Computers & Geosciences 61 (2013) 83–93

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

A virtual tour of geological heritage: Valourising geodiversity using Google Earth and QR code

A.M. Martínez-Graña *, J.L. Goy, C.A. Cimarra

Geology Department, External Geodynamics Area, Sciences Faculty, University of Salamanca, Plaza Merced s/n, 37008 Salamanca, Spain

ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form
18 July 2013
Accepted 24 July 2013
Available online 13 August 2013

Keywords:
Virtual tour
Geological heritage
Google Earth
KML
Augmented reality
QR code

ABSTRACT

When making land-use plans, it is necessary to inventory and catalogue the geological heritage and geodiversity of a site to establish an apolitical conservation protection plan to meet the educational and social needs of society. New technologies make it possible to create virtual databases using virtual globes – e.g., Google Earth – and other personal-use geomatics applications (smartphones, tablets, PDAs) for accessing geological heritage information in "real time" for scientific, educational, and cultural purposes via a virtual geological itinerary. Seventeen mapped and georeferenced geosites have been created in Keyhole Markup Language for use in map layers used in geological itinerary stops for different applications.

A virtual tour has been developed for Las Quilamas Natural Park, which is located in the Spanish Central System, using geological layers and topographic and digital terrain models that can be overlaid in a 3D model. The Google Earth application was used to import the geosite placemarks. For each geosite, a tab has been developed that shows a description of the geology with photographs and diagrams and that evaluates the scientific, educational, and tourism quality.

Augmented reality allows the user to access these georeferenced thematic layers and overlay data, images, and graphics in real time on their mobile devices. These virtual tours can be incorporated into subject guides designed by public. Seven educational and interpretive panels describing some of the geosites were designed and tagged with a QR code that could be printed at each stop or in the printed itinerary. These QR codes can be scanned with the camera found on most mobile devices, and video virtual tours can be viewed on these devices. The virtual tour of the geological heritage can be used to show tourists the geological history of the Las Quilamas Natural Park using new geomatics technologies (virtual globes, augmented reality, and QR codes).

1. Introduction

The geological heritage of a site can be defined by various elements, including the intrinsic nature and the social and cultural significance of the site. These elements have a geological dimension (e.g., stratigraphical, geomorphological, lithological, palaeontological) and a heritage dimension, which each have their own implications for land-use planning. Therefore, proper management should involve inventorying and cataloguing natural and cultural landmarks to establish a comprehensive policy for their protection and conservation. In Spain, conservation criteria have focused almost exclusively on biodiversity and have ignored the geological interest of a site due to the lack of available geological information.

The implementation of new technologies includes the use of databases integrated with virtual globes and other applications, Android operating system geomatics (Weng et al., 2012), and personal devices (e.g., smartphones, tablets, and PDAs). With these tools, different georesource layers can be accessed in "real time" for various scientific and educational purposes. Thus, geological heritage can become more than just a scientific and educational resource; it can also be an economic resource (Braga, 2004) based on the growing interest in geotourism and sustainable development strategies for natural parks (Hose, 1997).

This paper describes how to take advantage of new technologies to promote geodiversity through a virtual geological itinerary (Bailey and Chen, 2011) using a series of geological attraction geosites (geosite or LIG acronym in Spanish: Lugar de Interés Geologico) mapped and georeferenced in ArcGIS in Keyhole Markup Language (KML). This method allows these sites to be loaded into virtual globes for displaying and manipulating these layers (Blenkinsop, 2012; De Paor and Whitmeyer, 2011) and interacting with other digital map layers (e.g., geological, topographical, and digital terrain model (DTM)) and allows the user to analyse the spatial distribution of the various destinations within

* Corresponding author. Tel.: +34 923294496.
E-mail address: amgranna@usal.es (A.M. Martínez-Graña).

0098-3004/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cageo.2013.07.020

the geological context (Karabinos, 2010) and to plan itineraries. The KML-formatted maps are superimposed on Google Earth (Tewksbury, 2009; Whitmeyer, 2012) and facilitate the understanding of certain geological structures (e.g., anticlines, synclines, and faults) and the locations of different lithologies and outcrops much better than traditional maps can.

2. Example: global virtual geological analysis of the Las Quilamas Natural Park

The Las Quilamas Natural Park has an area of 11,100 ha and forms part of the Spanish Central System of the Hercynian Massif. The massif contains different lithological units, such as sedimentary rocks from the Pre-Cambrian and Lower Cambrian Schist-Greywacke complex, and Ordovician, Silurian, and Devonian sedimentary rocks with granite outcrops and Cenozoic covering the piedmonts (Fig. 1).

First, we analyse the geological context, superimposing the geological mapping and topographic digital vector format and the DTM shading to better visualise landforms (Fig. 2). These maps were obtained from geological mappings from the SIGECO website – consultation and geological mapping distribution of continuous web –, which is part of the GEODE project (IGME, 2012).

From the table of contents on the right side of the Google Earth display (Fig. 2), the views of the three thematic layers of the georeferenced KML format – namely, geology, topography, and DTM – can be activated or deactivated. Thus, an analysis can be made of the various geological formations and their spatial distribution with respect to the three-dimensional representation of the relief by superimposing different urban areas and linear infrastructures.

Taking advantage of the properties of the display, we approach different geological attractions according to geomorphological type (e.g., Appalachian reliefs with synclines in topographically elevated areas in the Sierra de Francia, the Alagón River encasement in granite outcrops) or structural type (e.g., fractures coincident with river directions, Silurian shale outcrops in the core of the Tamames syncline) (Fig. 3). This three-dimensional spatial view facilitates understanding of the geological context, allowing the development of educational tours for different geological formations, structures, and landscapes.

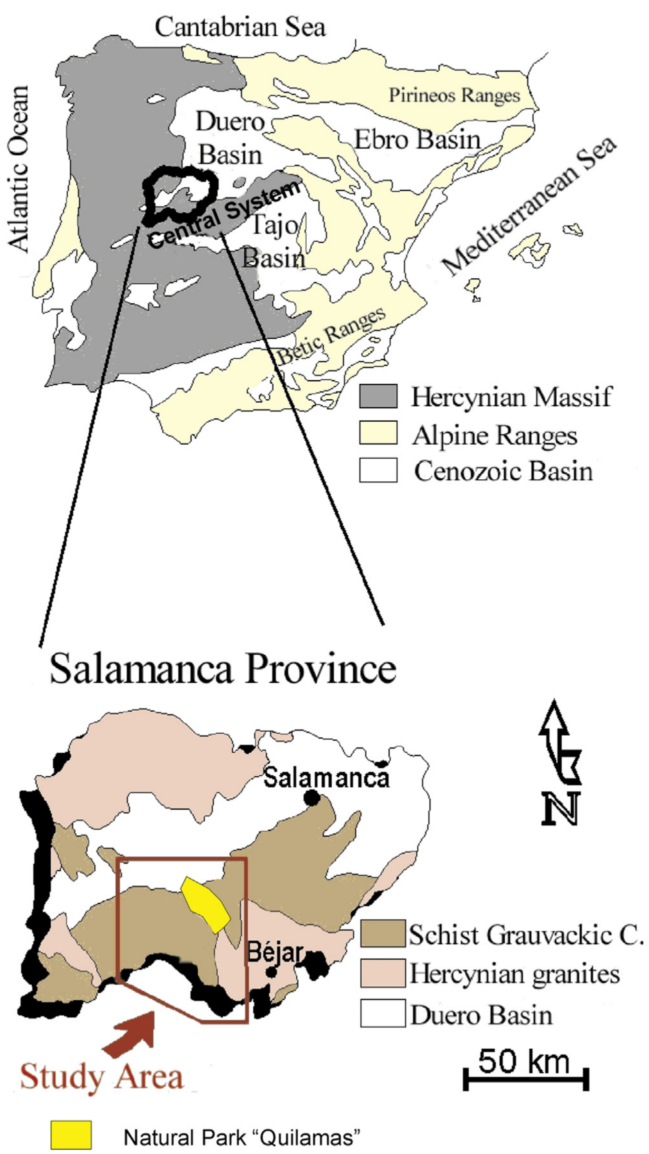

Fig. 1. Area of study.

3. Virtual geological itinerary in Las Quilamas

The virtual map allows one to take an inventory and catalogue points of geological interest, called "geosites", which are places with outcrops of materials, processes, or their sedimentary environment that provide insight into and understanding of the history and geology of Las Quilamas (Martínez-Graña et al., 2011). Each geosite is a virtual geological itinerary destination (Fig. 4).

The Google Earth application allows the user to import geosites georeferenced in vector format (points) and shown in a KML layer, or they can be generated with the menu function "add" by a "placemark", placing the mark at an exact location. The properties of each point of geological interest include a description of the place and different icons that can be used to produce different thematic itineraries (e.g., lithological route or active process route). Each destination is indicated with a different symbol (Fig. 5). One can also add pictures of an outcrop, reservoir, structure, or interpreted geological section. If a Google Earth item is generated, it must be saved using "save place as" in the KML format. The online distribution of these points is a quick process because of their small size (text only between 1 and 10 kilobytes and images between 1 and 10 megabytes, depending on the quality of the imported image). On the left side of the Google Earth display, "my places" is used to enable or disable each geosite and to modify and add new images. The scrolling feature can be used to zoom in so that the user appears to approach the information (text and images) associated with the closest points.

A tab is made for each geosite (Fig. 6) indicating the type of geosite, i.e., whether it is geomorphologic, stratigraphic, mineralogical, petrological, palaeontological, or structural. This tab provides an overview of the interpretation, processes, and genesis of the geosite, including photographs and interpretive schemes that show the characteristics of the outcrop and existing processes. Additionally, the geosite's biological, cultural–historical, scientific, educational, and/or touristic interest is indicated. Photographs and interpretive schemes for most representative structures are included (e.g., forms of granite outcrops with folds and faults). Both the placemark of each geosite and the tab and pictures are displayed automatically, doing different zoom with mouse scroll, when the viewer is close to the location of each point, and the different digital maps can be enabled or disabled in the table of contents.

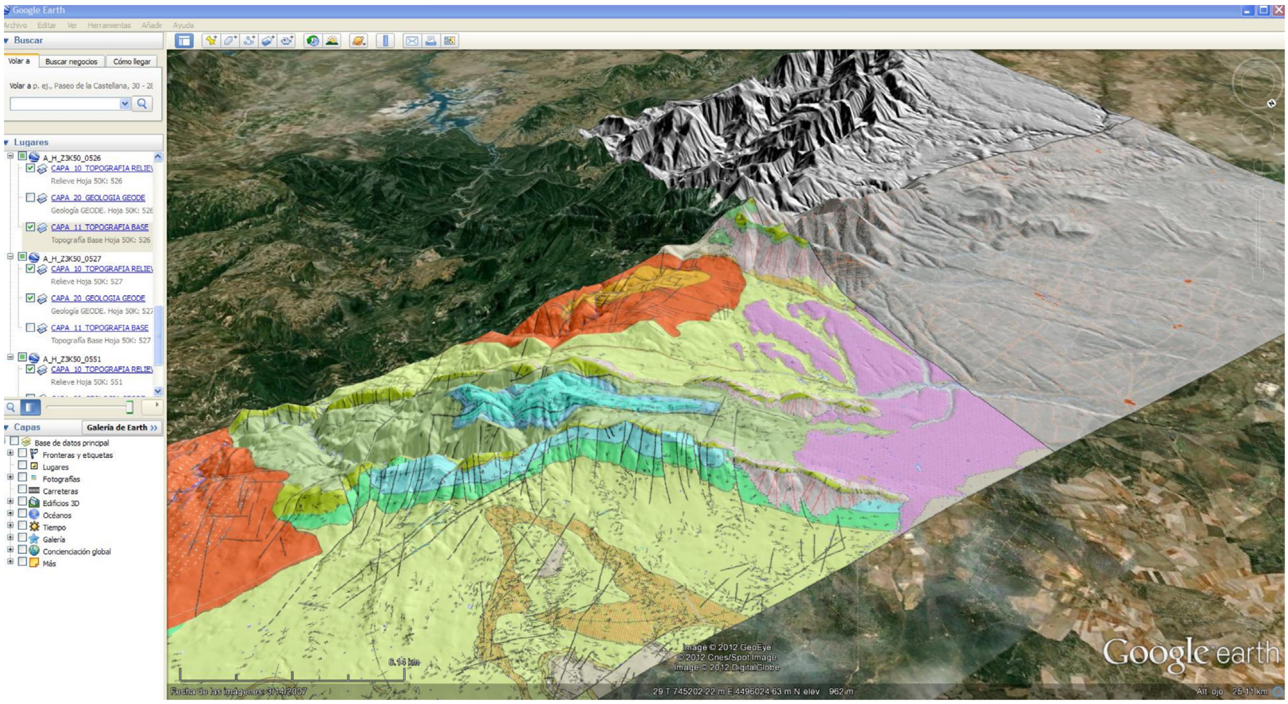

Fig. 2. View of the geological mapping, topography, and shaded digital terrain model in the KML format implemented in Google Earth.

A total of 17 geosites has been analysed, and for each geosite or LIG (Fig. 7), a fact sheet has been produced that contains descriptive data (side A) and a qualitative assessment of their importance or intrinsic value, the potential use, and the need for protection (side B). These latter parameters may change over time.

The descriptive data consist of the number and names of each geosite, the geosite location (location mapping and orthophotography), diagrams, and photographs representing the geological phenomenon of interest and location in the context of the geological and geomorphological geosite.

To evaluate each geosite, one considers the geological importance or intrinsic value of the site. This parameter is referred to as the quality of scientific use (SQU). Two other potential uses are also taken into account: the use as a teaching resource (TeQU) and as a tourist resource (ToQU) (Bruschi and Cendreros, 2005).

Finally, we evaluate the need for protection by considering the fragility of the site and the state of degradation, which provides information on the need for preservation and conservation measures. Each of these areas has been included by selecting some criteria that we considered representative.

The quality of scientific use (SQU) establishes the geological importance of the geosite from a scientific point of view. The assessment is made by taking into account the following criteria: abundance–rarity–diversity, importance as a leader in regional geology, and processes useful in interpreting scientific interest and research (Table 1).

The quality of educational use (TeQU) establishes the possibility of using a geosite as a teaching resource. The criteria used for evaluation are ease of understanding, observing conditions, possibility of performing activities at the site, and association with other elements of geological interest (Table 2). The quality of tourist use (ToQU) establishes the possibility of using a geosite as a tourist resource, based on the following criteria: proximity to infrastructure and equipment, landscape quality, accessibility, and association with other natural, historical, and cultural elements (Table 3).

The fragility and degraded state (FDS) allows for the possibility of a geosite being damaged, degraded, or destroyed, either by natural causes or by impact intervention. The following criteria are considered: the intrinsic fragility of the item or process in the context of maintaining the current degree of human impacts and the need for protection (Table 4). The weighting of each criterion has a minimum value of 1 and a maximum of 3; the total value is obtained by calculating the arithmetic mean of the criteria considered. Based on the values of the various criteria, the principal values of the SQU, TeQU, and ToQU parameters vary between 4 and 12 and the principal value of the FDS parameter varies between 3 and 9.

Based on a statistical analysis of the different parameters assessed (SQU, TeQU, ToQU, and FDS) and taking into account the fact that the minimum estimate for each of the criteria is 1 and the maximum is 3, the sum of the main parameters varied between a minimum value of 3/4 and a maximum of 9/12. Given that the minimum value for the sum of the first three parameters (SQU, TeQU, and ToQU) is 5.75 and the maximum is 8.75, with an average of 7.27, we observed that 53% of the geosites (over half) had above-average values, and 94% of geosites had total values greater than 6, indicating the high quality. There was direct correlation between TeQU and ToQU in general. Generally, geosites that have a higher quality of educational use also have a higher quality of tourist use. For the geosites with a quality of educa tional use greater than 2, we note that the quality of tourist use is the same or less than the quality of educational use (i.e., LIG 1, 2, 3, 4,…) (Fig. 7).

Sites within the study area that obtained the highest score in the valuation were the sites whose quality of educational use was greater. This means that people not educated in this field can still easily identify and understand the novelty and value of geosites. Notable places with scores greater than 8, such as LIG 1 (Appalachian relief of the Sierra de Francia) and LIG 2 (vertical folds outcrop in Paso de los Lobos) had high-quality landscapes. Analysing the sum of the absolute values for each geosite highlights the following highly rated geosites: LIG 1, 2, and 17 (Fig. 7).

In terms of the fragility and state of degradation of the different geosites catalogued, all need to be protected because they have a high degree of fragility and degradation, so as yet, there is no

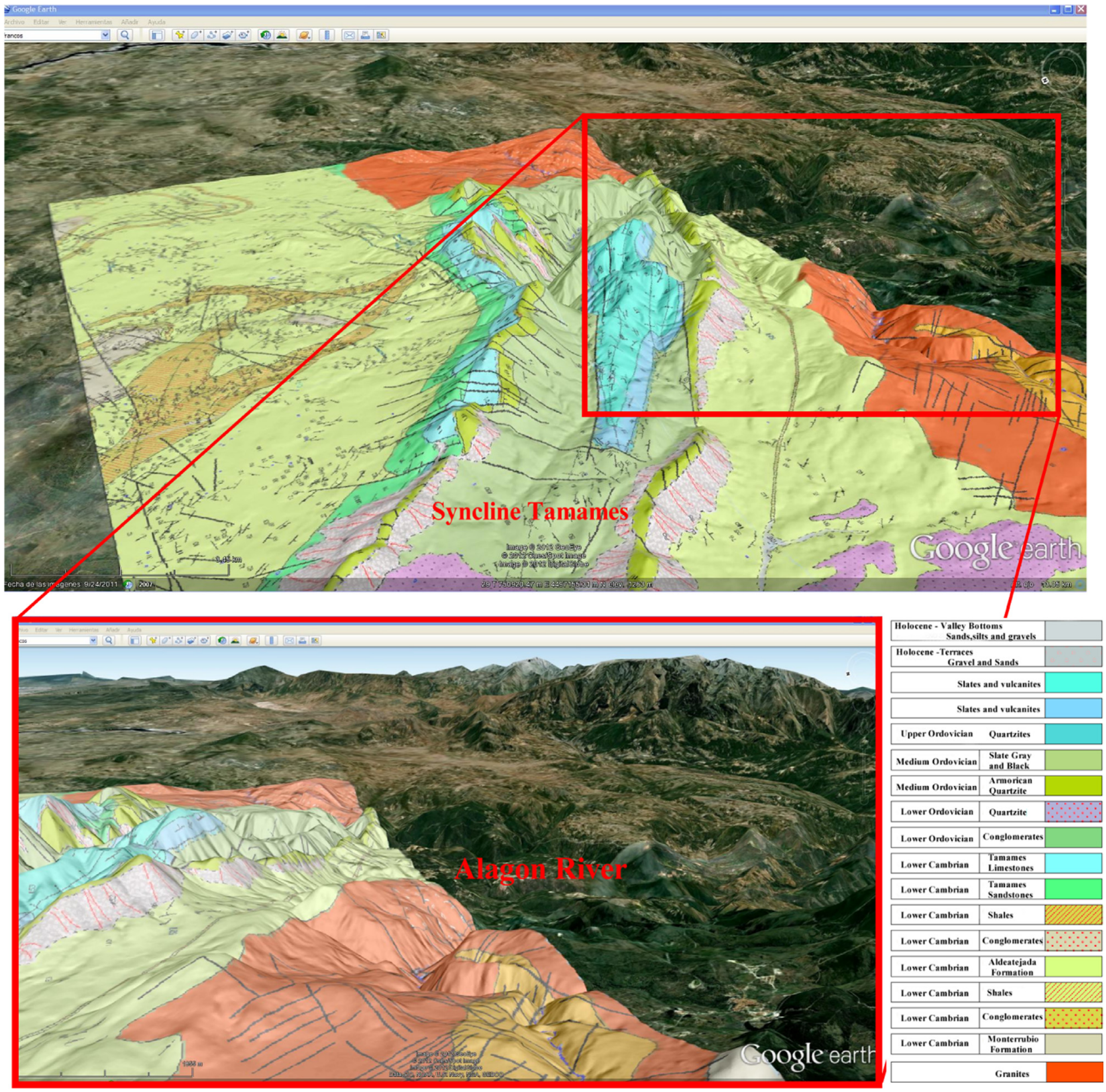

Fig. 3. View of the available geological formations (e.g., colluvial, granite outcrops, and Armorican quartzites in summits) and structures (e.g., faults, dips, and synclines) and their relationship with the morphologies of the current model (e.g., in relationship to river scree distribution slopes and structural surfaces).

specific assessment that should be used to recognise and protect these sites in the short term. The two lowest values were obtained for LIG 12 (vertical stratifications) and LIG 17 (Alagón river bends) (Fig. 7).

These itineraries constitute a georesource that can enhance the geological heritage of a region, are important as a management tool and for social use, and may promote geoconservation and help preserve geodiversity (Gray, 2003) (Fig. 8).

4. Augmented reality for mobile devices

Augmented reality is a new way to access information and thematic layers of georeferenced databases, overlapping data, and graphics or images in real time. Augmented reality is currently of significant interest because of its implementation in mobile devices such as smartphones and tablets. Because of the integrated GPS receiver and internet connection, these mobile devices can set the user's position and load and overlay georeferenced maps and geodatabases from web platforms and geoportals over public and/or private connections to servers, using light and heavy loads or the KML format from Google Earth (Ghadirian and Bishop, 2008; Stuart, 2012).

The Google Earth superimposes one's location on an orthophoto along with the geological itinerary information and places of interest and their associated information (e.g., files, photographs, educational schemes). 3D virtual flight software applications leverage greater social use (e.g., Google Earth and Terra Explorer) and facilitate the plotting of elaborate itineraries to follow in “real time” with mobile devices. The development of a Google Earth flight is performed using the command “record a tour”, running the red “record”, and closing the window to end the recording. The window that appears in the lower left corner is used to save or play the tour (Fig. 9).

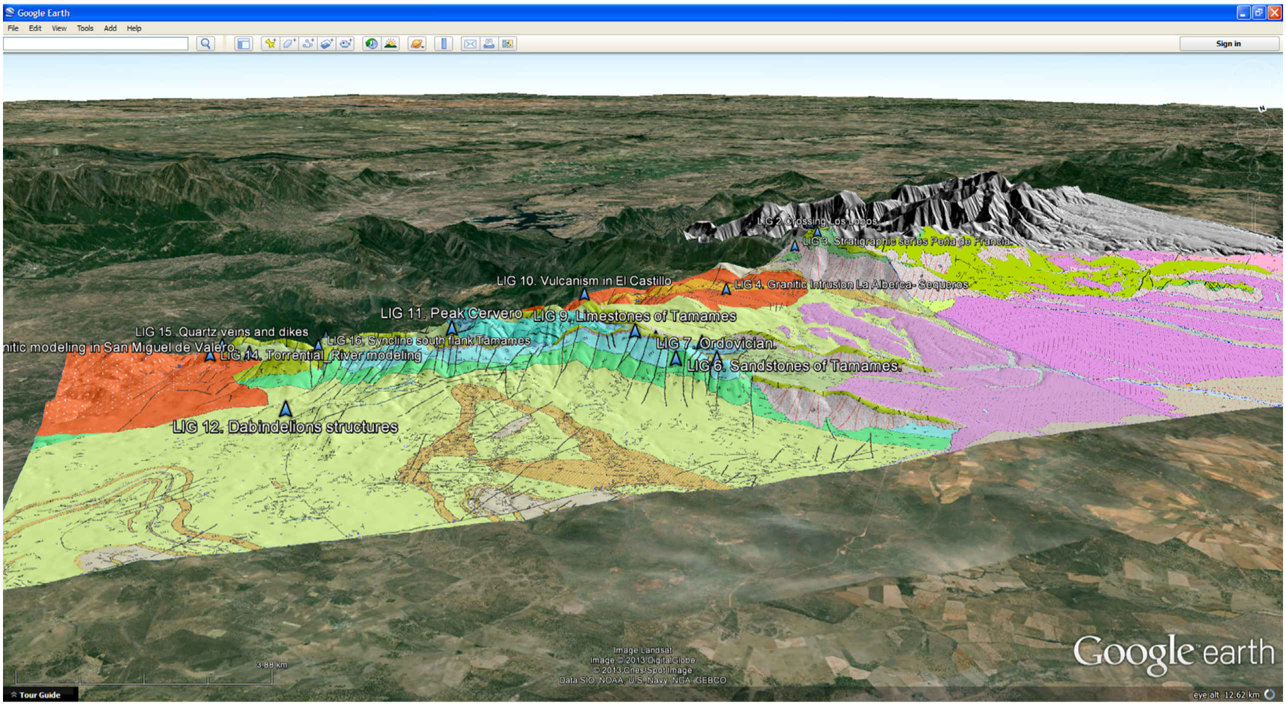

Fig. 4. Distribution of different geosites within the geologic context.

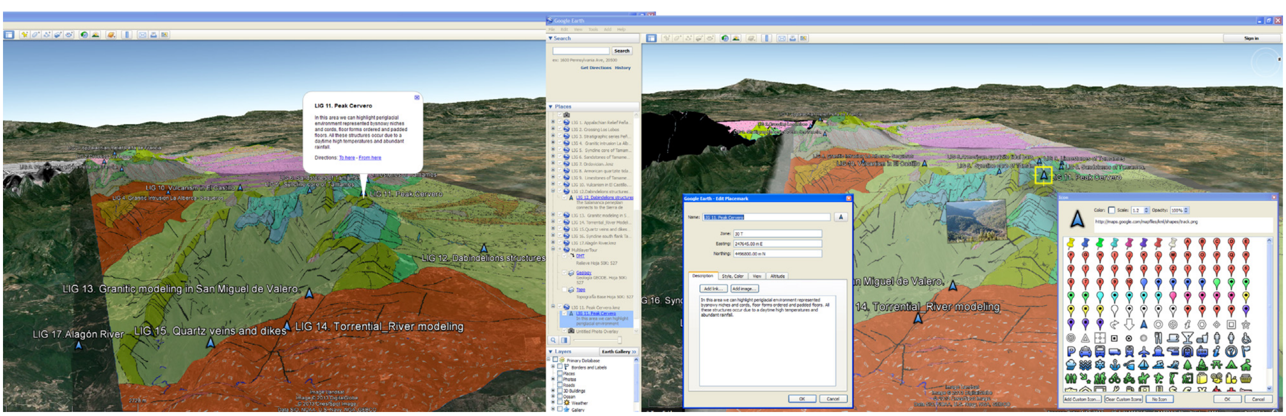

Fig. 5. Geosite generation number 2 (LIG-2) with the Google Earth interface.

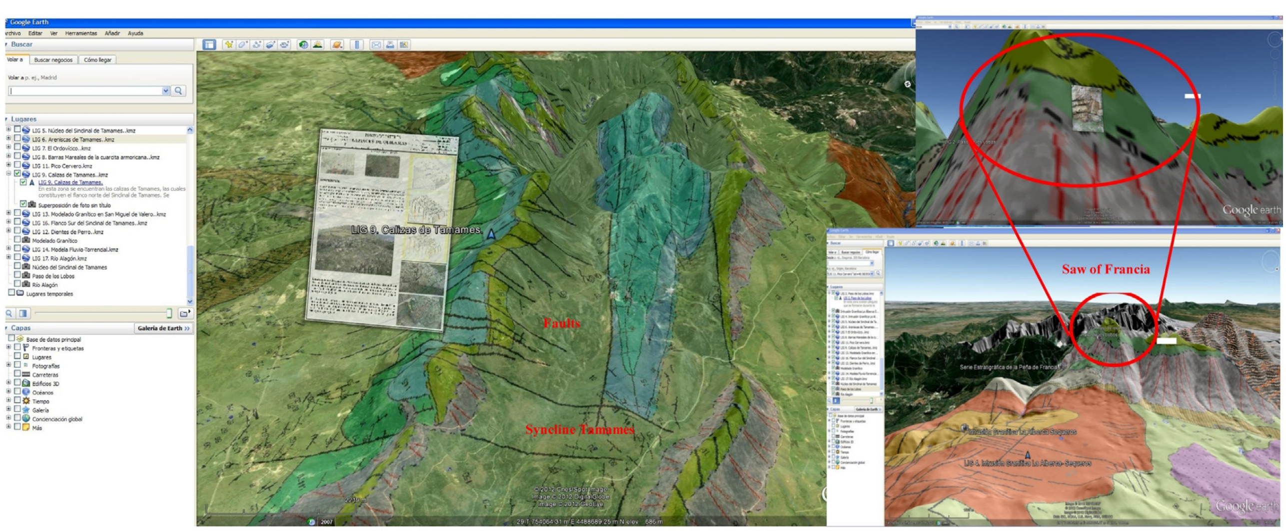

Fig. 6. Sheet geosite on a geological layer with 50% transparency to view orthophotography with planimetry. A display example of the right image that has been vertically zoomed in.

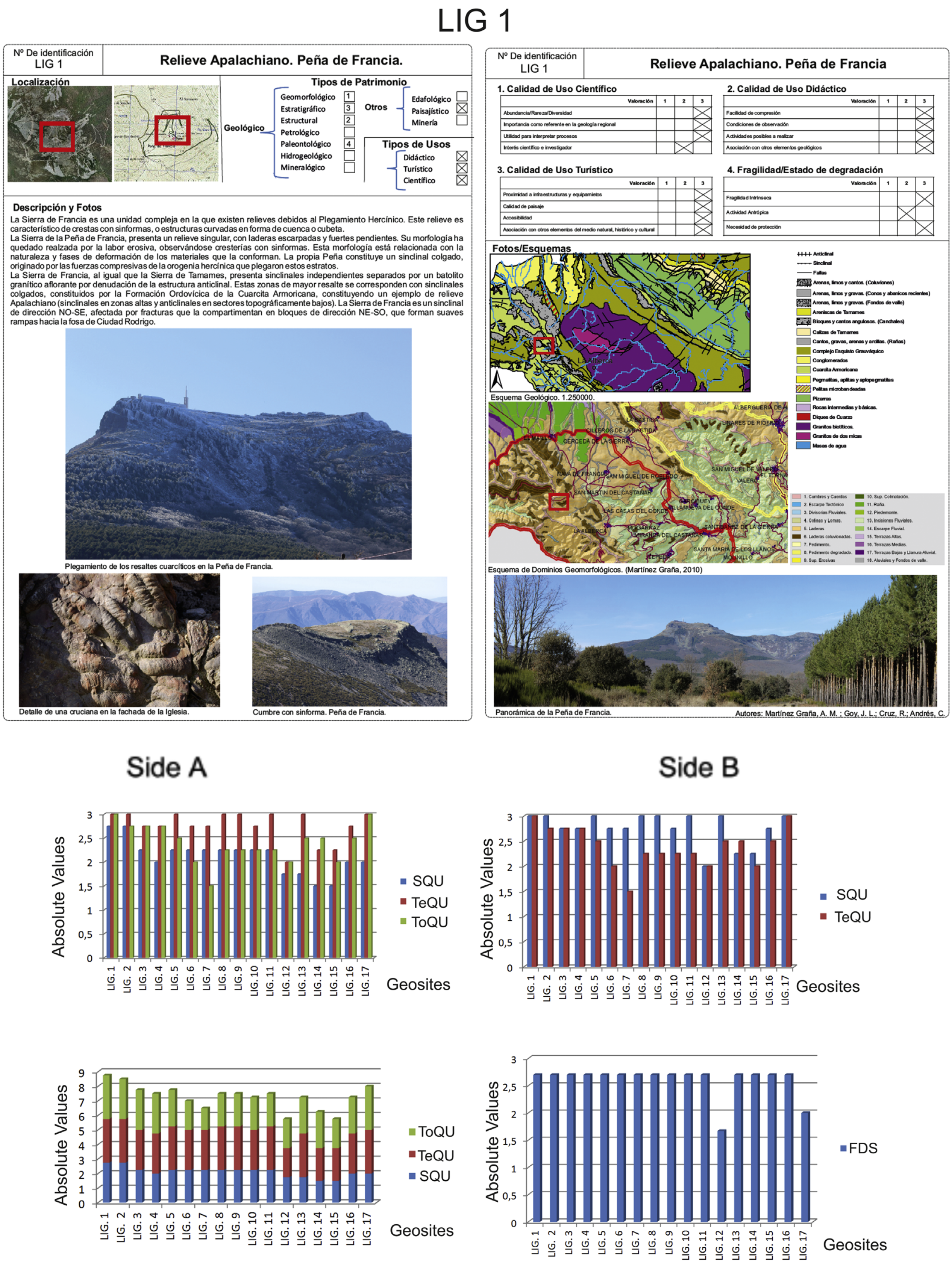

Fig. 7. Geosite LIG 1 (sides A and B). The graphic weight statistics are presented by geosites and the parameters evaluated.

The virtual geological itineraries that are generated can be used in conjunction with mobile devices for evaluating the educational, cultural, and touristic value prior to a visit, downloading digital information necessary preselecting the most interesting route. The compatibility of the export formats of virtual flights (avi and mpeg) and video applications when using computers or other

Table 1
Criterion for Quality of Scientific Use (SQU).

Scientific Quality Use (SQU)		
Criteria	**Value**	**Explanation**
Abundance/rarity/diversity	1	There are numerous examples
	2	There are several examples
	3	There are few examples
Importance as a leader in regional geology	1	It provides information on a regional
	2	It is important but not the best example
	3	Key role in regional geology
Utility to interpret processes	1	Not useful
	2	Moderately useful
	3	Very useful
Scientific interest and researcher	1	There are no published work in this geosite
	2	There is an article in national, regional or local this geosite
	3	There are Ph.D. theses and articles in international journals of this geosite

Table 2
Criterion for Quality of Educational Use (TeQU).

Teaching Quality Use (TeQU)		
Criteria	**Value**	**Explanation**
Ease of understanding	1	It requires a specialized level
	2	Suitable for school groups
	3	It is useful and attractive to all audiences
Seeing conditions	1	Not shown in its entirety
	2	Good observing conditions
	3	Exceptional conditions of observation
Possible activities to be performed	1	You cannot make any kind of activity
	2	There are activities but in small numbers
	3	There are many possible activities to be performed
Association with other geological features	1	No other geosites of interest
	2	Several nearby geosites of interest
	3	There are many geosites nearby

Table 3
Criterion for Quality of Tourist Use (ToQU).

Tourist Quality Use (ToQU)		
Criteria	**Value**	**Explanation**
Proximity to infrastructure and equipment	1	There are no services of any kind
	2	There are but few services
	3	There are all kinds of services
Quality landscape	1	Has little interest
	2	Nice environmental and is known locally
	3	The place is known for its beauty and is marked on maps and guides
Accessibility	1	Only accessible by foot
	2	Track or narrow paved road
	3	Is accessible by car and bus
Association with other elements of the environmental: natural, historical and cultural heritage	1	No other items of interest
	2	Several nearby items of interest
	3	There are a lot of items nearby

Table 4
Criterion for Fragile and Degraded State (FDS).

Fragility and Degraded State (FDS)		
Criteria	**Value**	**Explanation**
Intrinsic fragility	1	Sensitive elements large-scale changes
	2	If there is a change in the environmental can be modified but not destroyed
	3	Elements susceptible to minor variations
Anthropogenic activity	1	Unaffected except large-scale
	2	Is affected if there is a transformation in the environment
	3	It affects any change
Need for Protection	1	No need protection
	2	Use restriction
	3	Need protection

systems (e.g., DVD, multimedia hard drives) can facilitate the globalisation of our shared geological heritage. These videos can be shown to the participants prior to the start of a tour to provide a general spatial layout of the route and information regarding factors such as the degree of difficulty, alternative routes, and rest areas (Fig. 10).

These itineraries can be incorporated into scientific and educational subject guides designed by different organisations and associations. For some geosites, didactic panels can be designed that combine didactic process diagrams, photographs, fragments of maps, and simple explanations of the different locations (Fig. 11).

5. QR Codes for mobile devices

The information generated for valourising geodiversity of this tour (thematic layers, panels and virtual flights) can be displayed at each geosite, to minimise their visual impact, can be identified by just a locational QR code, allowing one to view digital information associated with that geosite with free applications for mobile devices. In our case, we generated QR codes from the free website http://www.qrstuff.com/index.html (QRStuff, 2012) and stored them on the free web platform http://uqr.me/private/profile. (uQR.me, 2012) Thus, any device with an android operating system (e.g., a smartphone or tablet) can capture the code and automatically display the panel in pdf format, allowing a better understanding of the geosite being viewed. The user needs internet access. Seven interpretive educational panels with simple explanations, charts, and graphs have been designed that improve the teaching–learning process for the general public, facilitating the understanding of natural processes. These panels have been encrypted using QR codes created using the free reader QuickMark (http://www.quickmark.cn/En/basic/index.asp) (Quickmark, 2012) to scan, capture, and download the panel using its "application software" (Fig. 12). The QR code in Fig. 12 is active so if you are caught with a QR reader of a smarthphone are accessing one of the panels.

6. Conclusion

Geological heritage is a non-renewable resource and is a common and inseparable part of the natural and cultural heritage of humanity. The different geomatics tools available include

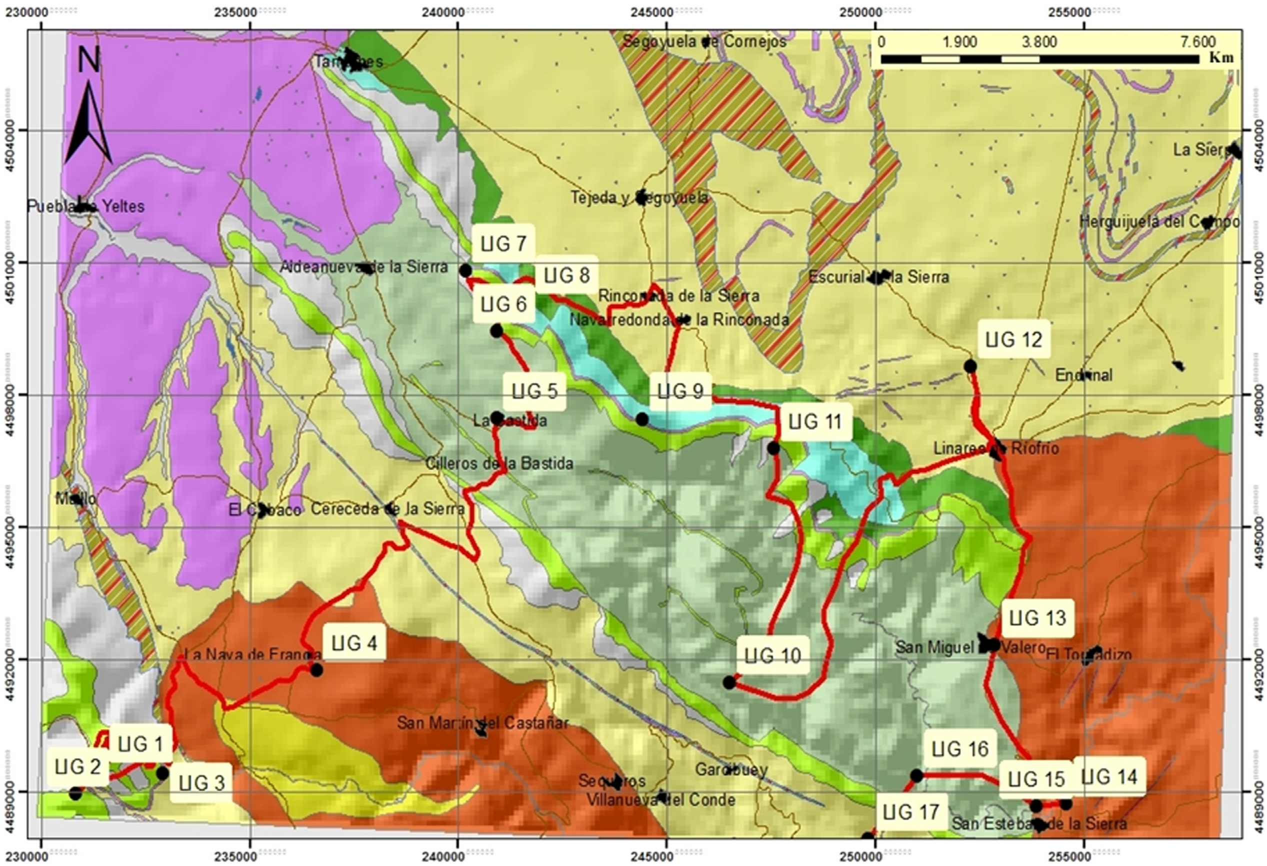

Fig. 8. Mapping of one of the proposed routes in Las Quilamas Natural Park, with the destinations sequentially ordered using geosites.

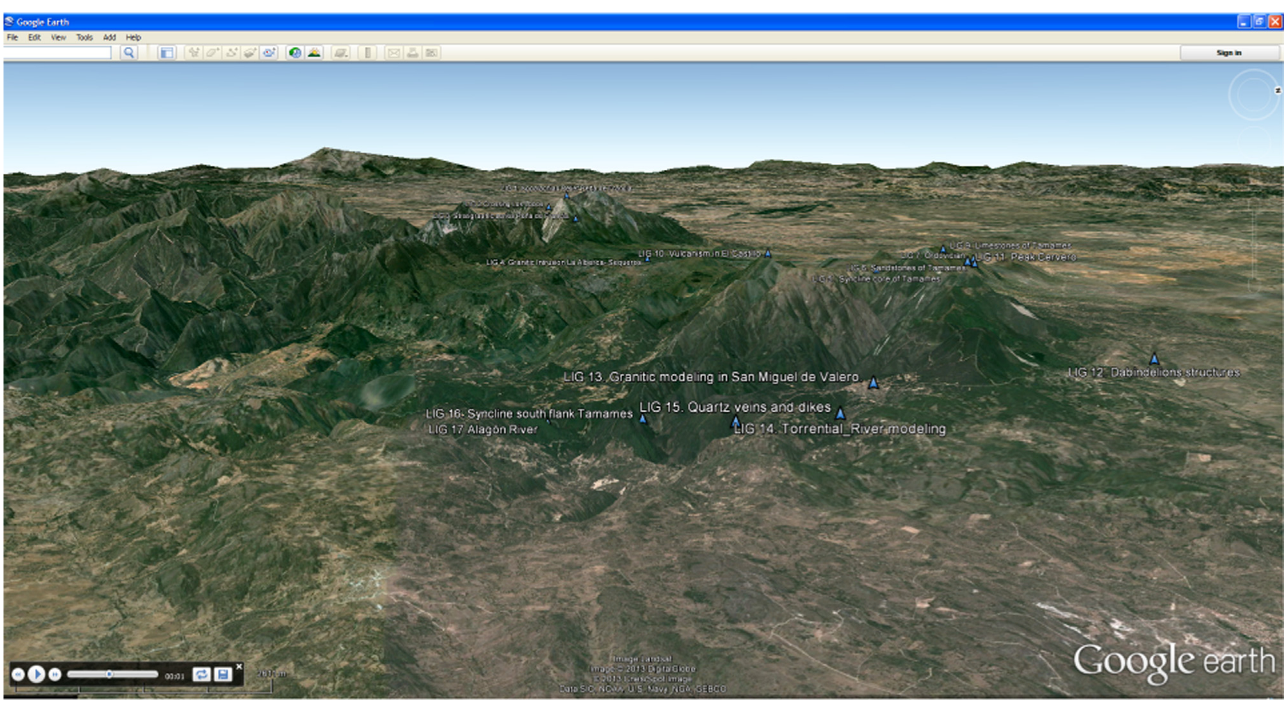

Fig. 9. 3D Virtual Tour of the geological heritage of Las Quilamas Natural Park performed with the tools of Google Earth as seen in the bottom of the image.

smartphones, Google Earth, virtual 3D flight modelling, the ability to access descriptive information via QR codes, and access to augmented reality in real time. These tools can be used to enhance geological culture, allowing a “geological view” of the relief and associated landscape and increasing social awareness regarding the protection of geological heritage. The implementation of this

Fig. 10. Virtual tour of the Las Quilamas Natural Park reproduced in avi format, playable on DVD players and computers.

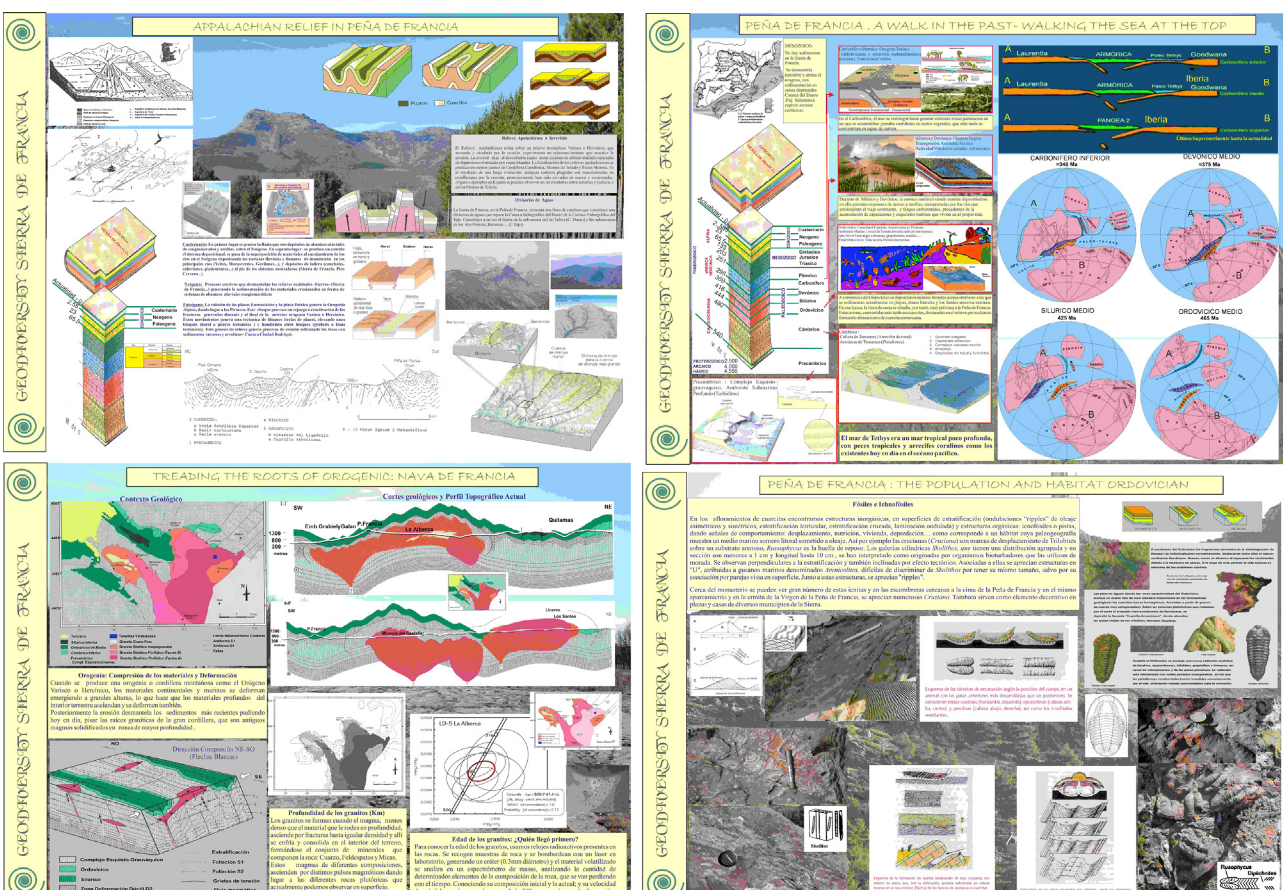

Fig. 11. Educational and interpretive panel compositions produced using descriptive texts, images, and graphics schemes.

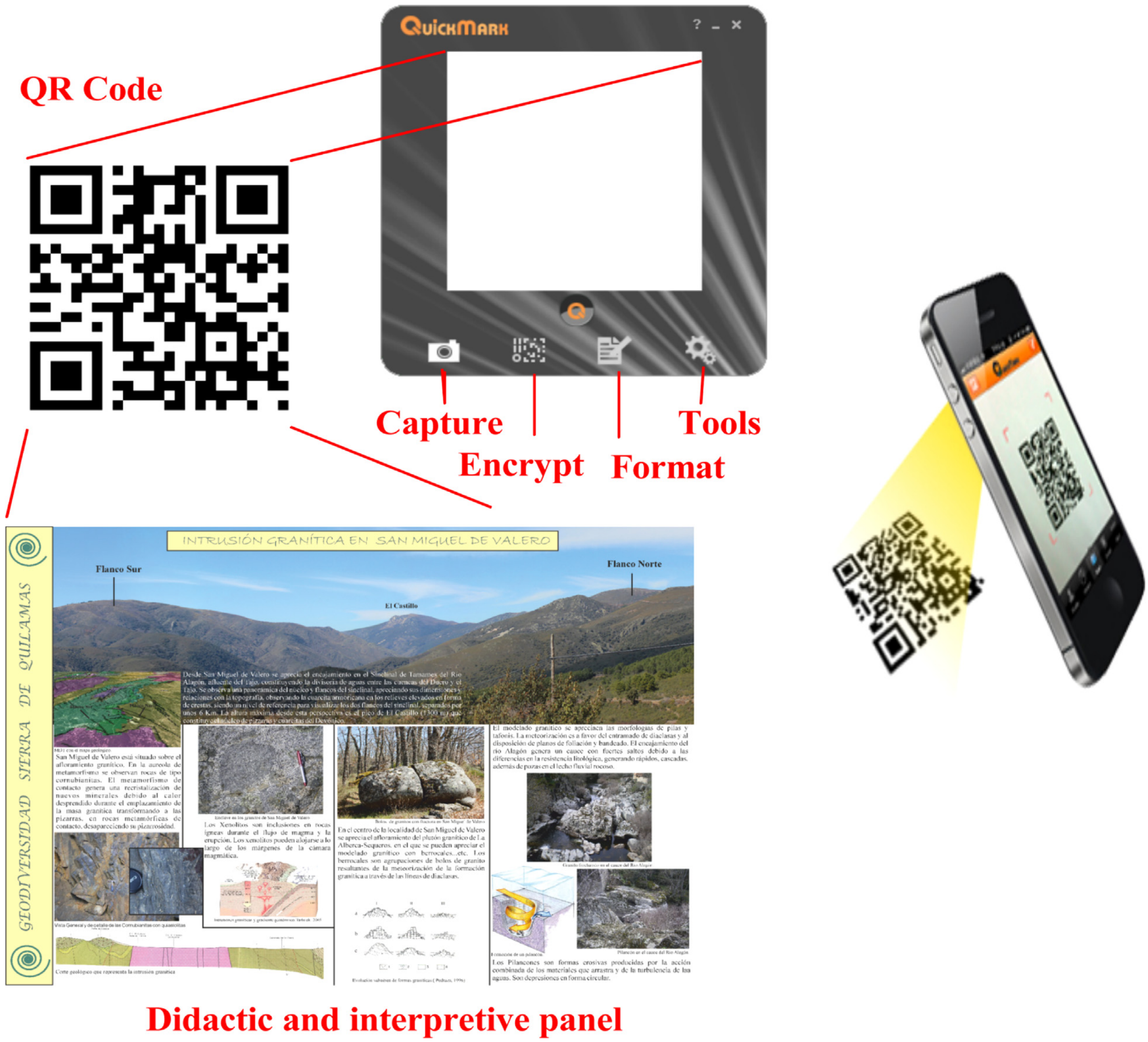

Fig. 12. QR code corresponding to the panel (bottom of the image) of a geosite in the QuickMark application window.

geological documentation on various mobile devices facilitates its use by the general population, social action associations (mountain hiking groups), and educational entities (e.g., scientific, environmental monitors).

Acknowledgements

Projects CGL2012-33430/BTE and CGL2012-37581-CO2-01 (Ministry of Science and Innovation of Spain).

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.cageo.2013.07.020. These data include Google maps of the most important areas described in this article.

References

Bailey, J.E., Chen, A., 2011. The role of virtual globes in geoscience. Computers and Geosciences 37, 1–2.
Blenkinsop, T.G., 2012. Visualizing structural geology: from Excell to Google Earth. Computers and Geosciences 45, 52–56.
Braga, J.C., 2004. Propuesta de Estrategia Andaluza de Conservación de la Geodiversidad, Consejería de Medio Ambiente, Universidad de Granada, Unión Europea, 103 pp.
Bruschi, V.M., Cendrero, A., 2005. Geosite evaluation; can we measure intangible values? Il Quaternario. Italian Journal of Quaternary Sciences, 293–306.
De Paor, D., Whitmeyer, S.J., 2011. Geological and geophysical modelling on virtual globes using KML, COLLADA and Javascript. Computers and Geosciences 37, 100–110.
Ghadirian, P., Bishop, I.D., 2008. Integration of augmented reality and GIS: a new approach to realistic landscape visualisation. Landscape and Urban Planning 86 (3–4), 226–232.
Gray, M., 2003. Geodiversity. Valuing and Conserving a Biotic Nature. Wiley, Chichester, UK p. 434.
Hose, T.A., 1997. Geotourism. Selling the Herat to Europe. In: Marinos, P.G., Joukis, G.C., Tsiambaos y, G.C., Stournaras, G.C. (Eds.), Engineering Geology and the Environment. Balkema, Rótterdam, pp. 2955–2960.
IGME, Sistema web de cartografía geológica continua SIGECO-GEODE. 〈http://cuarzo.igme.es/sigeco/default.htm〉, 2012 (accessed 13.11.12).
Karabinos, P., 2010. Adding structures to 3-D geologic maps. (Geological Society of America, 2010 Annual Meeting, Anonymous) Abstracts with Programs – Geological

Society of America – November 2010, vol. 42 (5), p. 421 (Geological Society of America, 2010 Annual Meeting, Anonymous).
Martínez-Graña, A.M., Goy, J.L., Zazo, C., 2011. Natural heritage mapping of the Las Batuecas-Sierra De Francia and Quilamas Nature Parks (SW Salamanca, Spain). Journal of Maps 2011, 600–613, http://dx.doi.org/10.4113/jom.2011.1172.
QRStuff.com 2012. ⟨http://www.qrstuff.com/index.html⟩ (accessed 02.12.12).
Quickmark. 2012. ⟨http://www.quickmark.cn/En/basic/index.asp⟩ (accessed 10.12.12).
Stuart, E., 2012. Augmenting phenomenology: using augmented reality to aid archaeological phenomenology in the landscape. Journal of Archaeological Method and Theory 19, 582–600, http://dx.doi.org/10.1007/s10816-012-9142-7.
Tewksbury, B., 2009. Teaching geologic map interpretation using Google Earth. Abstracts with Programs – Geological Society of America 41 (7), 384.
uQR.me. 2012. ⟨http://uqr.me/private/profile⟩ (accessed 02.12.12).
Weng, Yi-Hua, Sun, Fu-Shing, Grigsby, Jeffry D., 2012. Geotools: an android phone application in geology. Computers and Geosciences 44, 24–30.
Whitmeyer, S.J., 2012. OrientationSymbolGenerator,/⟨http://csmres.jmu.edu/Geollab/Whitmeyer/web/visuals/GoogleEarth/tools/SD.htmlS⟩ (accessed 10.12.12).