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Research Paper

Approaching geodiversity and geoconservation in Argentina

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ABSTRACT

The geodiversity and geoconservation status in Argentina is herein presented considering the geodidactic potential and tourism activity as geosystem services. The Geological Interest Sites (GIS) identified by the geological and mining national survey, the Natural Protected Areas (NPA) supported by the national park administration and the World Heritage Sites (WHS) declared by UNESCO are analysed. The geological periods involved, materials -including minerals, rocks, fossils and soils- and the endogenic and exogenic processes preserved in GIS are highlighted as geodidactic functions. Despite the geodiversity richness, the country does not yet have any Global Geopark. How geodiversity is considered in official descriptions of NPA and their emblems as well as the type of UNESCO's WHS declared in the country is revealed. This analysis demonstrates that Argentinian conservation policies have traditionally been designed on an ecological basis, undervaluing the role of geodiversity for itself while underpinning its supporting geosystem service as habitat for flora and fauna. Only 3 out of the 72 GIS are both NPA and WHS, other 4 are only WHS, 16 are only NPA and 49 are just GIS, which means they are not protected under any national or international conservation category. Geoconservation analyses reveal the urgent need for a federal geoheritage law.

1. Introduction

Argentina, in the southern extreme of South America, is –on its continental area- 3694 km long and has a maximum width of 1408 km. It extends from latitude 21°46′S to 55°03′S and from longitude 73°34′W to 53°38′W. This represents a wide territory of 2,791,810 km^2. Besides, the Atlantic Ocean covers 4700 km of coast to the east and south and the Andes Cordillera is a natural borderline along 3500 km to the west (Fig. 1).

As a consequence of its latitudinal extent, from tropical to sub-Antarctic regions, Argentina has a climate variety (Iglesias de Cuello, 1980; Rubí Bianchi & Cravero, 2010) (Fig. 2A). Climate is controlled by latitudinal insolation variations and the influence of the South Atlantic permanent high-system pressure in the east and centre, and the influence of the South Pacific permanent high-system pressure in the west and south. The relief variations and the distance to the Atlantic Ocean are definitory factors affecting regional climates in the inland. Most of the 70% of the territory extends in the South American Arid Diagonal, a vast region where climates are arid or semiarid, and therefore, chemical weathering and running water processes contribute to the preservation of materials and landforms.

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Fig. 1. Location of Argentina in South America.

The territory of the country is conformed by 34 geological regions that can be seen in Fig. 2B (Ramos, 1999; Turner, 1979); 15 morphostructural units (Sayago, 1980; Fig. 3); 7 main geomorphological regions with 50 units (Pereyra, 2019); and the 12 soil orders of the Soil Taxonomy Classification (USDA-NRCS, 2006) are present, including gelisols in the cold regions to deep mollisols in the Chaco-Pampean plains (Alonso, 1980; Panigatti, 2010). All these geological, geomorphological and pedological features turn Argentina into a geodiverse country. The history of the geological setting of the Andes Cordillera and the Extra-Andean Basement includes 7 orogenic cycles with magmatic events, deformation, metamorphism and different paleogeographic conditions (Ramos, 1999b). As a result of multiple rock formation environments and tectonic activity occurring from the Paleoproterozoic in Pre-Cambrian and all along the geological history, the relief varies among mountains, volcanoes, ranges, tablelands, plains, basins and tectonic down-sinking blocks. The westwards movement of the South American plate from the mid-Atlantic ridge since Gondwanic times towards the Nazca and Antarctic plates and the consequent extensional and compressive tectonic movements cracking and folding oldest rocks. Together with subsidence among plates and volcano formations, these processes are the main ones which have created varied reliefs.

Materials, reliefs, and climates result in a wide range of landscape units distributed around the country exhibiting diverse natural landforms. Most regions show clear examples of endogenic or exogenic processes through which locals and visitors could approach the abiotic components of nature and its history.

According to Gray (2004), geodiversity is the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, processes) and soil features. Geodiversity offers 5 groups of geosystem services: regulating, supporting, cultural, provisioning and knowledge; in all, at least 26 values have been identified (Webber, Christie, & Glasser, 2006 in Gray, 2011). Among them, knowledge and culture are interesting for this paper. Regarding knowledge, understanding physical processes and learning about Earth's history are viable through geodidactics, i.e. the use of goods and services to provide and satisfy the demand for information (Millán Escriche, 2011; Pralong, 2009) and to make visitors sensitive through interpretation facilities, such as educational resources, publications and websites, visitors centres, self-guided touring, trails, viewpoints and apps (Migoń, 2018). In this sense, geodiversity offers possibilities to learn about the Earth's natural history and its dynamics; we refer to these as geodidactic functions (Coronato, Schwarz, and Flores Barrera, 2022; M'Barki and Benssaou, 2016; Schwarz, 2017). Regarding culture, leisure is included and geotourism is the specific type that lets visitors learn about geodiversity through the provision of interpretation facilities under the scope of Earth Sciences (Hose, 1995). Usually, these facilities are designed in outstanding georesources that are part of a country's geoheritage. In Argentina, geotourism is underdeveloped mainly because the potential of geodiversity and geoheritage is not completely established. Several public or private initiatives promote visits to in situ

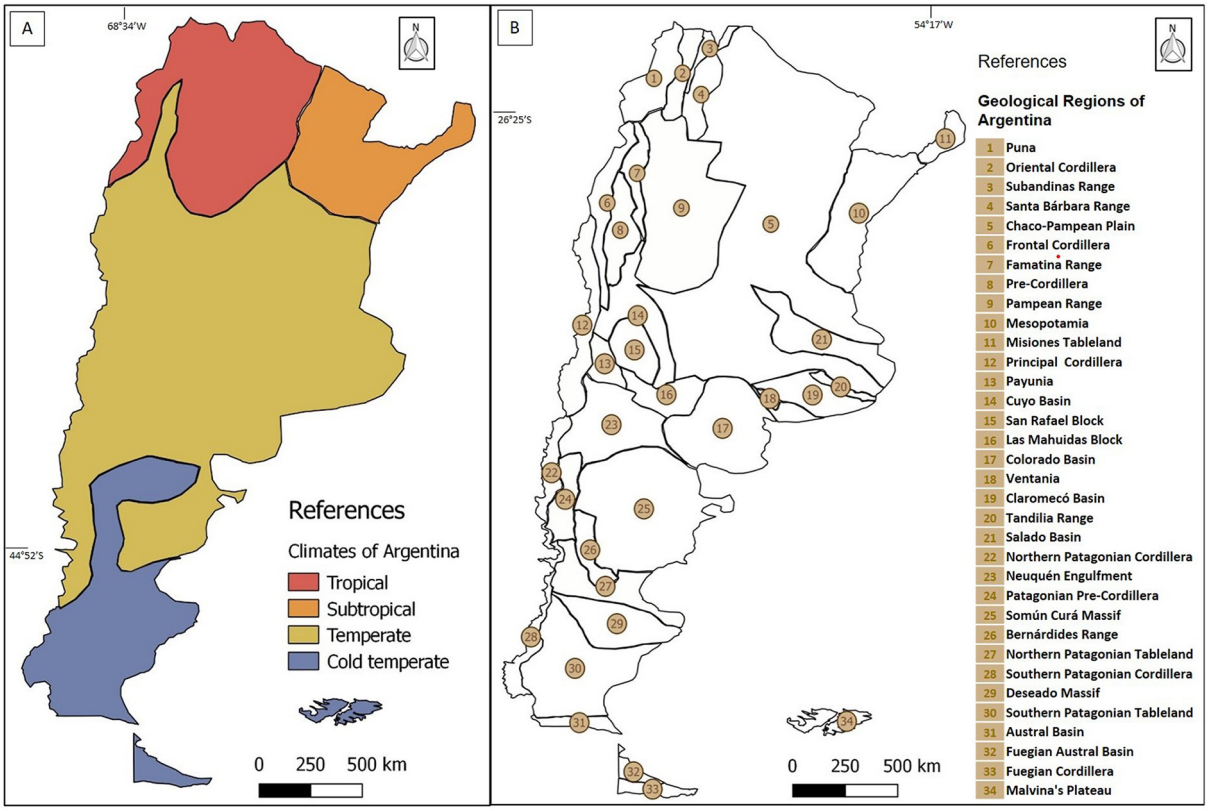

Fig. 2. A. Main climate types of Argentina after Iglesias de Cuello (1980). B. Geological regions of Argentina after Ramos (1999). The western regions follow the extent of the Andes Cordillera from north to south.

museums to know about fossil fauna remains (Vejsbjerg, 2015), petrified forests (Lech, Reinoso, and Marcus, 2017) or the oldest rocks exposed in Argentina (Camino, Gómez, Donna, Bó, and del Río, 2022). A few opportunities are offered through some Natural Protected Areas such as Ischigualasto Provincial Park and Talampaya National Park in the northwest of the country or at Monte León National Park in the southern Atlantic coast (Miranda, Panza, Sacomani, and Morosini, 2017). Other activities such as mineral collection exhibitions and geological pathways in nature are performed indistinctly by private, municipal or provincial institutions.

On the other hand, it is known that the concepts of biodiversity and ecosystem services are widely accepted especially within nature conservation circles (Gray, 2011). In the case of Argentina, the national government has contributed to nature protection since 1922 when the predecessor of the first national park was created. Since then, there is a government office that looks after Natural Protected Areas (NPA) of national jurisdiction that is called Administración de Parques Nacionales (APN). It recognizes 53 NPA under different conservation categories: parks, reserves, natural monuments and marine areas. Most of them have been settled on an ecological basis. Since 2003, the APN has integrated a federal system called Sistema Federal de Áreas Protegidas which includes provincial and municipal offices with their own regulations to protect local natural resources in more than two hundred areas. Despite the history of conservation throughout almost a century and the amount of areas, as it widely happens, "the existence and importance of abiotic nature often goes unrecognised and is certainly undervalued" (Gray, 2011, p. 1).

Witness of this situation is the fact that Argentina lacks a specific national law devoted to the protection and diffusion of geological and geomorphological sites. There is only one national law (N 25743) that penalises the extraction, transport and commercialization of fossils, i.e. palaeontological heritage. Despite the fact that this law somehow promotes geoconservation, it does not outline actions to foster the spread of geosciences. Moreover, it is not only devoted to Palaeontology but also refers to Archaeology. At a provincial scale, however, Medina, Vejsbjerg, and Aceñolaza (2016) studied the presence of geology in regulations about Natural Protected Areas and demonstrated that half of provincial laws include the importance of geological and geomorphological formations directly whereas 35% do it in an indirect way, in the rest 13% geology is completely absent.

Together with these described facts, there are no Global Geoparks declared by UNESCO in Argentina, although some initiatives are being considered, as Pillán Mahuiza in the northern Patagonian Andes (Carut, Torre, Moscoso, and Carut, 2017) or Pun Antü in the Tandilia ranges (Camino et al., 2022; Del Río et al., 2017). Anyway, and considering UNESCO as a conservation agent, it is needed to say that the country hosts 11 World Heritage Sites (WHS).

Additionally, the terms geodiversity and geoheritage are not well renowned among the Argentine society. Academic circles have started to explore the theme since the late 90's in very specific sites or processes. One of the most important initiatives was carried out by the Instituto de Geología y Recursos Minerales and the Servicio Geológico y Minero de Argentina -the national

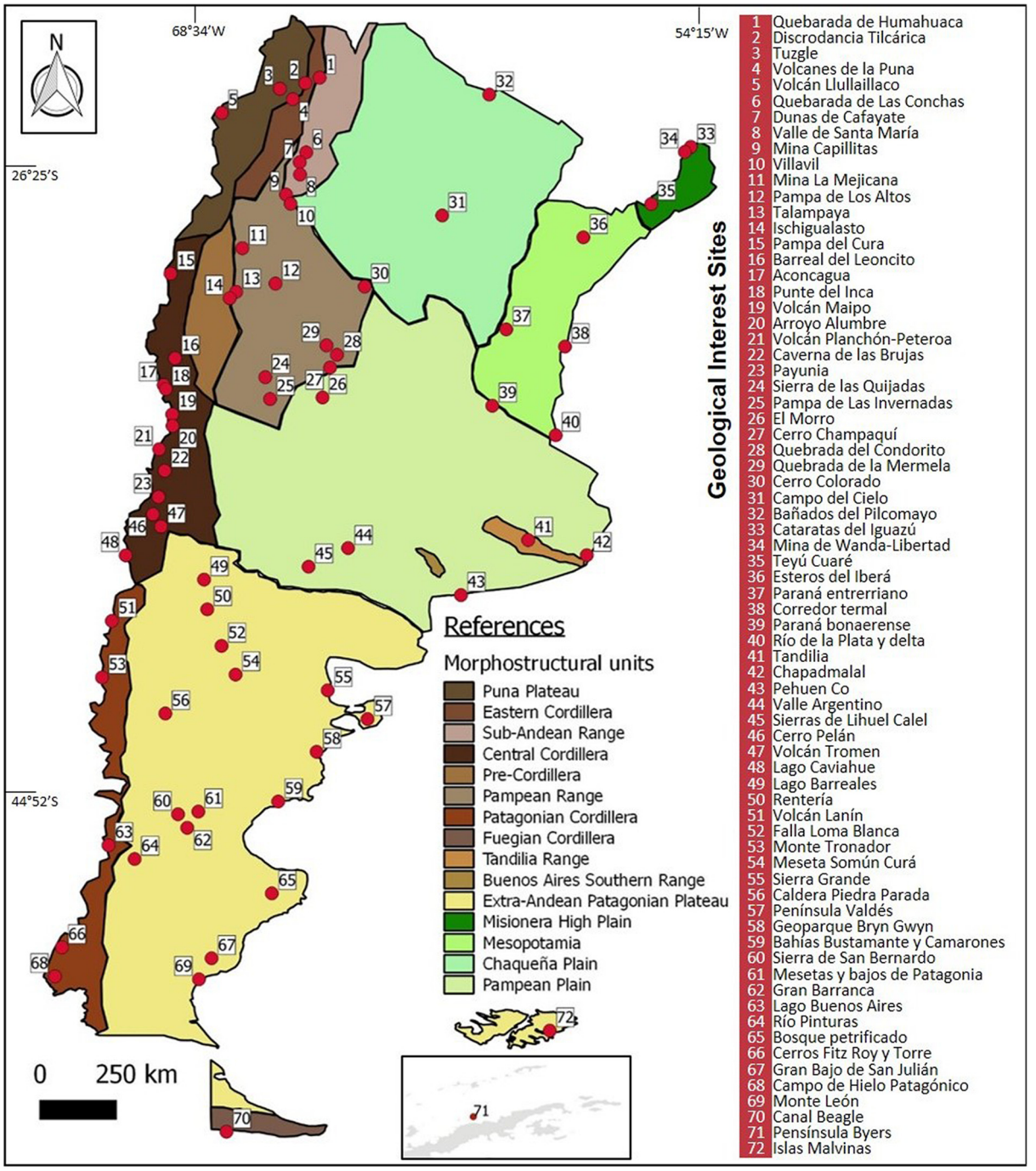

Fig. 3. Distribution of the 72 Geological Interest Sites after Comisión de Sitios de Interés Geológico de la Argentina (CSIGA) (2008) located in the morphostructural units of Argentina (Sayago, 1980). Part of the Antarctic Peninsula and Subantarctic Islands are also shown: out of scale.

geological and mining survey (Comisión de Sitios de Interés Geológico de la Argentina [CSIGA], 2008): 72 Geological Interest Sites (GIS) were selected after a direct inquiry made to the geological community (Fig. 3). GIS are defined as those places which are especially appropriate because of their exposure or content to recognise and interpret the geological processes involved in the Earth's formation (Mendía, 2008). The GIS were described by scientists in order to contribute to their knowledge and preservation; tourist use stands out in many of these sites. In fact, in the field of tourism, geotourist enterprises have been proposed during the last decade in many of them. Though this list of sites integrate part of the Argentine geoheritage, it does not imply any kind of protection for itself. As Gray (2018) states "geoheritage is a value-laden term to identify those specific elements of geodiversity that are selected for geoconservation" (p. 15). However, geoconservation practices are not explicitly defined in most of the GIS.

Another milestone took place in 2002, when the first symposium devoted to geological heritage was held in the frame of the Argentine Geological Congress (AGC). In 2013, Argentina celebrated the First Symposium on Geological Heritage, Geoparks and Geotourism. This event promoted the inclusion of a thematic session on the topic from 2014 onwards in the AGC, which congregates mainly geologists, geographers and tourismologists all along the country, every 3 years. Some other important events in Argentina as regards the development of geoheritage and its conservation were reviewed by Miranda, Lema, and Mendía (2016).

Among the scientific progress on geodiversity and geoheritage, several papers and reports deal on assessment methodologies (Medina, 2015; Romanelli et al., 2017; Schwarz and Coronato, 2018, 2019; Soliz, López de Azarevich, Alonso, and Azarevich, 2022; Vejsbjerg, 2015), on the proposal of geosites devoted to specific materials or processes (Coronato et al., 2022; Cortez Taillant and Arroqui Langer, 2021), or even, in the identification of urban geosites (Leguizamón, Gil, and Gil, 2018). Previous works have not studied geodiversity considering variety, frequency and distribution (Carcavilla, López Martínez, and Durán Valsero, 2007) at a national scale.

In light of this panorama, we pretend to analyse geodiversity resources comprised in the 72 GIS of Argentina, considering their geodidactic potential and tourism as geosystem services. We also want to explore the state of geoconservation through Natural Protected Areas (NPA) of national jurisdiction as well as the UNESCO World Heritage sites.

2. Methods

In order to analyse geodiversity resources of Argentina, the list of 72 GIS and their descriptions provided by Comisión de Sitios de Interés Geológico de la Argentina (CSIGA) (2008) was mapped using *QGIS 2.18* and assessed focusing on the following criteria: the type of materials, processes and geological times as geodidactic functions, the existence of conservation categories at different levels and the current tourist use as a geosystem service. As shown in Table 1, the analyses of each GIS included: a. the geological periods in which the components of each GIS were formed; b. the materials as rocks, minerals, fossils or soils; c. the morphological processes classified into endogenic and exogenic, the former includes plutonism, volcanism, tectonism and seismicity whereas the latter includes glacial, periglacial, fluvial, aeolian, lacustrine, littoral, karst and mass wasting; d. the protection level considering international, national, provincial, municipal or none; and e. the tourist use whether the GIS is visited directly, indirectly or it is not.

In order to explore how geodiversity is considered in the NPA of national jurisdiction we compiled the available information of the 53 areas provided by the official website[1] in May 2022. We considered their name, location, conservation category, creation year and legal instrument. After this, we analysed different characteristics throughout their descriptive files and emblems. The latter are distinctive marks that represent each area based on aspects that have special conservation values for the APN, including: a- species of flora and fauna, b- features of the landscape like reliefs and fossils, and/or c- cultural resources. We consider a- as biodiversity, b- as geodiversity and c- as culture. In the case of b, we distinguished 3 categories: intrinsic value, value as a habitat and scenic value. Elements were qualified with "1" if they were mentioned in the official descriptions or with "0" if not (Table 2).

The emblems were analysed by two means: their official description and the shot in which the different elements appear in the picture, if in the foreground, in the background or not. The content described in each emblem was classified considering

Table 1
Data collection matrix to assess Geological Interest Sites. Geological time, materials and processes are considered geodidactic functions while regulations and tourism complement the analysis of geoconservation aspects.

Geological Interest Sites of Argentina (GIS) according to Servicio Geológico Minero Argentino (SEGEMAR) (2008)				Geological time	Materials				Endogenic processes				Exogenic processes								No. of geodidactic functions	Regulations					Tourist use	
No.	Name	Region	Province		Minerals	Rocks	Fossils	Soils	Plutonism	Volcanism	Seismicity	Tectonism	Glacial	Periglacial	Fluvial	Aeolian	Lacustrine	Littoral	Karst	Mass-wasting		No regulation	International	National	Provincial	Municipal	Yes	No
1																												
2																												
3																												
4																												
5																												
6																												
7																												
8																												
9																												
…																												
72																												

[1] https://www.argentina.gob.ar/parquesnacionales

the presence ("1") or absence ("0") of birds, other fauna, flora, culture or geodiversity elements. The shot analysis included biodiversity, geodiversity or culture as they appear in the emblem itself, considering "1" if they are in the foreground, "2" in the background or "0" if they are absent (Table 2).

The WHS analysis was based on the cultural and natural site type definition using UNESCO's descriptions in the official website[2] with the available information in May 2022. We classified natural sites according to UNESCO's criteria applied for the selection, i.e. criteria vii: superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance; criteria viii: outstanding examples representing major stages of Earth's history or significant geomorphic or physiographic features; and criteria x: relevant for in situ conservation of biological diversity, including those containing threatened species of outstanding universal value. Besides, we pointed out if each WHS was included in a NPA and/or if it was part of a GIS. This analysis follows the structure of Table 3.

All the data obtained through the three tables was processed using quantitative content analysis (Hernández Sampieri, Fernández Collado, & Baptista Lucio, 2006), which means selecting criteria before the data collection. The data was analysed by descriptive statistics, obtaining percentages and frequency distributions, using Microsoft Excel tools.

Table 2
Data collection matrix for geoconservation appraisal based on official descriptions and emblems used to promote the visit of Natural Protected Areas of national jurisdiction, after Administración de Parques Nacionales de la República Argentina (2022).

NPA		General description					Analysis through descriptive files of APN													
							1. Elements valued in descriptions (1 if mentioned, 0 if not)					2. Emblems								
No.	Name	Source	Province	Conservation category	Creation year	Legal instrument	Biodiversity	Geodiversity			Culture as a complement	Elements described (1 if mentioned, 0 if not)					Elements according to the shot (1 foreground, 2 background, 0 none)		
								Intrinsic value	As habitat	Scenic value		Birds	Other fauna	Flora	Culture	Geodiversity	Biodiversity	Geodiversity	Culture
1																			
2																			
3																			
...																			
53																			

3. Results

3.1. Geodiversity resources throughout Geological Interest Sites (GIS)

Diversity of GIS comprises time, materials and processes. These three aspects are understood as geodidactic functions, included in one of geodiversity's geosystem services: knowledge.

After analysing the 72 GIS, it is possible to state that Argentina's valuable identified geodiversity includes features from different geological times, through the Pre-Cambrian up to the Quaternary. The oldest materials and reliefs, i.e. that started to be formed in Pre-Cambrian and Permian times, conform many of the lower elevation ranges of the country while the youngest materials and processes from the Quaternary reveal volcanism, fluvial, aeolian, mass wasting, littoral and glacial genesis in a vast territory, from the mountains to the plains and coasts. The Quaternary is the most represented period in the GIS due to the persistence up to the present of materials and landforms originated in that time, mainly in those regions where semi-arid climates preserve rocks and sediments from weathering and erosion (Fig. 4).

In terms of diversity of geological periods, only one site, Quebrada de Humahuaca (GIS#1 in Fig. 3; Fig. 5) is the most representative since it preserves materials that belong to 12 geological periods out of the 13 considered. On the contrary, more than half of the GIS include materials or processes of only one or two periods (Fig. 6A). Among them Quaternary is the most representative period (80,8%), followed by the Neogene (Fig. 6B).

Considering materials valued in GIS (Fig. 7A), minerals are the less represented category and soils are not even represented. Several groups of ranges are formed by Precambrian granites; basalts and sedimentary rocks shape the Patagonian tablelands;

[2] https://whc.unesco.org/en/list/

Table 3
Data collection matrix to determine the role of geodiversity in World Heritage Sites, after UNESCO (2022). Criterias have been explained in Section 2 (Methods).

No.	Name	Creation year	3. Cultural site	4. Natural site after criteria:			5. Is it a NPA?	6. Is it a GIS?
				vii	viii	x		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								

metamorphic schists are found along the Andes mountains. Plants as well as invertebrate and vertebrate fossils of various ages are preserved in marine and continental sedimentary rocks in 30% of the sites. As an example, a special mention must be made to the rich Triassic fossiliferous content of plants and vertebrates at the in situ museum of Ischigualasto (GIS#14 in Fig. 3) and guided tours in Talampaya (GIS#13 in Fig. 3). Other GIS, Centro Paleontológico Lago Barreales (GIS#49 in Fig. 3), shows fluvial Cretaceous ecosystems through plants, fishes, turtles, crocodiles, pterosaurs and world biggest herbivorous and carnivorous saurus (Calvo, Sánchez, Heredia, and Porfiri, 2008); while Geoparque Bryn Gwyn (GIS#58 in Fig. 3) is one of the classic paleontological sites

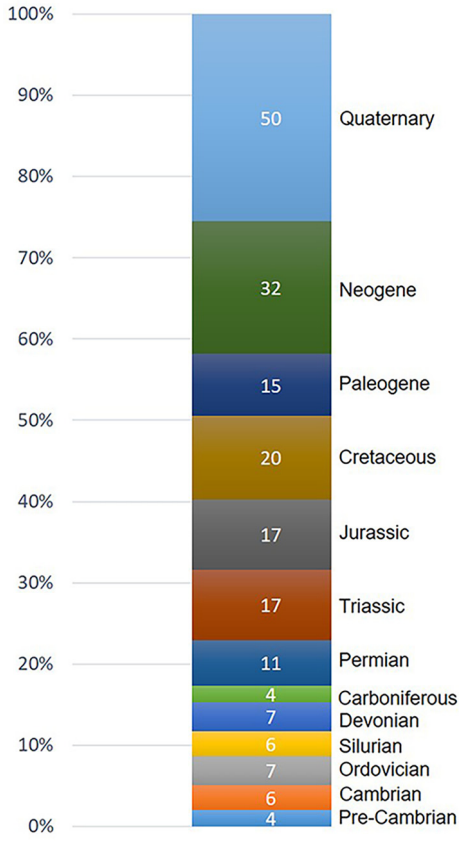

Fig. 4. Geological periods' occurrence in the 72 Geological Interest Sites.

Fig. 5. Sector of Quebrada de Humahuaca Cultural World Heritage Site, located at #1 in Fig. 3 (photo by the authors). Multiple colours of rocks testify the diversity of geological periods along 600 million years.

devoted to the Paleogene-Neogene in South America (Cúneo, 2008) including insects, marine invertebrates, marine and terrestrial birds and mammals and extinguished fauna as bears and marsupials. This GIS includes the term "geopark" in its name, but it is actually not part of the Global Geopark Network. Minerals and metals such as iron, gold and copper appear only in a few GIS. Silica in Bosque Petrificado (GIS#65 in Fig. 3) stands out after its function on the fossilisation process of the arboreal flora. Mina Capillitas (GIS#9 in Fig. 3) preserves metallic and non-metallic minerals, among them, rhodochrosite exhibits a wide palette of classical tones but also includes white brownish as proper of the locality (Márquez Zavalía, 2008) due to the strong enrichment in iron and zinc oxides at the expense of manganese oxide. Rhodochrosite, also known as the Inca rose stone, is pointed out as the national stone in Argentina. Campo del Cielo (GIS#31 in Fig. 3) preserves metals contained in big meteorite fragments, some of them of 3 tons, fallen 5,800 years BP (Villar and Asato, 2008).

Endogenic and exogenic modelling processes are very well represented in the GIS list (Fig. 7B and C, respectively). Seismicity is the only absent among the former, although the W of Argentina is seismically active, and several examples of this process are available in many GIS. Tectonism is best represented due to the convergent movement between the South American, Nazca

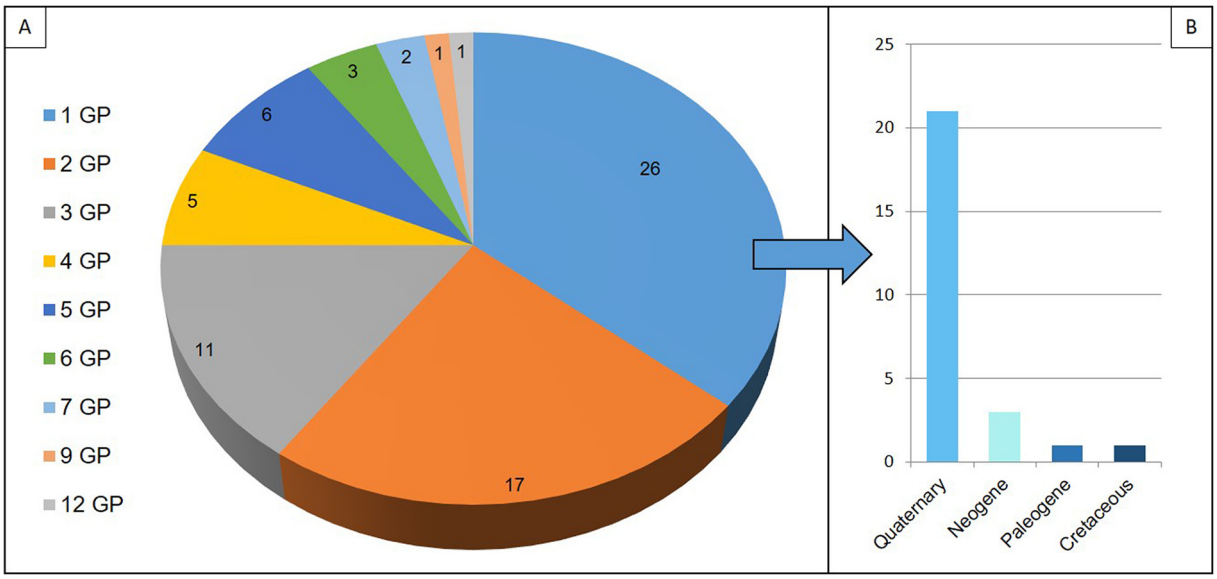

Fig. 6. A. Number of Geological Interest Sites (GIS) ($N = 72$) that include 1 to 12 geological periods (GP). Through the 13 periods considered, 12 is the maximum in only one GIS. B. The 26 GIS that represent only one geological period are mainly from the Quaternary (81%).

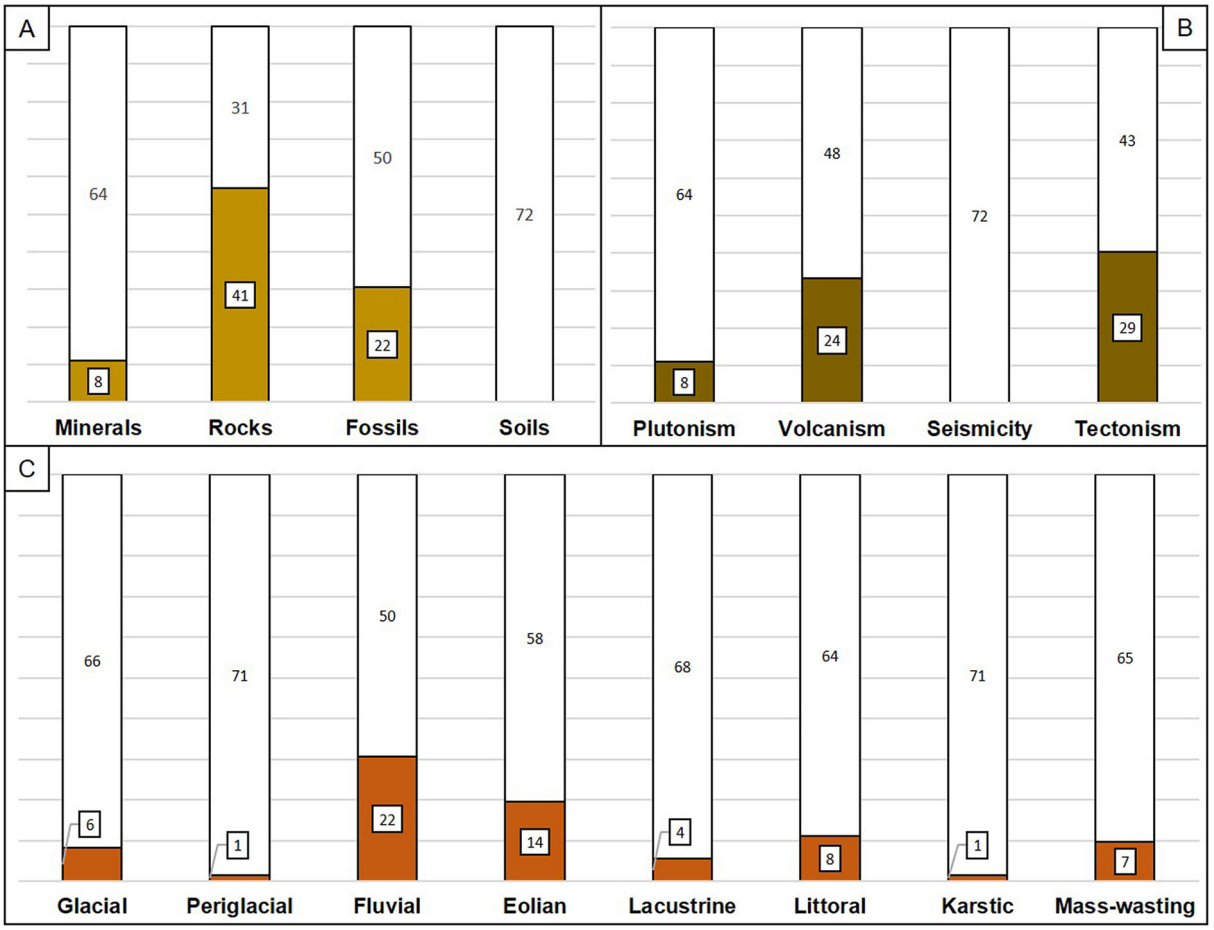

Fig. 7. Geodidactic functions present in Geological Interest Sites (GIS). A. Number of GIS according to the type of materials. B. Number of GIS according to the type of endogenic processes. C. Number of GIS according to the type of exogenic process.

and Antarctic plates and the consequent genesis of mountains, volcanoes and ranges, also because of vertical movements and basin formation. Volcanism is important and very well distributed along time and around the territory. The provision of magmas by fissures and monogenetic volcanic systems in GIS such as Puna in the north (GIS#4 in Fig. 3), Payunia in the centre (GIS#23 in Fig. 3) and Lanín in the south (GIS#51 in Fig. 3) contributed to the genesis of different volcanic materials and landforms of varied age, from the Jurassic to the Quaternary (Ramos, 1999a). In relation to exogenic processes, most of them are well represented along the territory (Fig. 8). Quaternary and present fluvial processes occur in those GIS located in the eastern plains. Waterfalls, fluvial cliffs and wetlands are also low gradient landscapes located in tropical and subtropical climate domains and enhance fluvial geodiversity. Aeolian processes created erosion and accumulation landforms in GIS located in semi-arid or temperate regions as Barreal del Leoncito (GIS#16 in Fig. 3; Cortés, Yamín, and Pasini, 2008) and Dunas de Cafayate (GIS#7 in Fig. 3; Rivelli, 2008). Besides, ancient aeolian processes have formed extensive and thick sandstone units representing a huge Triassic-Jurassic sand desert valued at Teyú Cuaré (GIS#35 in Fig. 3; Marengo, 2008), as well as loess units which shaped the very extensive eastern plains of the country and preserved extinguished Pleistocene mammals remains (Voglino, 2008). Littoral processes are included in those GIS located along the present deltaic and marine environments in GIS such as Río de la Plata y Delta (GIS#40 in Fig. 3; Violante, Cavallotto, and Kandus, 2008), Bahías Bustamante and Camarones (GIS#59 in Fig. 3; Ardolino, Busteros, Fauqué, Franchi, and Lema, 2008) at the Patagonian Atlantic coast and Canal Beagle (GIS#70 in Fig. 3; Bujalesky, Coronato, Rabassa, and Acevedo, 2008). Most of them can not only teach about coastal dynamics but also about Quaternary marine environments through landforms and fossils. Glacial processes are mainly restricted to the Patagonian cordillera environments. Cirque, discharge and ice-sheet type glaciers are present in the mountainous landscape but also ancient glacial landforms as nested morainic arcs remain in the landscape pointing out that drastic climatic changes occurred in the planet in the most recent geological time. These are the cases of Cerros Fitz Roy y Torre (GIS#66 in Fig. 3; Kosmal and Miranda, 2008), Campo de Hielo Patagónico (GIS#68 in Fig. 3; Malagnino, 2008) and Lago Buenos Aires (GIS#63 in Fig. 3; Escosteguy and Gema, 2008). The less represented exogenic processes are karst and periglacial. The former is represented in the west of Argentina by Caverna de las Brujas (GIS#22 in Fig. 3), the unique GIS devoted to highlight karstic landforms and processes (Barredo, 2008). Though other caverns and underground rivers exist in some more regions, they have not been valued yet as GIS. However, Cortez Taillant and Arroqui Langer

Fig. 8. Examples of Geological Interest Sites (GIS) that can teach about different materials. A. Gemstones in "Minas de Wanda" (GIS#34 in Fig. 3), located in "Misiones tableland" geological province (photo photo by the authors). B. Dinosaurs' fossils in "Northern Patagonia tableland" geological province, exposed at Carmen Funes Museum, Plaza Huincul city (photo by L. Vejsbjerg). C. "Lanín volcano" (GIS#51 in Fig. 3) as an example of endogenic landforms in the Northern Patagonian Andes (photo by the authors). D. The only karstic cave identified as a GIS in "Caverna de las Brujas" (GIS#22 in Fig.3), in the Central Andes (photo by. A. Cobo, retrieved from https://tintero.com.ar/). E. Aeolian landscape in pediments (GIS#16 in Fig. 3) at the foot of the Central Andes (photo by the authors). F. "Fitz Roy mount" (GIS#66 in Fig. 3) which is part of the Andean batholith in the Southern Patagonian Andes geological province (photo by the authors).

(2021) recently proposed a geotourist route based on karst sinkholes landscape in the surrounding of the aforementioned GIS. Although periglacial processes are common in the summits along the Andes, no GIS was defined focussing on them. The only GIS which preserves ancient periglacial landforms is Islas Malvinas (GIS#72 in Fig. 3), where inactive stone rivers formed by Palaeozoic quartzite sandstone irregular blocks occur over gentle slopes (Mendía, Anselmi, and Negro, 2008). Their spectacular development caught the attention of Charles Darwin (1846) who firstly described them from a geological point of view.

After analysing the materials and processes included in the 72 GIS, it results that most of them (75%) offer 1 to 3 geodidactic functions, indicating they are very specific and reveal singularity. For example, Lago Buenos Aires (GIS#63 in Fig. 3) can teach about the glacial processes by which the most complete morainic system of the Plio-Pleistocene glaciations is represented in Argentina (Escosteguy and Gema, 2008). Villavil (GIS#10 in Fig. 3) shows factors controlling active and high velocity landslides triggered in sedimentary rocks as strata tilted in the same angle and direction of the slope, fractures and seismic activities (Fauqué, Tchillinguirián, and Yamin, 2008). Valle Argentino (GIS#44 in Fig. 3) preserves a group of dunes of varied types and ages formed by winds coming from different quadrants (Silva Nieto, Montalvo, Zárate, and Szelagwoski, 2008), teaching the variability of wind directions along the Quaternary and its influence in the landscape modelling. The remaining 25% of GIS offer between 4 and 9 geodidactic functions giving the chance to learn about multiple materials and processes and offering the knowledge of landscape dynamics. As an example, the following GIS could be mentioned: Quebrada de Humahuaca (GIS#1 in

Fig. 3) has 9 geodidactic functions, while Gran Bajo de San Julián (GIS#67 in Fig. 3) has 6 geodidactic functions and Cerros Fitz Roy y Torre (GIS#66 in Fig. 3) has 5 geodidactic functions.

In most of the GIS (69%) tourism is developed at different levels, some of them receive thousands of visitors every year and some are just in between other attractions and are only used in an indirect way. For instance, Península Valdés (GIS#57 in Fig. 3) in the south and Esteros del Iberá (GIS#36 in Fig. 3) in the northeast are examples of famous tourist destinations, very well consolidated. However, their real geodiversity values are not fully exploited due to the prevalence and interest in their biodiversity resources (Fig. 9 A and B respectively). A good example of the wise use of geodiversity resources by tourism is the provincial park Ischigualasto (GIS#14 in Fig. 3) in the northwest of the country, where public institutions carry out geotourism activities around fluvial and aeolian landforms; they even include a modern in situ museum that values the fossiliferous richness of the region (Fig. 9 C). In the other sense, GIS as Quebrada de las Conchas (GIS#6 in Fig. 3) in the northwest and Caldera Piedra Parada (GIS#56 in Fig. 3) in the southwest only offer a few basic services to satisfy a limited demand. The former is basically located on the main road to access Cafayate City, devoted to cultural tourism (Fig. 9 D and E respectively).

3.2. The role of geodiversity in Natural Protected Areas and World Heritage Sites

Some GIS have different levels of protection through multiple conservation categories. Many of them are listed as NPA included in the federal system of Natural Protected Areas and just a few are also recognised by UNESCO as WHS. The role of geodiversity in these two categories is studied to analyse the state of geoconservation, as it follows.

The APN is the main governmental agency in charge of nature conservation in federal jurisdiction (Law No. 22351). It protects 53 areas under the following categories: 39 parks, 6 reserves, 6 natural monuments and 2 marine areas. The whole group of 53

Fig. 9. Available facilities for developing tourism in some Geological Interest Sites (GIS). A. "Península Valdés" (GIS #57 in Fig. 3), (photo by the authors). B. "Esteros del Iberá" (GIS#36 in Fig. 3), (photo by M.N. Catalán Unrei). C. "Ischigualasto" (GIS#14 in Fig. 3), (photo by the authors). D. "Quebradas de las Conchas" (GIS# 6 in Fig. 3), (photo by G. Espeche Ortiz, retrieved from https://cronicasdelsur.com/). E. "Piedra Parada" (GIS # 56 in Fig. 3), (photo by B. Wengier).

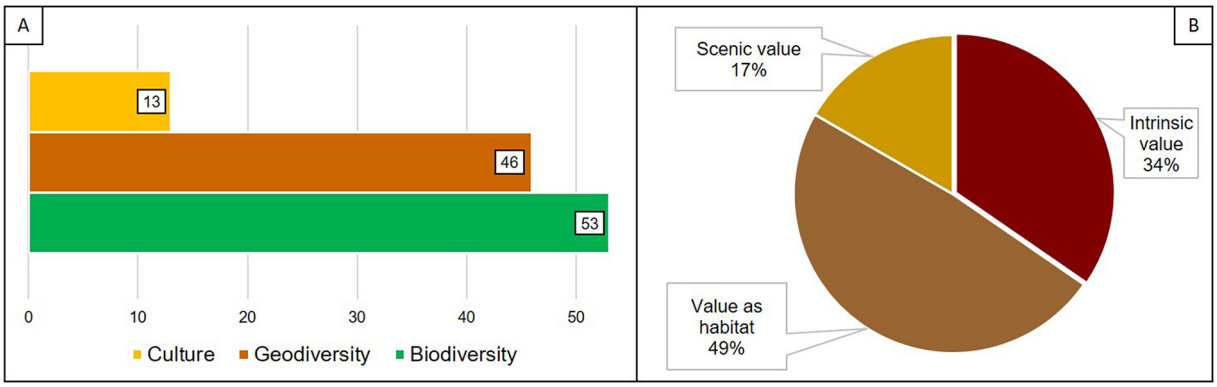

Fig. 10. A. Number of Natural Protected Areas of national jurisdiction (NPA) that value different elements included in each category. B. Roles of geodiversity in the NPA descriptions.

NPA are described using biodiversity elements, only 13 mention cultural elements and 46 recall geodiversity elements (Fig. 10A). As to the roles of geodiversity in these cases, its value as habitat is included in 49% of the times, whereas its intrinsic value appears in the 34% and its scenic value in the 17% (Fig. 10B). Recognising geodiversity for its role as habitat for protected flora and fauna reinforces the idea that abiotic nature is mainly appreciated after its supporting geoservice. Most NPA recognise geodiversity in only one role. Moreover, only 8 NPA of the total recognise the 3 geodiversity roles. Seven of these are also included as part of the GIS list and are located in the GIS map (Fig. 3): Talampaya (GIS#13), Sierra de las Quijadas (GIS#24), Cataratas del Iguazú (GIS#33), Volcán Lanín (GIS#51), Bahías Bustamante y Camarones (GIS#59), Campo de Hielo Patagónico Sur (GIS#68) and Canal Beagle (GIS#70).

The parks and reserves include an emblem as a distinguishing mark; some examples are shown in Fig. 11A. Biodiversity is represented in the 100% of them, while culture is in the 15% and geodiversity only in the 13% (Fig. 11B). Emblems describe 87 elements, out of which only 8% refer to geodiversity (Fig. 11C), specifically they are canyons, gullies, glaciers, fossil trees, mountains and cliffs. Most elements (84%) are biotic: 38% represent flora, 30% birds and 32% other fauna.

If the shots in emblems are considered (Fig. 12), foregrounds are dominated by biodiversity elements (98%). On the contrary, geodiversity icons appear only once (a petrified forest which corresponds to Bosques Petrificados (GIS#65 in Fig. 3), in the southeast of the country. On the other hand, geodiversity elements appear in 80% of the backgrounds, underpinning -again- its supporting service. Geodiversity is not part of 18% of the emblems. Culture is the less represented element since it does not even appear in 85% of the cases, which seems to be correct since APN is mainly devoted to nature.

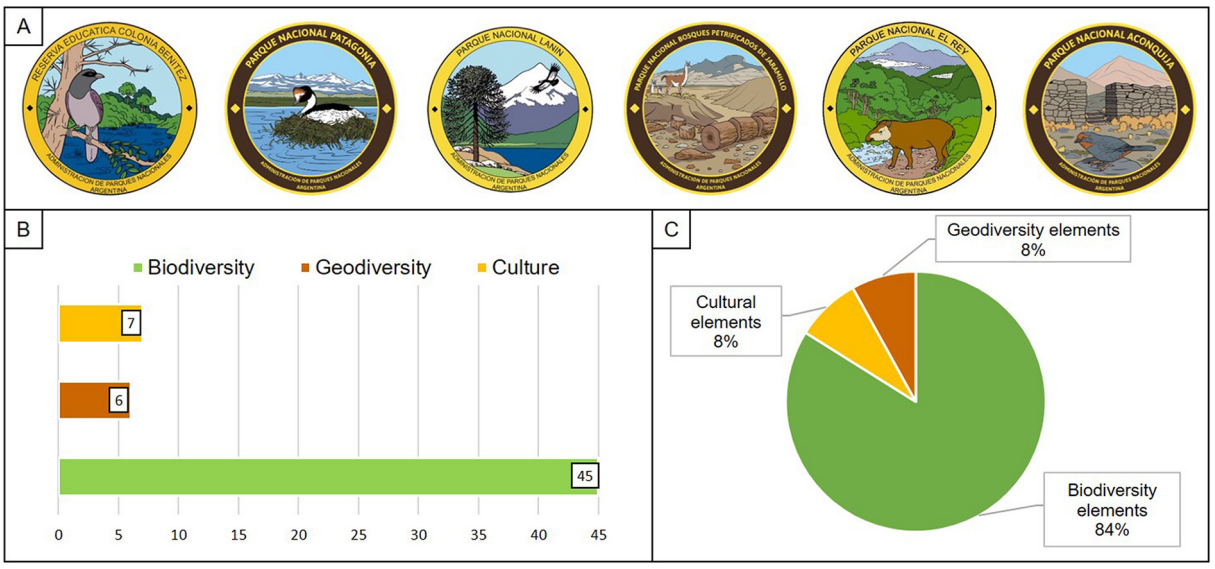

Fig. 11. The role of geodiversity in Natural Protected Areas of national jurisdiction. A. Emblems of some of the national parks. B. Number of emblems that include the 3 different contents. C. Type of elements included in the emblems.

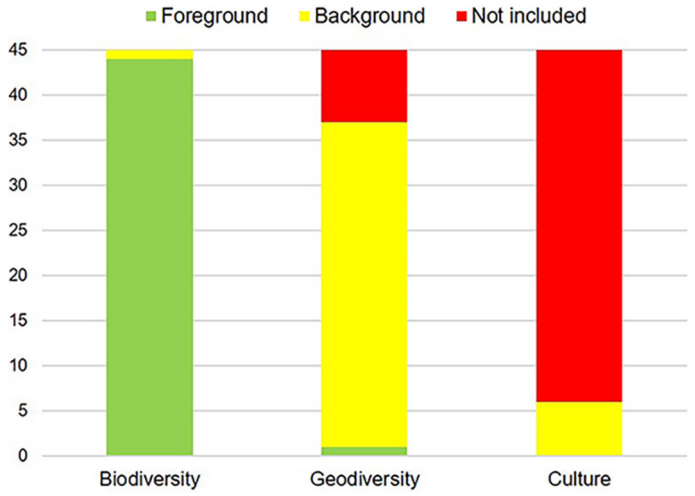

Fig. 12. Type of elements according to the different shots in the 45 emblems considered in Natural Protected Areas of national jurisdiction.

Regarding the 11 WHS declared in Argentina, 5 are natural. After analysing UNESCO's descriptions and the criteria applied for the selection, it is clearly seen in Table 4 that the intrinsic value (criteria viii) of geodiversity is considered only in 2 WHS. These sites preserve aeolian landforms, rocks and fossils or glacial landscapes. In most WHS, geodiversity stands out because of its scenic beauty (criteria vii). Península Valdés (located in GIS#57 in Fig. 3) is specially recognised because of its relevant biodiversity though it is formed by several depressions below the sea level, extensive field dunes, high rocky cliffs and marine pleistocene cliffs and beaches, representing an excepcional example of marine and terrestrial processes relationships (Codignotto, 2008) occurred in the Argentine Atlantic coast during the Postglacial times, between 19,000–6,000 years BP.

Table 4
Characteristics of the Natural World Heritage Sites declared in Argentina. Criterias have been explained in Section 2 (Methods).

Natural WHS by UNESCO	GIS in Fig. 3	Criteria vii	Criteria viii	Criteria x
Iguazú National Park	GIS#33	✓		✓
Ischigualasto/Talampaya Natural Parks	GIS#14-13		✓	
Los Alerces National Park	Not a GIS	✓		✓
Los Glaciares National Park	GIS#68	✓	✓	
Península Valdés	GIS#57			✓

3.3. How are GIS protected?

As it was presented before, geodiversity is explicitly valued in the 72 GIS (Comisión de Sitios de Interés Geológico de la Argentina [CSIGA], 2008) distributed through most of the geological regions, climates and morphostructural units of the country (see Figs. 2 and 3). These identified GIS definitely compose Argentina's geoheritage. However, it is necessary to reinforce that this list is an academic selection of sites which does not imply geoconservation by itself. Nevertheless, almost 54% of the GIS or part of them are regulated with multiple aims (i.e. archaeological, historical, mining), and categories (municipal, provincial, national or international). Those which are not under any type of regulations (the other 46%) include marine and terrestrial fossils, minerals (several under mining) or active landforms such as migrating dunes, flooding or landslides. Fortunately, most of the GIS with more geodidactic functions have some type of protection, except for Gran Bajo de San Julián (GIS#67 in Fig. 3), a − 150 m sea level endorheic depression, located in private lands, that contains abundant marine and terrestrial fauna and flora remains and yet has not been included under any protection category. A special mention must be made to Quebrada de Humahuaca (GIS#1 in Fig. 3, Fig. 5): this is the only GIS under the four possible regulation levels and, as it was already said, offers the maximum amount of geodidactic functions, including 12 out of 13 available geological periods.

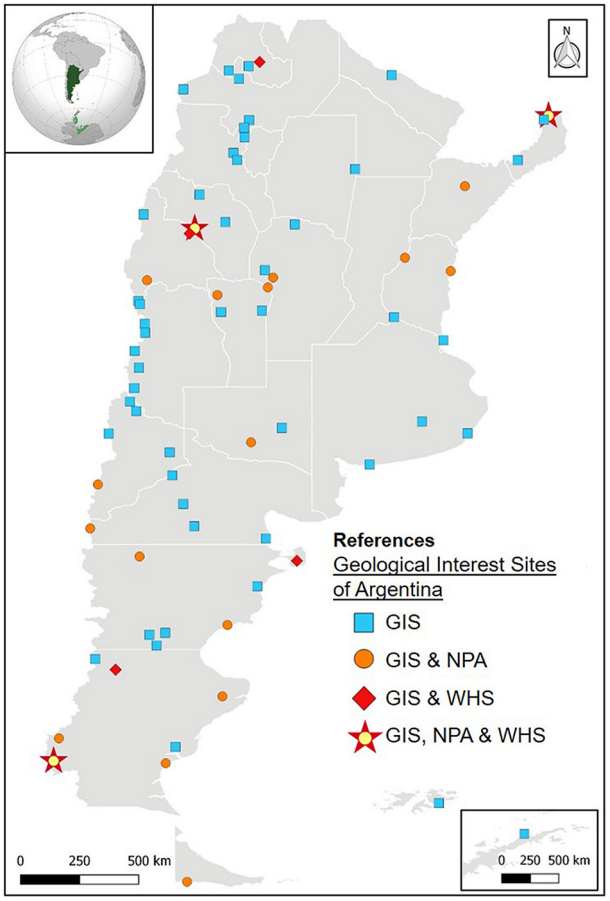

Fig. 13. Distribution of Geological Interest Sites (GIS) around the country according to their conservation status, whether they are only GIS or also a natural protected area of national jurisdiction (NPA) and/or a World Heritage Site (WHS). Four possible status were detected: GIS with no protection (49), GIS & NPA (16), GIS & WHS (4) and GIS, NPA & WHS (3). Note that most GIS are not under any conservation category.

Focusing on how the 72 GIS are protected under APN and/or UNESCO categories, it could be pointed out that 4.2% are regulated under both, 5.6% are regulated by UNESCO, 22.2% are regulated by APN and 68.1% are not under any category. The conservation situation of the GIS is shown in Fig. 13.

Four GIS are also WHS (but not NPA). Half of them are cultural sites and the other half are natural. Among the former, it is Quebrada de Humahuaca (GIS#1 in Fig. 3, Fig. 5) with lots of geological singularities but recognised by UNESCO as part of the Andean Road System or "Qhapaq Ñan", an INCA trail in a mountainous environment with visible traces of prehistoric hunter-gatherer communities; and Río Pinturas-Cueva de las Manos (GIS#64 in Fig. 3), an example of volcanism, tectonism and mass wasting but pointed out by UNESCO only because of its exceptional prehistoric cave art. Among the latter, it is Península Valdés (GIS#57 in Fig. 3), valued by UNESCO after its biodiversity since it is considered significant for the conservation of endangered marine mammals; and Ischigualasto (GIS#14 in Fig. 3), this is the only WHS valued for its intrinsic geodiversity, i.e. an extraordinary Triassic fossil record and rocks eroded by wind and ancient rivers that represent major stages of Earth's history (criteria viii).

Three GIS are both NPA and WHS (Fig. 14) having the most complete protection possibilities. Geodiveristy plays the three analysed roles (intrinsic value, value as a habitat and scenic value), according to the description of APN in these three national parks. One of them is Cataratas del Iguazú (GIS#34 in Fig. 3), valued by UNESCO after both its biotic and abiotic nature - the latter after its aesthetic importance. Talampaya (GIS#13 in Fig. 3) and Perito Moreno (GIS#68 in Fig. 3) are valued by UNESCO specially after their intrinsic geodiversity. The former includes red rocky vertical outcrops containing paleontological records and the latter is a discharge glacier from the Andean icefield. All of them represent varied geological periods with a wide range of geodidactic functions. Besides they are already being used by tourism, for example, during 2019, Iguazú National Park (where GIS#34 is) received 1,635,000 visitors and Los Glaciares National Park (where GIS#68 is) sold 681,563 entrance tickets.

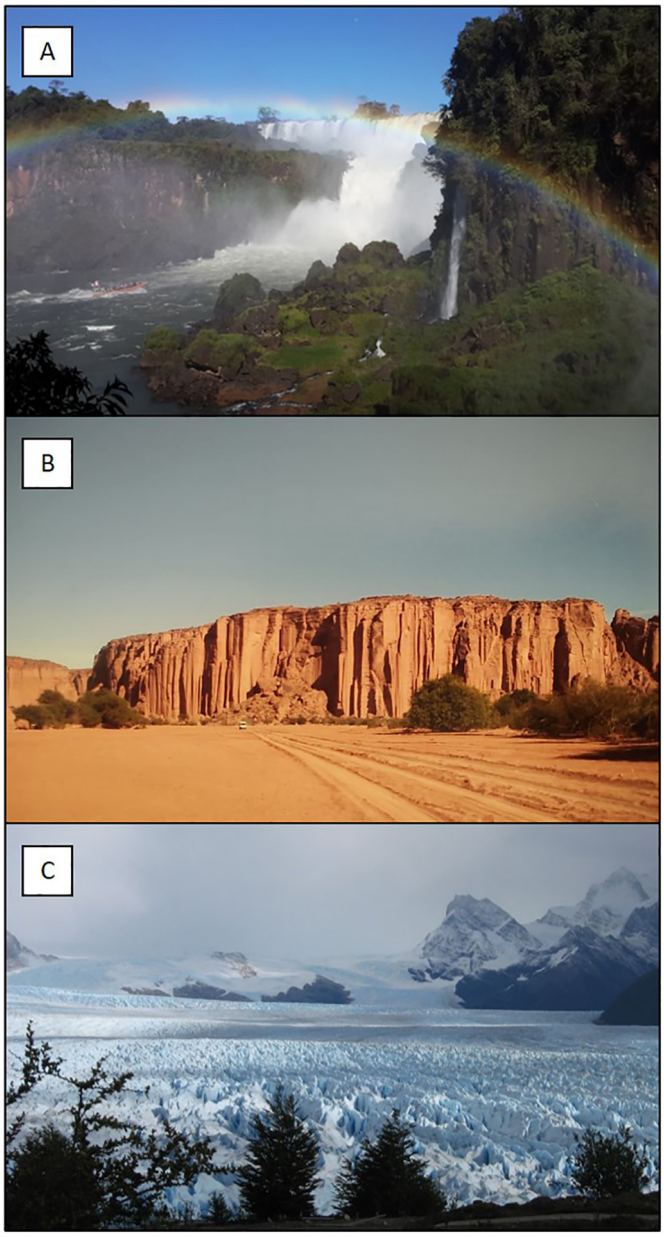

Fig. 14. Views of the only 3 Geological Interest Sites (GIS) of Argentina which are part of a Natural Protected Area of national jurisdiction declared by the national park administration and also a Natural World Heritage Site recognised by UNESCO. They are represented with stars in Fig. 13. The three of them are aesthetically appreciated by national and international visitors due to their magnificent landscapes. They are very suitable places to trigger geotourist facilities under the scope of Earth Sciences. A. "Iguazú falls" (GIS# 33 in Fig. 3). B. "Talampaya" outcrops (GIS#13 in Fig. 3). C. Perito Moreno glacier in GIS# 68 (Fig. 3). All photos by the authors.

4. Discussion

As it is demonstrated along this contribution and according to Medina et al. (2016), Argentina has a great variety of natural sceneries which deserve to be considered as GIS or included in any other type of action tending to highlight their geodiversity values and geodidactic functions. By these days, it can be postulated that geodiversity in Argentina is mainly guaranteed based on the 34 different geological regions it has and more than 30° of latitudinal extension that provides extreme and opposite climate conditions and, therefore, the occurrence of all the exogenic geomorphological processes, providing 15 morphostructural units. Besides, the 72 Geological Interest Sites selected and described by Comisión de Sitios de Interés Geológico de la Argentina (CSIGA) (2008) were formed sometime in the 12 different geological periods of all 3 Phanerozoic's eras, some of them even did it during Pre-Cambrian times. Undoubtedly, this result shows a remarkable opportunity geoheritage offers to

understand the Earth's evolution at this southern part of South America. As a consequence, and following Hose (1995), interpretation facilities must be designed and used in order to disclose the meaning of our landscapes throughout geotourism.

Most of the GIS include materials, endogenic and exogenic processes that reveal a wide range of abiotic nature. Taking into account the geodiversity concept (Gray, 2004), it is interesting to highlight that GIS point out geological and geomorphological features and processes but anyone is devoted to value soil features. However, the richness of soils types in the country has been outstanded by Panigatti (2010) who highlighted Argentina as one of the few countries in the world with all the orders of the Soil Taxonomy Classification (USDA-NRCS, 2006).

As to geoconservation, an alarming result of 46% of the GIS without any kind of regulation proves Gray's (2011) statement about abiotic nature: it is often unrecognised or undervalued. Despite the fact that almost a third of the GIS are part of Natural Protected Areas of national jurisdiction, our analysis demonstrates that the national parks administration emphasises on biodiversity and mainly recognizes geodiversity for its supporting service, i.e. because it provides the physical conditions that allow habitats for species of flora and fauna. Though 46 out of 53 NPA mention geological aspects in their descriptions, just a few of them acknowledge geodiversity after its intrinsic value. Emblems evidence that these aspects are almost exclusively part of the background. In the same line, World Heritage Sites value geodiversity only in 4 sites out of the existing 11 and mainly after its scenic beauty.

In the light of these results, we can state that on the one hand Argentina's territory provides a huge chance to address geodiversity values and geoheritage importance but on the other hand these features may be under risk if a specific geoconservation policy continues without being outlined. As it was postulated by Medina et al. (2016), geoconservation still needs public policies together with the implementation of strong strategies to protect the geological heritage by itself. Examples of those actions were stated by Miranda et al. (2016) who proposed the creation of a complete inventory of geodiversity resources, the creation of a federal agency strictly involved in the topic, the creation of geological parks and the implementation of geodiversity communication strategies for society, among others. Although time has passed, these are still good ideas and a debt to the Earth Sciences' community. Geoconservation actions must be supported by clear public legislation under the scope of nature conservation and territorial planning (Brilha, 2010), a fact not yet achieved in Argentina.

Anyway, this is possible because there is a federal system of protected areas which includes a strong administration of national parks and, according to Dingwall (2000), long-term geoconservation is more effective when it is implemented in legally protected areas, although the principal objectives may be others.

A national geoheritage law is an important need in Argentina (Medina et al., 2016; Miranda et al., 2016). This must lead to the recognition, wise use and protection of materials and processes developed along the geological time in the surface of the country, discriminating those resources needed for development and society wellness and those to be preserved for future generations to understand the Earth's formation and evolution. The protected materials and processes must be clearly identified in legislation instead of mentioning them implicitly under vague names, such as landscapes or natural features (Medina et al., 2016). Considering that not all the georesources have the same importance or recognition, inventories and assessments must be carried out in order to identify those of major relevance, i.e., the geoheritage, and hence be wisely used (Palacio Prieto, Sánchez Cortez, and Schilling, 2016).

Academic approaches and a few governmental initiatives have been developed during the last 20 years. Nevertheless, the need to consolidate an awareness of the geopotential of the country seems to be urgent.

5. Final comments

Argentina is a vast country with a wide variety of geological domains, climates and morphostructural units. These conditions are the main reasons why the territory is geodiverse. Several Geological Interest Sites were identified by government offices, but others are academic or private initiatives, out of the list of the 72 GIS proposed by Comisión de Sitios de Interés Geológico de la Argentina (CSIGA) (2008). GIS value rocks, fossils, reliefs, volcanism, tectonism and many exogenic processes occurred from the Pre-Cambrian to the Quaternary. These resources are part of the Argentinean geoheritage but also hold diverse types of biomes, archaeological resources and social interests.

However, GIS are much more than the physical support where life takes place. Actually, they can teach a lot about the Earth's dynamics because they offer a great opportunity to enhance geodiversity for its geosystemic services of knowledge and culture throughout tourism and leisure. In this sense, GIS must be protected under a clear geoconservation policy. Many of the GIS are included in Natural Protected Areas of national jurisdiction but almost half are not under any kind of regulation. Only 3 GIS out of 72 are both national parks under the APN umbrella and are also declared as Natural World Heritage Sites by UNESCO.

Conservation policies in Argentina have traditionally been devoted to flora and fauna. Moreover, there is not a geoheritage law. Nature protection offices of all jurisdictions should highlight the importance of geodiversity and geoheritage and lessen the attention they give to biodiversity to make a balance. Besides, it must be understood that geodiversity promotes a holistic vision of nature when it is considered together with biodiversity. Otherwise, our natural history may be under a great risk and at the same time society is missing the opportunity to learn about it and raise awareness of the different geosystem's services. This could be easily done including interpretation facilities in the present NPA.

Efforts have been made in academic circles during the last decades to spread the concept of geodiversity, now it is time to strengthen it as a new domain of research and to reinforce the importance of geoheritage in all educational levels, among authorities and society, in order to encourage the joint work of communities and government. Until this happens, the creation of an Argentinean Global Geopark or new geological WHS, may not find fertile ground. In the meantime, all types of initiatives, such as

papers, public and academic workshops, in situ museums development, geological trails and geotourism routes must be promoted under the umbrella of land use planning, understanding they are the way to spread geoheritage's importance. Further studies and actions could engage in spatial analyses of GIS, which may lead to the identification of more sites and therefore ensure representativeness in the stock of non-living natural assets.

This contribution helps to show how geodiverse Argentina is as well as the geodidactic potential it has and the need to safeguard the national geoheritage. Therefore, the future of geodiversity and geoconservation holds many challenges which are indeed worthy to face.

CRediT authorship contribution statement

Andrea Coronato: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Soledad Schwarz:** Conceptualization, Formal anlysis, Methodology, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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