District and the Oliveira mine Geosite.

The First Uruguayan IUGS Geological Heritage Site

Geological Setting

In South America, the Paraná Magmatic Province (PMP; Peate 1997), with calculated lava volumes of approximately 1.0 × 106 km3, infills and covers the Paraná Basin (PB) with an approximate area of 1.2 × 106 km2 over southern Brazil, eastern Paraguay, northern Argentina, and northwestern Uruguay (Melfi et al 1988, Fig. 2).

In Uruguay, the so-called North Basin is part of the Paraná Basin, an extensive Gondwanan basin that in Uruguay occupies about 100,000 km^2 and contains in deep sectors more than 2,500 m thickness of sedimentary and volcanic rock succession (Ubilla *et al.* 2004). This thick sequence was deposited under different structural styles from the Devonian to the Upper Cretaceous, forming a succession of genetically related strata bounded at the base and top by regional unconformities (de Santa Ana *et al.* 2006).

Deposits of Amethysts of Los Catalanes Gemological District

Uruguay is a small country in South America; with 176,215 km2 of continental territory, it owns a very diverse geology. Its geological records date from the Archean to the Phanerozoic, showing numerous geological processes of Earth´s evolution. Recently, under the influence of the Grutas del Palacio UNESCO Global Geopark (GdPUGGp), the University of the Republic and initiatives with the support of the National Geological Survey (DINAMIGE), some studies of Uruguay's geological heritage have been published (Goso *et al.* 2016; Picchi *et al.* 2018; Goso 2021; Goso & Faraone 2022; Martínez & Goso 2022). Taking account of examples of inventories from Spain, Portugal, Brazil, and Argentina, in addition to criteria proposed by ProGEO and IUGS, some inventories have been carried out following the methodology of Brilha (2016) and García-Cortés *et al.* (2014).

In this contribution, we present the first Uruguayan Global Geosite, Los Catalanes Gemological District (DGLC), adopted in 2022 and represented by an abandoned amethyst mine. Probably this IUGS-UNESCO designation will encourage more specialists in Uruguay to submit nominations, where the heritage value of sites can be inspired by the case argued for the first global geosite of the country. The Oliveira mine is located in northern Uruguay (Artigas department), about 600 km from the city of Montevideo, close to a small village named La Bolsa. The relief in the area has the typical features of a basaltic plateau, with an altitude of about 200 m above the mean sea level. Since 2016 it has been visited yearly by several hundreds of primary, secondary and university students as well as other visitors, totalling 9000 visitors per year.

Deposits of Amethysts: Historical Mining Review

Deposits of agates and amethysts in Uruguay have been recognized since the time of the Spanish rule. Reyes (1830 in Bossi 1969) mentions the existence of these semi-precious gemstones around the Catalán and Pintado streams, which were extracted and sent to the Baltic. De la Sota (1841 in Pivel Devoto et al 1965) transcribes documents of 1750 from the King of Spain, in which he orders the allocation of funds to investigate deposits of agates and amethysts in the north of the Banda Oriental. Fernández & Miranda (1920 in Pivel Devoto et al 1965) pointed out that the first mines date back to 1844 by a German who, together with others, sent the gemstones to Europe to be cut and polished. In 2007, DINAMIGE published the first detailed study of the area, defining Los Catalanes Gemological District (LCGD). Currently, several mining companies are producing very high-quality amethysts (Fig. 2) employing hundreds of employees and some abandoned mines support locals and different geotouristic entrepreneurship, such as Mining Tours (https://www.facebook.com/amatistasartigastour/) and Mining Safaris (https://safariminero.com/). Achieving an understanding of the genesis of this mineralization and the origin of its intense purple color has motivated national and international geological research, including among others one geological Master thesis in Uruguay and a Doctoral thesis in Germany for example (Techera et al 2007; Techera 2011; Waichel *et al.* 2010; Da Silva 2011; Duarte *et al.* 2011; Arduin *et al.* 2022; Goso & Faraone 2022).

Figure 2. Details views of amethysts geodes and mega geodes of Los Catalanes Gemological District. Photos: Mateo Acosta (Mining Safari)

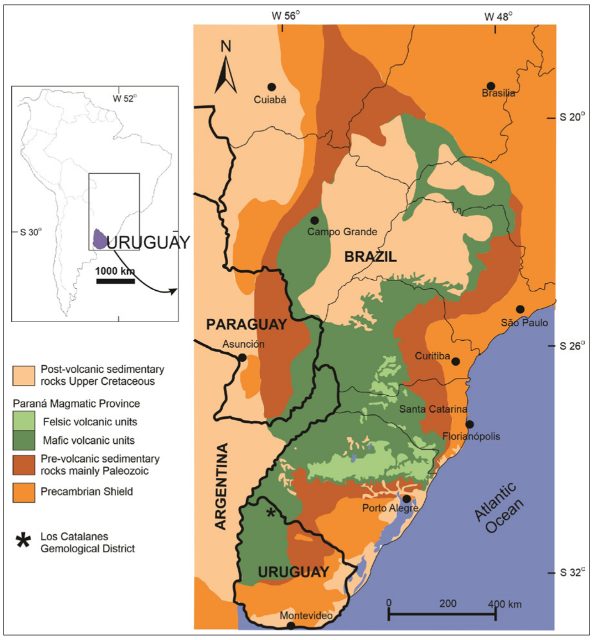

Figure 3. Localization map of the Paraná Magmatic Province. Modified of Muzio et al. (2022).

The Upper Jurassic-Early Cretaceous Sequence in particular is marked by reactivation of the cratonic basement in response to the development of a regional extensional stress field from the slow rate of convergence between the Pacific plate and the western edge of Gondwana. The association of Mesozoic magmatism with tectonic events responsible for the opening of the South Atlantic Ocean is well represented on the South American platform. These tectonomagmatic processes were precursors of the geological transformations related to the continental break-up and the oceanic expansion (Tankard et al 1996). The tholeiitic or alkaline magmatic manifestations associated with this tectonic event belong to the Paraná-Etendeka Province, comprising the South American and African remnants (Peate 1997, Fig. 3).

Uruguay presents a bimodal volcanism Mesozoic record, part of the Paraná Igneous Province (locally, Arapey Formation), the northeast with basic magmatism and in the southeast with acid extrusive rocks. Rapid eruption rates (i.e., over a few million years) according to Renne et al (1992) and Peate (1997) reflect adiabatic decompression melting in the convecting mantle whereas a much longer duration of igneous activity (perhaps over 10s million years) is associated with alkaline volcanism.

The Arapey Formation, almost 40,000 km2 in extent (Fig. 4), is mainly composed of medium- to fine-grained basaltic rocks of tholeiitic nature (Muzio 2004). These lava flows (Russo *et al.* 1979) are up to 1050 m thick, and correlate with the Alto Paraná Formation in Paraguay (450 m maximum thickness), Serra Geral Formation in Brazil (1700 m thick), and the Posadas Member of the Curuzú Cuatiá Formation in Argentina (185 m thick).

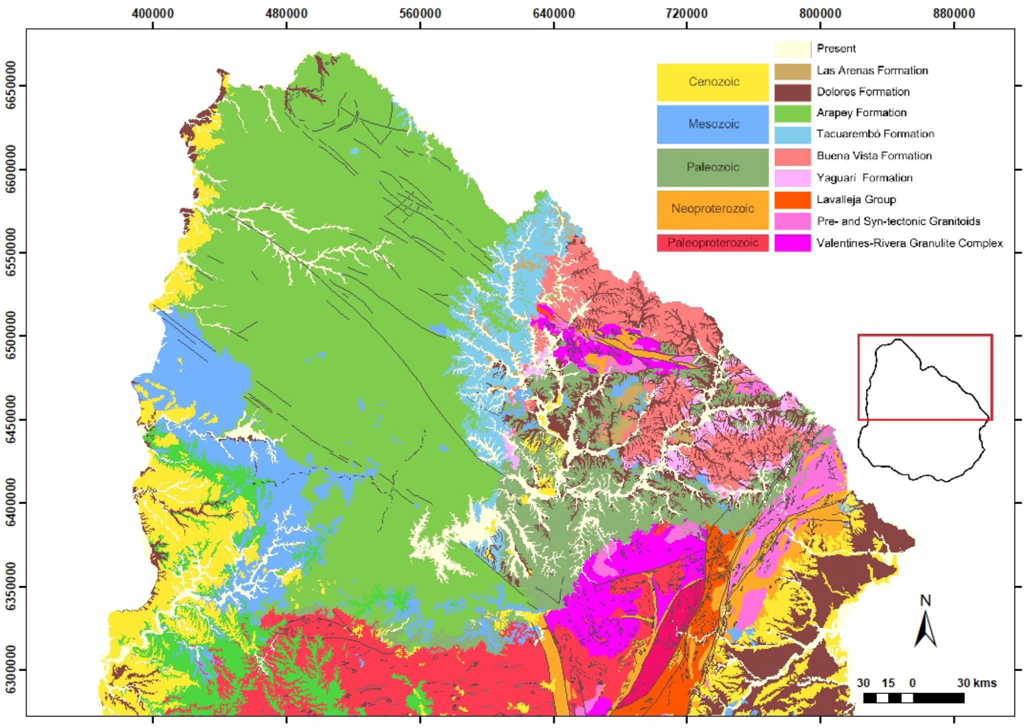

Figure 4. Geological map of northern Uruguay showing Arapey Formation distribution (green color). Based on Preciozzi et al (1985).

During the first phase of a geological survey of amethyst and agate occurrences in the northern Artigas Department conducted by DINAMIGE (Fig. 5), Techera *et al.* (2007) defined LCGD as an area of about 500 km2 located 50 km SE from Artigas city. These authors identified six spill basaltic flows about 200 m thick in total in that area, three of them rich in mineralized geodes (numbers 2, 3 and 4). Intercalating aeolian sandstones each 7 to 14 m thick were described between number 3 and 4 spills (Fig. 5).

Duarte *et al.* (2009) described both the Los Catalanes and Ametista do Sul districts as thinner (10–30 m) spill lavas (type I; Gomes 1996) with a massive internal portion containing a geode-bearing mineralized zone (Fig. 6). Thicker (30–60 m) layer lavas (type II; Gomes 1996) display vertical joints of colonnade and entablature types (Fig. 7). Upper and lower vesicular zones are present in both types I and II.

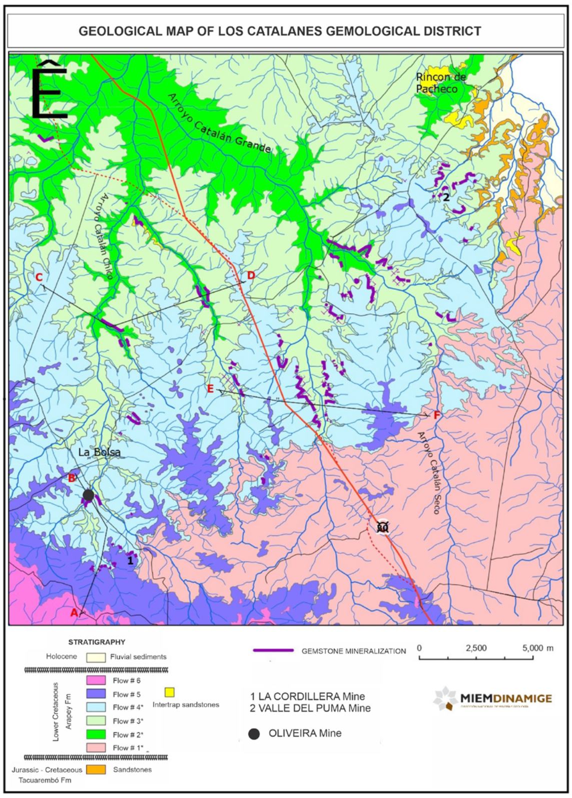

Figure 5. Geological map of the LCGD and localization of the Oliveira mine. Source: Techera et al (2007)

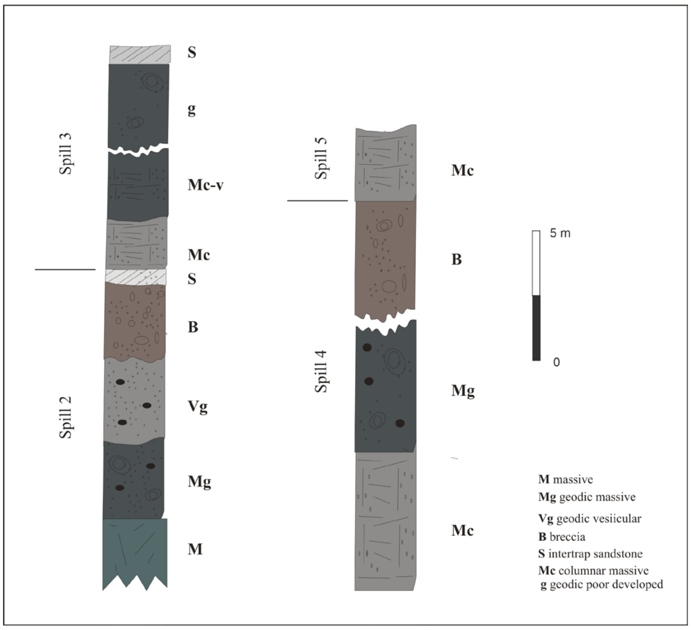

Figure 6. Internal structure sketch of basaltic mineralized flows in LCGD. Modified from Techera et al (2007)

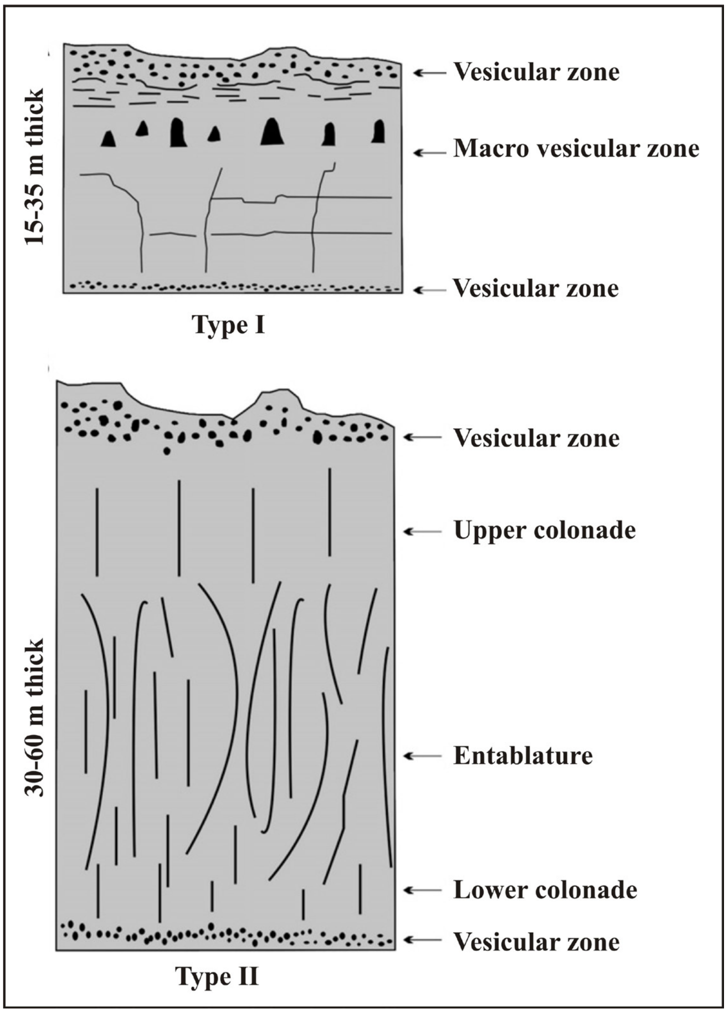

Figure 7. The internal structure of lava flows from the mining districts. A) Type I described by Gomes (1996); B) Type II, also named by Gomes (1996) and previous description by Long and Wood (1986).

Morteani *et al.* (2010) proposed that these mineral deposits were formed as protogeodes by bubbles of CO2-rich basalt-derived fluids. The formation of the celadonite rim and the

lining of the geodes by agate followed by quartz and amethyst were driven by the artesian water of the Guaraní aquifer percolating the basalts from below. The temperatures of the amethyst formation were estimated from fluid inclusion data to be between 50° and 120°C.

In a regional study of the Arapey Formation, Waichel *et al.* (2010) identified three types of extrusive patterns: pahoehoe, ‘a’a and massive. According to these authors, the predominance of pahoehoe flows at the base of the sequence in Uruguay indicates a low eruption rate established on soft paleosurfaces that must have facilitated the displacement of lava generating volcanic successions with great lateral extension. The overlapping ‘a’a effusions indicate an increase in the eruption rate and/or paleosurfaces with a steeper slope. Artigas geodes occur associated with thin ‘a’a flows.

Duarte et al (2011) proposed for the gemological district that two flows are mineralized, a basalt and a basaltic andesite (both low-Ti, Gramado type). Fluid inclusions, alteration mineralogy, and oxygen isotopes indicate the involvement of low-temperature fluids of meteoric origin in the formation of the geode fillings. Low sulfur isotope values on altered basaltic host rocks, down to -15%, indicate the involvement of sedimentary sulfur affected by bacterial sulfate reduction.

Da Silva (2011) reports the discovery of many gossans in the intraplate Paraná volcanic province, based on observations of satellite images and field work associated with rock geochemistry and geophysics. The study area is located on the border between Brazil and Uruguay and covers the mining district of Quaraí and the gemological district of Los Catalanes. Gossans also indicate a straightforward prospecting guide for agate and amethyst deposits in the subsurface.

Arduin *et al.* (2022) proposed three stages in the filling of the geodes based on mineralogy and fluid inclusion analysis. The first stage includes celadonite, zeolite, chalcedony, calcite, microcrystalline quartz, pyrite and chalcopyrite, the second macro-crystalline colorless quartz and amethyst, and the third stage late calcite and sporadic fluorite. The authors proposed an interaction between the lava flows and meteoric water.

Regarding the study of these mineral resources, Techera (2011) presents a mining report with special references to the gemstone quality properties of these deposits and economic data about export and main countries’ sales. The main markets for these gemstones are Germany, the United States of America, Brazil, and China, with exports reaching annually several million dollars.

Deposits of Amethyst Inventory Assessment

The inventory and quantitative assessment of geological heritage, the most valuable occurrences of geodiversity, are essential steps in any geoconservation strategy and the establishment of priorities in geosite management (Brilha 2016). Despite the existence of many geological heritage inventories at different scales, the inventory assessment proposed by Brilha (2016) was applied by Salles (2023) in LCGD focusing on the Oliveira Mine geosite. As mentioned above, the gemological district covers an area of about 500 square kilometers, but the Oliveira mine was chosen as the geosite, because of its amethyst mega geodes, location near a village, accessibility, and the support of the mining entrepreneur. It is located in the southeast of the department of Artigas, about 80 km from the city of Artigas, on a local road that connects by 15 km to the National Route #30. The relief in the area has typical features of a basaltic plateau, with an altitude of about 200 m above mean sea level. The Oliveira Mine Geosite is made up of a series of large (6–10 m wide by 3 m high) galleries over 1000 m in length. There are several in-situ amethyst irregular-shaped to oblate geodes (decametric to metric sizes) on massive dark gray basalt belonging to colada (or spill) # 4. Although the site has no legal protection, both mining and tourism operators have committed to maintaining the abandoned mine in a condition suitable for visits and education, without extracting gems from the mine in the future. The mine is equipped to receive groups of tourists with safety equipment, accompanied by local guides and led through the galleries to the exhibition and events (cultural, educational) rooms.

Salles (2023) was the first to show the scientific, didactic and touristic values of this geosite in a geopark project in that region (Botucatú Mining Geopark Project). Los Catalanes Gemologic District represented by de Oliveira Mine in the quantitative assessment of scientific value according to Brilha (2016) scored as a very important geosite, corroborating the IUGS decision.

Deposits of Amethyst Conservation And Valorization Initiatives

The Catalanes creeks in northern Uruguay are in a region with a mining tradition of more than a century. Currently, 30 mining companies employing hundreds of workers are producing world-class amethysts in about 80 quarries and mines. Three entrepreneurs (Mining Safari, Mining Tour and Los Catalanes Glamping) currently support geotouristic activities in abandoned mines. In addition, this district is one of the most important areas with archeological vestiges mainly from the supply of lithic material (gems and silicified sandstones) to produce both jewelry pieces and projectile points by early human cultures since the Pleistocene-Holocene transition (Suárez 2014). It is for these reasons that, in certain areas of the district, initiatives for visualization and valorization through cultural and mining tourism are carried out.

Los Catalanes Gemological District is defined as a complex area site sensu Fuertes-Gutiérrez & Fernández-Martínez (2010). Within this complex site, the Oliveira mine stands out by its exposure, number of galleries, size and quality of in situ geodes and gems. Two geologically important aspects of these deposits are related to the mining of gemstone resources (prospecting, exploration, mining methods, environmental impact) and scientific research on magmatic processes in preserved mining areas. An initiative to preserve part of the district in Oliveira mine has been developed by private entrepreneurs and contributes to geoscientific knowledge and geoconservation (Bruschi & Coratza 2018). Both touristic and mining entrepreneurs have even applied for and received funding to develop educational and tourist projects (Fig. 8A), improve infrastructure and develop internal interpretive signage (i.e., Tourism Ministry, Innovation and Research National Agency, Development National Agency, Fig. 8B).

A new cultural center called the Stone Museum (http://www.museos.gub.uy) is currently under construction in Artigas City with funding from the Ministry of Culture. Among other initiatives, the Botucatú Mining Geopark project located in northern Uruguay stands out, with amethyst deposits in Oliveira mine geosite as one of its main sites of geological interest.

Conclusions

The presentation of the "First 100 IUGS Geological Heritage Sites" in the context of the International Geoscience Programme of UNESCO is an important contribution to broader recognition of geoconservation worldwide (IUGS 2022). The designation of the amethyst deposits of Los Catalanes Gemological District (Artigas Department) as the first Uruguayan IUGS Heritage Site is an

Figure 8. Valorization and interpretation. A) Tourists visiting Oliveira mine Geosite B). Information panel explains gemstone characteristics and usages. Photos: Mateo Acosta.

important milestone for Uruguay. It is also a mark of recognition for the geoscience community and the promotion of research in geological heritage and the beginning of its geoconservation in the country.

Acknowledgments

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