Environ Earth Sci
DOI 10.1007/s12665-014-3747-y

ORIGINAL ARTICLE

Virtual 3D tour of the Neogene palaeontological heritage of Huelva (Guadalquivir Basin, Spain)

J. A. González-Delgado · A. M. Martínez-Graña · J. Civis · F. J. Sierro · J. L. Goy · C. J. Dabrio · F. Ruiz · M. L. González-Regalado · M. Abad

Received: 17 February 2014 / Accepted: 26 September 2014

Abstract Virtual fieldtrips in palaeontology and geology offer an expanded environment to make field sites more accessible for a broader audience. Based on extensive experience working in upper Neogene deposits in the province of Huelva, on the western edge of the Guadalquivir Basin, we have selected 10 sites for their regional palaeontological-geological interest (geosites). By applying geoinformatic tools, we have produced a virtual 3D tour of the georeferenced geosites, integrating multiple thematic digital layers (including geological maps, topographical maps, a digital terrain model and orthophotos). Each stop in the tour contains 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 tourism, scientific and educational value of the geosite. From this digital 3D geodatabase, we propose a virtual flight itinerary that can be displayed in compatible video formats and using new technologies, such as smartphones, tablets or iPads.

Keywords Palaeontological heritage · Virtual tour · Heritage assessment · Upper neogene · Google Earth

Introduction

Neogene marine deposits in the province of Huelva cover the western edge of the Guadalquivir Basin (González-Delgado et al. 2004a), a foreland basin that once formed the Northbetic Strait, which, along with the South Riffian–Moroccan corridor, connected the Atlantic and Mediterranean domains before the Messinian salinity crisis. The progressive restriction of Atlantic water exchange through these corridors and their final closure in the late Messinian culminated with one of the most dramatic environmental crisis in the Mediterranean, the so called Messinian Salinity crisis. The consequence of this crisis was the deposition of a huge volume of salt in the deep sea and other evaporites

J. A. González-Delgado · A. M. Martínez-Graña (✉) · J. Civis · F. J. Sierro · J. L. Goy
Geology Department, Sciences Faculty, University of Salamanca, Caídos square s/n, 37006 Salamanca, Spain
e-mail: amgranna@usal.es

J. A. González-Delgado
e-mail: angel@usal.es

J. Civis
e-mail: civis@usal.es

F. J. Sierro
e-mail: sierro@usal.es

J. L. Goy
e-mail: joselgoy@usal.es

J. Civis
Geological Survey of Spain, Street Ríos Rosas, 23, 28003 Madrid, Spain

C. J. Dabrio
Stratigraphy Department, Geological Sciences Faculty, University Complutense, 28040 Madrid, Spain
e-mail: dabrio@ucm.es

F. Ruiz · M. L. González-Regalado · M. Abad
Geodynamics and Paleontology Department, Experimental Sciences Faculty, University of Huelva, Avenue 3 de Marzo s/n, 21071 Huelva, Spain
e-mail: ruizmu@uhu.es

M. L. González-Regalado
e-mail: montero@uhu.es

M. Abad
e-mail: manuel.abad@dgyp.uhu.es

M. Abad
Manuel Abad De Los Santos, Departament of Geology, University of Atacama, Avenue Copayapu 485, Copiapó, Chile

Published online: 07 October 2014

in the continental margins and the disappearance of most of the marine species. However, the Huelva region is located in the Atlantic edge of the corridor and therefore was not affected by this dramatic event. The palaeontology of the Huelva region has been studied extensively, especially by researchers from the universities of Salamanca and Huelva, and numerous doctoral theses have examined the extraordinary fossil record, including bivalves (Andrés 1983), gastropods (González-Delgado 1984), planktonic foraminifera (Sierro 1984), calcareous nanoplankton (Flores 1985), ichnofauna (Mayoral 1986), benthic foraminifera (González Regalado 1987), ostracods (Ruiz-Muñoz 1994) and fish (García 2007).

Civis et al. (1987) defined the following formations in this area: "Niebla Calcarenite" (Tortonian), "Gibraleón Clays" (Latest Tortonian/ Upper Messinian) and "Huelva Sands" (early Pliocene). The "Bonares Sands Formation" (early Pliocene), with lower palaeontological content, complete the marine record (Mayoral and Pendón 1987). The stratigraphic architecture of these sediments has been described in detail by Sierro et al. (1996), who define five depositional sequences (from "A" to "E") based on correlated events in the calcareous plankton associations. In addition, in collaboration with the Geological Survey of Spain, two boreholes were drilled in 1997 and 2001 in the city of Huelva, next to the bullring and near the hermitage of Montemayor (Moguer city) (González-Delgado et al. 2002). Ongoing recovery of index fossils from these boreholes, combined with palaeomagnetic calibration and event stratigraphy (Larrasoaña et al. 2008), has provided high-resolution correlations.

For more than 30 years, palaeontology students from various universities have visited certain unique outcrops during their fieldtrip courses. These outcrops have been the subject of numerous national and international publications and fieldtrip guides, such as the Ninth Congress of the Regional Committee on Mediterranean Neogene Stratigraphy in Barcelona, 1990 (Sierro et al. 1990); the Third Geological Congress of Spain in Salamanca, 1992 (Sierro et al. 1992); and the Second Regional Committee on Atlantic Neogene Stratigraphy Congress (González-Delgado et al. 1997).

We selected 10 of these outcrops (Fig. 1), considered points of geological interest (geosites), for a general tour that could be performed in a single day and quantitatively assessed their scientific, educational and cultural tourist value. The sites were sorted in ascending stratigraphic order (from oldest to most recent) for better understanding. They were selected (between 64) for their high geological and palaeontological interest and included formation stratotypes and spectacular panoramic macrofaunal sites that help to clarify the sedimentation of the Guadalquivir Basin.

Using geoinformatic tools, we organised a virtual tour of the 10 georeferenced sites, supported by geoportals (web portal with multi-thematic geospatial information: geosites, lithology, natural parks …, on spatial data infrastructure of geographic services: roads, hotels, petrol-station …; as, for example, the geoportal of Spanish Environment Ministry: http://sig.magrama.es/geoportal/) and free browsers (e.g., Google Earth), following the methodology of Martínez-Graña et al. (2013). Thus, any user can view and interact with the tour through various thematic layers (digital elevation model, geological maps, topographical maps, and orthophotos) using new technologies (smartphones, tablets, and iPods) and digital formats, as established by the

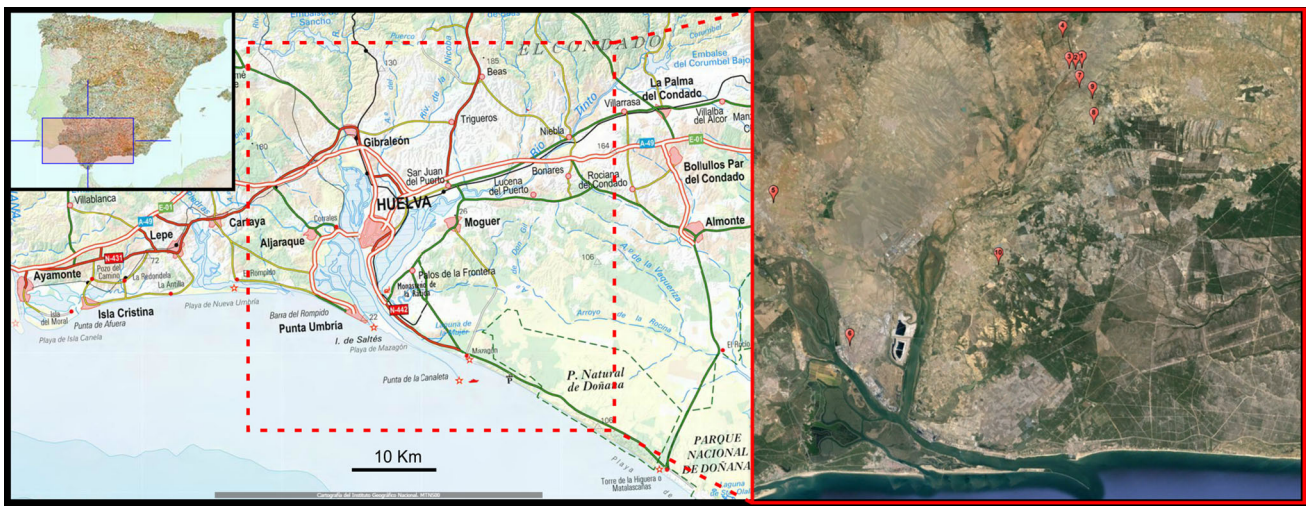

Fig. 1 Study area and locations of the numbered sites (Geographical National Institute: https://www.ign.es)

INSPIRE directive (DOUE L-108 2007). These virtual visual resources are editable in various formats (mpeg, avi and wma) and reproducible on different media systems (PCs, DVDs and MP4s). A preview of this tour was submitted (González-Delgado et al. 2013) to the Fifth Regional Committee on Atlantic Neogene Stratigraphy Congress (Huelva, September 2013), and this work is now complete.

Methodology

To develop the virtual tour, we first collected digital information from various thematic layers used to display the relevant geological data (Martínez-Graña et al. 2011). These layers consisted of geological maps that were imported into vector format using the "kmz" format of the Geode platform of the Geological and Mining Institute of Spain and a digital terrain model. We also obtained orthophotos and satellite data from the National Geographic Institute in raster format. This information was integrated in a geographic information system (Arcgis v10.2) in a uniform reference system for superimposition on the virtual globe (Table 1, Fig. 2).

Table 1 List of layers used

Vector format	Raster format
Stops geosites	Digital terrain model
Lithology layer	Orthophoto
Geomorphologic map	Satellite data landsat
Topographic and infrastructures map	

Each site on the tour was quantitatively assessed using the latest version (July 2013) of the methodology proposed by García Cortés and Carcavilla (http://www.igme.es/internet/patrimonio/novedades/METODOLOGIA%20IELIG%20web.pdf) for developing the Spanish Inventory of Sites of Geological Interest. This procedure applies 18 criteria encompassing the representativeness, type-locality status, degree of scientific documentation, geoconservation, observational conditions, rarity, geological diversity, educational content and use, logistical infrastructure, surrounding population density, 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 (Goy et al. 2013). Each of these parameters is assigned a valuation of 0–4 points, and the parameters are weighted according to their tourism-recreational, scientific, and educational interest (García Cortés and Carcavilla 2013). Based on the final total score for each site, the selected sites can be evaluated and compared with other geosites evaluated using the same methodology (Table 2). We selected 10 geosites of a previous analysis of 64 geosites.

Fig. 2 Distribution of thematic layers (geological map, digital terrain model and topographic map; 1:50,000 scale) on the Google Earth satellite images. The top left denotes the Strait of Gibraltar

Table 2 Evaluation scoring of geological places of interest (S)

Parameters evaluation of geological interest places	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Representation	1	2	1	2	2	1	2	1	2	1
Character type locality	1	2	1	2	2	2	2	1	2	1
Degree of scientific knowledge of the location	4	4	4	4	4	4	2	2	4	4
Geoconservation	4	2	2	2	2	2	2	1	4	1
Observing conditions	2	4	2	2	2	2	4	2	4	2
Rarity	0	1	1	2	1	1	2	1	1	1
Geological diversity observed	2	2	2	1	1	2	2	1	2	1
Content/ educational use	4	4	4	4	4	4	4	4	4	4
Logistics infrastructure	4	4	4	4	4	4	4	4	4	4
Population density in the environment	2	2	2	2	2	2	2	2	2	2
Accessibility	4	1	4	4	4	4	4	1	2	1
Size	1	2	2	1	2	2	2	1	2	2
Association with other cultural elements	2	2	4	2	1	4	2	2	2	2
Eco-beauty	0	0	2	0	0	1	0	0	1	1
Content/ informative use	2	2	2	1	1	1	2	1	2	2
Potential for activities	1	1	2	0	0	1	0	0	1	4
Proximity to recreational areas	1	1	1	1	1	4	1	1	1	2
Socio-economic environment of the place	1	1	1	1	1	1	1	1	1	1
Total	35	37	39	35	34	42	38	26	41	38

Next, we georeferenced each site of interest and created a short description of each. We established placemarks with different symbols and added field photographs, interpretive information, and value assessments at each site on the virtual globe (Figs. 3, 4 and 5).

The selected sites (Fig. 6) were (1) Los Bermejales (Niebla), (2) the Niebla City Unconformity, (3) Puerta del Buey (Niebla city), (4) the *Isognomon* level (Niebla city), (5) the Gibraleón Quarry, (6) the Huelva Bullring, (7) Piedra del Rayo Quarry (Niebla city), (8) the Bonares housing development, (9) Pine House (Bonares city) and (10) the Hermitage of Montemayor (Moguer city).

Finally, the virtual tour was integrated with the free Google Earth platform and other digital media by establishing a 3D virtual flight itinerary, which was implemented in various formats (mpeg, avi and wma) playable on various multimedia systems (such as PCs and DVDs). Distribution can realise upload in geoportals via web-hosted sites of different state organisations: departments, town halls … or download from any web of geological heritage for his small size (every geosite occupies less than 2 Kb and if include the images associated can come to a size of 1 Mb in high quality to visualise it in smartphone or computers).

Results and discussion

Table 2 shows the values of each of the 18 parameters and their unweighted sums for each site. Sites 6 (Huelva Bullring) and 9 (Pine House) show the highest unweighted scores (42 and 41 points, respectively), while site 8 (Bonares Housing Development) shows the lowest score (26 points). All sites have the maximum value (4 points) for the parameters "instructional content/educational use" and "logistical infrastructure" because all sites are commonly used for educational activities and because lodging and restaurants are available within 5 km. All sites except 7 and 8 also receive the maximum value (4 points) for the parameter "degree of scientific documentation" because all have been investigated by scientific teams and have been described in doctoral theses and treated in several papers published in national and international scientific journals. The sites receive the lowest scores for the parameter "eco-aesthetic value" because they generally do not possess the three criteria required (high topographical variety, large rivers or a remarkable colour range in the landscape).

To facilitate understanding, we provide a brief description of the main geological and palaeontological features at each site, followed by the valuation reached after weighting each parameter.

Site 1: Los Bermejales (coordinates: $x = 706.242$, $y = 41.368.13$, ETRS89). From this point, geologically located in the Niebla Calcarenite Formation -NCF-, an overview of the horizontal arrangement of the Neogene of Huelva can be seen. Looking southward, the formation can be observed, including the overlying Gibraleon Clays and the Pine House site, where the Huelva Sands formation appears (site 9). Looking northward, Palaeozoic rocks can be seen in the Tinto River, along with the walled city of Niebla, situated over the NCF.

The weighted valuation (Fig. 6) is 605 points, of which 180, 270 and 155 correspond to its scientific, educational and tourism/recreation value, respectively.

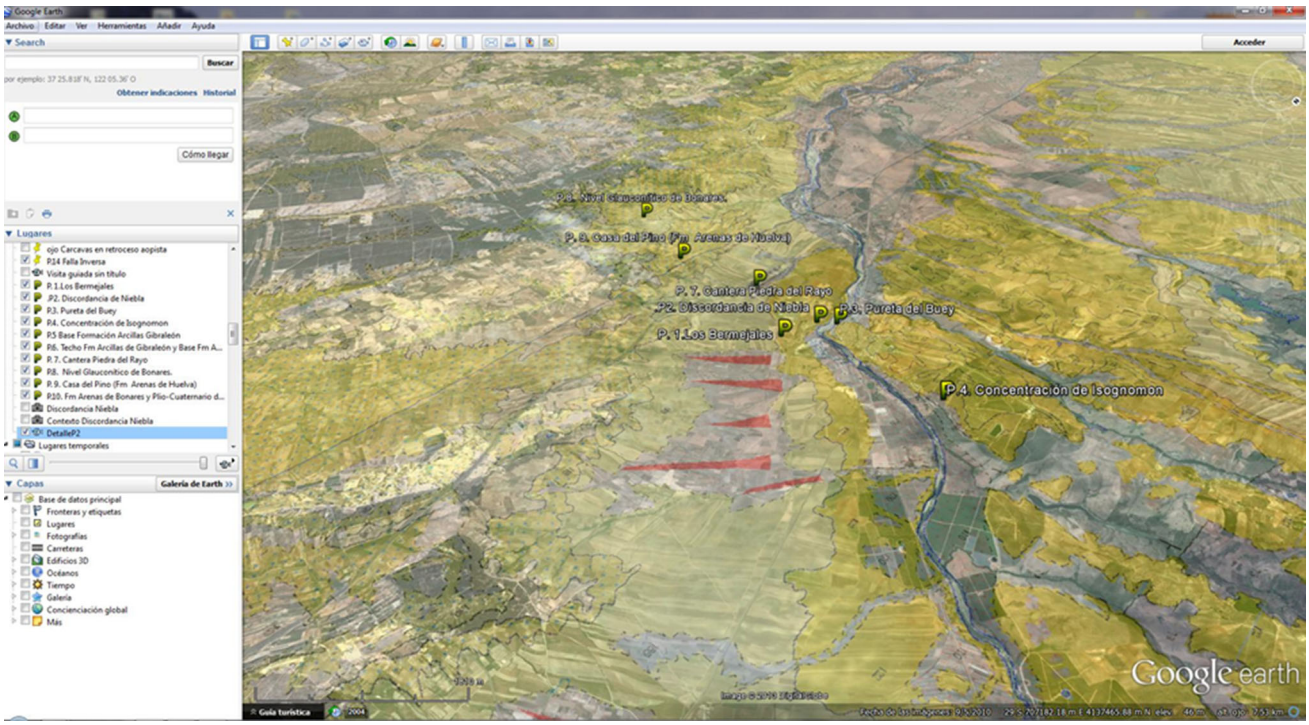

Fig. 3 *Left* implementation in the table of contents format (kmz) for each site on the georeferenced geological map sheet 983, La Palma del Condado. *Right* orthophoto overlying the Google Earth view

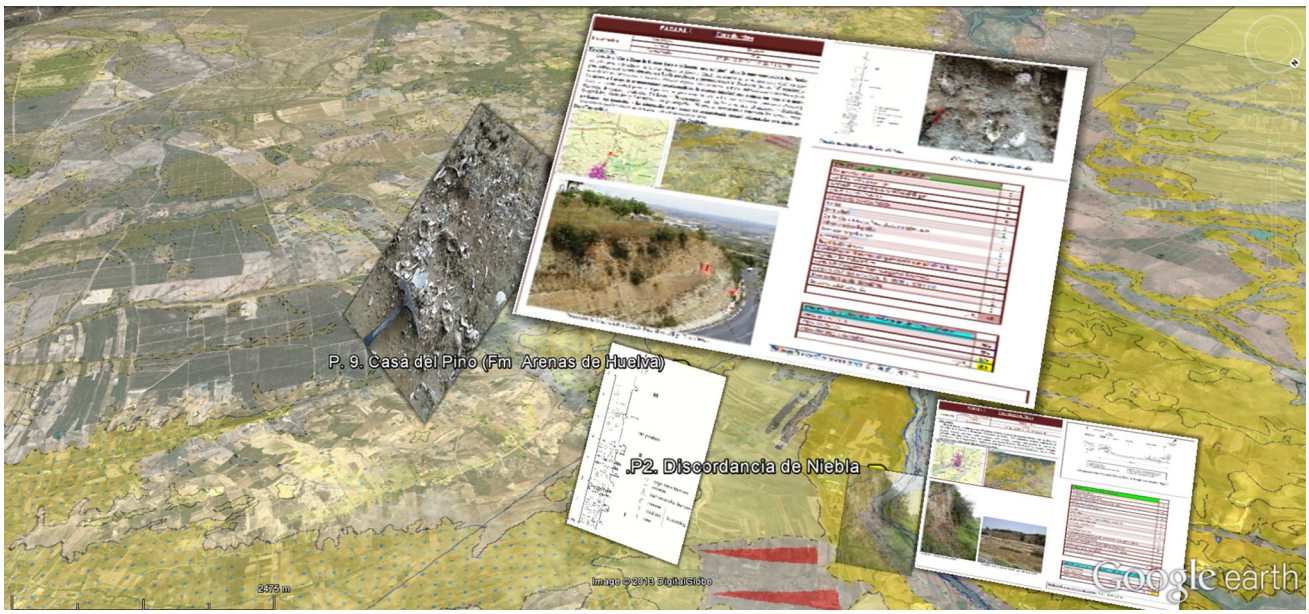

Fig. 4 Google viewer screen captures corresponding to sites 2 and 9, showing field photographs, interpretive diagrams and tabs

Site 2: Niebla City Unconformity ($x = 705.524$, $y = 41.369.32$). This locality is the stratotype for the base of the NCF (Civis et al. 1987), which rests unconformably over Permian shales (Culm facies). The Neogene sequence begins with 0.5 m of conglomerates, followed by up to 18 m of yellowish-white calcarenites. At the southern (site 2) and northern (site 3) cuts, the relationship of this formation to the deformed Palaeozoic shales across the Tinto river can be seen.

The rating of this site is 635 points, of which 235, 250, and 150 correspond to its scientific, educational, and tourism/recreational interest, respectively. The scientific value of this site is the second-highest in the tour.

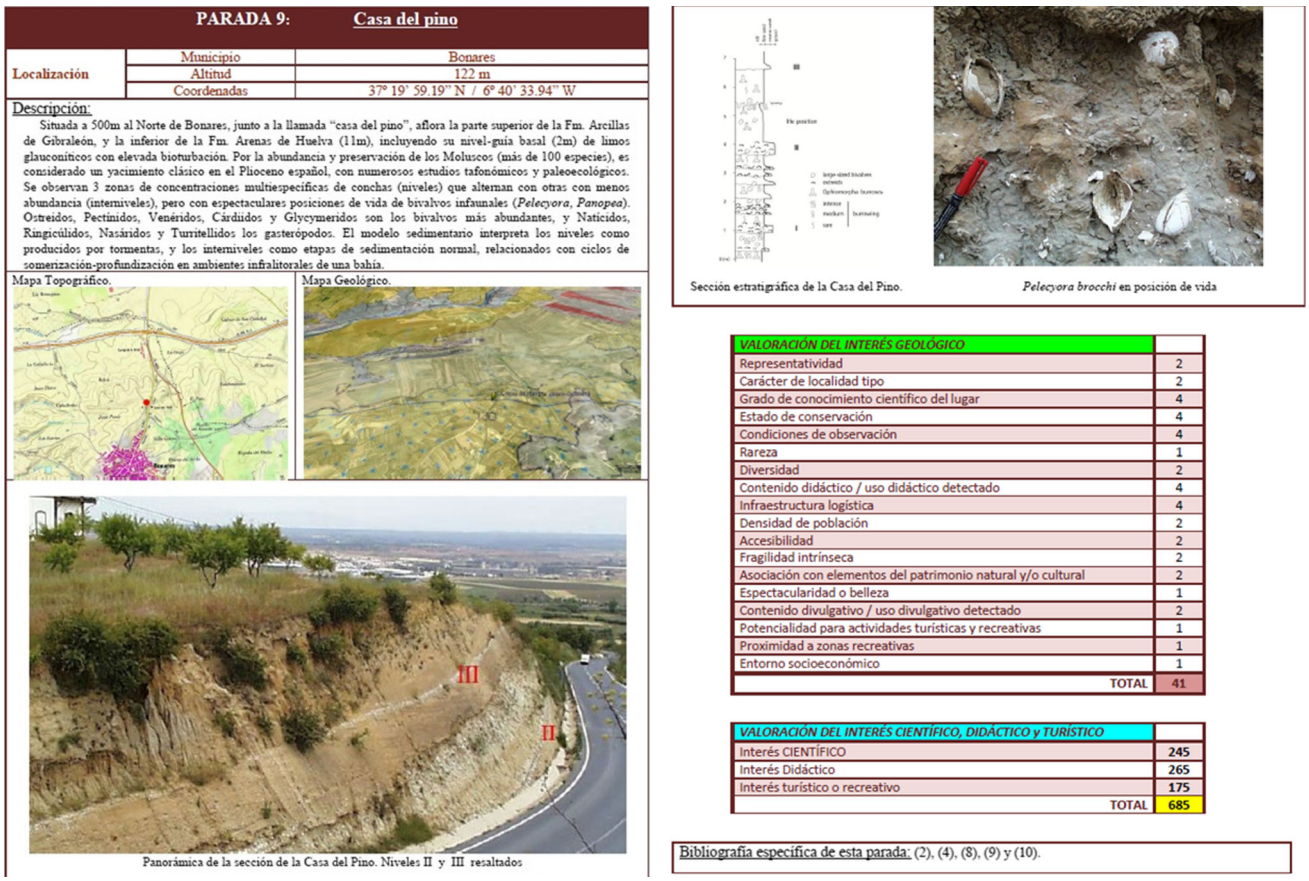

Fig. 5 Data sheet showing the location, description, photos, stratigraphic section and parameters corresponding to the Pine House site (number 9)

Site 3: Puerta del Buey ($x = 705.392$, $y = 41.371.72$). The Niebla Calcarenite Formation can be viewed in polymictic, heterometric conglomerate facies with large *Ostrea*, sometimes arranged in triads.

The overall score, 695, is the highest in the tour (along with stops 7 and 9). The scientific interest of this site reaches 175 points; its educational interest is 295 points (the second-highest in the tour); and its tourism/recreational interest is 225, the highest in the tour, due to the historical and artistic city of Niebla.

Site 4: *Isognomon* level (Niebla city) ($x = 705.971$, $y = 41.394.07$). This site is included within the Niebla Calcarenite Formation. This level shows a remarkable concentration of the tropical bivalve mould fossil *Isognomon maxillatus*, up to 1 m thick, with many articulated specimens transported slightly and permitting detailed taphonomic observations. This level represents the passage of one detrital to another carbonate platform in the context of a deepening basin (Civis et al. 1994).

The total score for this site is 635 points, with 220, 280, and 135 points for its scientific, educational, and tourism/recreational value, respectively.

Site 5: Gibraleón Quarry ($x = 681.452$, $y = 41.382.34$). This site, located in the Santa Isabel quarry, is the stratotype for the base of the Gibraleón Clays Formation (Civis et al. 1987). When the water level is low, glauconitic silt is also evident. These clays are rich in microfossils and contain small moulds of scallop shells (*Amusiopecten*) and echinoids. The Tortonian/Messinian boundary is located in this level (coinciding with event 3 of Sierro et al. 1996), and carbon and oxygen stable-isotopes analyses have allowed researchers to recognise for the first time in Molluscs, the global event known as the Messinian Carbon Shift (González-Delgado et al. 2004b).

The overall score is 620 points, of which 205, 270, and 145 correspond to its scientific, educational, and tourism/recreational value.

Site 6: Huelva Bullring ($x = 681.717$, $y = 41.263.20$). This site is the stratotype for the top of the Gibraleón Clays Formation and the base of the Huelva Sands Formation (Civis et al. 1987). The last few metres of silt from the former formation and 15 m of sands from the latter formation can be viewed. Stretches of glauconite (clearly visible at site 8), which serve as a guide to set the limit

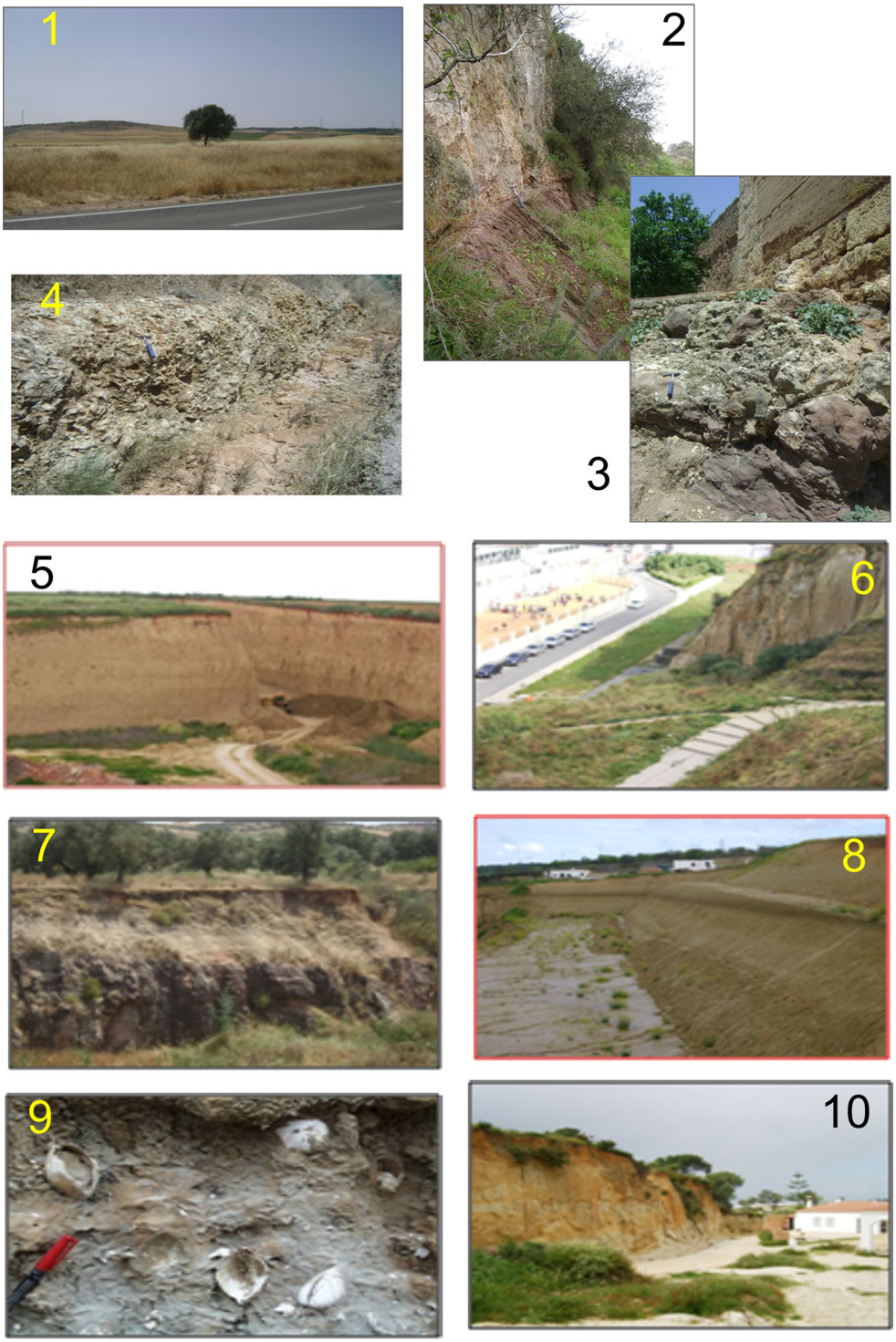

Fig. 6 Pictures and weighted values of the selected sites according to their scientific, educational and tourism value

CUADRO DE VALORACIÓN DEL INTERÉS CIENTÍFICO, DIDÁCTICO Y TURÍSTICO										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Interés científico	180	235	175	220	205	185	220	125	255	155
Interés didáctico	270	250	295	280	270	295	300	190	265	240
Interés turístico o recreativo	155	150	225	135	145	200	175	105	175	180
TOTALES	605	635	695	635	620	680	695	420	695	575

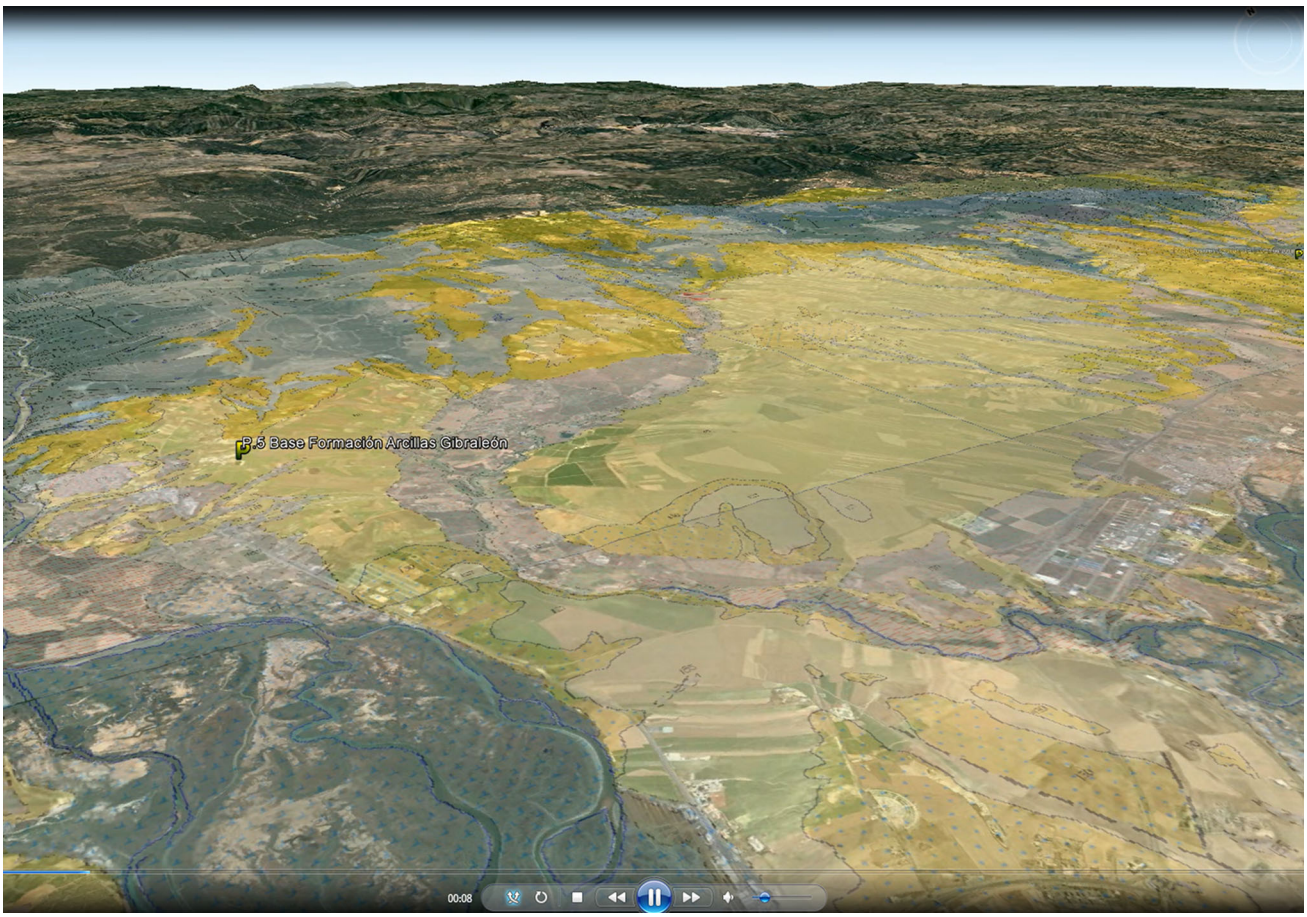

Fig. 7 Screen capture of a one-eighth second flyover in the "avi" 3D format showing the geological map and orthophotos. The video-management commands appear at the bottom

between the two formations in the region, are located approximately 5 m above the contact zone. The 176-m deep ongoing recovery survey designated "Huelva-1", which runs through the Gibraleón Clays Formation, is located at this site.

This site receives a high rating, 680 points. Its scientific interest is 185, while its didactic value (295 points) and tourism/recreational value (200 points) are the second-highest in the tour.

Site 7: Piedra del Rayo Quarry ($x = 707.266$, $y = 41.357.38$). This site shows a Triassic section formed by 10 m of pink dolomites, followed by 2 m of green cinerites and 2 m of pillow lavas, unconformably overlaid by the blue Gibraleón clays. The volcanic materials are related to the post-Palaeozoic opening of the Atlantic Ocean. The total score of this site is 695 points, of which 220 correspond to scientific interest, 300 (the maximum) correspond to educational interest, and 175 correspond to tourism/recreational value.

Site 8: Bonares Housing Development ($x = 705.071$, $y = 41.326.57$). At this abandoned quarry, the contact zone between the Gibraleón Clays Formation (20 m of clays and blue silts) and the Huelva Sands Formation can be seen. At this point, the sediments are rich in ostreids, scallops and calcareous concretions, indicating a fossil-diagenetic solution of molluscs with aragonite shells. The contact zone consists of a 2-m thick horizon of glauconite-rich, greenish-blackish silt with high bioturbation and abundant shark remains, interpreted as a condensed level (Sierro et al. 1996).

This site receives the lowest total value, 420 points, with low scores for all areas of interest: 125, 190, and 105 points for scientific, educational, and tourism/recreational value, respectively. These low scores are due to the difficult access and deterioration of the outcrop, which make its features difficult to observe.

Site 9: Pine House ($x = 705.872$, $y = 41.343.30$). This section displays the last metres of the Gibraleón Clays Formation and 11 m of the Huelva Sands Formation, including the diagnostic 2-m basal level of glauconitic silts. The abundance and preservation of molluscs (over 150 species) make this site a classic Spanish Pliocene locality,

with numerous taphonomic and palaeoecological studies (González-Delgado 1984, González-Delgado et al. 1995, 1997). Three zones of multispecific shell concentrations (levels) alternating with less-abundant interlevels are present. The infaunal bivalves *Pelecyora brochii* and *Panopea glycymeris*, spectacularly preserved in life positions, are particularly notable (Fig. 6). According to the sedimentary model, the levels were likely produced by storms, while the interlevels represent normal sedimentation related to shallowing-deepening cycles in an infralittoral environment in a bay.

The overall score of this site is 695 points, of which 255, 265, and 175 points correspond to its scientific, educational, and tourism/recreational value, respectively.

Site 10: Montemayor Hermitage (Moguer city) ($x = 694.082$, $y = 41.267.61$). This site exhibits 10 m of white-yellow sands from the Bonares Sands formation. These sands show bioturbation, very few mollusc remains, and reddish-coloured Plio-Quaternary conglomerates. The ongoing recovery borehole "Montemayor-1" is located at this site (González-Delgado et al. 2002). This borehole is 265 m deep and spans 10 m of the Bonares Sands Formation, 50 m of the Huelva Sands Formation, 201 m of the Gibraleón Clays Formation and 4 m of the Niebla Calcarenite Formation.

The overall score is 575 points, of which 155, 240, and 180 points correspond to its scientific, educational, and tourism/recreational value, respectively.

Conclusion

Using a variety of information technology and communication tools, we have created a virtual journey with 10 georeferenced sites, supported by multiple web platforms. This virtual tour integrates various thematic layers, including the geological and palaeontological heritage of each site, in formats compatible with other European spatial data infrastructure, as required by the INSPIRE directive. Thus, users can view and manage this geographic information via internet using map servers [e.g., Web Map Service-Web Feature Service (WMS-WFS)] that are editable in geographic information systems.

This 3D virtual tour contains multiple types of digital information (vector: sites, routes; raster: photographs and valuation notes at each site), so that from any free or commercial browser (e.g., Google Earth or Terra Explorer), any user (e.g., teachers, students) can easily view and interact with the virtual route, orthophotos and thematic maps. This model has previously been applied to a route in the Quilamas Natural Protected Area, Salamanca (Martínez-Graña et al. 2013). Using GPS-receiver technologies, the user can orient the information to his or her real-time location (e.g., using a smartphone or tablet). This results in greater user ease and understanding of the route, as the user can fly over the different maps (geological, topographical and orthophotographical) on a 3D virtual globe where the route is installed (Fig. 7). This scheme also allows real-time descriptive consultation and graphical information for each site. The interoperability of the tour enables its use in multiple activities by large numbers of users or local associations that demand new geotourism activities, such as themed walks, which will undoubtedly result in the enhancement and dissemination of the geological heritage of Huelva.

This virtual tour is a learning resource designed to improve the teaching and learning process of the general public and to facilitate understanding of the geology, geography and cartography of the region at each site on the tour using up-to-date technologies of great interest to the population. This geological heritage is stored in "kmz" format, facilitating digital sharing and deployment on mobile devices, similar to the information encrypted in QR codes.

Acknowledgments Ministry of Economy and Competitiveness: Projects CGL2009-11539/BTE, CGL2012-33430/BTE and CGL2012-37581/BTE.

References

Civis J, Sierro FJ, González-Delgado JA, Flores JA, Andrés I, Porta JD, Valle MF (1987) El Neógeno marino de la provincia de Huelva: antecedentes y definición de las unidades litoestratigráficas. In: Civis J (ed) Paleontología del Neógeno de Huelva. Edic. Univ, Salamanca, pp 9–21

Civis J, Alonso-Gavilán G, González-Delgado JA, Braga JC (1994) Sédimentation carbonatée transgressive sur la bordure occidentale du couloir nord-bétique pendant le Tortonien supérieur (Fm. Calacarenita de Niebla, SW de l'Espagne). Géol. Méditerranéenne. XXI 1–2:9–18p

DOUE L-108 (2007) Directiva 2007/2/CE del Parlamento Europeo y del Consejo, de 14 de marzo de 2007, por la que se establece una infraestructura de información espacial en la Comunidad Europea -INSPIRE-. Diario Oficial de la Unión Europea -DOUE-, Volumen 50, 25 de abril de L 108, 1–14

Flores JA (1985) Nanoplancton calcáreo en el Neógeno del borde noroccidental de la Cuenca del Guadalquivir (SO de España). Tesis Doctoral Univ, Salamanca 714p

García EX (2007) Condrictios y Osteíctios del Neógeno de Huelva (Formación "Arenas de Huelva"). Tesis Doctoral Univ, Salamanca 313p

García Cortes M, Carcavilla L (2013) Documento metodológico para la elaboración del inventario español de lugares de interés geológico (IELIG). p 64. http://www.igme.es/internet/patrimonio/novedades/METODOLOGIA%20IELIG%20web.pdf (in spanish)

González-Delgado JA (1984) Estudio de los Gasterópodos del Plioceno de Huelva. Tesis Doctoral Univ, Salamanca 474p

González-Delgado JA, Andrés I, Sierro FJ (1995) Late neogene molluscan faunas from the NE Atlantic (Portugal, Spain, Morocco). Geobios 28:459–471

González-Delgado JA, Sierro FJ, Pais J (1997) The guadalquivir basin and algarve (Spain, Portugal) field trip guide excursion 2. In: Second RCANS Congress Salamanca, p 55

González-Delgado Civis J, Dabrio CJ, Goy JL, Ledesma S, Pais J, Sierro FJ, y Zazo C (2004a) Cuenca del Guadalquivir. In: Vera JA (ed) Geología de España. SGE-IGME, Madrid, pp 543–550

González-Delgado JA, Martínez-Graña AM, Civis J, Goy JL, Dabrio CJ, Ruiz F, González-Regalado ML, Abad M (2013) Itinerario paleontológico virtual 3D en el Neógeno de Huelva (Oeste de la Cuenca del Guadalquivir, España). In: Abad M, Izquierdo T, Ruiz F (eds) V Regional Committee on Neogene Atlantic Stratigraphy-RCANS. Huelva 24–26, pp 15 (ISBN: 978-84-695-8480-4)

González-Delgado JA, Civis J, Larrasoaña JC, Sierro FJ, García-Cortés A, Alonso-Gavilán G (2002) El sondeo de testigo continuo "*Montemayor-1*" (Huelva, Neógeno superior): diagrafías, eventoestratigrafía y calibración paleomagnética. En: Civis J, González-Delgado JA (eds) Resúmenes XVIII Jorn. Soc. Esp. Paleontología-Interim-colloquium RCANS, Salamanca. pp 194–195

González-Delgado JA, Sierro FJ, Civis J (2004b) La bajada global del $\delta^{13}C$ (*Miocene Carbon Shift*) registrada en Pectínidos del Messiniense de la sección tipo de la Fm. Arcillas de Gibraleón (Huelva, W de la Cuenca del Guadalquivir). En: Calonge A, Gonzalo R, López Carrillo MD, Pardo MV (eds) Resumenes XX Jorn. Soc. Esp. Paleontología, Alcalá de Henares, pp 83–84

González-Regalado ML (1987) Las asociaciones de Foraminíferos bentónicos en las arenas fosilíferas del Plioceno de Huelva. Tesis Doctoral Univ, Sevilla 314p

Goy JL, Martínez-Graña AM, Sanz J, Cruz R, Andrés C, De Bustamante I, Zazo C, González-Delgado JA, Martínez-Jaraíz C (2013) Inventario y Catalogación del patrimonio geológico de los Espacios Naturales del Sur de Castilla y León (Salamanca-Ávila, España). En: Vegas J, Salazar A, Díaz Martínez E, Marchán C (eds) Libro: Patrimonio Geológico, un recurso para el desarrollo. 389–400. Cuadernos del Museo Geominero, p 15, IGME ISBN: 978-84-7840-901-3

Larrasoaña JC, González-Delgado JA, Civis J, Sierro FJ, Alonso-Gavilán G, Pais J (2008) Magnetobiostratigraphic dating and environmental magnetism of Late Neogene marine sediments recovered at the Huelva-1 and Montemayor-1 boreholes (Guadalquivir basin, Spain). Geotemas 10:1175–1178

Martínez-Graña, AM, Goy JL, Zazo CZ (2011) Natural heritage mapping of the Las Batuecas-Sierra De Francia and Quilamas Nature Parks (SW Salamanca, Spain), J Maps, 600–613. Ed: Kingston Univ. ISSN: 1744–5647 doi: 10.4113/jom.2011.1172

Martínez-Graña AM, Goy JL, Cimarra CA (2013). Virtual tour of geological heritage: Valourising geodiversity using Google Earth and QR code. Computers and Geosciences 61, 83–93.Editorial Elsevier. ISSN: 0098-3004. http://dx.doi.org/10.1016/j.cageo.2013.07.020

Mayoral E (1986) Tafonomía y Paleoecología del Plioceno de Huelva-Bonares. Tesis Doctoral Univ, Sevilla 599p

Mayoral E, Pendón JG (1987) Icnofacies y sedimentación en zona costera, Plioceno superior?, litoral de Huelva. Acta Geologica Hispanica 21–22:507–514

Ruiz-Muñoz F (1994) Los Ostrácodos del litoral de la provincia de Huelva. Tesis Doctoral Univ, Huelva 275p

Sierro FJ (1984) Foraminíferos planctónicos y bioestratigrafía del Mioceno superior-Plioceno del borde occidental de la Cuenca del Guadalquivir (SO de España). Tesis Doctoral Univ, Salamanca 391p

Sierro FJ, González-Delgado JA, Dabrio CJ, Flores JA, y Civis J (1990) The neogene of the Guadalquivir basin (SW Spain). Paleont i Evolució Mem Esp 2:211–250

Sierro FJ, González-Delgado JA, Dabrio CJ, Flores JA, Civis J (1992) The Neogene of the Guadalquivir basin (SW Spain). En Guías de las Excursiones Geológicas III Congr. Geol. España-VIII Congr. Latinoam. Geología, Salamanca, pp 180–236

Sierro FJ, González-Delgado JA, Dabrio CJ, Flores JA, y Civis J (1996) Late Neogene depositional sequences in the foreland basin of Guadalquivir (SW Spain). In: Friend PF, Dabrio CJ (eds) Tertiary basins of Spain. Cambridge Univ, Press, pp 329–334