Geological heritage and conservation challenges in Andorra

Margalef A. [1,*] , Echeverria A. [1]

[1] *Andorra Recerca + Innovació; Av. Rocafort, 21-23, 3ª planta; AD600 Sant Julià de Lòria (Andorra)*

**Corresponding author: amargalef@ari.ad*

Geographical and geological setting

Andorra is a small, mountainous country covering approximately 470 km^2 in the central Pyrenees. The average altitude is about 1.900 m.a.s.l., with values ranging from 840 m to 2.942 m, and with 65 summits more than 2.500 m high. The Pyrenees are an Alpine orogen in southwestern Europe, straddling the border between France and Spain (Figure 1). The Pyrenees were originated by the convergence between Iberian and Eurasian plates from Late Cretaceous to early Miocene [1]. The Alpine deformation gave rise to E–W trending thrust sheets, some of which involved basement Neoproterozoic and Paleozoic rocks, forming an antiformal stack, which constitutes the so-called Axial Zone.

The country is carved by two main rivers and its corresponding valleys: Valira del Nord in the west and Valira d'Orient in the east. These two rivers converge in Andorra la Vella to form the Valira river.

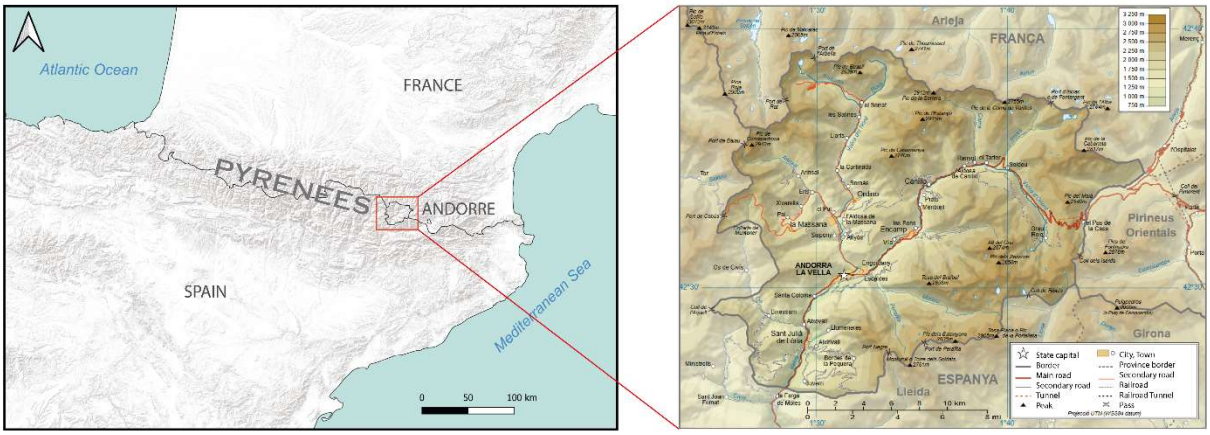

Figure 1. Location of Andorra in the Central Pyrenees.

Demographic and economic context of Andorra

The population is about 87.000 inhabitants, that gives a population density in the country of about 185 inhabitants/ km^2 [2], which are concentrated mainly in the valley bottom.

There are three main alpine ski resorts that occupy 30,75 km^2 (6,6% of its territory). In the 2023-2024 season, 2.2 million ski passes were sold [3], which makes the ski industry one of the main sources of income for the country. In this sense, Andorra is under significant urban and tourist pressure that could put at risk the preservation of the natural environment.

Protection of the natural environment in Andorra

In this context, in the early 2000's three protected natural areas were created in the country: the Sorteny Valley Natural Park (SVNP, 2003), with a total of 1,080 ha; the Comapedrosa Valleys Natural Park (CVNP, 2003), with a total of 1,542 ha; and the Madriu-Perafita-Claror Valley (MPCV, 2004), with a total area of 4,247 ha, the latter declared a World Heritage Site by UNESCO in the category of Intangible Cultural Heritage. Moreover, the entire Parish of Ordino was declared a UNESCO Biosphere Reserve in 2020.

One of the main objectives established by the decrees for the creation of the natural parks is to protect the unique character and integrity of the natural values of geological heritage, vegetation, wildlife, the water system, the atmosphere, and the landscape.

Regarding natural parks, the protection regime is regulated at the national level by Law 7/2019, of February 7th, on the conservation of the natural environment, biodiversity, and landscape. This law includes the protective nature of representative natural systems or elements of particular interest due to their fragility,

uniqueness, landscape value, scientific significance, or ecological and geological interest. The law states that "Natural protected areas are considered the zones of the territory of the Principality of Andorra that contain representative, unique, fragile natural systems or elements, or those of special ecological, scientific, landscape, or geological interest, and are declared as such in accordance with this Law"; as well as “It is prohibited to destroy, alter, or degrade places of geological interest, as well as collect fossils and minerals, even in natural or artificial underground cavities". However, the law does not specify which are the geological interest sites, nor does it foresee their declaration.
Furthermore, Andorra has had a protected flora regulation since 2021 and a protected fauna regulation since 2024. There is also the National Landscape Strategy of Andorra 2035, and the National Biodiversity Strategy of Andorra. All these laws and regulations include inventories that always referred to flora and fauna, but in any case they include an inventory of geological interest sites.
On the other hand, Law 9/2003, of December 19th on the Cultural Heritage of Andorra, establishes measures for the protection, conservation, and dissemination of cultural heritage, including paleontological heritage, and provides for the creation of specific inventories to identify and preserve sites of paleontological interest. In this context, in 2006 the "Inventory of the Paleontological Heritage of the Principality of Andorra" [4] was presented. In this work, 16 outcrops were defined based on bibliographical information and field validation; and it included an assessment of the sites along with a proposal for protection. Based on this inventory, areas of paleontological presumption (EPP) were defined, which include a buffer area around the outcrops. A revision of the 2006 inventory was carried out in 2021 [5]. There is no evidence that the cartography of EPPs has been updated.
Within the framework of this law, when any construction work affects an EPP, authorization from the Department of Cultural Heritage is required to proceed. This department requests an expert report to assess whether to authorize the work or not, or if a modification of the construction plan is requested. Moreover, if during the execution of any type of construction work, paleontological remains are discovered, the site manager is required to halt the work and notify the Ministry responsible for Culture, which must assess the significance of the finding.

Case study: assessing the impact of a ski resort expansion on a paleontological site
In 2023, a potential impact on an EPP was identified due to a project for the development of a new ski area in the Pal-Arinsal ski resort. This project included the construction of new slopes, chairlifts, access roads, water catchment areas, water storage ponds, etc. In response, the Department of Cultural Heritage consulted external geologists—specifically, the team responsible for the 2021 inventory update—to evaluate the potential impact on the EPP.
The area of interest corresponds to the Port Negre peak (Arinsal), one of the zones classified as of special interest in the 2021 inventory, where around twenty outcrops were identified. The area is formed by Silurian rocks (black shales and limestones) and Lower Devonian rocks (Rueda Formation, formed by grey shales and grey and brown limestones). The fossil content is rich, including remains of cephalopods (orthocerids and onchocerids), crinoids, gastropods and brachiopods (Figure 2).
To conduct the assessment and expert analysis, a field survey was carried out, with a particular focus on the location of the chairlift pylons, as these structures appeared to pose the greatest risk to the EPP. The study included detailed geological mapping, site prospecting, the collection of macrofossils, and the sampling of materials for subsequent micropaleontological analysis.
The final report recommended the designation of two protection and conservation areas due to the site's geological significance. Of particular significance is the site's well-preserved Silurian-Devonian transition, characterized by a sedimentary, original and gradual contact.

Conclusions
The case of Andorra underscores the delicate balance between economic development and the preservation of geological heritage. While some regulations exist, their implementation and enforcement remain a challenge. Strengthening conservation measures, promoting awareness, and incorporating geological heritage into broader environmental policies will be crucial steps toward ensuring the protection of these invaluable sites for future generations.

Figure 2. Fossils in Port Negre peak. Left: crinoids. Right: orthocerids.

References

[1] Muñoz, J. A. (1992). Evolution of a continental collision belt: ECORS-Pyrenees crustal balanced cross-section. *Thrust tectonics,* 235-246

[2] http://www.estadistica.ad, 2024

[3] Grandvalira Resorts report: https://www.grandvalira.com/ca/estacio/noticies/grandvalira-resorts-ven-un-total-de-2230604-dies-desqui-en-una-temporada-molt

[4] Turu, V. (2006). Inventari del Patrimoni Paleontològic del Principat d'Andorra. Mapa i memòria. Technical report.

[5] Institut d'Estudis Andorrans (2021). Carta Paleontològica d'Andorra. Actualització 2021. Technical report.