Geoheritage (2017) 9:121–131
DOI 10.1007/s12371-016-0182-3

REVIEW ARTICLE

Augmented Reality in a Hiking Tour of the Miocene Geoheritage of the Central Algarve Cliffs (Portugal)

A. M. Martínez-Graña [1] · P. Legoinha [2] · J. A. González-Delgado [1] · C. J. Dabrio [3] · J. Pais [2] · J. L. Goy [1] · C. Zazo [4] · J. Civis [1,5] · I. Armenteros [1] · G. Alonso-Gavilan [1] · R. Dias [6] · T. Cunha [6]

Received: 30 July 2015 / Accepted: 29 March 2016 / Published online: 30 April 2016

Abstract Eight sites with geological (including palaeontological and geomorphological) interest (geosites) representative of the Lower and Middle Miocene carbonate deposits near Albufeira in central Algarve (southern Portugal) have been selected based on our extended working experience. The sites can be visited by hiking in a 1-day field trip. A virtual 3D tour of the georeferenced sites was produced using augmented reality technique and geoinformatic tools which integrate thematic digital layers such as geological maps and orthophotos. Every stop in the tour includes descriptive and graphic elements that can be viewed in free virtual globes (e.g. Google Earth) combined with diagrams, photographs and information sheets that quantitatively assess the cultural-touristic, educational and scientific value of the geosites. A virtual flight itinerary compatible with video formats in the new free technologies (smartphones, tablets and iPads) is also presented.

Keywords Augmented reality · Geological heritage · Palaentology · Geomorphology · Miocene-Algarve

In memoriam: Prof. João Pais (1949-2016) was the Portuguese specialist in Paleobotany (10 n. sp.) and in the Cenozoic stratigraphy of Portugal, author of more than 160 scientific articles, 10 books and several geological maps. He was an excellent colleague, always ready to help those who knocked at his door asking for any kind of collaboration or support, with an unmistakable smile that we will not forget.

Electronic supplementary material The online version of this article (doi:10.1007/s12371-016-0182-3) contains supplementary material, which is available to authorized users.

✉ A. M. Martínez-Graña
amgranna@usal.es

1 Departamento de Geología, Facultad de Ciencias, Universidad de Salamanca, Plaza de los Caídos s/n, 37008 Salamanca, Spain

2 GeoBioTec, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

3 Departamento de Estratigrafía, Facultad de Ciencias Geológicas, Universidad Complutense, 28040 Madrid, Spain

4 Dpto. Geología, Museo Nacional de Ciencias Naturales, CSIC, Madrid, Spain

5 Instituto Geológico y Minero de España, 23 Ríos Rosas Street, 28003 Madrid, Spain

6 Laboratório Nacional de Geologia e Energia (LNEG), Ap. 7586, 2721-866 Alfragide, Portugal

Introduction

Increasing social sensitivity towards the preservation of the geological heritage in natural areas has led to the implementation of measures aimed at adapting geotourism to preservation. However, geological heritage is a rarely used educational resource which, adequately managed, should generate attitudes and aptitudes concerning the natural fragility of the Earth through the geological history (Martínez-Graña et al. 2011). This aim can be attained through understanding the catalogue of geosites, particularly those presenting fossil records and active processes related to geological hazards. In recent times, there has been an increase in the role of geosites as touristic hubs to generate georoutes and educational activities capable of promoting rural tourism. They are also a means of attracting population to these often depressed areas. The intrinsic value of geosites significantly increases when they are packaged with geological parks or geoparks. These offer carefully selected routes or itineraries along which explanatory posters, sketches and photographic information which are strategically placed to present and explain the geological features that crop out in the park.

The present status and social penetration of the so-called new technologies allow the desirable and welcome transition from conventional education resources, prone to a passive attitude of visitors to the geosites along geotouristic routes, to new geoinformatic tools that can provide an active role for participants, thus enhancing rapid and pleasant comprehension and learning.

Shelf carbonate deposits of the Lower and Middle Miocene ages dominate the Algarve Cenozoic continental shelf (Antunes et al. 1981a, 1981b, 1990; Antunes and Pais 1992; Pais et al. 2000, 2012). They have been named as the Lagos-Portimão Formation (LPF), an up to 60-m-thick, highly fossiliferous unit, made up of skeletal packstone/grainstones and rudstones, with interbedded sandstone layers. Brachert et al. (2003) related the sandstone-dominated intervals inside the LPF with sea-level highstands and the limestone-dominated ones with lowstands. Later, Dabrio et al. (2008) distinguished three orders of sequences in LPF at the Rocha-Vau beaches (25 km west of Albufeira) interpreted as produced by storms, Milankovitch forcing and eustatic forcing, in increasing magnitude. The age of LPF in the area (Arrifão beach) has been calibrated using Sr isotopes and ranges from 19.5 to 14.2 Ma (Pais et al. 2012). Miocene sediments in the Algarve are overlain by siliciclastic deposits (Ludo Formation (LF)) of the Plio-Pleistocene age.

The sub-horizontal LPF crops out along a 40-km-long coastal tract where the spectacular sea cliffs of Algarve in southern Portugal have been carved. Cliff development is the result of an especial conjunction between recent sea level changes; neotectonic, local processes of strong karstification (the study area is the most conspicuous example of coastal karst in the Algarve); coastal erosion and lithology of the Cenozoic succession. In contrast, outcrop inlands are of poor quality owing to tectonic influence (in the present study, area related to the Albufeira diapiric salt dome), thick vegetal cover and human population. The LPF rests unconformably on the Paleozoic and Mesozoic basement of the Caldeirão Mountains which are the present-day expression of the Neogene hinterland adjacent to a narrow mixed carbonate-siliciclastic shelf during the Lower and Middle Miocene times.

Various European universities have organized field courses and visits for students of palaeontology (at Degree, Masters, and PhD level) to the magnificent outcrops of the LPF over the last 20 years—in part, as a result, peer-reviewed papers (Brachert et al. 2003; Kroeger et al. 2007), PhD theses (Forst 2003), books (Pais et al. 2012) and communications and fieldtrip guides in international congresses, such as the 2nd Regional Committee on Atlantic Neogene Stratigraphy (RCANS) (González-Delgado et al. 1997) and the 5th RCANS Congress (González-Delgado et al. 2013) have been published.

We have selected eight of these outcrops between the Arrifão and Galé beaches in the East of Albufeira (Fig. 1) as points of geological interest or geosites and integrated them in a 4.5-km-long itinerary which can be visited on foot during a single-day tour. In this report, we assess the scientific, educational and cultural-touristic values of every geosite.

Changing marine fossil assemblages of pectinids, ostreids, spondylid bivalves, echinoids, branching bryozoans, symbiotic associations of bryozoans and corals, algal rhodoliths and macroforaminifers as well as moulds of many bivalves and gastropods are exposed in the geosites. Detailed taphonomic observations, both biostratonomical and fossildiagenetic, related to mono-, pauci- and multispecific shell concentrations, with distinctive taphonomic signatures, can be easily and readily made, opening a door to a deeper knowledge of the palaeontological wonders of the Algarve.

González-Delgado et al. (2013) studied nine different fossil assemblages in ascending stratigraphic order between São Rafael and Galé beaches and described that the most remarkable palaeontological change in the area was observed between their assemblages 6 and 7. It is worth noting that this change is close in age and might be related to the global Middle Miocene climatic transition, which, in turn, has been linked to an event of major growth of the East Antarctic ice sheet (Flower and Kennett 1994). Such an event is likely to have produced a significant fall of sea level and aridification in mid-latitudinal continental regions.

The sites also have a high geomorphological value. The coast is oriented E-W and high, steep cliffs alternate with little coves, shore platforms and sandy beaches. The fracturing and weathering processes (karstification) are the leading processes of the coastal landscape. Cliffs, tens of metres high, are carved in the carbonate and sandy rocks of the LPF where differences in compaction and permeability control small hanging aquifers along clay-rich beds which favour dissolution of rocks forming the typical notches of the area (Moura et al. 2011).

Related to fracturing processes, the cliffs are cut by waves which undergo retreat by successive slumps; common caves, arches, stacks, pinnacles, stumps and islets evidence marine erosion and coastal retreat. Some of these features, such as notches, hanging caves and wave-cut platforms, may indicate previous positions of sea level during the Pleistocene and Holocene times.

Inland of some beaches (sites 6 and 8), there are wave-cut platforms oriented along the prevailing directions of wave approach (W-SW). Besides the lowermost wave-cut surface, there are other two topographically higher platforms of marine origin. Th/U dating of *Balanus* shells indicates that the platforms are coeval of two Middle Pleistocene highstands.

The second essential landscape-forming is the weathering process, mainly chemical dissolution, related to karst. They generate abundant depressions of various sizes, some of which are precursors of coves while others are funnel-shaped (dolines), several metres across and more than 12 m deep, either filled with fine sediments (mud/clay) or empty. The fact that some of them have reached the present sea level suggests that they have been generated through successive morphogenetic phases during the Quaternary. These karst features,

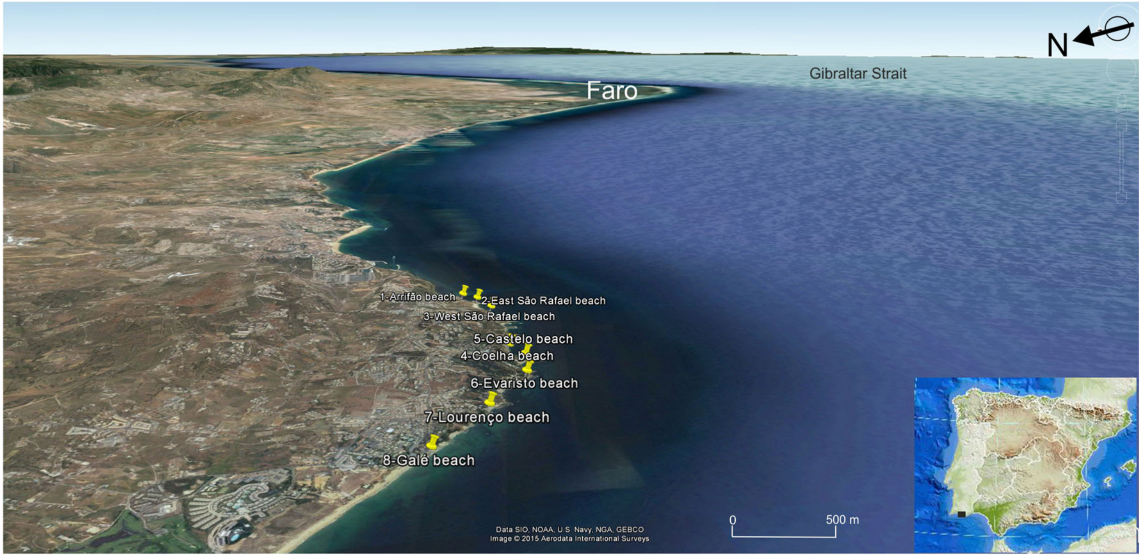

Fig. 1 Location map

called dissolution pipes, cut bedding and fracture surfaces, and this modifies their shape and diameter.

Infiltrated ground waters, vegetation and a permeable detrital cover are essential factors in the generation of a type of karst called cryptokarst (Marsico and Selleri 2005). This is the case of Algarve, where calcarenitic LPF is covered by the permeable clastic cover of the edaphically reddened pebbly sands of the Ludo Formation. All typical morphologies of cryptokarsts—depressions, pipes, ruinous pinnacles and cryptodolines—are found in the geotour and have had their surfaces exposed by recent erosion.

Examples of these morphologies have been cited in the Pleistocene Mediterranean (Crete (Caron et al. 2009) and Puglia, Italy (Marsico and Selleri 2005)) and Atlantic realms (Cádiz (Cabero et al. 2009)).

Methods

This report presents an on-foot itinerary (georoute) where divulgation resources are shared between participants and their portable electronic devices (smartphone, tablet, iPad). The stored information includes georeferentiation of geosites and description of the geological heritage in each stop, geological maps, interpretative sketches, stratigraphic sections and pictures. The desired or required information along the itinerary can be readily downloaded using a QR code found in the Web page of the itinerary or in a link in the local public or private tourism offices. In this way, much of the paper-linked material which usually hampers those working or simply hiking in the field is eliminated as a single ergonomic device allowing easy handling of a huge source of material and information.

In our opinion, using the augmented reality (AR) in the georoute is a resource that allows real-time view of the physical environment of the real world (in our case, the itinerary) through a mobile device. Therefore, AR combines the real rocks and outcrops, which the visitor must locate and observe by himself, with the virtual description and interpretation of the observed geologic features. In this way, visitors enjoy a mixed reality made up of the physical reality of the sites and the data presented in this paper as virtual geotouristic resources, referenced on the 3D Google Earth globe. In this way, the observational information gathered by the visitors at the geosites is transformed into interactive and digital and contributes actively to the learning process. The interaction greatly increases the interest of the visitor, enhances the 3D picture of the geological reality and offers an overall integrated picture of the geosites visited along the georoute.

The methodology used in this report is intended to enhance the value of the geological heritage through an itinerary, including eight stops. A series of educational resources, such as a virtual itinerary, flight simulator, videos and augmented reality, constructed in Google Earth provides a friendly and efficient environment for learning. These resources are implemented in new technologies (social networks, smartphones, tablets, iPads) to help as many people as possible derive benefits from their stimulating effects on learning.

The methodological process followed several steps:

First, potential geosites were identified through field work in the study area, and relevant (or even exceptional) features of each site were identified. This includes lithology, fossil content and geological processes and events that allow understanding of the recent regional geological evolution of the central Algarve traversed by the proposed georoute (Fig. 2).

Second, an inventory and catalogue of eight geosites were carried out according to the geological singularity reached while confronting field data with the study of palaeontological sites and fossil-rich beds, geological forms and processes. Every

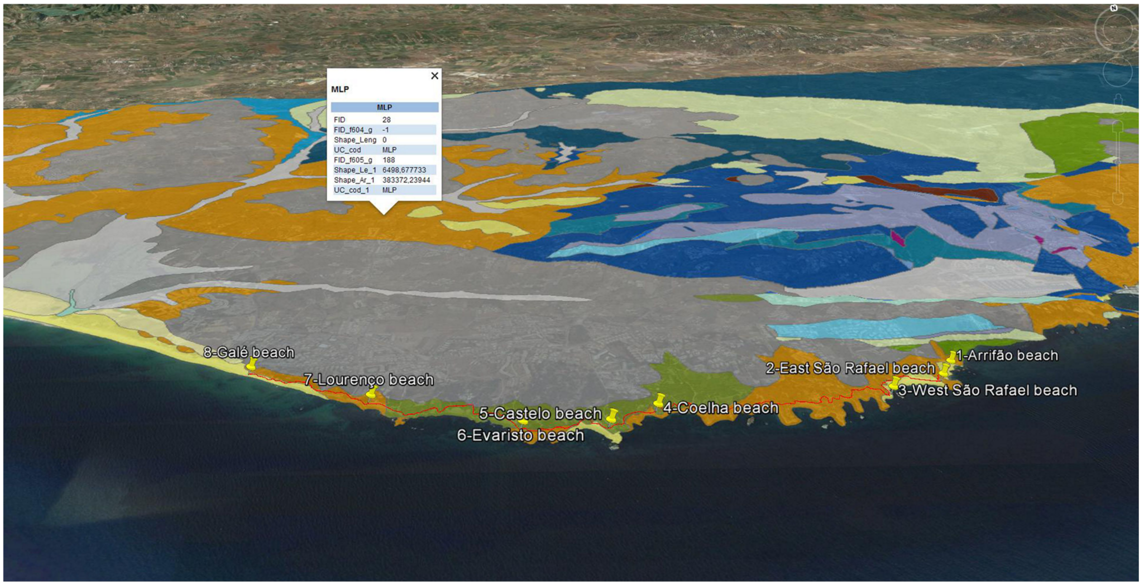

Fig. 2 Geological map on the Google Earth with a virtual legend

geosite was georeferenced in the 3D Virtual Globe of the free platform Google Earth: Geological maps are superposed on orthophotographs and, using Geographical Information System (GIS) techniques (ArcGis 10.2), were transformed from shapefile format to "kml/kmz", which is easily integrated in geoportals and free tridimensional visors. Geosites were georeferenced and integrated in the various geological formations present at this part of Central Algarve. Next, a descriptive file for each geosite was prepared. These are intended to help the user better understand the scientific and didactic issues to be addressed in each stop and to graphically describe the features by means of stratigraphic sections and field photographs.

Each site on the tour was quantitatively assessed using the latest version of the methodology proposed by García Cortés and Carcavilla (2014)for assessing the Spanish Inventory of Sites of Geological Interest. It can be obtained at http://www.igme.es/patrimonio/novedades/METODOLOGIA%20IELIG%20V16%20Web.pdf.

The procedure considers 18 criteria (Table 1) encompassing the representativeness, status of the type-locality, degree and quality of the available scientific documentation, geoconservation, observation conditions, rarity, geological diversity, educational content and use, logistical infrastructure, density of population around the site, accessibility, size, association with other cultural elements, eco-aesthetic value or informative use, activity potential, proximity to recreational areas and socio-economic environment of the site. Each of these parameters is given a value ranging from 0 (poor) to 4 (good) points, and it is weighted according to its tourism-recreational, scientific, and educational interest. The weighted values for each parameter are based on the weighting coefficients (Table 2). The value for each parameter in Table 1 and for each of the proposed sites indicated by the weighting coefficient yields a total value that represents the scientific, educational and tourist/recreational interest, which can be used to quantify the value of each stop as the potential use. Thus, the selected sites can be evaluated and compared with other geosites using the total score reached by each geosite under the same normalized methodology as in the ichnites of the Ordovician age dramatically exposed in the Biosphere Reserve of Sierra de Francia—Las Batuecas, Salamanca, Spain (Martínez-Graña et al. 2014) and in the Neogene palaeontological heritage of Huelva (Guadalquivir Basin, Spain; González-Delgado et al. 2015) (Table 1 and Fig. 3).

All selected geosites can be reached on foot following an East-West transect along walking (hiking) trails that connect the small but spectacular beaches of (1) Arrifão, (2) East Sao Rafael, (3) West Sao Rafael, (4) Coelha, (5) Castelo, (6) Evaristo, (7) Lourenço and (8) Galé (Figs. 1 and 4).

Third, all digital data (geological maps, descriptive files, valuation tables, field photographs, and so on) are implemented in the free 3D navigator; in addition, an interactive tour and virtual 3D flight across the selected georoute is generated (Martínez-Graña et al. 2013).

Finally, the geodatabase of stops, files and referenced photographs is downloaded and integrated into last-generation mobile applications (smartphones, tablets, iPads). In this way, geosites can be observed in real time in the 3D visor.

Stops can be located and found using the GPS integrated in mobile devices, and users can interact with the digital virtual information and download virtual flights and videos to recreate the selected geological itinerary. Potential users are familiar with this methodology thanks to the widespread usage of these geomatic apps in social networks.

We have not enclosed a geological glossary in our virtual tour because any geological concept is easily explained "in situ" on the Web.

Table 1 Evaluation scoring of geological places of interest (sites 1–8)

	s1	s2	s3	s4	s5	s6	s7	s8
Representativeness	2	2	2	1	2	1	1	2
Character type locality or benchmark	1	1	1	1	1	1	1	1
Level of scientific knowledge of the location	4	2	4	2	2	2	1	4
State of conservation	2	2	4	4	4	4	2	4
Viewing conditions	4	4	4	4	4	4	2	4
Rarity	1	1	1	1	1	1	1	1
Geological diversity	2	2	2	2	2	2	2	2
Educational content/educational use identified	1	4	4	1	1	1	1	4
Logistics infrastructure	4	4	4	4	4	4	4	4
Population density	2	2	2	2	2	2	2	2
Accessibility	2	2	2	2	2	2	2	4
Intrinsic fragility due to its size	2	2	2	2	2	2	2	1
Association with other nature/cultural elements	2	2	2	2	2	1	1	1
Visual beauty or spectacular trait or quality	2	2	2	2	2	2	2	2
Informative content/use detected	2	2	2	2	2	2	2	2
Potential for tourism and recreational activities	2	2	2	2	2	2	2	4
Proximity to recreational areas	4	4	4	4	4	4	4	4
Socioeconomic environment	0	0	0	0	0	0	0	0
Total	39	40	44	38	39	37	32	46

In the proposed georoute, we have uploaded stratigraphic sections, data sheets and selected photographs (Fig. 5). A red line drawn with Google tools (Fig. 6) allows visitors to visualize the distance travelled (Fig. 6(a)), and using the GPS-receiver technologies incorporated in their mobile devices, users can orient the information to their real-time location (e.g. using a smartphone or tablet), find the best ways to access the desired stop (to

Table 2 Weights for each parameter as a function of interest

Parameter	Scientific interest	Educational interest	Tourist/recreational interest
Representativeness	30	5	–
Character type locality	10	5	–
Degree of scientific knowledge of the location	15	–	–
State of conservation	10	5	–
Viewing conditions	10	5	5
Rarity	15	5	–
Geological diversity	10	10	–
Learning objectives/educational use	–	20	–
Logistics infrastructure	–	15	5
Population density	–	5	5
Accessibility	–	15	10
Intrinsic fragility	–	–	15
Association with elements natural and/or cultural	–	5	5
Beauty or spectacularity	–	5	20
Informative content/use	–	–	15
Potential for tourism/recreation activities	–	–	5
Proximity to recreational areas	–	–	5
Socioeconomic environment	–	–	10
Total	100	100	100

SITE 8:	Galé beach
Coordinates	N 37º 4' 50.2" / W 8º 18' 59.2"

Description: In this site the uppermost fossil assemblages of LPF can be easily observed. At low tide, two meters of the algal biorudstone (very rich in rodoliths) outcrops, with common Pectindis, Oysters and *Spondylus*. At elevation 4.5 m, there is a layer very rich in the Echinoid *Scutella*, and 1,5m above it, there occur some specimens of the infaunal bivalve *Pinna*, both articulated and horizontalized, in an "*in situ*", "event-type" shell concentration.

Fig. 5 *Scutella* assemblage

Fig.: 6 Rhodoliths

Fig. 1: General view

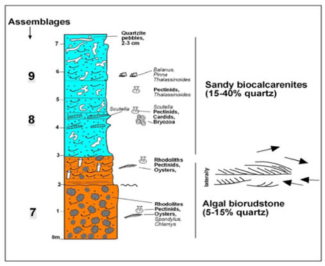

Fig. 2: Stratigraphic section

Fig. 3 Panoramic view in low tide

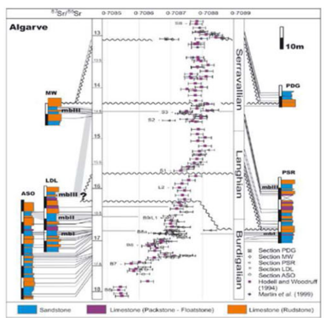

Fig. 4: Sr LPF ages in Algarve (Kroeger *et al.*, 2007): PDG is Galé beach. Yellow, algal biorudstone. Blue: upper sandy biocalcarenites.

GEOLOGICAL VALUES	
Representativeness	2
Character type locality or benchmark	1
Level of scientific knowledge of the location	4
State of conservation	4
Viewing conditions	4
Rarity	1
Geological diversity	2
Educational content/educational use identified	4
Logistics infrastructure	4
Population density	2
Accessibility	4
Intrinsic fragility due to its size	1
Association with other nature/cultural elements	1
Visual beauty or spectacular trait or quality	2
Informative contente/use detected	2
Potential for tourism and recreational activities	4
Proximity to recreational areas	4
Socioeconomic environment	0
TOTAL	46

SCIENTIFIC, EDUCATIONAL AND TOURISTIC VALUES	
Scientific	245
Educational	305
Touristic	220
TOTAL	770

Fig. 3 Model of sheet of geosite 8: identification and graphical description in side A (*left*) and quantitative valuation in side B (*right*)

here or from here, Fig. 6(c)) and preview the topographic profile of the tour (Fig. 6(b, d)).

This gives users ease and understanding of the route, as they can fly over a diversity of maps (geological, topographical and orthophotographical) on a 3D virtual globe where the route is installed. The virtual tour, integrated with the free Google Earth platform, allows us to generate a 3D virtual flight of the itinerary implemented in various formats—mpeg, avi (Fig. 7) and wma—and playable on various multimedia systems (such as PCs and DVDs). Distribution can be uploaded in geoportals via Web-hosted sites of different state organizations, departments and town halls or be downloaded from any website on geological heritage due to its small size. (Every geosite in kmz/kml formats occupies less than 2 kb and if it includes the images associated can come to a size of 1 mb in high quality which is easily visualized in smartphones and tablets.)

Results and Discussion

Table 1 presents the values of the 18 parameters and their unweighted sums for each site. It follows a synoptic description of the sites and the valuation obtained after weighting each parameter. It should be noted, however, that all sites, being beaches frequented by tourists, were given a similar maximum value of the proximity parameter (4 points) owing to the vicinity of recreational areas. Conversely, considering the high socioeconomic value of the entire area, all then obtained a 0, the minimum value in the socioeconomic environment (according to García Cortés and Carcavilla, op. cit., methodology for sites with per capita income levels, education and occupation upper to the regional average scores a value of zero.)

Site 1: Arrifão beach (coordinates: N 37° 4′ 32″/W 8° 16′ 40″).

An 18-m-thick section of the LPF is exposed resting in angular unconformity on the Lower Cretaceous carbonate deposits. It is also observed that the deformation of Mesozoic and Cenozoic deposits is caused by the Albufeira diapir located nearby. The Miocene deposits overlay directly the Cretaceous by a conglomerate of round pebbles of limestones, dolomitic limestones and quartz, with

Sites	1	2	3	4	5	6	7	8
Scientific value	225	195	245	185	215	185	130	245
Educational value	210	270	280	215	220	210	190	305
Touristic value	210	240	210	210	210	205	195	220

Fig. 4 Pictures and weighted values of the selected sites according to their scientific, educational and touristic values (*red colours* indicate the highest values). Each number fits with the stops described in the text. *1* panoramic view from the sea, *2* lower and middle levels of LPF, *3* upper levels of LPF. Note the transition from yellow sandstone to white rhodolite limestone (*red line*), *4* panoramic view of Coelha beach from the sea, *5* Cyclicity in LPF beds, *6* marine abrasive platform at Evaristo beach, *7* panoramic view from the sea, *8* uppermost levels of LPF

valves of large oysters and other bivalves, corals and bryozoans. At the top, there is a remarkable oyster-rich conglomerate overlaying a bioclacarenite rich in *Heterostegina* with echinoderm (*Clypeaster*).

Near the top, there is a yellowish pink level very rich in bryozoans, oysters and pectinids; rhodoliths are very abundant in the upper part. The ostracod *Bosquetina pectinata*, only known in the Burdigalian of the Lower Tagus Basin (Portugal), occurs in the middle part of the section (Antunes et al. 1981b). Sr isotopes from molluscs sampled from this site yielded an age of LPF ranging between 19.5 and 14.2 Ma (Pais 1982; Pais et al. 2012). As prominent features of the LPF succession, note at the base the remarkable accumulation of bryozoans, the rhodolith level near the top of the section and the oyster-rich conglomerate at the top.

Fig. 5 Augmented reality capture for geosite 3

The weighted valuation of the scientific (225), educational (210) and touristic/recreational (210) values amounts to 645 (Fig. 4).

Site 2: East São Rafael beach (coordinates: N 37° 4′ 28.7″/W 8° 16′ 44.8″).

This site exposes the lower part of the LPF, with two remarkable concentrations of bryozoans. The occurrence of foraminifera *Globoquadrina baroemoenensis*, *Globigerinoides subquadratus*, *Globigerinoides bisphericus* and *Praeorbulina transitoria* indicates a late Burdigalian age (Antunes et al. 1981b). Notable is the prominent accumulation of red clay

Fig. 6 Interactive route with position indicating topographic profile in "real time". Distance travelled (*a*), desired stop (*c*) and the topographic profile of the tour (*b*, *d*)

Fig. 7 Virtual video capture of site 5 (Castelo beach) with augmented reality over geological map, sheet and palaeontological and geomorphological photographs

related to karstic processes next to the steps down to the beach. This karst infill has yielded thousands of fish teeth (selaceans and teleosteans), and other vertebrate remains, including a marine crocodile. The fauna is consistent as a whole with a Burdigalian and/or Langhian age and indicates shallow warm, although not tropical, waters (Antunes et al. 1981a). The fossils come from the dissolution of carbonates and were preserved in karst filling.

The rating of this site is 705 points with the scientific being 195, the educational being 270 and the touristic/recreational being 240. The third value (touristic) is the highest reached in the whole itinerary, as the site lies next to the splendid Sao Rafael beach.

Site 3: West São Rafael beach (coordinates: N 37° 4′ 25.8″/W 8° 16′ 57.2″).

A panorama of the cliffs enclosing the beach allows observation of depressions in the shape of inverted cones: sinking holes (up to 15 m deep) generated by karstic processes.

In this site, the LPF section includes three shell concentrations which can be observed in detail: (1) assemblage of horizontally placed *Chlamys*, (2) sandstone rich in the bryozoan *Celleripora palmata* associated with the coral *Culizia parasitica* and (3) a rhodolite limestone. The transition from assemblages (2) to (3) is the most significant palaeontological change recorded in the Algarve; it is most likely related to a prominent climate change (the above-mentioned assemblages 6–7 transition of González-Delgado et al. (2013)).

The weighted valuation is 735 points, the second highest in the tour, with high scientific (245), educational (280) and touristic/recreational (210) values.

Site 4: Coelha beach (coordinates: N 37° 4′ 26.1″/W 8° 17′ 43.7″).

This site is an excellent outcrop of the middle part of LPF succession, where bryozoans, echinoids, bivalves, gastropod moulds and the macro benthic foraminifer *Heterostegina* are common.

The rating of this site is 610 points, the sum of 185 (scientific), 215 (educational) and 210 (touristic/recreational).

Site 5: Castelo beach (coordinates: N 37° 4′ 23.2″/W 8° 17′ 53.4″).

The middle and upper parts of the LPF succession are beautifully exposed in this site, with several taphonomic signatures of rich macrofaunal horizons. The three orders of sequences recognized in the LPF by Dabrio et al. (2008) and interpreted as the result of storms, Milankovitch forcing, and eustatic forcing are also observed and easily accessed. Some geomorphological features related to karstification are spectacular. Meteoric waters have percolated through the vegetated detrital cover and dissolved the underlying calcarenite, producing a reddish insoluble residuum that fills the depressions. This may take place under a seasonal wet climate with dry summers. At this site, the uppermost part of the sequence, pipes and sediment-filled karstic depressions may correspond to different karst stages.

The weighted valuation is 645 points, the second highest in the tour, made up of 215 (scientific), 220 (educational) and 210 (touristic/recreational) values.

Site 6: Evaristo beach (coordinates: N 37° 4′ 24.9″/W 8° 18′ 9.0″).

In this site, the fossil assemblages (2) and (3) described in site 3 can be observed 2 m above the high tide mark. The LPF is capped by a well-marked Quaternary marine erosion surface with a shell concentration of large bivalves such as *Pecten* and articulated *Spondylus*.

Evaristo beach exhibits a coastal protuberance consisting of a wave-cut platform connected with the toe of the cliff. There are two other wave-cut platforms at higher elevations: the more laterally continuous of the two is located at +5 m above present sea level and reaches a maximum width of 80 m. It contains fossil *Balanus* that have been dated with Th/U, yielding ages of 229 + 14/−12 ky and 294 + 56/−36 ky (Moura et al. 2006).

The weighted valuation is 600 points, the sum of 185 (scientific), 210 (educational) and 205 (touristic/recreational).

Site 7: Lourenço beach (coordinates: N 37° 4′ 36.5″/W 8° 18′ 35.7″).

In this site, the change between assemblages (2) and (3), as well as the geomorphological features of karstification, can be observed.

The weighted valuation is 515 points, the lowest in the tour, incorporating 130 (scientific), 190 (educational) and 195 (touristic/recreational) values.

Site 8: Galé beach (coordinates: N 37° 4′ 50.2″/W 8° 18′ 59.2″).

In this site, the uppermost fossil assemblages of LPF can be easily observed. At low tide, 2 m of the algal biorudstone (very rich in rhodoliths) outcrops, with common pectinids, oysters and *Spondylus*. At an elevation of 4.5 m, there is a layer very rich in the echinoid *Scutella*, and 1.5 m above, the infaunal bivalve *Pinna* is present, both articulated and horizontal, in an in situ, event-type shell concentration. Associated with the presence of echinoids are spectacular fossil traces (burrows) of *Thalassinoides*, produced by the feeding and dwelling activities of crustaceans, and these can be observed at the top of a small isolated hill situated to the right on the same beach.

The weighted valuation is 770 points, which is the highest in the tour and the sum of 245 (scientific), 305 (educational) and 220 (touristic/recreational) values. It is remarkable that the didactical and scientific aspects reach the highest values in the whole itinerary.

Following García Cortés and Carcavilla (2014) methodology and proposals, the sites of geological interest whose valuation exceed 665 points are labelled as being of very high value, whereas those ranging between 335 and 665 are considered of high value. In our case, three of the eight proposed sites—(2) East São Rafael, (3) West São Rafael, and (8) Galé—exceed 700 points (very high value), but all the others are of high geological value.

Conclusions

This paper presents a 1-day hiking geological field itinerary across a magnificent natural area of the Portuguese Algarve that gives value to the geological heritage and provides educational resources and a virtual 3D flight based on augmented reality techniques.

Internet browsers, such as Google Earth, assist students in the spatial visualization of the geoheritage in Algarve. The implementation of innovative educational resources and new technologies stimulates creativity and knowledge for the rapid acquisition of a greater degree of collaborative, autonomous and interactive skills, which introduces the development of a flight simulation game to the teaching-learning process based on new technologies (smartphones, tablets, iPads). This methodology represents a practical perspective using a technological approach to the processing and transmission of geological information using daily interaction amongst social groups in familiar digital formats (images, videos, and augmented reality in "real time").

The itinerary, considered of high palaeontological, geomorphological and landscape values, covers the Middle Miocene Lagos-Portimão Formation exposed in seven magnificent, cliff-bounded beaches. If we consider separately the scientific, educational and touristic values, we can conclude that seven sites are of high scientific value (133 < SV < 266), being the site 7 of medium scientific value (SV < 133). Sites 2, 3 and 8 are classified as sites of very high educational value (EV > 266), while the other five are classified as being of high educational value (133 < EV < 266). At least, all the sites are of medium touristic value, with site 2, the highest value, attaining 240 points.

The interoperability of the tour enables its use in multiple activities by a wide range of individual users and local associations that demand new geotouristic activities, such as thematic hicks and promenades, which will undoubtedly enhance the geological heritage of the Algarve and contribute to the widespread dissemination of knowledge. Visitors to these geosites should be careful as to the geoconservation of the rich geological heritage, namely the impressive fossil assemblages that must be preserved in situ for maintaining the possibility for future studies on the taphonomy and palaeoecology, palaeoenvironmental reconstructions and the geological history of the area.

Acknowledgments Ministry of Economy and Competitiveness: Projects CGL2009-11539/BTE, CGL2012-33430/BTE and CGL2012-37581/BTE. We are grateful to Laboratório Nacional de Energia e Geologia (LNEG, Portugal) for the geological cartography contributed.

References

Antunes, M.T. and Pais, J. 1992. 4-Cenozóico. Estratigrafía, Algarve oriental. In: Carta geol. Portugal 1:200.000, folha 8. Serviços Geológicos de Portugal: 64-67

Antunes MT, Bizon G, Nascimento A, Pais J (1981a) Nouvelles données sur la datation des dépôts miocènes de l'Algarve (Portugal) et l'évolution géologique régionale. Ciências da Terra 6:153–168

Antunes MT, Civis J, Dabrio CJ, Sierro FJ, González-Delgado JA, Flores JA, Pais J, Valle M (1990) El Neógeno del Algarve (Portugal) y de la cuenca del Guadalquivir (España). Actas de Paleontología Universidad de Salamanca 68:65–73

Antunes MT, Jonet S, Nascimento A (1981b) Vertébrés (crocodiliens, poisson) du Miocène marin de l'Algarve occidentale. Ciências da Terra 6:9–38

Brachert TC, Forst MH, Pais J, Legoinha P, Reijmer JJG (2003) Lowstand carbonates, highstand sandstones? Sediment Geol 155:1–12

Cabero, A.; Lario, J.; Zazo, C.; Goy, J.L., Dabrio, C.J.; Borja, F., Roquero, E.; Silva, P.G.; García Blázquez, A.; Bardají, T., Hillaire-Marcel, C. and Mercier, N. 2009. Stop 5. Geomorphologic setting and 1755 tsunamic deposits at cape Trafalgar In Field Trip 3. Quaternary Tectonics in the Gibraltar. 74-84. INQUA and IGCP 567. Baelo Claudia (Cádiz, Spain).

Caron V, Bernier P, Mahieux G (2009) Record of late Pleistocene (axygen isotopic stage 5) climate changes during episodes of karst development on the north coast of Crete: sequences, stratigraphic implications. Palaeogeogr Palaeoclimatol Palaeoecol 277:246–264

Dabrio CJ, González-Delgado JA, Armenteros I, Civis J, Pais J, Alonso-Gavilán G, Legoinha P (2008) Facies changes and paleogeographical implications in the Serravallian of the Lagos-Portimão Formation Praia da Rocha, southern Portugal). Geo-Temas 10: 131–134

Flower BP, Kennett JP (1994) The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. Palaeogeogr Palaeoclimatol Palaeoecol 108: 537–555

Forst, M.H. 2003. Zur Karbonatsedimentologie, Biofazies und sequenzstratigraphischen Architektur eines fossilen Hochenergie-Schelfs aus dem Neogen der Algarve (Miozän, Südportugal). Unpubl. doctoral dissertation. J. Gutenberg Univ. Mainz, 175p, 7Tf

García Cortés, A. and Carcavilla, L. 2014. Documento metodológico para la elaboración del inventario español de lugares de interés geológico (IELIG). 64p. http://www.igme.es/internet/patrimonio/novedades/METODOLOGIA%20IELIG%20web.pdf. (in Spanish).

González-Delgado JA, Martínez-Graña AM, Civis J, Sierro FJ, Goy JL, Dabrio CJ, Ruiz F, González-Regalado ML, Abad M (2015) Virtual 3D tour of the Neogene palaeontological heritage of Huelva (Guadalquivir Basin, Spain). Environ Earth Sci 73:4609–4618

González-Delgado, J.A., Pais, J., Dabrio, C.J., Civis, J., Armenteros, I., Legoinha, P. and Alonso-Gavilán, G. 2013. Changing marine fossil assemblages in Albufeira (Miocene Lagos-Portimão Formation, Algarve, Portugal). *Abstract book V RCANS Congress: Two decades of Atlantic Neogene study*, Huelva: 29

González-Delgado, J.A., Sierro, F.J. Pais, J. (coord.). 1997. The Guadalquivir basin and Algarve (Spain, Portugal). 2nd RCANS Congress Salamanca, Excursion 2, Field Trip Guide, 55p

Kroeger KF, Reuter M, Forst MH, Breisig S, Hartmann G, Brachert TC (2007) Eustasy and sea water Sr composition: application to high-resolution Sr-isotope stratigraphy of Miocene shallow-water carbonates. Sedimentology 54:565–585

Marsico, A. and Selleri, G. 2005. The solution pipes. In: Puglia 2003-Final conference Quaternary Coastal Morphology and Sea Level Changes (Ed. Mastronuzzi and Sanso, P.). IGCP 437 Project 113-115.

Martínez-Graña AM, González-Delgado JA, Pallarés S, Goy JL, Civis J (2014) 3D virtual itinerary for education using Google Earth as a tool for the recovery of the Geological Heritage of Natural áreas: application in the "Las Batuecas Valley" Nature Park (Salamanca, Spain). *Sustainability* 6:8567–8591

Martínez-Graña AM, Goy JL, Cimarra C (2013) A virtual tour of geological heritage: Valourising geodiversity using Google Earth and QR code. Comput Geosci 61:83–93. doi:10.1016/j.cageo.2013.07.020

Martínez-Graña, A.M., Goy, J.L. and Zazo, C.Z. 2011. Natural Heritage Mapping of the Las Batuecas-Sierra De Francia and Quilamas Nature Parks (SW Salamanca, Spain), Journal of Maps, v2011, 600-613 pp. doi: 10.4113/jom.2011.1172.

Moura D, Gabriel S, Ramos-Pereira A, Neves M, Trindade J, Viegas J, Veiga-Piers C, Ferreira O, Matias A, Jacob J, Boski T, Santana P (2011) Downwearing rates on shore platforms of different calcareous lithotypes. *Mar Geol* 286:112–116

Moura D, Albardeiro L, Ceiga-Pires C, Boski T, Tigano E (2006) Morphological features and procersses in the central Algarve rocky coast (South Portugal). Geomorphology 81:345–360

Pais, J. 1982. O Miocénico do litoral Sul portugués. Ensaio de síntese. Trabalho complementario obt. Grau Doutor, Univ. Nova Lisboa, 47p.

Pais J, Cunha PP, Pereira D, Legoinha P, Dias R, Moura D, Silveira AB, Kullberg JC, González-Delgado JA (2012) The Paleogene and Neogene of Western Iberia (Portugal) , 158p*Springer Briefs in Earth Sciences*

Pais J, Legoinha P, Elderfield H, Sousa L, Estevens M (2000) The Neogene of Algarve (Portugal). Ciências da Terra 14:277–288