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Review

The Historical and Current Role of the Nature Reserves Network in Preserving Geoheritage in France

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Abstract: Nature reserves in France, along with national parks and biological reserves, are one of the main tools for strong environmental protection. Nature reserve status was officially introduced in France by a law in 1957 and the first nature reserve was subsequently created in 1961 in the Alps. Since 1982, nature reserves are connected nationwide within the network of the Réserves Naturelles de France (RNF). The RNF members have played a significant role in the recognition and protection of geoheritage in France which has notably resulted in the establishment of nature reserves based on geological criteria and the creation in 1986 of a specific working group: the Geological Heritage Commission. The French geological reserves encompass a diversity of geological objects, including stratotypes, major paleontological and mineralogic sites, exceptional metamorphic, volcanic or geomorphologic sites, and outcrops of historical significance. Over time, RNF, alongside its collaborative partners, has been actively engaged in the protection, management, and recognition of geoheritage inside the French network of nature reserves and beyond. Despite these efforts, broader recognition of concepts like geodiversity and geological heritage remains somewhat limited, even within environmental protection organizations.

Keywords: geoconservation; protection; management; awareness; geodiversity

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1. Introduction

The variety and diversity of geological elements, such as rocks, minerals, fossils, landforms and landscapes record the processes and changes which have formed our planet and shaped the evolution of life over billions of years. They constitute an integral part of our natural environment.

The perception prevails that the living realm is fragile and demands preservation, contrasting with the perception of geological features as robust, non-vulnerable, and therefore less threatened. Yet, geodiversity faces numerous threats including both natural phenomena and human activities [1,2]. When geological features are destroyed, the history of the Earth encapsulated within them is lost forever and the ongoing dynamic processes of the natural world altered.

Geoconservation focuses on protecting geodiversity and geological heritage [1,3,4]. While geological heritage comprises the significant geological features that hold historical, scientific, cultural, and aesthetic value that need to be preserved, geodiversity includes the variety of geological features, forms, and processes that are an essential part of the natural world that sustains biological, cultural, and landscape diversity [5].

The emergence of geoconservation and the recognition of geoheritage in Europe occurred in the 20th century, influenced by the development of nature conservation [6–8].

In France, key policies and strategies for geoheritage protection came in the mid-20th–early 21st century [9,10]. A significant development in nature protection in France was the establishment of legal tools such as nature reserves by the 1957 law. This legislation laid down the foundations for environmental conservation efforts, and nature reserves were instituted as important areas of natural heritage to be conserved and protected over the long term and were later reinforced by the 1976 law on nature protection [11–13]. In the 1980s, members of the first nature reserves played an active role in the recognition and protection of geoheritage. Notably, the creation in 1982 of the first nature reserve based on geological criteria marked a significant step in integrating geoheritage into French conservation strategies.

Over the last two decades, the legislative frameworks formulated to conserve and manage sites of geoheritage significance has gained attention [10,14]. Today, a diversified range of regulatory tools, including national parks, nature reserves, classified sites, and prefectural decrees, is available to ensure the protection of France's geological heritage. Among these, the nature reserve stands as a key instrument for geoconservation. This paper aims to present an historical overview of the role of France's nature reserve network in geoconservation and the diverse strategies and resources employed by nature reserves to conserve the geoheritage.

2. French Nature Reserves

2.1. Status, Objectives, and Mission

Nature reserves are legal tools defined by the French Environmental Code. Reserves are defined as specific terrestrial or maritime areas where "the conservation of fauna, flora, soil, water, mineral deposits, and fossils, and, in general, the natural environment, is of particular importance or should be safeguarded from any artificial intervention likely to degrade them" [15]. Therefore, these areas are created to provide long-term protection for unique natural habitats, important species, or geological and paleontological sites. The law of 27th of February 2002 concerning Local Democracy officially recognized geological heritage by including "geological, mineralogical, paleontological richness" within the definition of natural heritage [16]. This law also conferred more strength to the nature reserves by making management plans mandatory and by introducing three types of reserves: National Nature Reserve (RNN), Regional Nature Reserve (RNR), and Nature Reserve in Corse (RNC). As of 2002, RNR replaced the former Voluntary Nature Reserves (RNV) that were previously created on private initiatives.

A nature reserve is designated by a decree that clearly defines the geographical boundaries of the reserve and outlines the applicable regulations. The decree may incorporate the creation of a buffer zone surrounding the reserve.

The reserve management can be delegated to public institutions, local authorities, or to third parties, like associative structures for nature protection. A management plan, drafted by the organization in charge of managing the reserve, sets out the objectives and the resources to be deployed in the field to maintain or preserve the relevant biological or geological heritage.

The status of a French nature reserve corresponds to three categories of protected areas as defined by the International Union for Conservation of Nature (IUCN) [17]: Category Ia, strict nature reserve; Category III, natural monument or feature and Category IV, habitat or species management area.

France has developed a national strategy for protected areas ("Stratégie Nationale pour les Aires Protégées 2030" or SNAP 2030), outlining its goals and action plan for 2030. The objective is to encompass a minimum of 30% of the country's land territory (including both mainland and overseas territories) and marine waters within protected areas, with 10% designated under high-level protection.

Nature reserves constitute one of the primary tools on which the state can rely to achieve these strategic objectives.

2.2. Nature Reserves in France Today

France currently comprises 361 nature reserves, spanning both the mainland and overseas territories (Figure 1). These reserves cover a total area of 171 million hectares. However, there is significant diversity among these sites: the smallest reserve, located in the foothills of the Massif Central, spans only 0.05 hectares (RNR Mine du Verdy), while the largest (RNN Terres australes françaises), situated in the French Southern Territories, extends over 166 million hectares, primarily within the marine realm (Table 1).

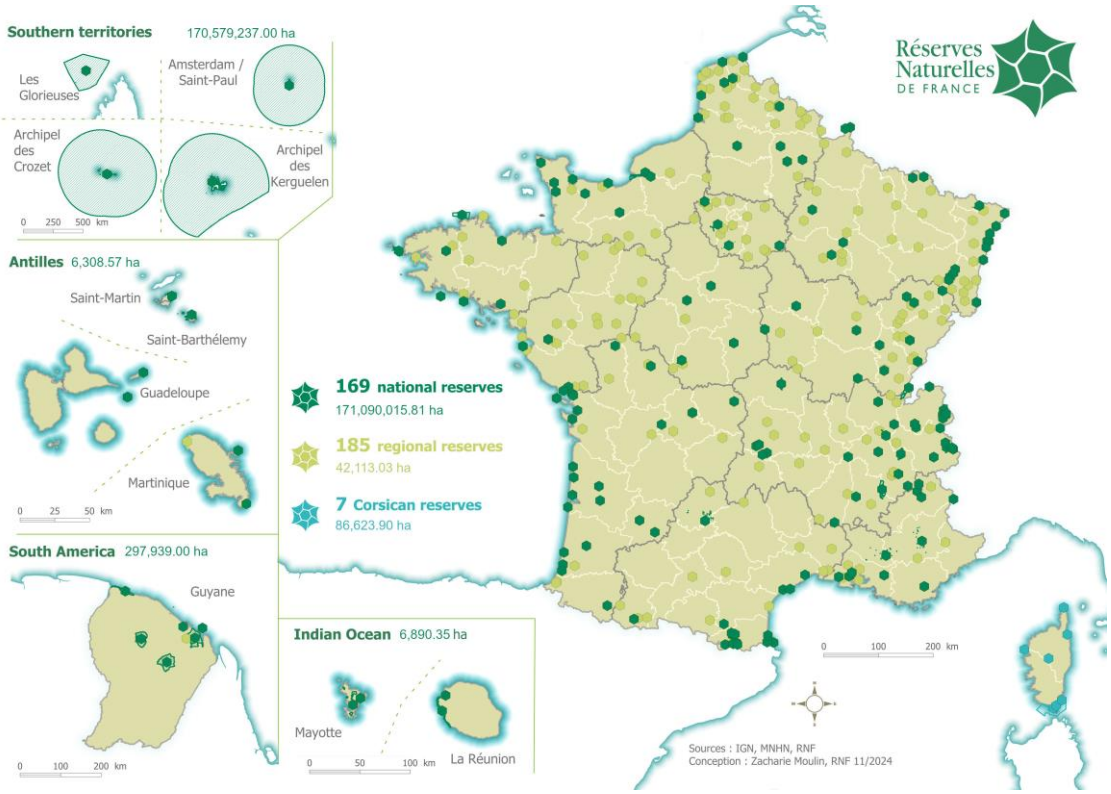

Figure 1. Distribution map of the French nature reserves, November 2024. ©RNF.

Table 1. Key data on French nature reserves (number, type and surface area), December 2023.

	National Reserves	Regional Reserves	Corsica Reserves	Total
Mainland	151 $203 \cdot 10^3$ ha	183 $39 \cdot 10^3$ ha	7 $87 \cdot 10^3$ ha	341 $328 \cdot 10^3$ ha
Overseas	18 $171 \cdot 10^6$ ha	2 $3 \cdot 10^3$ ha	0 -	20 $171 \cdot 10^6$ ha
Whole territory	169 $171 \cdot 10^6$ ha	185 $42 \cdot 10^3$ ha	7 $87 \cdot 10^3$ ha	361 $171 \cdot 10^6$ ha

French nature reserves are distributed across the country, encompassing diverse landscapes, ranging from mountainous regions to coastal areas, sedimentary basins to crystalline massifs, the equatorial forests of French Guiana to the fjords of the Kerguelen Islands, and with varying degrees of urbanization (from old-growth equatorial forests to nearly urban environments).

The reserves showcase France's rich biodiversity and geodiversity. Among the 361 reserves in France in 2023, 22 are dedicated to protecting marine environments, 26 to protecting geoheritage, and 20 are situated within the French overseas territories (Figure 1). Remarkably, approximately 20% of France's known species, including 67% of species that are protected or facing endangerment, can be found in mainland nature reserves [18].

During the early 1980s, France had approximately 40 nature reserves. The reserve managers of these, scattered across the country and dealing with similar challenges, came together to create a collaborative network that would federate nature reserve professionals. As a result, in 1982, the Réserves Naturelles de France (RNF) network was founded in the form of an association that is now recognized as promoting the public interest.

Since its creation, the RNF network has significantly expanded. As of 2023, it encompasses almost 700 members, including 170 organizations managing nature reserves, along with nature professionals, volunteers, experts, nature conservation associations, regional and national parks, and competent authorities at the national, regional, and local levels.

As the network continued to grow, specialized thematic working groups were established including:

- The Geological Heritage Commission;
- The Biological Heritage Commission;
- The Professionalization and Environmental Policing Commission;
- The Education and Nature Awareness Commission;
- The Territories and Sustainable Development Commission.

The presence of a working group dedicated to geoheritage within RNF sets it apart from other nature conservation networks in France. Established since 1986, the Geological Heritage Commission within RNF has played a crucial role in recognizing and preserving geoheritage.

3. Nature Reserves: Strongholds for Geoheritage

3.1. Emergence of Geoheritage Protection

The concept of geological heritage conservation emerged in France at the beginning of the 20th century, with an initial attempt to protect threatened geological sites [10,19,20]. A proposed piece of legislation, dated 25 October 1910, focused on regulating excavations related to archaeology and paleontology, requiring individuals conducting such excavations to declare them. The objective was to limit the trade associated with excavations and the export of valuable artifacts abroad. However, this pioneer initiative was abandoned following a protest campaign organized by the French Prehistoric Society and the French Paleontological Association, as they wanted to preserve the freedom to excavate and trade artifacts [21,22].

On 31 December 1913, a law related to historical monuments allowed for the protection of former mines. Later, the law enacted on 2 May 1930, specifically addressing natural monuments and sites of artistic, historical, scientific, legendary, or picturesque significance, allowed the classification and protection of geological sites. The paleontological site of Sansan in southern France was safeguarded under this law in 1948.

During the seventies, France experienced an increased recognition of the value of geological heritage. This was prompted by the widespread looting of mineralogical and paleontological sites, along with the development of mineral and fossil tradeshows. The legislation established on 10 July 1976 finally provided a suitable legal framework to protect remarkable geological sites [10,20].

In 1978, the creation of a geological reserve in the southern Alps was proposed to protect heavily looted geological sites. This initiative was a pivotal moment for the conservation of geological heritage in France, but the actual establishment of this reserve (Réserve géologique de Haute-Provence) only occurred in 1984.

During that time, a small group within the network of nature reserves worked towards the better recognition and protection of geological sites. Their work led to the creation of a ministerial commission called “Commission Bouchardeau” in 1982–83. Established to tackle specific issues related to geological heritage, the commission effort ultimately resulted in the creation of the first national geological nature reserve.

In 1991, the International Declaration of the Rights of the Memory of the Earth was proclaimed during an international meeting in Digne-les-Bains (Alpes-de-Haute-Provence),

organized by the geological national reserve of Haute-Provence under the patronage of UNESCO [23].

From 1998, the RNF was involved in the Conférence Permanente pour le Patrimoine Géologique (Permanent Conference for Geological Heritage or CPPG), a counseling group initiated by the Ministry of Environment for assembling referent structures such as the French national Natural History Museum, the French Geological Survey (Bureau de Recherches Géologiques et Minières or BRGM), the learned society "Société Géologique de France" (SGF), etc. The purpose of the CPPG was to guide the Ministry in its policies towards geoheritage.

In the 2000s, the Commission of Geological Heritage of RNF raised awareness within the Ministry of Environment about the necessity of conducting a national inventory of geological heritage. While the national inventory only began in 2007 [24], a regional inventory of geological sites was being carried out by RNF members in the Brittany region as early as 1992 [25].

3.2. The First Geological Reserves and RNF Geological Heritage Commission

"Geological reserves" have the same legal status as nature reserves, but they are specifically created to protect geoheritage. These reserves safeguard geological heritage sites (geosites), which are areas of geological significance that provide valuable insights into the Earth's history and geological processes [26–28].

The first national geological nature reserve established in France was Saucats-La Brède (Gironde) in 1982 (Figure 2). This reserve protects the stratotypes of the early Miocene Aquitanian and Burdigalian stages [29,30]. During that same year, the François Le Bail-Île de Groix (Brittany) geological nature reserve was created, followed by the Cap-Romain (Calvados) and the Haute-Provence (Alpes-de-Haute-Provence) nature reserves in 1984, the Hettange-Grande nature reserve (Moselle) in 1985, Grotte du TM 71 (Aude) and Luberon (Vaucluse, Alpes-de-Haute-Provence) in 1987 (Figure 3, Table 2).



Figure 2. Burdigalian coastal deposits of the Saucats-La Brède geological nature reserve. © Corentin Guinault.

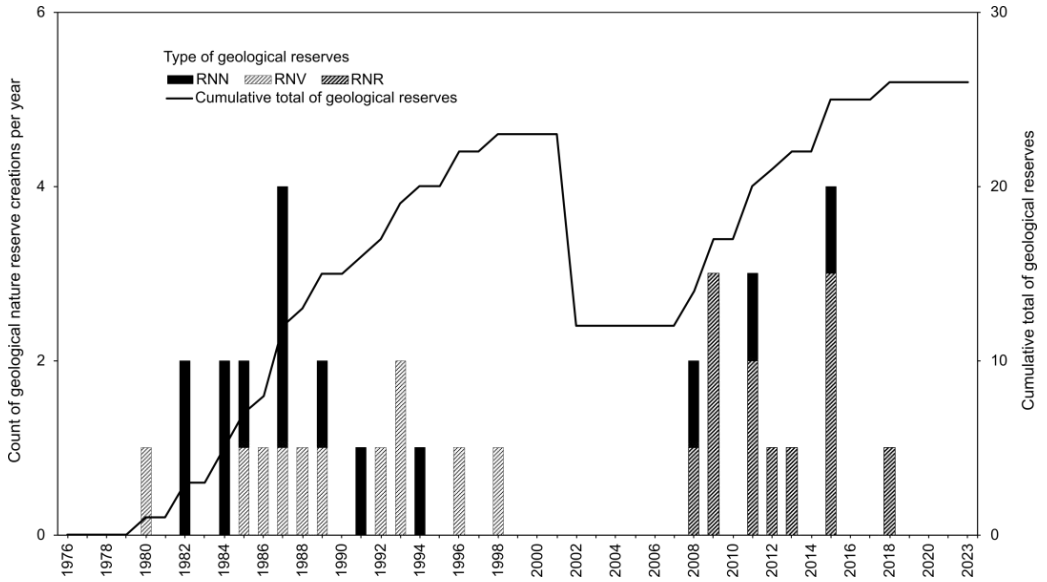

Figure 3. Evolution of the number of nature reserves created on geological heritage criteria per year and cumulative total of geological reserves since 1976. The different types of geological nature reserve: RNN, Réserve Naturelle Nationale (National Nature Reserve); RNR, Réserve Naturelle Régionale (Regional Nature Reserve), RNV, Réserve Naturelle Volontaire (Voluntary Nature Reserve). Over distinct time periods, from 1980 to 1998 and then from 2008 to 2018, a significant number of geological nature reserves were established, influenced by legislative changes. The drop in the overall count of geological reserves in 2002 is attributed to the disappearance of RNV status.

Table 2. List of the 11 former geological voluntary reserves that no longer exist.

Name	Creation Date	Area (ha)	Location	Main Geological Interest
Montredon	1980	9.88	Hérault	Paleontology (Miocene fossils)
Longeville-lès-Saint-Avold	1985	79.13	Moselle	Mineralogy (lead and copper mineralizations)
La Lieude	1986	0.1	Hérault	Paleontology (Paleozoic fossil tracks)
Saint-Martin-de-Bromes	1987	6	Alpes-de-Haute-Provence	Paleontology (Hauterivian fossils)
Menat	1988	1	Puy-de-Dôme	Paleontology (Paleocene fossils)
Robiac	1989	9.51	Gard	Paleontology (Eocene fossils)
Lavergne	1992	3.82	Lot	Paleontology (Eocene fossils)
Saturnin-Garimond	1993	14	Gard	Paleontology (Mesozoic and Cenozoic fossils)
Aumelas	1993	5	Hérault	Paleontology (Eocene fossils)
Itteville	1996	0.71	Essonne	Paleontology (Oligocene fossils)
Coumiac	1998	8.36	Hérault	Stratigraphy (Frasnian-Famennian boundary)

During the eighties and the nineties, thirteen voluntary geological nature reserves were established on private initiatives. However, most of these reserves (11 out of 13) did not transition from voluntary to regional reserves status, a change that began in 2002, and they no longer exist (Table 2).

As the number of geological nature reserves increased, discussions within RNF network arose regarding the establishment of a commission specifically dedicated to geoheritage. In 1986, the Commission for Geological Reserves and Protected Geological Sites was

officially formed. It held its inaugural meeting in 1987 and was officially named the Geological Heritage Commission in 1988. It set ambitious goals, including the documentation of protected geological sites and a synthesis of international conservation strategies. Since 1992, the commission has advocated for the initiation of a national geological inventory to evaluate the heritage value and conservation needs of sites. This national inventory only began in 2007 and has undergone continuous updates ever since.

The Geological Heritage Commission has significantly expanded since its establishment. It now encompasses around a hundred members, representing nearly as many reserves. Since its creation, the Commission of Geological Heritage of RNF been a key player in the recognition and protection of geoheritage in France.

3.3. Overview of France Geological Reserves

Among the 361 reserves within the network, 26 are geological reserves that have been established to protect unique geological heritage (Figure 4). They constitute a mere 7% of the French nature reserve network. The change in the legal framework in 2002 (Law on Local Democracy) which reinforces the possibility of protecting geoheritage led to a significant increase in the number of nature reserves, alongside an increasing protection of geoheritage [10,20]. Since 2008, 10 Regional Nature Reserves and 3 National Nature Reserves were created on the main basis of the geoheritage criteria (Figure 3). The latest geological reserve (Pierriers de Normandie) was established in 2018 to protect quartzite scree slopes in the eastern Armorican massif.

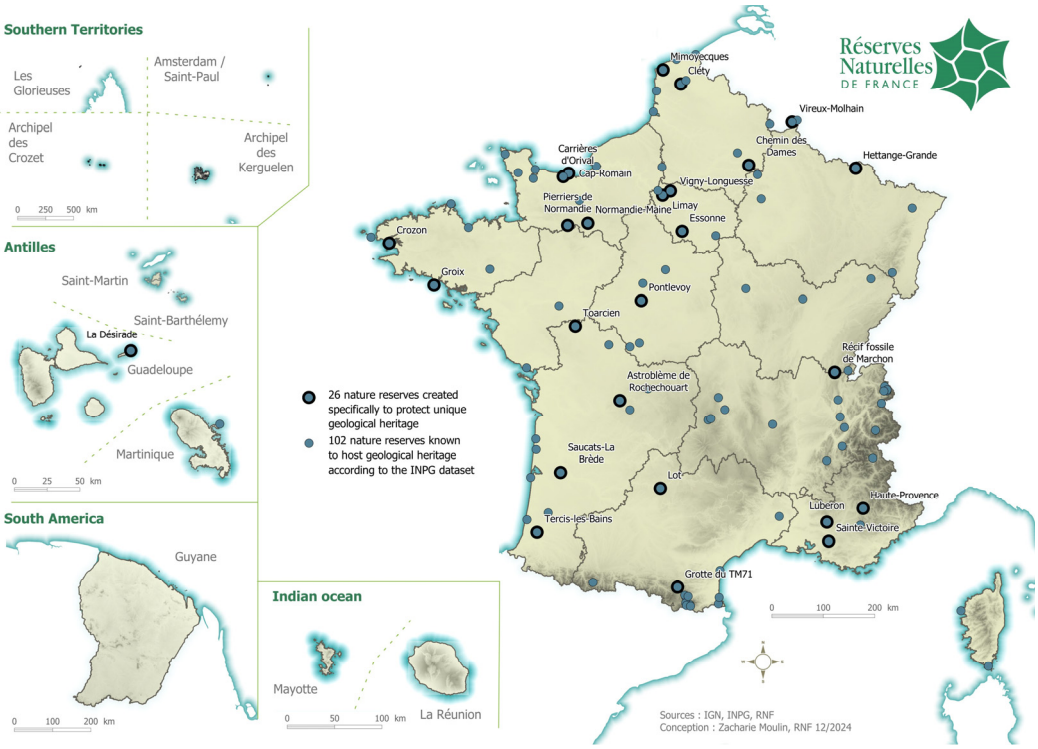

Figure 4. Distribution map of geological reserves and other reserves hosting geoheritage (Table S1) according to the National Geological Heritage Inventory (INPG). Twenty-six geological reserves were created specifically to protect unique geological heritage, while 102 nature reserves host known geological heritage based on the INPG dataset published to date. December 2024. ©RNF.

The geoheritage housed in the reserves reflects the geodiversity of the French territory and the significant role the country has played in the history of Earth sciences. The 26 geological reserves encompass a diversity of geological objects, including stratotypes, major paleontological and mineralogic sites, exceptional metamorphic, volcanic or geomorpho-

logic sites, and outcrops of historical significance (Table 3). They vary considerably in size and encompass one or multiple sites with varying levels of vulnerability.

Table 3. List of the current French nature reserves created on the main basis on the geoheritage criteria. RNN Réserve Naturelle Nationale (National Nature Reserve); RNR Réserve Naturelle Régionale (Regional Nature Reserve).

Name	Creation Date	Area (ha)	Status	Main Geological Interest
Géologique de Saucats et La Brède	1982	75.5	RNN	Stratigraphy (Burdigalian and Aquitanian stratotypes)
François Le Bail (Île de Groix)	1982	98.2	RNN	Mineralogy (Paleozoic subduction metamorphic series)
Falaise du Cap-Romain	1984	23.85	RNN	Paleontology (Bathonian coral reef)
Géologique de Haute-Provence	1984	269.32 *	RNN	Stratigraphy (Barremian stratotype, Bathonian GSSP) Paleontology (Mesozoic and Cenozoic fossils)
Hettange-Grande	1985	6.1	RNN	Stratigraphy (Hettangian stratotype)
Grotte du T.M. 71	1987	96.02	RNN	Geomorphology (Karstic system) Mineralogy (Concretions)
Géologique du Luberon	1987	397.74 **	RNN	Paleontology (Cenozoic fossils) Stratigraphy (Aptian historical stratotype)
Toarcien	1987	0.61	RNN	Stratigraphy (Toarcian stratotype)
Sites géologiques de l'Essonne	1989	27	RNN	Stratigraphy (Stampian stratotype) Sedimentology (Marine to lacustrine sedimentation markers)
Vireux-Molhain	1991	1.82	RNN	Paleontology (Cenozoic fossils) Paleontology (Devonian fossils)
Sainte-Victoire	1994	139.84	RNN	Paleontology (Cretaceous dinosaurs' eggs)
Anciennes carrières d'Orival	2008	19.32	RNR	Sedimentology (Sedimentation figures)
Astroblème de Rochechouart-Chassenon	2008	50	RNN	Metamorphism (Markers of an early-Jurassic major asteroid impact)
Site géologique de Vigny-Longuesse	2009	21.87	RNR	Stratigraphy (Danian co-stratotype)
Site géologique de Limay	2009	70.84	RNR	Stratigraphy (Sedimentary sequence from Campanian to Lutetian)
Géologique de Normandie-Maine	2009	0.58	RNR	Stratigraphy (Ordovician limestone) Sedimentology (depositional environment indicators)
Géologique de Pontlevoy	2011	1.91	RNR	Paleontology (Miocene fossiliferous sands)
Anciennes carrières de Cléty	2011	2.04	RNR	Stratigraphy (Turonian/Coniacian limit)
La Désirade	2011	62	RNN	Volcanism (Pillow-lavas) Sedimentology (quaternary sedimentary sequence)
Forteresse de Mimoyecques	2012	1.57	RNR	Stratigraphy (Turonian sedimentary sequence)
Sites d'intérêt géologique de la presqu'île de Crozon	2013	156.4	RNR	Mineralogy, metamorphism, stratigraphy, volcanism (Paleozoic sedimentary rocks with multiple interests)
Récif fossile de Marchon-Christian Gourrat	2015	0.1	RNR	Paleontology (Kimmeridgian fossil reef)
Intérêt géologique du département du Lot	2015	800	RNN	Paleontology (Tertiary fossiliferous phosphate deposits and pterosaurs fossil tracks)
Site des carrières de Tercis-les-Bains	2015	44.8	RNR	Stratigraphy (Maastrichtian GSSP)
Coteaux du Chemin des Dames	2015	32.93	RNR	Stratigraphy (Eocene sedimentation)
Pierriers de Normandie	2018	0.87	RNR	Geomorphology (Quartzite scree slopes of Quaternary periglacial origin)

*: additional buffer zone of 231,804 ha. **: additional buffer zone of 69,663 ha.

Major paleontological sites are protected by the nature reserve. For example, the Sainte-Victoire National Nature Reserve (Bouches-du-Rhône) was established in 1994 to protect over 140 hectares of red clay deposits where dinosaurs laid eggs during the Cretaceous period. Other significant paleontological sites are preserved in the geological national reserves of Haute-Provence (Alpes-de-Haute-Provence), Vireux-Molhain (Ardennes), the Cap Romain cliff (Normandie), the geological sites of Essonne and Lot, and the Luberon (Vaucluse, Alpes-de-Haute-Provence).

Some reserves were established to protect mineralogical deposits, igneous and metamorphic rocks featuring exceptional mineral species or crystallizations. The National Nature Reserve of Cave T.M. 71 (Aude) protects an extensive karstic system that yields rare speleothems. The reserve of La Désirade in the Guadeloupean archipelago displays Jurasssic volcanic rocks, which had witnessed the tectonic history of the Caribbean Plate. La Désirade is the first, and so far only, French overseas nature reserve created on the main basis of geoheritage criteria.

Geomorphological features have been less frequently used as the primary basis for establishing geological reserves compared to other types of geological objects. This is partly due to the fact that geomorphological sites are often protected under different legal frameworks. For instance, France's "Landscape Sites" policy is designed to preserve areas of exceptional value, including those with remarkable geological or geomorphological characteristics. Rooted in the laws of 1906 and 1930, this policy protects sites of scenic, artistic, historical, scientific, or legendary significance. While it initially focused on specific features, such as notable trees or waterfalls, its scope has expanded over time to encompass larger landscapes, including valleys and mountain ranges.

In addition to their major geological significance, geological nature reserve holds considerable ecological interest for both fauna and flora. The regional nature reserve of Vigny-Longuesse (Val d'Oise) harbors several remarkable species, most of which are associated with pioneer herbaceous habitats (thermophilic calcicolous grasslands and meadows) colonizing the former quarry [31]. The François Le Bail National Nature Reserve (Brittany) established in 1982, protect the petrological diversity of metamorphic rocks of the island of Groix and serves as a nesting site for colonies of seabirds.

Among the approximately forty stratotypes in the country, twelve are located within a nature reserve (Table 4).

Table 4. List of the 12 stratotypes located hosted by nature reserves.

Stratotype	Reserve	Type
Burdigalian	Géologique de Saucats et La Brède	Stratotype
Aquitanian	Géologique de Saucats et La Brède	Stratotype
Stampian	Sites géologiques de l'Essonne	Stratotype
Danian	Site géologique de Vigny-Longuesse	Co-stratotype
Maastrichtian	Site des carrières de Tercis-les-Bains	GSSP **
Gargasian	Géologique du Luberon	Stratotype
Aptian	Géologique du Luberon	Stratotype
Barremian	Géologique de Haute-Provence	Stratotype
Bathonian	Géologique de Haute-Provence *	GSSP **
Toarcian	Toarcian	Stratotype
Hettangian	Hettange-Grande	Stratotype
Givetian	Pointe de Givet	Stratotype

* In the buffer zone affiliated to the reserve. ** Global Boundary Stratotype Section and Point.

Geological reserves are not the only reserves that host geoheritage. Among the 361 reserves within the network, 76 other nature reserves, accounting for 20% of all reserves, hold a recognized geological heritage according to the INPG dataset published to date (Table S1). For instance, the Givetian stratotype is located within the Pointe de Givet nature reserve in French Ardennes. The reserve is not considered as a geological reserve per se, because it was created based on faunisitic, floristic and geological criteria. Another example

is the Bois du Parc nature reserve in Burgundy, which hosts a Jurassic coral reef whose paleontological interest was identified only after the creation of the reserve.

As part of the deployment of the National Strategy for Protected Areas ("Stratégie Nationale pour les Aires Protégées 2030": SNAP 2030), several creation and extension projects for reserves are expected to materialize by 2030.

4. Nature Reserves Geoconservation Tools and Resources

4.1. Knowledge Towards Nature Conservation

The knowledge of geodiversity and geoheritage stands as an essential foundation for effective nature conservation efforts. Knowledge acquisition in nature reserve advances the understanding of the geodiversity and geoheritage. It helps to protect natural heritage as a whole, to understand the geological objects and processes that constitute and shape the Earth through research, and to identify geological heritage through the study of geodiversity.

Advancing and refining the comprehension of geodiversity involves various activities, including scientific investigations, excavations, and inventories. The reserves contribute significantly to scientific research through collaboration with academics from universities and museums. Excavation permits on reserve sites are granted for scientific and educational purposes and for safeguarding geological heritage. The amateurs collaborating with nature reserves play an essential role in enhancing the understanding of geological heritage. They are often grouped in local or regional associations and have codes of ethics. These associations are grouped within a national federation, the Fédération Française des Amateurs en Minéralogie et Paléontologie (FFAMP). These groups have expertise in paleontology and geology, maintain a significant field presence, and possess good knowledge of the issues surrounding fossils and minerals trade.

The reserves aim to identify all sites and objects of geological interest, both in situ and ex situ, within their territory and beyond. The knowledge of geological heritage localized within nature reserves relies on two main sources. Historically, it was based on the expertise of members of the RNF Geological Heritage Commission, and more recently, it relies on the data published in the French National Geological Heritage Inventory (INPG) [24].

The reserves collect data and characterize the geodiversity housed within the network. The RNF Geological Heritage Commission published a technical manual in 2015 [32] that contains basic guidelines to document the geological features present within a reserve. Subsequently, a web application named "Socle", a digital geodiversity observatory, was deployed.

Launched officially by the Ministry responsible for the Environment in 2007, the National Geological Heritage Inventory (INPG) constitutes an important milestone in the identification of geological heritage to which the RNF and the Geological Heritage Commission has greatly contributed.

In December 2023, 3647 sites were published in the framework of the INPG [33]. 236 sites from the inventory are situated within or partially intersected by a nature reserve, representing approximately 6.5% of the overall INPG sites.

4.2. Protection and Geoconservation

Geoheritage is vulnerable and can face damages and destruction caused by human activities (looting of paleontological sites, excavation, development of urbanization, mining) or natural elements such as erosion, weathering, and vegetation growth [1].

During the 2000s, the RNF Geological Heritage Commission conducted a comprehensive survey to identify the various legal measures available for safeguarding geological heritage. This initiative resulted in the publication of a practical guide on legal protection for geoheritage in France [34]. Among the array of policies and strategies in France, nature reserves stand as the most robust legal tool.

Compared to solely regulatory tools to protect geoheritage [10,35], reserves integrate both regulatory and management approaches. There are strict regulations within the

perimeter of the reserve associated with a long-term management plan of geoconservation and technical operations. Nature reserves, once designated, are protected against destruction or alteration: "Territories classified as nature reserves can neither be destroyed nor modified in their condition or in their shape, except for special authorization" [15]. Regulations within these reserves may vary, prohibiting various activities that could potentially alter the reserve [15]. The activities that are generally forbidden or at least controlled in nature reserve include hunting, fishing, agriculture, outdoor sports, etc.

The collection and extraction of minerals and fossils is prohibited within all geological reserves. Excavation permits on reserve sites can be granted for scientific or educational purposes. A buffer zone can be established around the reserve. Within the buffer zone, manual collection of naturally exposed rocks or fossils resulting from erosion is allowed in a limited amount. Guards are appointed by the minister to carry out a nature policing mission and enforce regulations.

Besides regulatory tools, the protection of geological heritage can be approached in two complementary ways: preservation of the object in situ, and the ex situ conservation of samples and fossils (collection) and associated scientific information.

The Nature Reserve of Haute-Provence was one of the first geological reserves in France to propose permanent in situ protection of fossils [36]. Some outcrops of the Saucats-La Brède geological reserve are also equipped with a showcase for protection and educational purposes. In the geological reserve of the Lot, in southern France, the famous "pterosaur beach" has been protected under a building that grants a full protection to the precious ichnofossils while allowing scientific research and educational activity (Figure 5).



Figure 5. Three examples of in situ protection of geoheritage in nature reserves © Photo 1 CD Alpes-de-Haute-Provence, Photo 2 Corentin Guinault, Photo 3 OT Cahors Vallée du Lot.

Preservation of the object in situ is not always possible, depending on its degree of vulnerability and the nature of the pressures exerted upon it. The protection of geological heritage ex situ involves safeguarding geological samples or fossils outside of their original location. Fossils and minerals collected within a nature reserve are catalogued, conserved, and curated in different types of public institutions like museums, universities, or within the nature reserve collection. By conserving geological materials ex situ, the nature reserve ensures their accessibility for research, educational and public outreach purposes.

4.3. Public Awareness of Nature Conservation

Beyond their core mission of safeguarding natural sites of interest, nature reserves also strive to educate the public about the significance of preserving natural heritage. While a few reserves have restricted areas, most are open to the public and are equipped to accommodate visitors.

Reserve managers have developed an array of educational and cultural activities. Facilities are installed to ensure public reception, safety, and site improvement. For example, the recent enhancements at the ammonite slab in Digne-les-Bains within the Haute Provence nature reserve involve a parking zone, reception area, observation platform, and diverse informative resources (Figure 6). These upgrades aim to facilitate access for people with disabilities and provide educational mediation [37].



Figure 6. The ammonite slab visiting facilities in the Haute-Provence nature reserve. © RNGHP.

Educational panels placed within the reserve along trails or near points of interest provide explanations about the reserve's natural heritage (Figure 7). The potential transformation and alteration of the site due to the presence of visitors and educational activities is always considered, as there is a critical balance to maintain between offering information and conserving the site.



Figure 7. Pedagogical panel along an interpretation trail in the Gorges de Daluis nature reserve. © Corentin Guinault.

The reserves often feature a visitor center functioning as an information hub, exhibition area, or museum space. For example, the Museum of Geology at the Luberon geological nature reserve is dedicated to educating the public through the display of its paleontology collection [38]. The Rochechouart-Chassenon Astrobleme nature reserve exhibit space showcases meteorites and features linked to phenomenal cataclysm produced during meteorite impact.

Reserve environmental education usually includes pedagogic activities organized either by the reserve staff or external contributors. Many educational activities, aimed at a school-aged audience, illustrate issues related to school programs. The Lot geological nature reserve provides an educational program focused on geology, paleontology, and sustainable development, allowing students to acquire scientific skills and take part in field trips.

Throughout the year, nature reserves host diverse activities and events (the Nature Festival, National Geology Days, International Geodiversity Day, the Science Festival, etc.), for both the general public and schools.

Reserves have been exploring the potential of new technologies for public outreach. They aim to engage new audiences such as younger people or people with disabilities and address management challenges like accessibility and high visitor numbers. For instance, the nature reserve of geological sites of the Crozon peninsula (Brittany) has provided a virtual tour of the Pointe du Gouin cliffs since 2021. This digital work was carried out in collaboration with the research community, focusing on both scientific and educational goals. Similarly, the nature reserve of the Geological Site of Limay (Ile-de-France) offers virtual reality visits to restricted-access outcrops.

Informative materials ranging from leaflets to comprehensive booklets can be distributed or sold at the reserve house or other visitor centers. For instance, RNF published a flyer in 2020 introducing the notion of geodiversity and the principles of geoconservation, illustrated with examples taken from nature reserves. This document was widely

distributed among the network, to be used as a support document for raising awareness among the visitors.

Publications and books are also used to educate, inspire, and mobilize communities toward preserving the geological heritage. These publications typically integrate scientific research, narratives, and visuals to outline the significance of geodiversity and biodiversity. Publications are aimed to communicate about sciences and conservation, bridging the gap between scientific knowledge and public outreach.

The BRGM Éditions (Bureau de Recherches Géologiques et Minières-French Geological Survey) maintain a close relationship with nature reserves, primarily through the publication of their materials. Documents published by the BRGM, such as books, geological maps, and guides, highlight geologically significant sites, many of which are often located within nature reserves.

The "Curiosités géologiques" collection is constituted of guides dedicated to specific territories. Within these publications, a section is often dedicated to showcase geological sites selected for their educational and scientific qualities. Some of these geosites are situated within protected areas, including nature reserves (Figure 8).



Figure 8. Example of content about nature reserves in the "Curiosités géologiques" collection by the BRGM. © BRGM.

These publications thus provide visibility and recognition to these nature reserves by featuring them in specialized guides and materials. This serves to raise awareness among a wide audience about the value of protected geological sites within these preserved natural spaces. Furthermore, these publications contribute to highlighting the importance of geoconservation.

4.4. Management

The management of a nature reserve typically involves an advisory committee and a management structure. The advisory committee usually comprises stakeholders of the reserve, including territorial and state administrations, local elected officials, landowners, users, and associations. Its role is to monitor and evaluate management and provide opinions on any decision concerning the nature reserve.

Each reserve has a management plan that defines long-term objectives regarding the conservation of natural heritage and sets a short- to medium-term operational framework (generally 5 to 10 years) to work towards these long-term objectives. Management plans include the following fields of activities: surveillance and environmental policing, knowledge and monitoring of natural heritage, creation and maintenance of reception facilities, interventions on natural heritage, management and support, communication and educational materials, and participation in research. The management structure develops and implements the management plan.

To assist the nature reserve manager and the advisory committee, a scientific council associated with the reserve provides guidance on the management plan and expertise on scientific issues related to the reserve.

In France, a new national methodology for management plans for protected areas has been developed [39]. All management plans include an evaluation of the conservation status of the reserve's natural heritage, along with an examination of the natural and human-induced factors impacting conservation efforts. However, implementing this methodology for geoheritage can pose challenges, due to the distinct nature of the abiotic aspect in the natural environment. Unlike biotic components, the geological heritage is non-renewable, and many geological processes are not perceptible within the duration of a management plan.

Even though the primary focus is on conserving geological heritage, the management plan for geological reserves aims to establish coherence between geo- and bioconservation actions.

4.5. Mutualization Within the Network and Beyond

An essential advantage of a network like RNF resides in its ability to share tools and resources, fostering the exchange of experiences, best practices, and expertise. Members of RNF can benefit from technical and institutional support, access a diverse set of tools and training opportunities, and actively engage in both technical and institutional meetings.

Members of the RNF Geological Heritage Commission usually have two annual meetings, including a congress and a technical seminar. These meetings, incorporating presentations, debates, collaborative workshops, and field trips, are fundamental and formative for the network's dynamics and its thematic commissions.

The collaborative nature extends beyond the RNF network, engaging in the development of various projects and tools in partnership with structures involved in geoheritage conservation. This field still involves a limited number of experts and often receives insufficient attention at decision-making levels. Throughout the years, the RNF has collaborated with amateur associations grouped within the FFAMP, the Société Géologique de France (SGF), the geological services of BRGM, the National Museum of Natural History (MNHN), as well as with ministries overseeing education, environment, and land-use planning. These partnerships significantly contribute to enhancing the national framework for geoheritage policy.

Since the International Declaration of the Rights of the Memory of the Earth in 1991, the RNF Geological Heritage Commission has organized and consistently participated in the National Geological Heritage Days about conserving and scientifically and culturally enhancing geoheritage (Table 5).

Table 5. List of the main events on geoheritage organized by RNF Geological Heritage Commission.

Year	Event	Location
1991	International symposium on geoheritage	Digne (Provence-Alpes-Côte d'Azur)
1997	National geoheritage days	Paris (Île-de-France)
1997	Regional geoheritage days	Lille (Hauts-de-France)
1998	Regional geoheritage days	Vannes (Brittany)
1999	National geoheritage days	Lille (Hauts-de-France)
2002	National geoheritage days	Brest (Brittany)
2008	National geoheritage days	Digne (Provence-Alpes-Côte d'Azur)
2010	Regional geoheritage days	Caen (Normandy)
2011	Regional geoheritage days	Trévou-Tréguignec (Brittany)
2013	Regional geoheritage days	Elbeuf (Normandy)
2013	National geoheritage days	Caen (Normandy)
2019	Geoheritage day	Paris (Île-de-France)
2023	Geoheritage day	Paris (Ile-de-France)

The territories of five nature reserves overlap with those of geoparks. Nature reserves often engage in collaborative partnerships with geoparks due to their common objectives in research, education, and preservation and share resources, expertise, and best practices.

The commission has also punctually collaborated with international actors and partners involved in geoconservation. In 2021, the IUCN World Conservation Congress took place in Marseille, France. The RNF seized this opportunity to raise awareness among nations worldwide about the necessity to develop and promote geoconservation by submitting a motion called "Geoheritage and protected areas". The latter resulted from a collaboration between RNF and several international partners such as the IUCN World Commission on Protected Areas Geoheritage Specialist Group, the Spanish Geological Society, the International Union of Speleology, etc. This motion notably encourages states to compile data about geoheritage and geodiversity in protected areas and calls for an IUCN initiative on Key Geoheritage Areas based upon the Key Biodiversity Areas program [40].

5. Discussion

Thanks to the national inventory (INPG) launched in 2007, France possesses an increasing knowledge of its geological heritage. Although the INPG does not grant protected status to the sites it covers, it provides information to establish priorities for safeguarding geological sites. These priorities consider technical aspects such as highly vulnerable or threatened sites, as well as opportunities for conservation. Once priorities are established, various tools are now available in France to ensure the protection of sites and geological features [10,14]. If nature reserves unquestionably remain one of the strongest tools, the most recent creation of a geological reserve dates back to 2018, and there are very few ongoing projects. The creation process is lengthy, and project proponents must contend with increasingly significant constraints (expansion of urbanization, maintain of agricultural areas, local opposition, etc). Other tools have been deployed in recent years, such as prefectural decrees of geotope protection (APPG) and departmental lists, but they lack dedicated funding and management structure, and thus fail to offer the same guarantees for protection and promotion of geological heritage. For instance, the Permian reptile tracksite of La Lieude in southern France, a former geological voluntary reserve that no longer exists, is listed on the INPG and registered on the departmental list (Hérault) of geological sites of interest. Although this status prohibits its destruction and degradation, the absence of active management leaves this internationally significant site vulnerable to deterioration and potential loss.

Today, the nature reserve emerges as the best tool to manage and preserve both geological and biological heritage. However, efforts focused on conserving geodiversity and biodiversity are often separated, commonly managed by geologists and ecologists or biologists, respectively [41]. Geologists are few within the teams managing nature reserves

and other types of protected areas, and even rarer within the administration. Environmental protection stakeholders often lack adequate training and awareness regarding geodiversity and geological heritage. To address this issue, the RNF network offers training to protected area managers focusing on geodiversity and geological heritage.

From the perspective of management and conservation of biodiversity and geodiversity, it is crucial to highlight and study the strong connections between geodiversity and bio-diversity. A better integration of geodiversity into protected area planning and management is beneficial for both geoconservation and nature conservation as a whole [42,43].

Since the 1980s, there has been a notable rise in awareness and efforts to safeguard geological heritage, particularly thanks to the efforts of the network of nature reserves. During distinct time intervals, particularly from 1980 to 1998 and again from 2008 to 2018, numerous geological nature reserves were established, notably driven by legislative developments. Since 2015, the introduction of new tools, such as prefectural decrees of geotope protection (APPG) and departmental lists, has marked a significant milestone in the ongoing efforts to protect geological sites. However, geodiversity still lacks sufficient consideration. Despite France's strong ambitions for expanding its protected areas, decision-makers and institutions responsible for environmental protection in France fail to fully acknowledge the importance of geological heritage. The geological aspects are notably absent from major documents issued at both national and regional levels. Biodiversity tends to be the primary focus in discussions about nature conservation, excluding other important aspects of the natural heritage, notably geological ones from biodiversity-based conservation strategies. While the term geodiversity [41] has been widely accepted, it has been neglected in nature conservation policies, strategies, and protected area management.

6. Conclusions

Among the 361 nature reserves in France today, 102, spread across all regions of metropolitan France and several overseas territories, house geological heritage according to the INPG dataset, among which 26 were created specifically to protect unique geological heritage. Since the mid-20th century, significant progress has been made in the protection of geological heritage, particularly through the establishment of nature reserves focused on geological features and initiatives like the French National Geological Heritage Inventory (INPG). While nature reserves provide a strong and reliable framework for safeguarding the Earth's heritage in France, challenges still persist, especially in creating new reserves and addressing the funding and management limitations of alternative protection mechanisms.

To ensure the long-term preservation of geodiversity and geological heritage, it is crucial to give these aspects greater attention. This involves enhancing training for environmental managers, increasing the involvement of geologists in protected area teams, and more effectively integrating geoheritage and geodiversity into broader conservation strategies. The recognition of geodiversity as an integral part of natural diversity that sustains biological, cultural and landscape diversity [5], and its better integration, are fundamental for achieving nature conservation and sustainablility objectives [44].

Supplementary Materials: The supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geosciences14120354/s1, Table S1: List of nature reserves hosting known geological heritage according to the INPG dataset published to date.

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