

Article

Geological Heritage in the “Arribes del Duero” Natural Park (Western, Spain): A Case Study of Introducing Educational Information via Augmented Reality and 3D Virtual Itineraries

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Abstract: The concept of geological heritage has been introduced into the protected area of the Arribes del Duero Natural Park, which is west of the Salamanca and Zamora Provinces, Spain for the purpose of developing a guide to places of geological and geomorphological interest, through which geoenvironmental itineraries were developed in order to demonstrate to both the students and tourists, the geological context of the events in the geological history of this natural park. Twelve of the most geologically representative geosites were assessed using 18 quantitative parameters dealing with the scientific, didactic and cultural-tourist interest of each site. The objective of this paper is to describe and analyze the points of interest that are of geoheritage significance and to develop of an inventory that will ultimately facilitate geoconservation and the dissemination of information through educational virtual itineraries that reveal the known geological history of an area. A 3D virtual geological route was created in Google Earth for educational use with superimposed georeferenced cartographies, together with a field guide and an app. The virtual route allows the participants to follow the geological events and the natural history of the park using digital devices in real time with the possibility of observing the relief, the geology and having access to the informative files describing each geosite. Using a field guide, each geosite is complemented with activities, and the participants have the option to evaluate what has been learned. An app makes the itinerary more interactive. These georesources allow a teaching–learning process where the student is an active part of the development and creation of the contents using technologies that provide an entertaining and didactic learning experience, and this involves working as a team and interacting with social networks, thus, potentially influencing the attitudes and skills development that are involved in geoconservation as an element for its sustainable development. The identification of geological heritage currently constitutes a great resource to promote the sustainable development of it and employment in very depopulated rural areas.

Keywords: geoheritage; geoeducation; augmented reality; 3D virtual tour



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1. Introduction

The Arribes del Duero Natural Park (west of the Salamanca and Zamora Provinces, Spain) is a 1061 km² large protected area which includes 37 municipalities and a population of about 17,000 inhabitants. The area has great geological and geomorphological values [1]. From a flat surface (the so-called penillanura salmantino-zamorana) of a uniform altitude of about 700–800 m (due to the deep canyons (arribes) that have been carved by the fluvial system (Duero, Tormes, Huces, Huebra and Águeda Rivers)), one descends to about 130 m. Consequently, this border area between Spain and Portugal is one of the areas with the greatest hydroelectric potential of the Iberian peninsula. To add to the topographical environment is that of the vegetation. The vegetation is very different in the “penplain” with respect to the Arribes due to its climatic conditions. In addition to the riparian galleries

and the anthropic action in the terraces where the slopes are high and there are processes of deforestation and erosion, the Mediterranean crops that are produced are usually unfit for this latitude, and there is an unusual thermophilic vegetation assemblage.

This work describes the 12 representative geosites for their rich geological heritage. The known geological information of the area is completed with the study of the geomorphological aspects which are characteristic of the area. Thus, we developed a guide of the places of geological-geomorphological interest, through which the geoenvironmental itineraries can be completed that identify the most representative geological and landscape interests and to facilitate the learning by the main students and tourists of the contexts and events in the geological history of this Natural Park. The area of the Natural Park that belongs to the province of Salamanca is included in the UNESCO World Geopark project [1–4] (<https://geo3sr.usal.es/> accessed on 1 august 2022). Geoparks are a recognized model that promotes sustainable development in areas that contain sites of geological heritage (geoh heritage) of international significance and promotes geoconservation and geotourism [5,6].

The objective of this paper, therefore, is to analyze points of interest in terms of their geoh heritage significance through the development of an inventory that will facilitate geoconservation and the dissemination of information through virtual educational itineraries that reveal the known geological history of the area. Augmented reality is used in order to provide the digital content of the geological heritage in geoapps and virtual flights in real time using smartphones, tablets, etc. Given the general absence of specific geological information on geoh heritage values, only the best geosites in the study area have been selected. In this study, we identify the best sites to assess their geoh heritage values and at the same time, we advocate for their protection and conservation once the values of them are known.

The educational value of geological heritage of the geosites were analyzed at different educational levels, as well as this, we updated the educational methods using new technologies such as AR and 3D virtual itineraries [2,7–11].

Using geomatic tools, the digital information was compiled from different thematic layers. Photographs, diagrams and descriptive cards were then incorporated to produce the didactic resources. By interacting with the digital information using the free Google Earth platform, 3D virtual “flights”, which can be followed in real time, were established and implemented in different formats (mpeg, avi, wma, etc.) that are reproducible in different multimedia systems, thereby increasing the possibility of educational and tourism use by broad sectors of the population.

2. Geological Context

The Arribes del Duero Natural Park is located on the western edge of the “Domo del Tormes”, which is an internal orogenic area of the Iberian Massif that is characterized by the development of high-grade plutono-metamorphic complexes. The materials that were affected by these orogenic events are the metasedimentary rocks of the Upper Neoproterozoic or Lower Cambrian age from the “Grauvachian Schist Complex”, which are discordant under the Lower Ordovician quartzites (Armorican quartzites). In the lower levels of the metasedimentary series, abundant glandular and fine-grained orthogneiss appear that are of pre-Variscan age [12–14] (Figure 1).

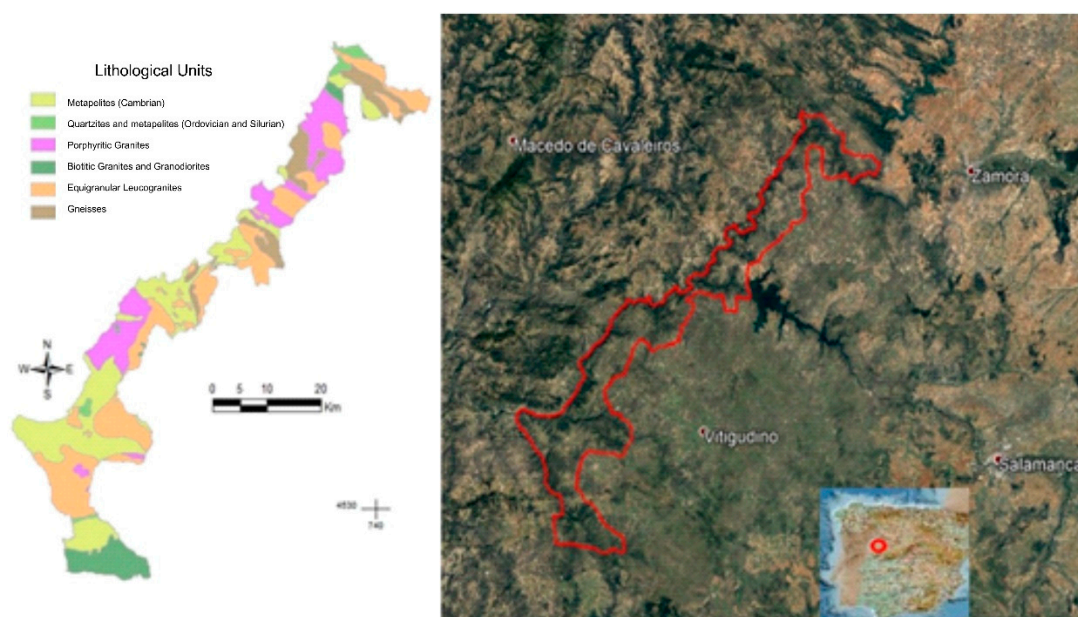


Figure 1. Geospatial distribution of the lithological units in the study area.

The Variscan Orogeny (Carboniferous age) affected these materials in various deformation phases, with there being structures in the NW-SE directions. The metamorphism that is associated with this orogeny transforms the sedimentary sequence into metapelites and gneisses, and it reaches a partial fusion with the generation and intrusion of anatectic granites [15–18].

Granitic rocks and the associated intermediate rocks, which intrude during the second phase of deformation D2 and up to D3 (older granites), show a great variety of rock types, some of which are represented in the Arribes del Duero Natural Park: leucogranites, biotitic granites and intermediate and basic rocks. The leucogranites contain two micas and of anatectic origin. They can be equigranular, i.e., fine-to-coarse grained, the latter sometimes occurs with tourmaline, garnet or cordierite and porphyritic. The biotitic granites are always porphyritic and can sometimes also have muscovite and/or cordierite. The intermediate rocks are spatially in relation to the biotitic granites and they vary in their composition from diorites and monzonites to tonalites and granodiorites [19,20].

All of this (granitic and metamorphic) basement is affected by the late Variscan and Alpine faults that condition the subsequent fitting of the river network. This fracturing has directions that run from NW-SE to E-W, although the most characteristic system has a NE-SW or NNE-SSW direction. Some of these faults are associated with large quartz dikes that constitute morpho-structural alignments of relevant ridges in the peneplain (the so called “Sierros”) [21]. From the geomorphological point of view, the fluvial embedding on the peneplain is very representative since it occurs throughout the Quaternary, leaving some remnants of an ancient hanging surface (La Peña geosite) as a result of the intense process of alteration of the primary surface. These relict witnesses are of epi-syenite that are more resistant to the alteration processes.

3. Materials and Methods

Twelve sites were selected for the purpose of assessing their scientific, educational and tourist cultural interest in local and regional studies. Some sites are referred to in the National Inventory as places of Geological Interest (LIGs). The entire natural park is considered a Global Geosite ([https://www.igme.es/patrimonio/descargas/BASES%20CONCEPTUALES%20Y%20METODOLOGIA%20DEL%20INVENTARIO%20ESPA%C3%91OL%20DE%20LUGARES%20DE%20INTERES%20GEOLOGICO%20\(IELIG\).pdf](https://www.igme.es/patrimonio/descargas/BASES%20CONCEPTUALES%20Y%20METODOLOGIA%20DEL%20INVENTARIO%20ESPA%C3%91OL%20DE%20LUGARES%20DE%20INTERES%20GEOLOGICO%20(IELIG).pdf) accessed on 30 July 2022). We have used the free Google Earth browser to make a virtual visit to

these 12 geosites (Figure 2). The itinerary, from north to south, begins in Las Barrancas de Fariza (P-1) (Zamora Province) and ends in La Fregeneda (P-12) (Salamanca Province).



Figure 2. Arribes del Duero Natural Park with selected geological sites.

The augmented reality is applied here by implementing the different cartographic layers and digital information that are sometimes found on paper or by downloading and implementing layers from geoportals of public administrations (points of cultural interest). This includes digital georeferenced information on highways, paths, archaeological remains, delimitation of geoparks, biological heritage: protected fauna and botany, anthropic and natural singularities, areas of spectacular landscape, etc.). The participant can relate to their geological route in Google Earth. All of this transversal information can be found in the same (free) application (app) and in the same geospatial format, thus helping the teaching–learning processes by integrating inter-operable thematic layers in real time for the area that is being studied. It constitutes a teaching complement for field practices where the contents are observed directly by the naturalist scientist or tourist in the natural outdoor laboratory.

3.1. Assessment of Places of Geological Interest (LIGs) or Geosites

The method that was used to assess geosites is that which is proposed by García Cortés et al. [22]. This method consists of evaluating 18 parameters in each site based on their intrinsic value, weighted from 0 to 4 points (0 is the minimum interest, and 4 is the maximum interest), which are multiplied by different coefficients to obtain their scientific, educational and tourist cultural value (Tables 1 and 2). Where geosites are of international significance, different geosite valuation methods were used [23–26] with the Garcia Cortés et al. [22] being the most accepted and applied method for assessing sites of geoh heritage significance in Spain [25,26].

Table 1. Parameters that were studied and coefficients based on the value that was sought (scientific, educational and tourist).

Parameters	Scientific	Educational	Tourist/Cultural
Representativeness	30	5	0
Character type locality	10	5	0
Degree of scientific knowledge of the location	15	0	0
State of conservation	10	5	0
Viewing conditions	10	5	5
Rarity	15	5	0
Geological diversity	10	10	0
Learning objectives/educational use	0	20	0
Logistics infrastructure	0	15	5
Population density	0	5	5
Accessibility	0	15	10
Intrinsic fragility (geosite size)	0	0	15
Association with natural and/or cultural elements	0	5	5
Beauty	0	5	20
Informative content/use	0	0	15
Potential for tourism/recreation activities	0	0	5
Proximity to recreational areas	0	0	5
Socioeconomic environment	0	0	10

Table 2. Data that were obtained from the evaluations of each parameter by stops and results of the scientific, educational and cultural interest of each geosite.

Parameters	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
Representativeness	2	1	2	2	2	2	2	2	2	1	2	4
Character type locality	0	1	1	1	1	1	1	1	1	1	2	2
Degree of scientific knowledge of the location	2	4	4	4	1	4	4	1	1	1	2	4
State of conservation	4	4	4	4	4	4	4	4	2	2	4	2
Viewing conditions	4	4	4	4	4	4	4	4	4	4	4	4
Rarity	1	1	1	1	1	1	1	0	1	1	1	2
Geological diversity	2	1	4	2	2	2	2	2	1	2	2	2
Learning objectives/educational use	2	4	4	2	2	2	2	1	2	2	2	4
Logistics infrastructure	2	4	2	1	2	4	2	1	1	1	4	2
Population density	1	1	1	1	1	1	1	1	1	1	1	1
Accessibility	2	4	2	1	4	1	1	2	2	4	4	1
Intrinsic fragility (geosite size)	4	4	4	2	2	4	1	4	2	2	4	2
Association with natural and/or cultural elements	1	4	4	1	2	2	2	2	2	2	4	2
Beauty	2	2	4	2	1	2	2	2	1	2	2	4
Informative content/use	2	4	4	1	2	2	2	2	2	4	2	2
Potential for tourism/recreation activities	2	4	2	1	2	2	2	1	1	4	1	4
Proximity to recreational areas	0	0	1	0	0	0	0	0	0	4	1	1
Socioeconomic environment	4	2	1	1	4	1	1	4	4	4	1	2
TOTAL	37	49	49	31	37	39	34	34	30	42	43	45
ASSESSMENT OF SCIENTIFIC, EDUCATIONAL AND TOURIST CULTURAL INTEREST												
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
Scientific interest	205	205	265	245	200	250	245	185	170	150	225	310
Educational interest	195	300	285	170	230	215	190	165	165	205	280	250
Tourist Cultural interest	240	305	300	145	215	220	160	235	185	290	255	240
Total	640	810	850	560	645	685	595	585	520	645	760	800

3.2. 3D Virtual Route on the Google Earth Platform

Once geosites had been identified, catalogued and assessed for their geoheritage significance, they were georeferenced with their GPS coordinates and geological context. For this, the Google Earth platform was used, which allowed us to place the points on a virtual 3D globe, as can be seen in the flowchart shown in Figure 3, in an area that was adjacent to Arribes del Duero Natural Park, thus obtaining georeferenced information in a simple and free-of-charge way that is suitable for all of the types of electronic devices, such as mobile phones, tablets, computers, etc. This makes it possible for the information that was collated to be accessible from anywhere, either in the classroom or on route between stops, thus facilitating the visualization of the itineraries by users and increasing their interest in the activity. The reference system that was established is the usual one that is used in Spanish cartography: Universal Transverse de Mercator—UTM [27]. Each geosite was georeferenced by means of a series of position marks, in which the spatial coordinates and a brief description of the area were shown (Figure 4). It also includes an information sheet with field photographs, interpretation of the information and evaluations of its scientific, educational and tourist cultural value (Figure 5).

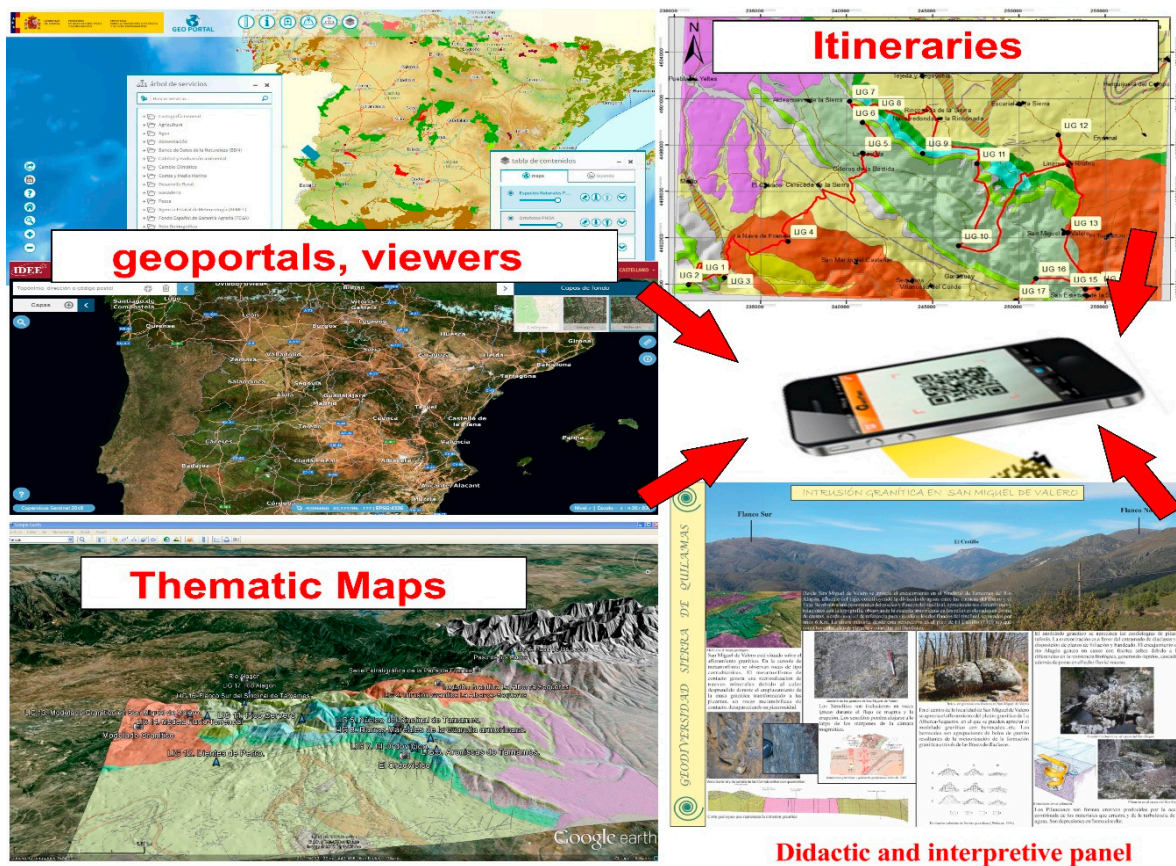


Figure 3. Graphical flowchart to understand the procedure and loading of layers in final implementation on smartphone.

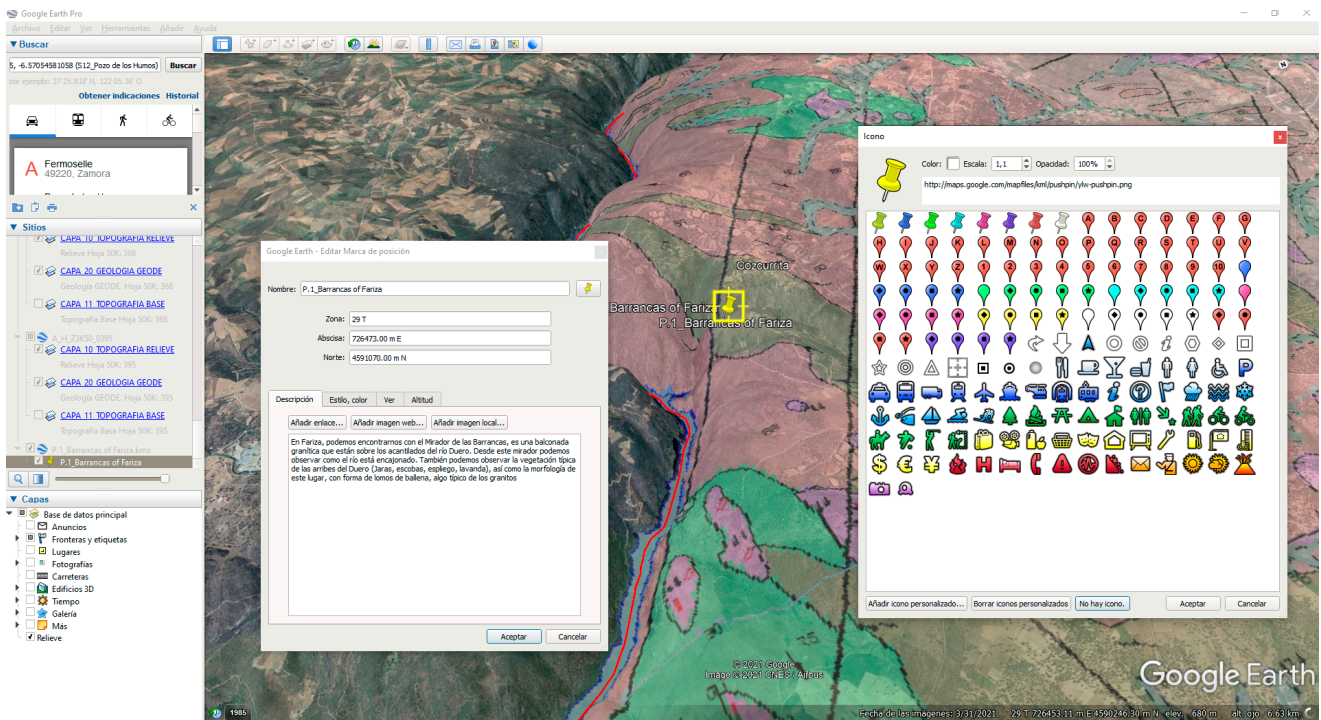


Figure 4. Screenshot of site P-1 (Barrancas de Fariza) with UTM coordinates, description and geological cartography.



Figure 5. Screenshot of geosite P-7 (La Peña) with photos and sheet of geosite.

The set of sites, or stops, of the itinerary in “kml/kmz” format generated a geodatabase, and the platform automatically georeferenced each selected site. With the virtual 3D digital model [28,29], by activating the option “Relief”, one can zoom in on the sites in the itinerary, and by activating “analyze the geological and geomorphological context”, one can obtain a spatial visual of the area. In addition to adding alphanumeric and text information, photographs were added to each site, as well as a file with their description and interpretation (Figure 5).

When all of this information was available for each site, the Google Earth platform generated a virtual route. The application generated the route by road or through other areas depending on the mode of movement from one site to another (by car, hiking, etc.). To do this, the departure and arrival sites must be selected, and the application will generate a route to follow like any other global positioning system would (Figure 6).

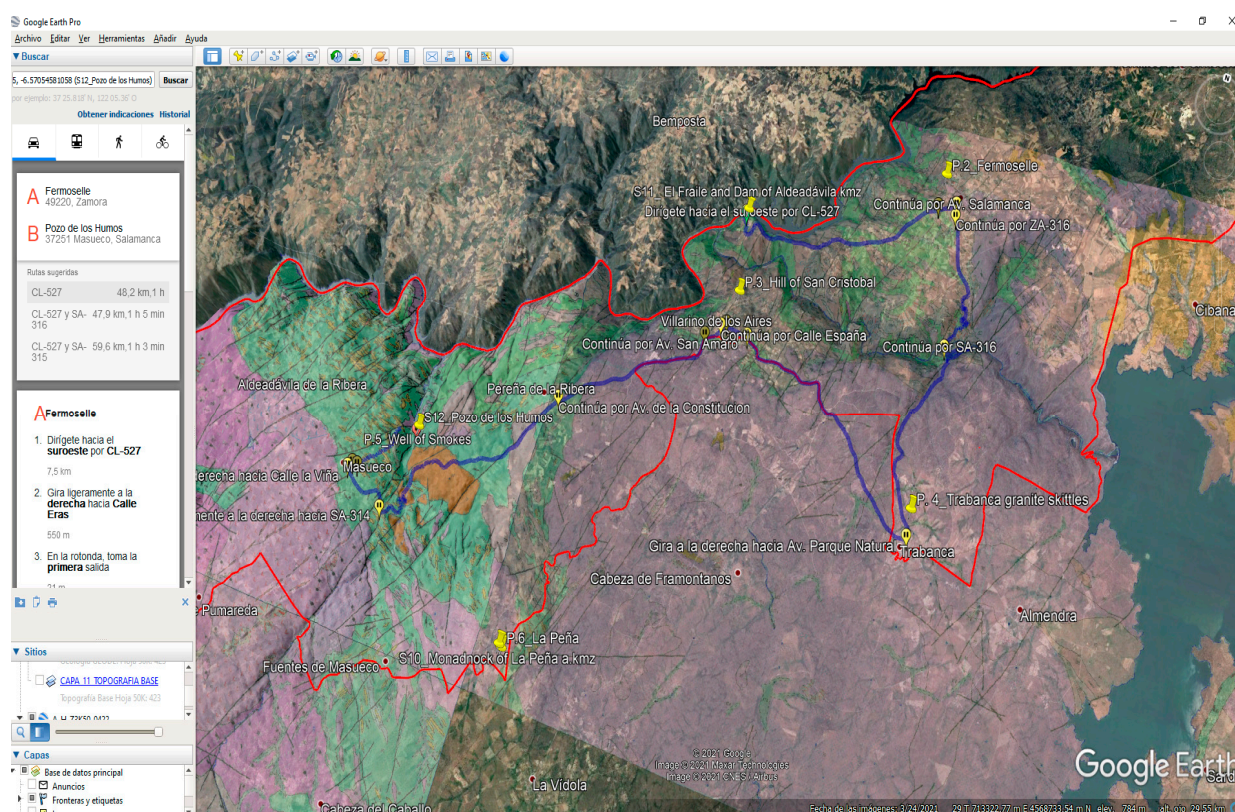


Figure 6. Capture of one of the possible routes that was generated by Google Earth (blue line) on the geological cartography with transparency on the orthophotography. Route from Mirador del Fraile to the Pozo de los Humos. Red line: limits of the Arribes del Duero Natural Park.

By interacting with the Street View application of Google Maps, structures or outcrops can be viewed “in situ” (Figure 7). In addition, a topographic profile of the route can be generated, allowing one to previously assess its complexity (Figure 8).



Figure 7. Capture on the selected route in “Street View” mode. Entrance to the Arribes del Duero Natural Park. Box on the left with GPS tracking. Bottom right: view of the La Peña geosite (P-7) from the route.

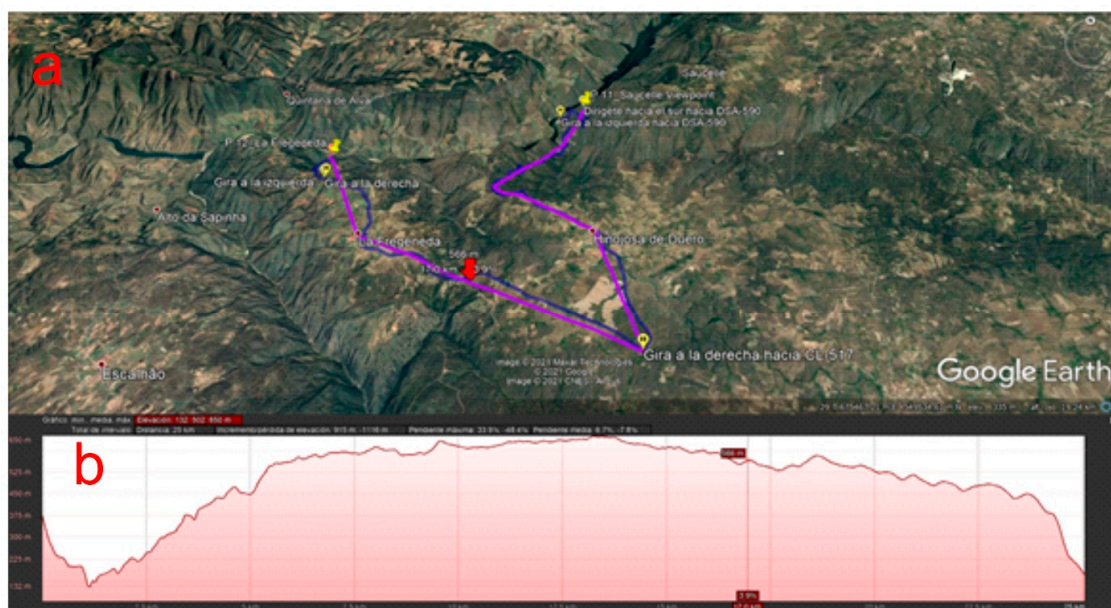


Figure 8. Route from site P-11 (Mirador de Saucelle) (a) to site P-12 (La Fregeneda) and topographic profile (b).

Users can perform a 3D virtual flight using the command “record route”. The flight includes a tour on the geological map that is superimposed on the 3D virtual globe for the route that is selected for the different geosites, with them being able to access the photographs of each stop and the information on the corresponding sheet [30]. The resulting virtual flight will be a recreation of the virtual 3D video which will be compatible with tablets, computers or mobile devices. The virtual tour of the selected itinerary can be presented in different video formats: mp4, avi, etc. (Video S1).

Another application that was implemented in the virtual route which provides height interactivity between students is the flight simulation mode, which allows one to choose a type of aircraft, activate the flight in a specific position, or establish the departure airport from anywhere on the globe (Figure 9).

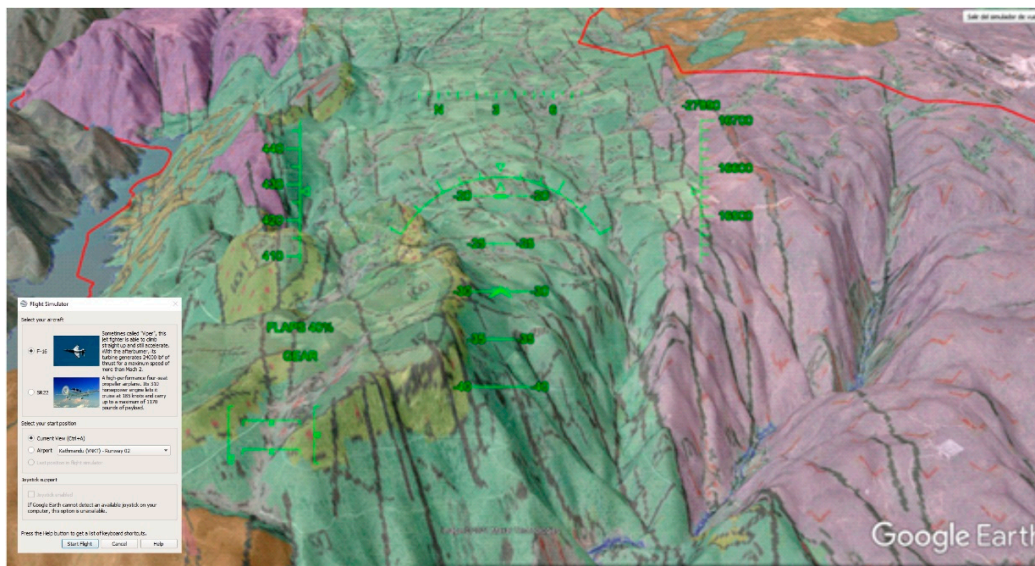


Figure 9. Capture of the virtual flight with the flight simulator of the F-16 plane over the geological distribution near of the site P-11 (Saucelle).

3.3. Educational Resources: Field Guide and Geoapp

Field Guide. A field guide was developed that includes sheets with basic information on each site, which were made with all of the materials, both descriptive ones (coordinates and field data) and graphic ones (photographs and diagrams). The guide includes questions about geological materials, structures, etc., which appear in each of the sites on the route that the participants will have to solve. This allows the participant to understand the main geological concepts. The field guide is available in PDF format, accessible with a QR code, or downloadable through a teaching platform.

Applications. Another educational resource that is presented is the creation of an app, which is free for the android operating system. Only internet access is required for its use. The application allows the information of the proposed route to be displayed by entering the data of each geosite into the platform assistant. In addition, one can obtain additional information on Google Maps, send messages directly to the mobile phones of all of the users regarding real-time information about the geosites, as well as attach links. The information that is included is in Spanish and English.

4. Results

4.1. Itinerary and Geological Heritage

The 12 stops (Figure 10) on the itinerary are located in Barrancas de Fariza (P1) and Fermoselle (P2) in the province of Zamora, while the other stops: Mirador del Fraile (P3), Teso de VillarinoSan Cristobal (P4), Berrocales de Trabanca (P5), Pozo de los Smokes (P6), La Peña (P7), Mirador de La Code (P8), Sierra de Peñahorcada (P9), Inselberg de Vilvestre (P10), Mirador de Saucelle (P11) and La Fregeneda (P12) are located in the province of Salamanca. Most of the stops are accessible by car or bus. Table 2 shows the evaluations of the 12 stops with their total value and the value of the scientific, educational and tourist cultural interests.



Figure 10. (A) Incision of the Duero River in the granite basement and formation of watercress-limes. (B) Granite sill highlights on migmatites. (C) Image of the flaking of the granite of the Mirador de El Fraile on the left and on the right the dam of the Aldeádavila Dam on the Duero River. (D) View of Cerro de San Cristóbal on the left and a rounded granite fragment, which is fractured in two parts on the right. (E) Landscapes and granite forms scattered around the Trabanca berrocal. (F) Pozo de los Humos waterfall.

4.2. Description of the Stops

Stop 1 (P1): Barrancas de Fariza (4,591,070.00 m N/726,473.00 m E).

The Mirador de las Barrancas, in the municipality of Fariza, consists of a granite balcony that is located on the cliffs of the Duero River. From this viewpoint one can see the confluence of the river. One can also observe the typical vegetation of the Arribes del Duero (rockrose, brooms and lavender), as well as its geomorphology (shaped like the back of a whale), which is atypical for granites (Figure 10A).

This first stop has a scientific interest value of 205, a didactic interest value of 195 and a tourist or recreational interest value of 240. In total, this stop has 640 points which reflect the sum its scientific, educational and cultural interest.

Stop 2 (P2): Femoselle (4,577,492.00 m N/717,530.00 m E).

The town of Femoselle, located to the SW of the Province of Zamora, constitutes an example of popular architecture that is adapted to the granite environment. One can also see the great embedding of the Duero River.

Femoselle's geology includes metamorphic rocks (migmatized gneisses and metapelites) and granite rocks. The granites, which are more resistant to erosion when they do not present a high degree of fracturing, the hills and the metamorphic rocks are located at lower elevations, forming smooth slopes like those of the Duero Valley (Figure 10B). Many houses have been built on granite, and there is an extensive network of cellars which have been dug out of the softer migmatitic rocks [31,32].

This stop has a scientific interest value of 205, a didactic interest value of 300 and a tourist or recreational interest value of 305. In total, this stop has 810 points.

Stop 3 (P3): Mirador del Fraile (4,574,916.00 m N/711,807.00 m E).

At the Fraile viewpoint, one can see the Duero River canyon and the granite modeling (bell-shaped domes and berrocales). Desquamation processes are abound, causing slabs and rounded shapes that are in favor of the river valley (Figure 10C). The Aldeadávila Dam is 139 m high, and there is 848,000 m³ of water in its reservoir. Its construction is represented a milestone in hydraulic engineering due to the large slopes and very complicated access points. In addition, the fractured granite massif has high permeabilities.

This stop has a scientific interest value of 265, a didactic interest value of 285 and a tourist or recreational interest value of 300. In total, this stop has 850 points.

Stop 4 (P4): Cerro De San Cristóbal (4,572,935.00 m N/714,265.00 m E).

It is located in the municipality of Villarino de los Aires. From this place, one can see the setting of the river Tormes near its mouth in the Duero, which has the structural characteristics of the old geological base. The views of the arribes del Tormes and granite outcrops with rounded morphologies forming berrocales stand out, and numerous fractures can be seen. From the site, one of the granite sills is cut by the river Tormes (Figure 10D). These granite bodies sometimes give rise to large waterfalls.

This stop has a scientific interest value of 245, a didactic interest value of 170 and a tourist or recreational interest value of 145. In total, this stop has 560 points.

Stop 5 (P5): Berrocal de Trabanca (4,568,747.00 m N/719,212.00 m E).

Located near the town of Trabanca, one can see striking berrocales, in this case, on two-mica, equigranular, medium-grained granites (Figure 10E).

This stop has a scientific interest value of 200, a didactic interest value of 230 and a tourist or recreational interest value of 215. In total, this stop has 645 points.

Stop 6 (P6): Pozo de los Humos (4,565,742.00 m N/703,656.00 m E). The Pozo de los Humos is located between the municipalities of Masueco and Pereña. It corresponds to a spectacular waterfall of the river Uces which is 50 m high, with a great flow in spring that originates in its fall large aerosols (the so-called “smokes”). The visualization of this geosite makes it possible to easily observe the structural relationships between the different lithologies, observing sub-horizontal granite sheets that are alternating with the metapelitic nesting rocks of slate [31] (Figure 10F).

This stop has a scientific interest value of 250, a didactic interest value of 215 and a tourist or recreational interest value of 220. In total, this stop has 685 points.

Stop 7 (P7): Inselberg de La Peña (4,561,397.00 m N/708,641.00 m E).

In Arribes del Duero, isolated granite forms appear that stand out on the peneplain (inselberg). One of the most impressive examples is the one in the town of La Peña. Its approximate dimensions are 71 m in diameter and 41 m in height. From the geomorphological point of view, its maximum elevation coincides with that of an old surface that has remained as a residual relief on the peneplain, which allows one to know the existence of value surfaces that were visible prior to the encasing of the Duero River. On the south face of La Peña, morphologies are observed that due to the wind action, generate gnammas and taphonis that are cavities which were formed by the attrition of the particles that the wind dragged against the rocks (Figure 11A).

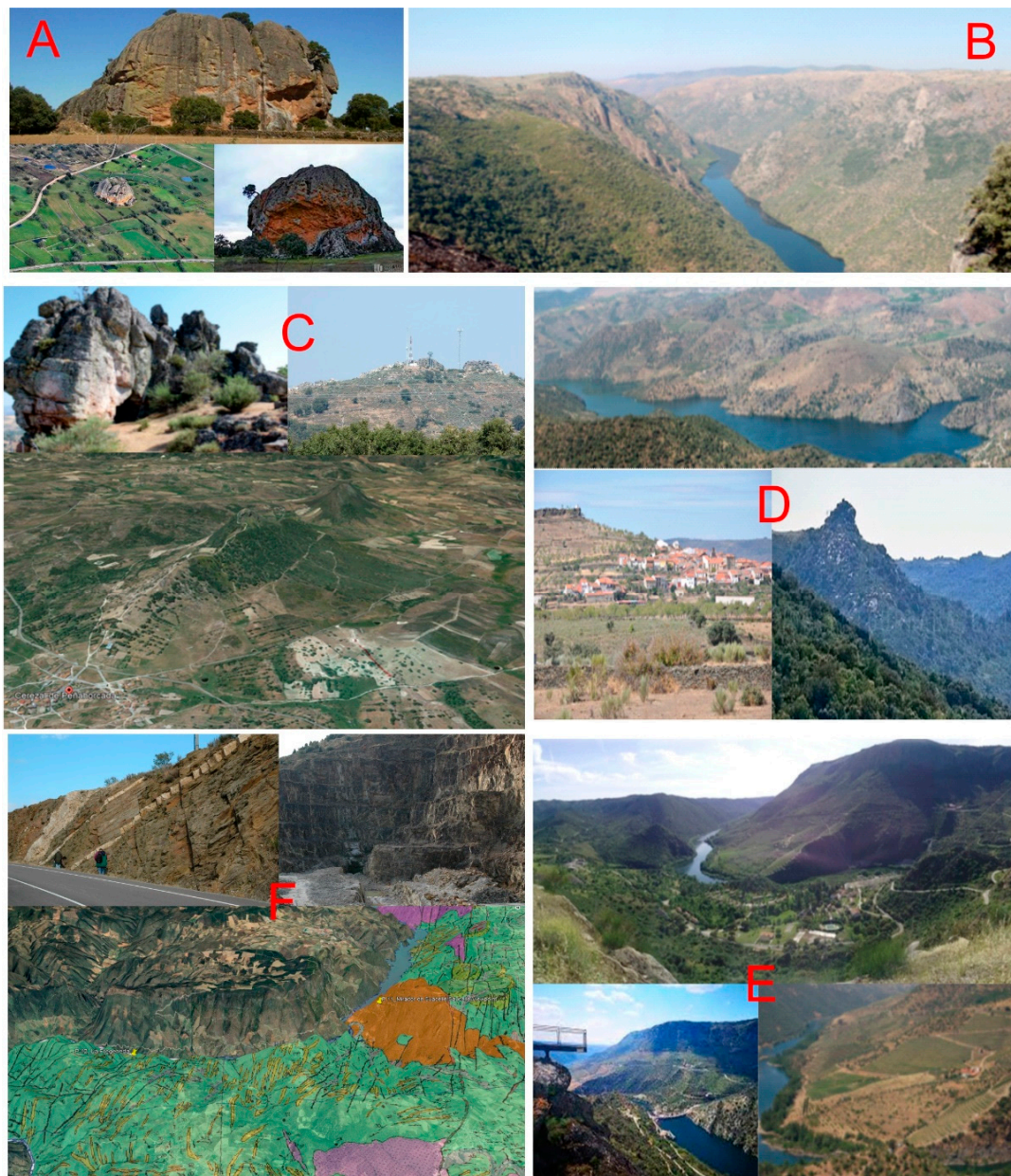


Figure 11. (A) Image of the rock seen from the front (top), which stands out on the current surface (bottom left) and with important structures of wind erosion (bottom, right). (B) View of the riverbed of the Duero river from the La Code viewpoint. (C) Panoramic view of the Sierra de Cerezal de Peñahorcada and detail of the quartz dike at its highest point where it is resistant to erosion (top right and left). (D) Capture of a panorama from the Bajo Duero de Vilvestre (above). In the lower part, one can see the town of Vilvestre with the elevated sector of El Castillo (left) and the pyramidal morphologies near the viewpoint in the riverbed (right). (E) Panoramic of the folded Ordovician materials on the Portuguese slope (top) and view of the softer slope (bottom left) and lower part of the slope with crops and terraces (bottom right). (F) Location of the La Fregeneda stop on the geological cartography wherein there are visible abundant pegmatite dikes (yellow), detail of the dikes in a section of the road (top left), and a view of the cut from Mina Feli (top right) where hydrothermal seams with cassiterite are cut by discordant pegmatites. Feli Mine view (top right) and hydrothermal quartz seams in reel cuttings (top left). One can also appreciate the previous stop of the Mirador de Saucelle and the Ordovician reliefs in the Portuguese part or right bank of the Douro River.

Lithologically, the rock is an epi-syenite, and with striking pink-two-reddish tones that were caused by the hydrothermal alteration of the granite.

This site stands out for its petrological, geomorphological and tectonic features.

This stop has a scientific interest value of 245, a didactic interest value of 190 and a tourist or recreational interest value of 160. In total, this stop has 595 points.

Stop 8 (P8): Mirador de La Code (4,560,698.00 m N/692,950.00 m E).

From this viewpoint, one can see the incision of the Duero (Figure 11B). The great difference between the peneplain and the steep slope can be appreciated. In the valley area, there is a mild and attenuated climate while, on the peneplain, the temperature and rainfall profile is more continental [33,34]. In these fluvial incisions, the vegetation is conditioned by the changes in the temperature and altitude, as well as by the rainfall. The geographical limitations that occur due to the slope have slowed down the expansion of the agricultural and livestock activities, which is why this has helped to conserve the vegetation species that have a great ecological importance (such as rockrose, brooms and lavender).

The geosite has a scientific interest value of 185, a didactic interest value of 165 and a tourist or recreational interest value of 235. In total, this stop has 585 points.

In the west of the province of Salamanca, the elongated elevations that stand out from the monotony of the peneplain are called “sierro”. Their heights can reach 60 to 80 m, and their lengths can be a few kilometers (Figure 11C).

These structures only develop within the granite and are characterized by the presence of dikes and quartz veins at their highest levels and slopes of altered granite (which are crumbly, without berrocal and without vegetation, which is used for cultivation in the plots that are perpendicular to the top). In contrast, the surrounding peneplain shows granite berrocal and is covered by shrubs and trees.

The formation of these mountains is linked to a family of (probably) tardivariscas fractures, although they may possibly rejuvenated later, with a very constant NNE direction (N20E to N35E). The repeated operation of these structures causes the fracturing and alteration of the granite in their vicinity, with the migration of the quartz to the central areas, which later remain as higher projections due to their greater resistance to erosion.

This stop has a scientific interest value of 170, a didactic interest value of 165 and a tourist or recreational interest value of 185. In total, this stop has 520 points.

Stop 9 (P9): Sierro de Cerezal de Peñahorcada (4,554,710.00 m N/696,144.00 m E).

Stop 10 (P10): Inserberg de Vilvestre (4,552,812.00 m N/690,603.00 m E).

This inselberg has a residual relief which is a highlight. These reliefs appear to coincide with harder levels of lithology, in which the structural platforms have the shape of tables (Figure 11D). It constitutes a conical inselberg that developed where the structural elements present a great resistance to erosion. In the area, which is known as the Bajo Duero, one can find morphologies that are not so abrupt. They have acid soils with a sandy texture that are poor in carbonates and with very little organic matter content, which is characteristic of granite substrates so they are not very fertile for agriculture and livestock.

This stop has a scientific interest value of 150, a didactic interest value of 205 and a tourist or recreational interest value of 290. In total, this stop has 645 points.

Stop 11 (P11): Mirador De Saucelle (4,545,817.00 m N/685,100.00 m E).

The viewpoint is located between the town of Saucelle and the dam of the same name. It can be seen that this stretch of the river has meanders since it is not as entrenched as it is upstream. From this viewpoint, one can see the Portuguese massif of Penedo Durao, highlighting the structural and tectonic aspects of the area (Figure 11E)

The most abundant rocks in this area are hillside colluvium and alluvial deposits that were left by the river. The softer slopes are present, which allows one to work the land more easily, and one can appreciate that there are large areas with vineyards on the metamorphic rocks (slates, gneisses and schists) and fewer vineyards on the acid soils that have developed on the igneous rocks (granites). The presence of the terraces indicates differential erosive activity in the steepest parts of the slopes.

This stop has a scientific interest value of 225, a didactic interest value of 280 and a tourist or recreational interest value of 255. In total, this stop has 760 points.

Stop 12 (P12): La Fregeneda (4,543,948.00 m N/ 677.779.00 m E).

La Fregeneda is located northwest of Salamanca on the border with Portugal. The sector is characterized by a swarm of discordant and concordant pegmatitic dikes that are rich in lithium which is associated with the hydrothermal quartz veins with tin mineralization (cassiterite). These pegmatites are embedded in a complex schist and have a great morphological variety. The Feli mine stands out (Figure 11F) where these hydrothermal quartz which form a seam with the cassiterite are observed to be cut by the lithium-rich pegmatite dikes.

This stop has a scientific interest value of 310, a didactic interest value of 250 and a tourist or recreational interest value of 240. In total, this stop has 800 points. This stop is the third one with the highest score and it also has a very high educational score.

Generally, the value of the degree of interest (scientific, didactic and tourist-recreational) which was observed for all of the stops is high. There are some stops that have a higher tourist or scientific interest value than the educational one, but in this case the interested is in those of greater educational value to establish the itinerary with the students.

The highest scientific values are at stop 12 (La Fregeneda) with 310 points, stop 3 (El mirador del Fraile) with 265 points, stop 6 (El Pozo de los Humos) with 250 points, stops 4 (Cerro de San Cristobal) and 7 (La Peña) with 245 points, stop 11 (Mirador de Saucelle) with 225 and stops 1 (Barrancas de Fariza) and 2 (Fermoselle) with 205.

Regarding the educational value, stop 2 (Fermoselle) stands out with 300 points, stop 3 (El mirador del Fraile) has 285 points, stop 11 (Mirador de Saucelle) has 280 points, stop 12 (La Fregeneda) has 250 points, stop 5 (Bolos graníticos de Trabanca) has 230 points, stop 6 (Pozo de los Humos) has 215 points and stop 10 (Inselberg de Vilvestre) has 205 points.

The highest tourist/recreational value corresponds to stop 2 (Fermoselle) which has 305 points, which is followed by stop 3 (El mirador del Fraile) with 300 points, stop 10 (Inselberg de Vilvestre) with 290 points, stop 11 (Mirador de Saucelle) with 255 points, stops 1 (Barrancas de Fariza) and 12 (La Fregeneda) with 240 points, stop 8 (La Code) with 235 points, stop 6 ("Pozo de los Humos" Well of Smokes) with 220 points and stop 5 (Granitic bowling of Trabanca) with 215 points.

4.3. Didactic Resources

With all of the information about the geosites (photographs, diagrams, spatially georeferenced coordinates, etc.), the field guide and app were designed so that the route would be more interactive and the students could perform dynamic participation during their completion of the itinerary. These resources are freely available and downloadable from the "cloud" through the Internet for students, teachers or any other participant on the route.

The field guide (Figure 12) contains the detailed information of the stops and graphic documentation such as photographs and interpretive diagrams, as well as different activities that are related to the geological concepts and general questions of the content of the curriculum. These activities deal with aspects of basic concepts, the recognition of structures and rocks, as well as geodynamic geological processes that occurred over time and the geological history of each stop. The activities can be carried out individually or in groups, and they take place during the completion of the itinerary, although some can be performed later at home. These exercises and questions will help the student to specify what has been learned and to consolidate the main ideas and concepts (Figure 12).

The field guide is available for printing and it was also uploaded to the educational center platform. Using a QR code, it will be easier to download it, and it can be viewed from any electronic device. A reference is also made in the app to a section of the field guide to facilitate its download.



Figure 12. Cover page of field guide and QR code. Screenshots of the geoapp: in the first screenshot there is the welcome message, both of them are in English and in Spanish, the different sections that the app has, the content of stop 12 (La Fregeneda), both of them in English and Spanish, and the group chat and the section on incidents and suggestions.

A positive feature of this application is its accessibility as it is free and downloadable for Android systems. All one needs is internet access. On the first screen, when the app is opened, a welcome message appears explaining the content of the app and how it works. Next, the main menu appears where all of the stops have been presented with the data and photos of the route. At the beginning of it, one can find a link to Google Earth, and in the next section, an image or diagram of the complete route. Subsequently, all of the LIGs appear with their information and photographs. It features a chat room for the users to interact with each other and forums for the participants to raise issues and/or questions. The content of the Geoapp is in Spanish and English in order to expand the range of users in schools and institutes that are bilingual. There is also access through a Google drive link to the field guide, where one can find more information on each stop and exercises to evaluate the skills that are learned using the itinerary. The application will be able to be downloaded through a link or using a QR code so that it is easily accessible (Figure 12).

The augmented reality application that is proposed in this work integrates specific thematic cartographies (geological, vegetation, topographic, etc.) with cartographies that

identify points of natural interest: geological, biological, historical, cultural, etc., in the same free application (Google Earth) and that allows one to implement, using the same inter-operable format, the different usable and downloadable layers of the geoportals of the official web pages, but that are scalable, that is, for a specific territorial sector. One can establish the options of greater spatial and temporal resolution, or even incorporate, for example higher quality digital terrain models or satellite images or drones (centimetric pixel size resolutions), thus improving the route information in real time and ensuring that they are geopositioned using the smartphone's GPS, which can facilitate the photo-interpretation of, for example, natural processes: landslides, geological risks, outcrops and geospatial distribution, etc. Technological progress occurs very quickly, and the information and its associated databases currently require applications that can interact with high-resolution information that is as up-to-date as it possibly can be, and the methodological proposal of this work allows it to be applied at the teaching level and integrated into activities of teaching and learning.

The georeferenced geographic information, as indicated in the previous point, was obtained from the websites, viewers and geoportals of the different public administrations of the state. Currently, although this information is implemented using different GIS types, the formats are inter-operable and easy to transform, so even if the native digital information is downloaded in a "shapefile" format from any GIS type, or from other programs for daily use such as autocad (formats dwg, dxf, dgn, etc.), they can be automatically converted to kml/kmz formats, which allows the different thematic tents to be transformed into a reference system that can be used worldwide, such as the wgs84 reference system, which is the one that is usually used by the GPS. This makes things easier since each country establishes different official reference systems for its official cartography, but the method that is indicated in this article generalizes and transforms them directly into an interoperable format. It constitutes in itself a strategy for the future since, in the end, the inter-operable free application is the one that will survive possible specific applications and those of specific groups.

5. Conclusions

A virtual geological route has been designed through the Arribes del Duero Natural Park that can provide educational resources to integrate the areas of geological interest at different educational levels and for all people.

The teaching resources that were used such as the field guide and the geoapp help to make the tour more entertaining and educational for the students. In addition, the geomatics that was applied with the tools that are available on the Google Earth platform allows us to implement augmented reality using a smartphone for its daily use in student life and interact with the generated resources such as the flight simulator, 3D maps, Street view, etc. They will make this experience fun as well as educational.

The designed geological route includes 12 geosites (Places of Geological Interest, LIG), which have been weighted according to their didactic, scientific and tourist cultural interest. All of the stops have a high interest value, although some have a higher tourist or scientific interest value than the didactic one (Supplementary Materials).

Of the 12 evaluated stops, those with the highest didactic scores are stops 2 (Fermoselle), 3 (Mirador del Fraile), 11 (Mirador de Saucelle) and 12 (La Fregeneda), and this allow one to design possible personal itineraries. There is no time to complete all of them in one day and group them by content or proximity. Stop 2 is in the Province of Zamora and stops 3, 11 and 12 are in Salamanca. They are easily accessible areas by road when one is using a minibus. The fact that students can see things with their own eyes makes them more curious and interested in geology. This also encourages both sustainable geotourism in economically depressed areas, such as the one that has been studied, as well as promoting careful attitudes towards the environment. The geosites of Arribes de Duero that are most unique due to their high educational value may in the future be subject to a

more detailed analysis (case-study) of the use and evaluation of the application of different pedagogical methodologies.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land11111916/s1>, Video S1: Kml Geodatabase, video virtual tour.

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