Geoheritage (2024) 16:31
https://doi.org/10.1007/s12371-024-00935-z

ORIGINAL ARTICLE

From Geoheritage to Geosites at the Oeste Aspiring Geopark (Portugal)

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Received: 10 July 2023 / Accepted: 5 February 2024 / Published online: 21 February 2024

Abstract
Geoheritage and geosites have been assessed as part of the work supporting the application of the Oeste Aspiring Geopark, in West Central Portugal, for an UNESCO Global Geopark. The geological framework is presented, describing the regional evolution of the Lusitanian Basin, related to the Mesozoic opening of the North Atlantic, since the Late Triassic until the Late Cretaceous, followed by the Cenozoic inversion of the basin, related to the Alpine orogeny. The overall geodiversity of the territory is described, and the main geological highlights are presented.
Within the scope and objectives of a Geopark, the criteria for the definition of geosites are presented and discussed. Geoconservation, geoeducation and geotourism have been considered to define 80 geosites, with different characteristics, purposes, relevance and potential. Six different encompassing themes have been defined, each one with a specific storytelling. Geoconservation issues are also addressed, showing the importance of protection strategies for the geosites at a local scale.

Keywords Geosites · Geoparks · Geodiversity · Oeste Aspiring Geopark · Portugal

Introduction

Defining geoheritage and geosites has been the focus of many debates, different approaches, and important opinions (Reynard 2009; Ruban 2010, Rybár, 2010; Henriques et al. 2011; Gray 2008; Gray 2013; Brilha 2016; Brilha 2018a). Whatever the definitions and the criteria, it must be stated that geoheritage only exists if someone is there to define it, to value it and inherit that legacy. This means having a community who looks at a certain geological object as important or meaningful and, thus, worthwhile to be inherited. The same goes for the geosites, as they do not exist on their own. They are a result of an appraisal and evaluation by a certain community and for a certain purpose.

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A geosite usually is defined by a scientific community, with the purpose of geoconservation. The main criteria are (Brilha 2018a) as follows: (i) the existence of scientific data already published about the site; (ii) its regional or international rarity; (iii) its integrity, related to the present conservation status of the site and (iv) its representativeness for a specific geological topic, process, feature or geological framework.

Within the UNESCO Global Geopark (UGGp) concept (UNESCO 2015), a geosite must above all serve the objectives of the geopark, in all its dimensions—geoconservation, geoeducation and geotourism (Brilha 2018b; Henriques and Brilha 2017). Therefore, although the intrinsic geological scientific value of the geosite should always be the starting point, its value for educational and touristic activities must also be taken into account (Lima et al. 2010; Henriques et al. 2012; Brilha 2016; Suzuki and Takagi 2018; Molokáč et al. 2023).

This paper presents the strategy followed by the Oeste Aspiring Geopark (OAG) to define, communicate and promote its geosites, in dialogue with different partners and entities (Fig. 1).

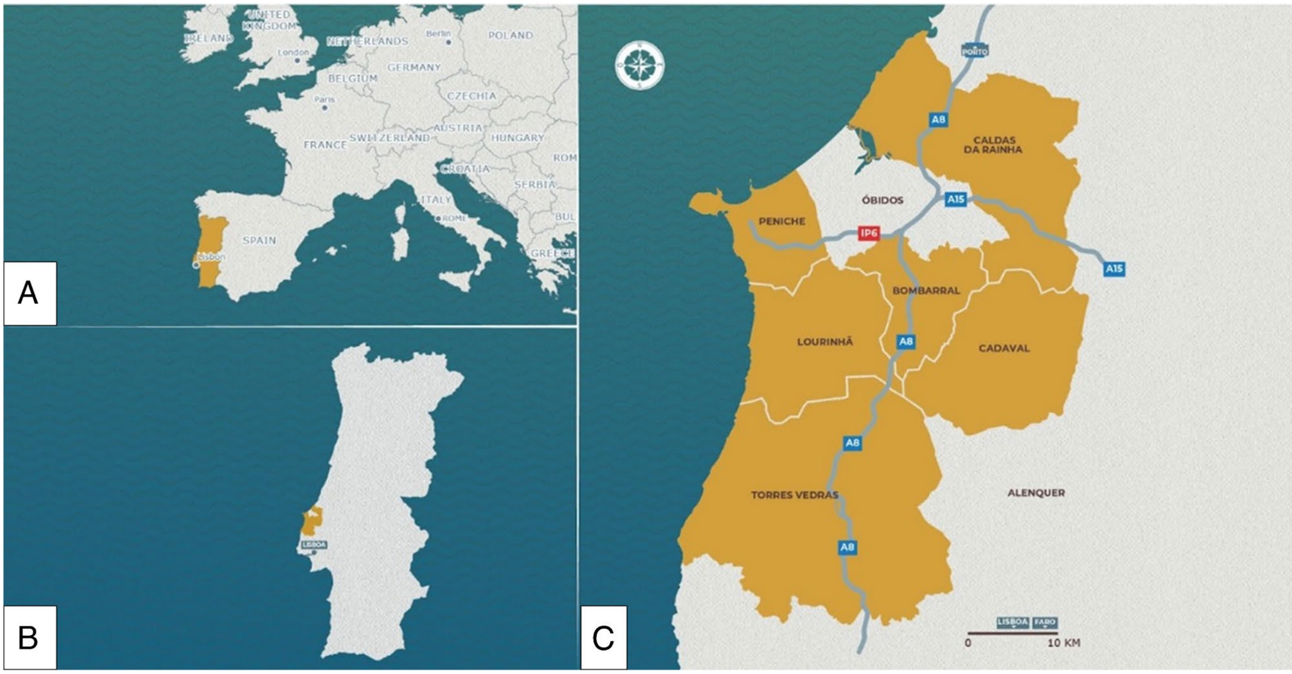

Fig. 1 Map with the location of the Oeste Aspiring Geopark (OAG). **A** Location of Portugal in Western Europe. **B** Location of the OAG in Central West Portugal. **C** Territory of the OAG, with the areas of the six municipalities (white limits) and main highways (blue lines)

Geological Framework

The OAG is located in Central West Portugal, occupying around one-third of the Lusitanian Basin (LB). Located in the West Iberian Margin, the LB was formed due to the breakup of the last supercontinent, Pangea, with the separation of the North American from the Euroasiatic Plates (Fig. 2). The LB is classified as an extensional basin on the continental margin of an atlantic-type rift (Montenat et al. 1988; Wilson et al. 1990; Rasmussen et al. 1998).

During the initial Mesozoic distension of Pangea, the Iberian Peninsula was in a key position between Laurasia (to the North) and Gondwana (to the South) continents. The crustal extension gave place to several west-Iberian

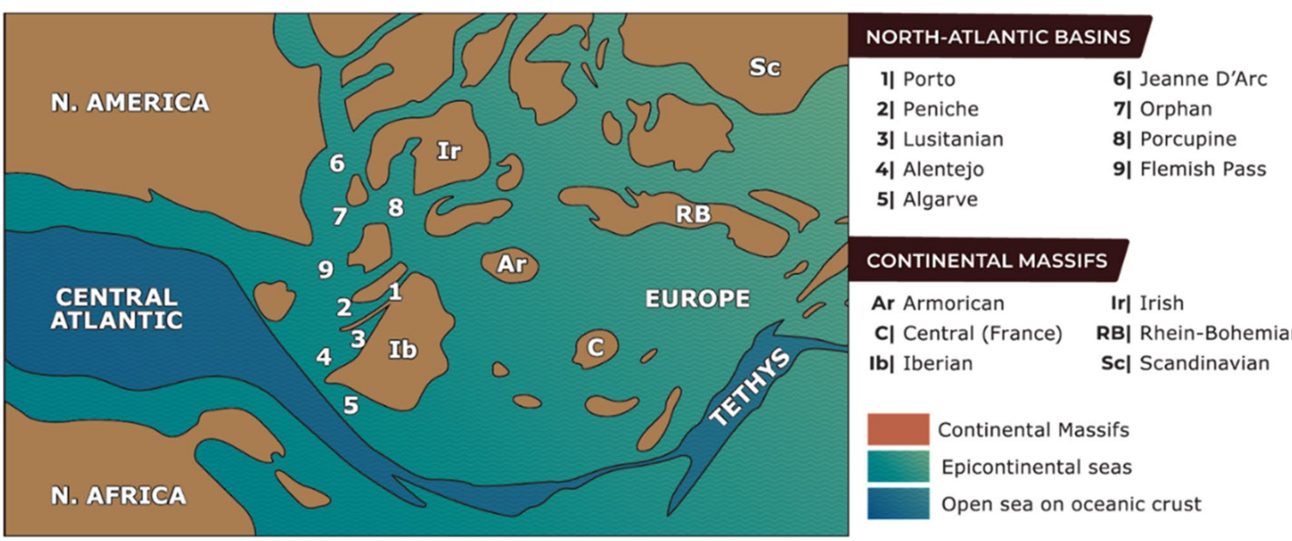

Fig. 2 Palaeogeographic reconstruction for the Iberian and North Atlantic realm in Late Jurassic times (Ziegler 1988)

basins, including the Porto, Lusitanian and Alentejo basins, leading to the opening of the North Atlantic Ocean. On the opposite side of the Atlantic, the conjugate margin includes the Canadian offshore (not exposed) Orphan, Jeane D'Arc and Flemish Pass basins.

The LB is a NNE-SSW elongated Mesozoic basin (approximately 200 km long and 100 km wide), with the *Berlengas*' horst as its western boundary and the Porto-Tomar fault and uplifted Palaeozoic basement rocks as its Eastern border. Its southern limit corresponds to the *Arrábida* fault and, northwards, it connects to the offshore Porto basin. Due to the alpine compression and uplift, it is the only North Atlantic marginal basin with an extensive outcropping area. This fact has attracted many geologists from around the world, to develop research projects and teaching courses, particularly associated with rifted margins' evolution and petroleum geology (Pena dos Reis and Henriques 2018).

The basement of the LB is a heterogeneous set mostly of Palaeozoic meta-sedimentary and igneous rocks, spanning from the Cambrian to the Carboniferous. In the Late Palaeozoic, the continental collision associated with the Variscan orogeny (around 300–270 Ma) promoted regional metamorphism and folding (Ribeiro et al. 2007). At a late stage, gradual erosion and uplift brought those rocks to shallower structural levels, and a set of mostly sinistral NNE-SSW and its conjugated dextral NW–SE faults and fractures formed. These basement structures constrained the shape and segmentation of the superimposed LB, also controlling the vertical movements and the sedimentation throughout the whole Mesozoic and even the Cenozoic. These basement faults propagated through the sedimentary cover and are still active, corresponding to most of the recent neotectonic accidents and related seismicity. By the end of the Permian, the metamorphosed Palaeozoic rocks were exposed and eroded throughout most of the Triassic, and later on capped and covered by the first Mesozoic sediments of the LB (Pimentel and Pena dos Reis 2016).

The oldest sediments known in the LB are dated from the late Middle Triassic (Ladinian), related to the initial extension and break-up of Pangea, with the development of an intra-continental rifting and asymmetric grabens (Azerêdo et al. 2003; Pena dos Reis et al. 2011). The initial sedimentary cover of the LB has been made by coarse-grained siliciclastic red-beds (Silves Group, Middle-Late Triassic), deposited by alluvial-fan systems infilling the recently created grabens. Gradually, towards more distal areas and also towards the top of the sequence, the alluvial systems gave way to finer deposits and ultimately to playa and sabkha deposits (Dagorda Formation, Carnian-Hettangian) (Fig. 3). These evaporitic-rich deposits, with thicknesses probably up to 400 m, would play a crucial role in later diapiric-related tectonics, as described below. The rocks from the Dagorda Formation are the oldest rocks observed in the OAG, and can only be seen in diapiric areas throughout its territory (Fig. 4).

At the beginning of the Jurassic, the increasing extension and subsidence allowed the penetration and installation of epicontinental seas, precursors of the North Atlantic. The first Lower Jurassic marine layers correspond to coastal and shallow marine dolomitic carbonates (Coimbra Formation, Sinemurian), containing the first ammonites. Gradually, a broad carbonate ramp developed, gently dipping to the West, and the shallow seas gave place to more open marine conditions and the deposition of thick marly carbonates (Brenha Group, Lower Jurassic) (Azerêdo et al. 2003; Pena dos Reis et al. 2011). By that time, the western border of the basin was not far away from the present-day coast-line, as testified by the presence of arkosic sands in the Toarcian sequences, at Peniche. The lower and also deeper units include organic-rich layers, with proven potential to generate hydrocarbons (Pimentel and Pena dos Reis 2016).

Towards the Middle Jurassic, marine conditions became shallower, and coastal high energy limestones, including oolitic and bioclastic units, were deposited (Candeeiros Group, Middle Jurassic). By the end of the Callovian, very shallow facies developed, and the eastern parts of the basin emerged (Azerêdo et al. 2003). This emersion caused by a global forced regression, led to subaerial exposure, creating a basin-wide unconformity, with different sedimentologic signatures (from karstification to the East to hardgrounds to the West). The total thickness of the Lower and Middle Jurassic carbonates is around 1 to 1.5 km.

The Upper Jurassic second rifting phase brought subsidence back to the basin, and marine sedimentation resumed in Oxfordian, initially with lagoonal carbonates (Cabaços Formation, Middle Oxfordian). These sediments lay in angular unconformity over the Brenha and Candeeiros Formations, consisting of laminated bituminous limestones, with recognised source-rock potential (Pimentel and Pena dos Reis 2016). This formation was followed by open marine carbonates, sometimes with marly intercalations (Montejunto Formation, Oxfordian) around 0.5 km thick.

The Kimmeridgian rift-climax is recorded by intense subsidence in depocentric areas, most of them within the OAG perimeter, with an infill up to 3 km thick, mostly of siliciclastic deposits (Pena dos Reis et al. 2000). Three hyper subsident sub-basins were then formed, separated by the Torres Vedras—Matacães diapir, around Bombarral, Arruda and Turcifal. A fourth less subsident sub-basin, Consolação, developed to the West of the diapiric alignment of Caldas da Rainha—Vimeiro—Santa Cruz. The sedimentary infill includes transitional sandy clays and marly limestones (Alcobaça Formation), and also marine turbiditic sandy marls and conglomerates (Abadia Formation) deposited in deeper areas.

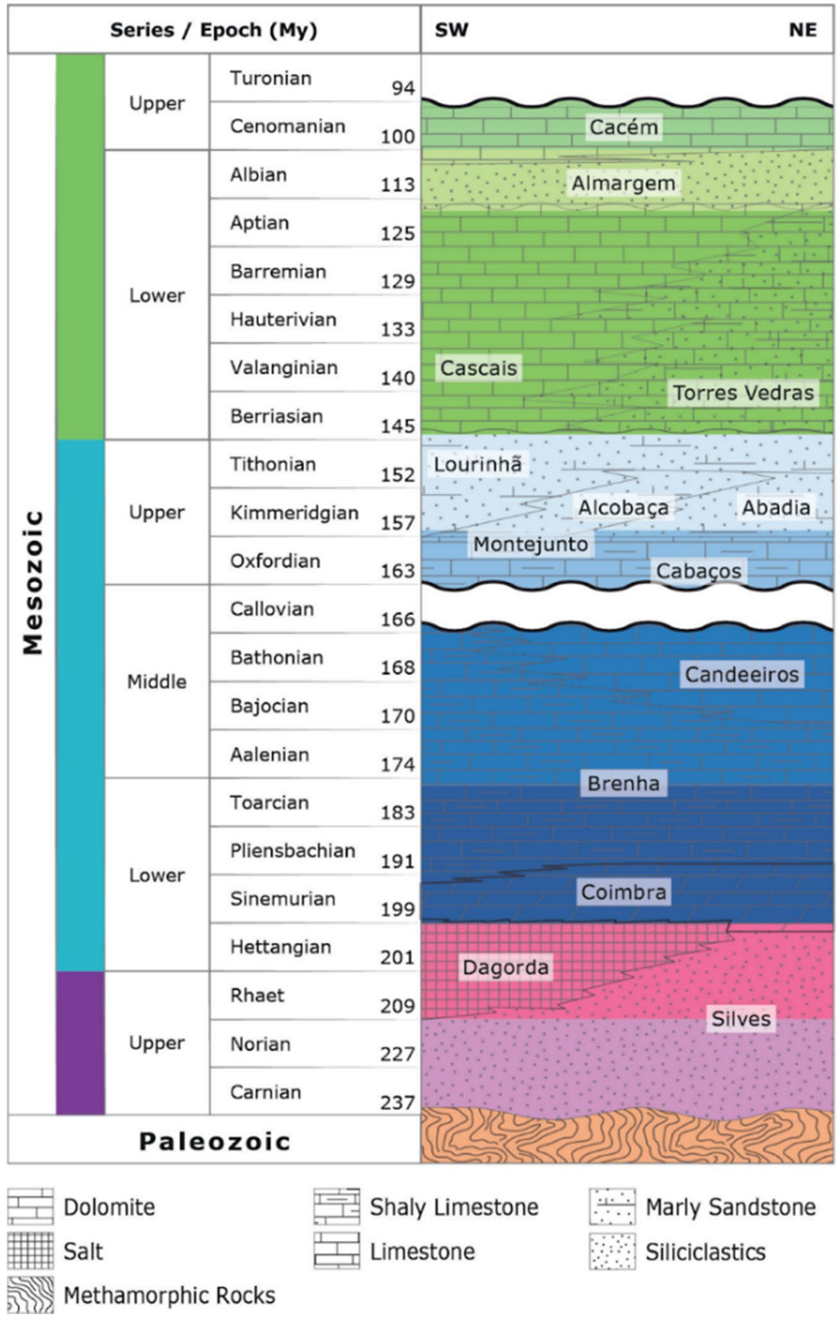

Fig. 3 Simplified lithostratigraphic chart of the Lusitanian Basin sedimentary infill (based in Azerêdo et al. 2003; Dinis et al. 2008; Pena dos Reis et al. 2011; Kullberg et al. 2013) (AGEO 2022)

As subsidence became gradually stabilised, the basin almost completely filled-up and, therefore, fluvial siliciclastics prograded into the whole basin, covering it with over 0.5 km of reddish sands and clays (Lourinhã Formation). These continental to transitional units contain the highlighted rich dinosaur fossils found within the OAG area. Those remains led to the recognition of 11 new dinosaur species, as previously mentioned, but these units also bear many other scientifically important fossils, such as crocodilomorphs and turtles (Mateus 2008; Mateus et al. 2017). In addition, the increasing knowledge of micro-faunas is revealing a huge potential for the discovery of previously unknown fossil vertebrates, such as small lizards, amphibians and mammals (Guillaume 2018).

Palaeogeographic reconstructions, based on paleocurrents and provenance analysis, clearly show that the Upper Jurassic basin had a NNE-SSW elongated trend (Fig. 5), dipping to the South and constrained by two active borders, contributing with terrigenous inputs into the axial depocenter. The Berlengas block produced sediments into the depocenters located along the eastern parts of the OAG territory. The northern areas and present day coastal cliffs

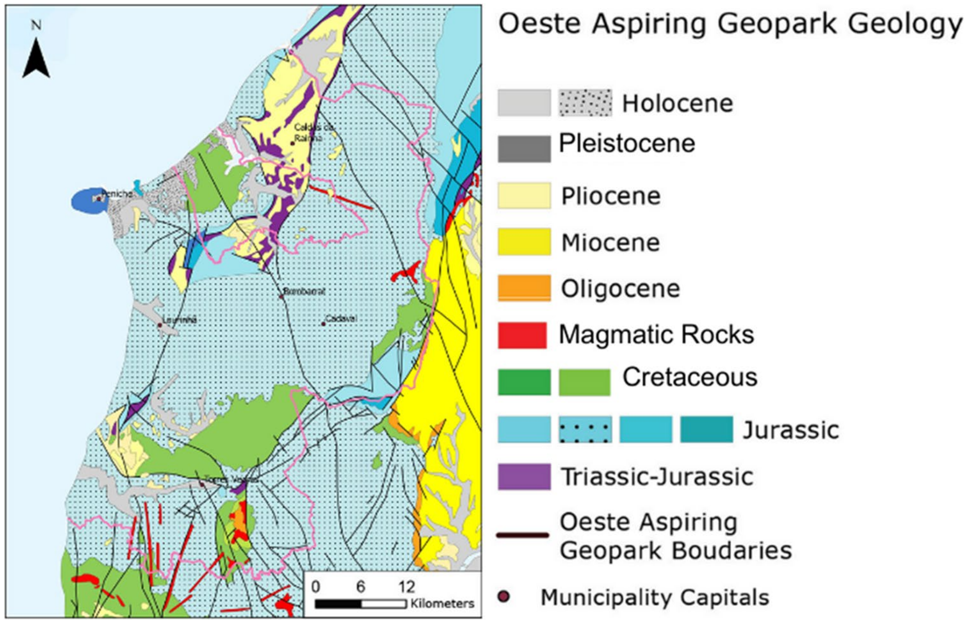

Fig. 4 Geologic map of the Oeste Aspiring Geopark territory, at 1:500.000 scale, produced by LNEG (Laboratório Nacional de Energia e Geologia, the National Geological Survey) (AGEO 2022)

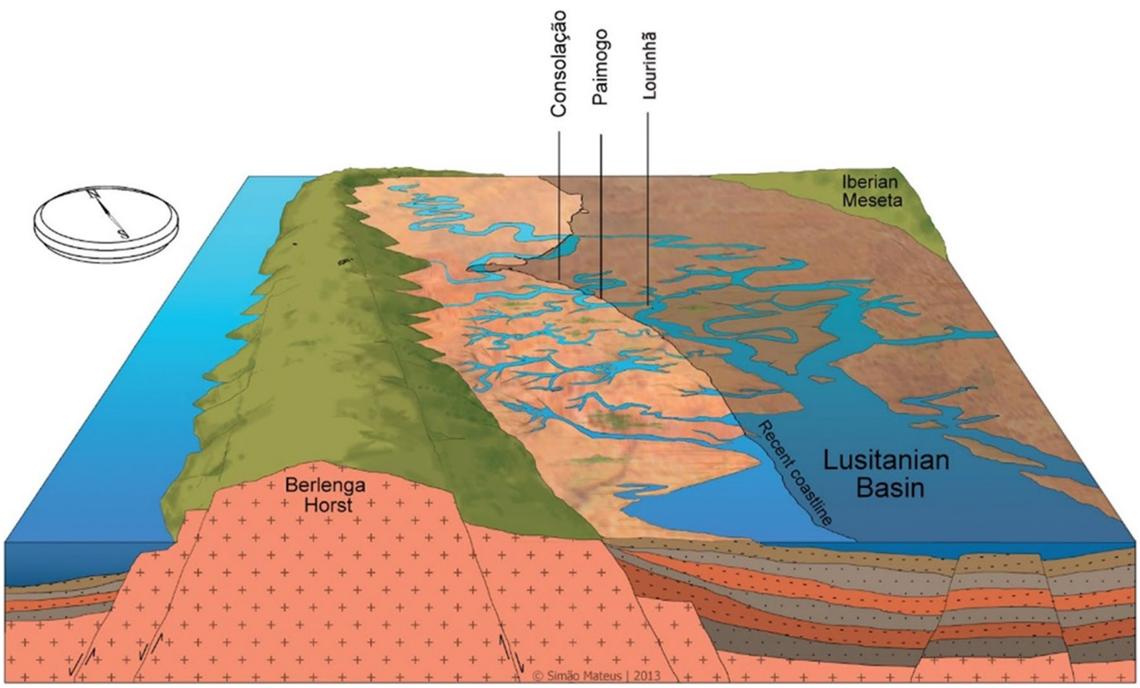

Fig. 5 Palaeogeographic reconstruction of the Lourinhã region, during the Late Jurassic (illustration by Simão Mateus, in Mateus et al. 2017)

of the territory corresponded to fluvial and transitional paleoenvironments, explaining the abundance of continental and coastal vertebrates, whereas the southern and eastern areas mostly corresponded to open marine facies (Garcia et al. 2021).

Predominantly fluvial (Torres Vedras Formation) to transitional (Cascais Formation) sedimentation continued throughout the Lower Cretaceous, recording geodynamic-driven eustatic variations, as the North Atlantic opened in successive segments northwards, with Berriasian, Barremian and Late Aptian break-up unconformities. This later unconformity marks the definite continental rupture and seafloor spreading, with total separation between the European and North-American continents (Dinis et al. 2008). These fluvial sands and clays (Almargem Formation) bear some continental fossils, namely one of the oldest mesofossil flora containing detailed angiosperm remains (Mendes et al. 2018; Friis et al. 2019). The Cretaceous basin infill, around 1 km thick, is sealed by Cenomanian–Turonian marine carbonates (Cacém Formation), related to a global transgression.

By the end of the Cretaceous, the relative motion of the African plate and the Iberian micro-plate became convergent. This geodynamic framework, a regional consequence of the broad peri-mediterranean alpine orogenesis, stopped subsidence, decreased sedimentation and promoted emersion and uplift of almost the whole Lusitanian Basin (Dinis et al. 2008). Another consequence of this geodynamic instability was the occurrence of intense magmatic activity with a continental alkaline signature, promoting the intrusion of many dykes and sills into the thick Mesozoic cover (Miranda et al. 2009).

A large depositional hiatus extended for around 40 Ma, when the erosion of uplifted mesozoic areas, such as the Montejunto anticline, resumed sedimentation, inside new intra-continental Tertiary basins. This is the case of the small Runa basin, with Paleogene alluvial conglomeratic sands and palustrine marls. Neogene deposits are present to the East of the Montejunto anticline, at the Lower Tagus Basin, with Miocene continental sandy marls.

Quaternary evolution is marked by predominant uplift, with recognised neotectonic activity. This uplift originated intense fluvial incision westwards, towards the Atlantic, intercalated with inter-glacial valley widening and stepped fluvial terraces. The last glaciation was particularly remarkable in this southern Europe region (Fig. 6), promoting a Wurmian sea-level fall over 100 m on the Atlantic coast and exposing an important part of the present-day continental platform (Dias et al. 2000). Contemporary karstic caves show evidence of prehistoric human occupation, throughout the OAG territory (Zilhão et al. 2011). The following sea-level rise, related to the Flandrian post-glacial period, promoted an intense alluvial fill-up, and is responsible for the present-day flat morphology and estuarine conditions of most terminal valleys (Dias et al. 2000).

A special highlight should be given to the influence of the diapiric phenomena in shaping the OAG territory. The Hettangian clays of the Dagorda Formation include abundant evaporitic layers and masses, rich in halite and gypsum. The over 2-km thick Jurassic overburden rocks promoted the compression and ascension of the salt-rich lower density materials towards the surface. These light materials rose up to 3 km, deforming the Jurassic cover, associated with deep-rooted fractures and fault systems (Rasmussen et al. 1998). Salt movements (or halokinesis) probably began in the Late Jurassic rift-climax and continued until today, and are the main cause for the deformation of the Mesozoic layers (Fig. 7). The arrival of the diapirs to the surface, piercing the whole Mesozoic

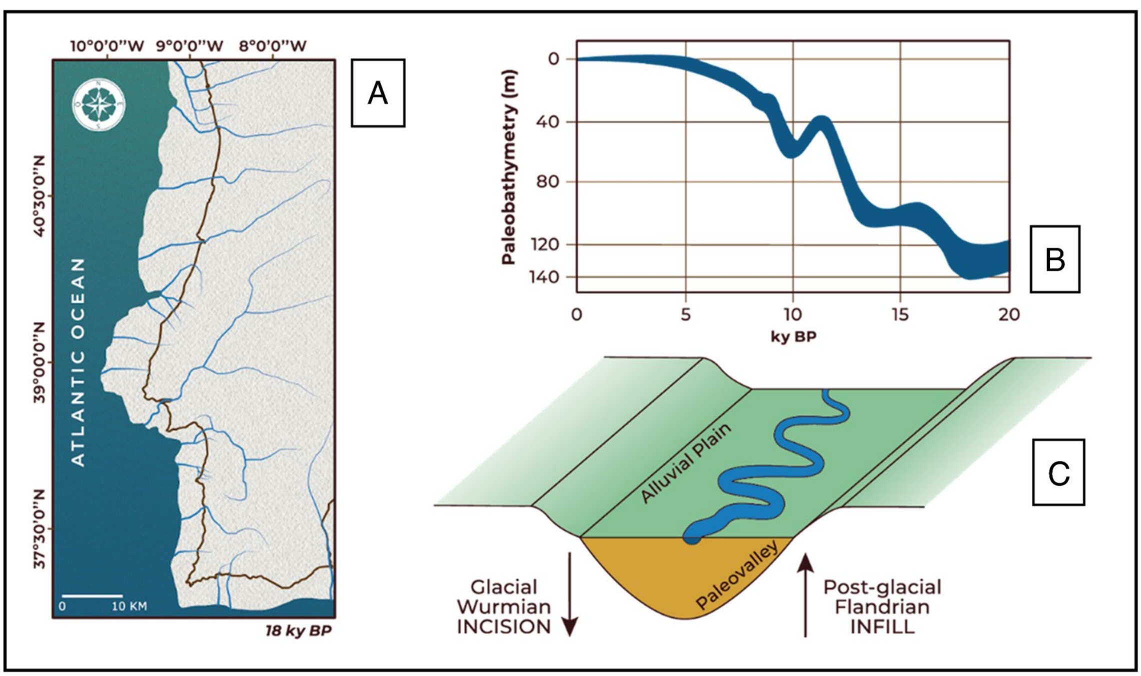

Fig. 6 Coastal evolution related to the Holocene sea-level rise. **A** Map with reconstruction of the Portuguese paleocoastline 18 ky ago, during the last glaciation (Dias et al. 2000). **B** Graph showing the variation of the sea-level for the Portuguese coast in the Holocene (Dias et al. 2000). **C** Sketch of the paleovalley incision and alluvial infill at the river-mouth of most Portuguese rivers (AGEO 2022)

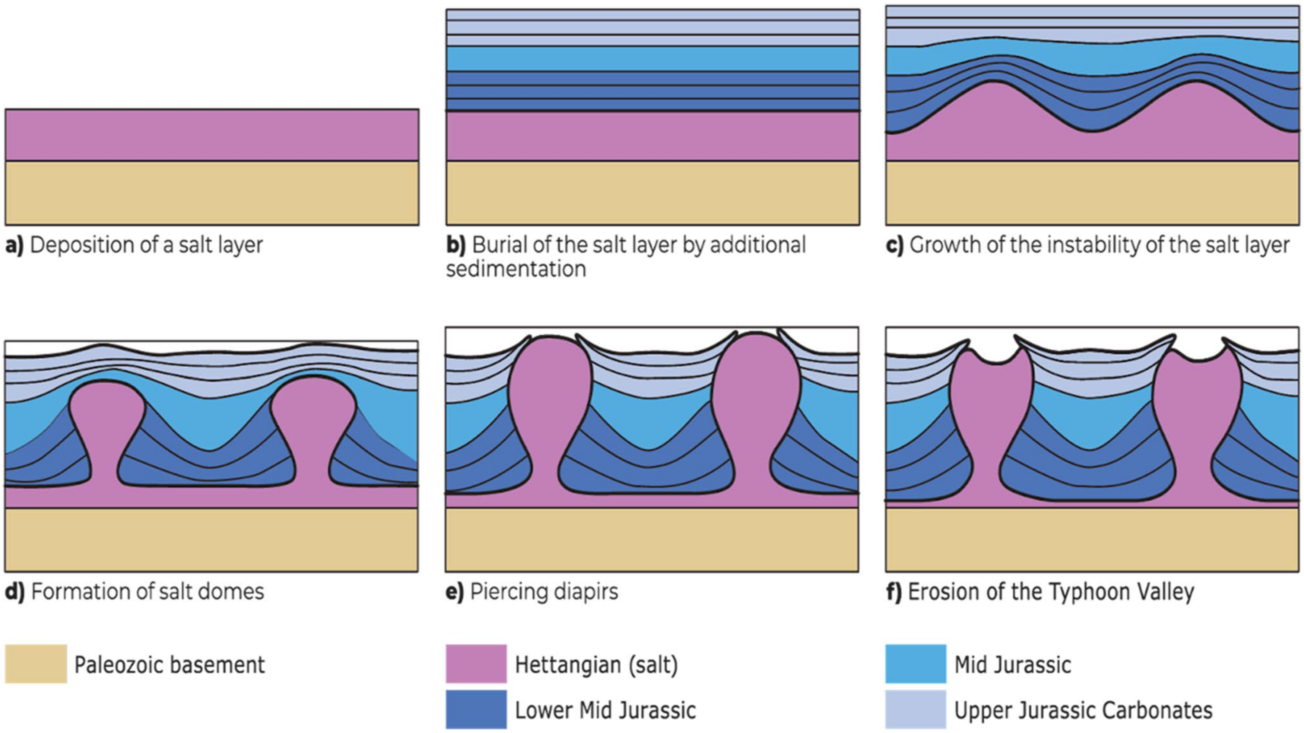

Fig. 7 Schematic evolution of a diapir and the formation of a typhonic valley (AGEO 2022). **a** Deposition of a salt layer. **b** Burial of the salt layer by additional sedimentation. **c** Growth of the instability of the salt layer. **d** Formation of salt domes. **e** Piercing diapirs. **f** Erosion of the Typhoon Valley

cover, occurred by the end of the Cretaceous, and was related to the first intense alpine compressional events and also to coeval magmatic activity and intrusion along some of the diapiric structures (Davison and Barreto 2020). Salt tectonics is also responsible for most of the present day geomorphology, particularly at the so-called "typhonic valleys" (after the Greek god *Typhon,* son of *Gaia*), which comprise erosion exhumed piercing diapirs and salt-walls. This term was first defined in the nineteenth century, based on the geomorphologic features of the Caldas da Rainha diapiric valley, in the OAG territory (Choffat 1882).

Geological Highlights of the OAG

The OAG has been a territory of science since the nineteenth century, permanently revisited and updated by both local and visiting researchers. Within this candidate territory, there are three geological highlights, with recognised international relevance: (a) the Toarcian GSSP, a worldwide stratigraphic reference; (b) the incredibly rich palaeontological record of Jurassic dinosaurs, including several unique holotypes and (c) the findings of remarkably preserved Cretaceous angiosperms.

Toarcian GSSP

The Toarcian GSSP (Global Boundary Stratotype Section and Point), at *Ponta do Trovão* (*Peniche*), is a worldwide reference to define the stratigraphic limit between the Pliensbachian and the Toarcian stages (Rocha et al. 2016). The international relevance of this section was recognised in 2014 by the International Commission on Stratigraphy, a scientific body of the International Union of Geological Sciences (IUGS). The Toarcian "Golden Spike" at *Ponta do Trovão* is frequently visited by researchers from all around the world, either to develop detailed scientific studies or as part of scientific field trips. The place is also regularly used to promote outreach and educational activities, related to the Toarcian record, namely to the worldwide TOAO (Toarcian Oceanic Anoxic Event) and its paleoclimatic significance and implications (Duarte et al. 2017).

Late Jurassic Dinosaurs

In the territory in question, the majority of the outcropping rocks are Upper Jurassic continental deposits from the Lourinhã Formation, internationally known for its dinosaur fossils (*e.g.*, Mateus et al. 2017). The first dinosaur fossils reported on Portugal date back to 1863, with several teeth presently assigned to the species *Torvosaurus gurneyi* found at *Peralta* beach (*Lourinhã*). This was the first of thousands more findings in the OAG territory (*e.g.*, Lapparent and Zbyszewski 1957; Antunes and Mateus 2003; Mocho et al. 2017*;* Mateus et al. 2017). Dating to approximately 150 Ma, so far 11 dinosaur species were erected based on fossils collected in the OAG, namely *Allosaurus europaeus*, *Dinheirosaurus lourinhanensis*, *Draconyx loureiroi*, *Eousdryosaurus nanohallucis*, *Lourinhanosaurus antunesi*, *Lusotitan atalaiensis*, *Lusovenator santosi*, *Miragaia longicollum*, *Oceanotitan dantasi*, *Torvosaurus gurneyi* and *Zby atlanticus.* Each year, more dinosaur fossils are being found, and there is always the possibility for defining new species. Also of high international relevance, four dinosaur nests have been found in this territory, so far. Fossil dinosaur nests are rather uncommon around the globe, even rarer when bearing embryos remain inside. Put into perspective, there are only 12 sites in the world where dinosaur nests with embryos were found, of which two are from Lourinhã (Fernandes et al. 2021).

Early Cretaceous Angiosperms

Also of significant importance and international relevance are the Cretaceous fossil plants found in the OAG territory. The early phases of angiosperms (flowering plants) diversification occurred around the Barremian-Aptian stages (Friis et al. 2019). Due to its terrestrial nature and type of biological tissues, these plants have a poor Mesozoic record, and their fossils are highly relevant, since they bring light to the evolution of this plant group. Three important fossil localities have been providing many Barremian-Aptian plant remains, which document an important time of angiosperm diversification. Particularly relevant are the fossil floras from (i) *Cercal* (N of *Cadaval*), containing a mixture of Aptian gymnosperm and angiosperm, studied since the nineteenth century (Saporta 1894; Teixeira 1947), which led to the description of several new plant species, with its dicotyledons being recognised as the oldest leaf remains of this group in Europe and (ii) two sites in *Torres Vedras* area, where one of the world oldest angiosperm mesofossiliferous assemblages was found, including flowers, fruits, seeds and other floral remains (Mendes et al. 2018; Friis et al. 2019), leading to the establishment of more than 20 new genera and 28 new species.

Other Relevant Geoheritage Elements

This OAG territory is also important for its rich geological record, spanning from the Late Triassic to the Holocene, thus showing us evidence of many different moments and stages of the Earth's evolution, namely the opening of the North Atlantic. World-class outcrops expose and document the long-lived Jurassic marine rifting, the continental post-rift units and the Tertiary alpine inverted basin. The extensive coastal cliffs are a privileged place of observation, continually exposing the gently dipping Mesozoic sedimentary units for hundreds of metres. Frequent scientific and technical fieldtrips visit this region which has for a long-time attracted the attention of national and international academic researchers and professionals.

The coastal location is also an important feature of this territory, showing the permanent interaction between continental and marine processes. This coastline, with its cliffs, sandy beaches, sand dunes, lagoons and estuaries, is a natural laboratory to understand coastal dynamics and the effects of centennial and recent sea-level rise and climate changes (Pimentel et al. 2022). Finally, this is a region with a very rich natural, cultural and intangible heritage, in many cases, closely related to the geological characteristics of the territory. These include coastal lagoons and swamps with rich fauna and flora, karstic landscapes with prehistoric caves, fortifications on several hill-tops or vineyards and orchards in clay-rich soils.

From Geodiversity to Geosites

The OAG territory is dominated by Late Jurassic rocks, with internationally well-known dinosaur remains. But this geopark should not focus on a single scientific feature, and instead should look to the territory as a whole (Pimentel et al. 2019; Pimentel and Pereira 2022).

These ideas led the OAG staff to search for geological sites which represent the geodiversity of the territory. To build a comprehensive list of geosites, the staff's personal geological knowledge of the region was taken in consideration, together with intense bibliographical research. The gathered data were complemented by field work and on-site observations and discussions. From this compilation, a preliminary geosites list was elaborated, taking into account, not only the scientific, but also the educational and touristic potential of each site (*vd*. Brilha 2018a).

The following step was to share and discuss this list and the relevant geological information for each site, with the local entities (active citizens, associations and schools), regional structures (municipalities and technicians managing the territory) and national partners (LNEG, the Portuguese Geological Survey and academic researchers from different universities). This interaction was very fruitful and led to a better understanding of the geosites importance, adding several new sites not previously considered.

A second step was to evaluate and assess the geosites. This is always a complex and quite arguable task, for which many different approaches and criteria have been used by many different authors in many different places and contexts (*vd*. discussion and references *in* Brilha 2018a). A simple qualitative approach has been adopted, grading different factors or values in four levels, from *Low* to *Very High*. For this assessment, we defined two kinds of values, named as intrinsic and extrinsic. Intrinsic values correspond to the existing and already recognised values, which may be (i) *Scientific*—presence of important geological features, validated by researchers through scientific publications; (ii) *Ecological*—presence of high biodiversity or important biological communities and (iii) *Cultural*—presence of historical monuments or strong local traditions. Extrinsic values correspond to the appraisal of the potential for future activities: (i) *Scientific*—potential to develop new or more detailed research; (ii) *Educational*—potential to use the geosite for promoting geoeducational activities (Martinez-Martin 2022) and (iii) *Geotouristic*—scenic and cultural values with storytelling potential to attract and please the visitors (Pralong 2006).

The relevance of the geosites has also been scored, as *International*, *National* or *Regional*. *International* relevant geosites include localities where important scientific discoveries have been made and published in referenced journals. *Regional* relevant geosites are also important places for different scientific studies, but with many examples in the OAG territory and worldwide. Lastly, *Local* relevance has been attributed to places with moderate scientific value, but with high potential for geoeducational or geotouristic activities for local or incoming visitors.

Obviously, the grading of each factor is subjective and therefore the numerical assessment tends to be an artificial sum of them all. Nevertheless, this qualitative approach has been a very important task for the OAG to discern the importance of each geosite, not only based on its geological value but, above all, as a tool to promote the geosites within the framework of the OAG holistic scope and activities. Moreover, recognising these different values is helping the OAG to define a better strategy for geoconservation, prioritising geosites with higher ranks and subjected to higher natural or human pressures.

From Single Geosites to Encompassing Themes

In the OAG territory, there are many important geosites to explain the local and regional geology. These geosites hold evidence of the Lusitanian Basin long Mesozoic evolution and the different organisms that lived in this region throughout time, as well as the importance of the alpine collision and uplift, exposing older layers and creating new reliefs. The relationships between geology, landscape, natural resources and communities are also an important aspect of this territory and, therefore, considered to define geosites.

Organising geosites into groups or types is an important task for an overall appraisal of its importance and, moreover to promote and communicate it to different communities (scientists, local populations, visiting citizens, students, etc.). Ruban (2010) defined 21 types of geosites, considering its geological characteristics, some being strictly petrological (sedimentary, igneous, metamorphic), others more thematic (e.g. stratigraphical, geochemical, seismical, structural, palaeogeographical) or even technical (e.g. engineering or radiogeological), covering a wide range of situations. For the holistic purposes of a geopark, which include, besides scientific also educational and geotouristic objectives, we preferred a strategy of grouping geosites into specific themes, aiming to represent and communicate the geological stories behind the places (*vd*. Stewart and Nield 2013; Macadam 2017). By doing so, a long list of geosites has been grouped into six themes, each theme covering a different aspect of the OAG territory geological evolution.

This strategy may be compared to the geological framework concept, initially developed by PROGEO—The European Association for the Conservation of the Geological Heritage (*vd*. Erikstad 2008; Wimbledon 2011; Wimbledon et al. 1999, and references therein)—"Geosites were selected in the countries as part of contextual regional frameworks, selected for the special part they play in understanding a particular interest and of major events in geological history" (PROGEO 2011). This strategy has also been applied in Portugal to its geoheritage, listing 25 frameworks, each one with a variable number of representative geosites (Brilha et al. 2005). However, instead of defining ab initio scientific frameworks, we begun with looking for potential geosites and, after its inventory and preliminary assessment, grouping them into six themes to be explored in the OAG territory.

The current 80 geosites are assigned to the different themes, although many of them naturally enclose several important values and bear geodiversity elements ascribed to different themes. When more than one theme is represented, the geosite has been categorised according to the most important one, and the other themes are referred to in the geosites detailed characterisation. The six themes are described below with its designation and also a correspondent leitmotif, aiming to storytelling. For each theme, an example of a representative geosite is described at the end.

a) Geological Record—The Story of Our Land

This theme comprises many scientifically relevant geosites (Table 1) that demonstrate the long-lived geological

Table 1 Geosites assigned to the geological record theme

Geological Record

Ref.	Geosite Name	Main Highlight (Main Interests)	Values: Scientific	Values: Educational	Values: Scenic	Values: Ecology	Values: Cultural	Values: Relevance	Accessibility: Walking difficulty	Accessibility: Reduced Mobility	Accessibility: Car	Accessibility: Bus	Facilities: Drinking fountain	Facilities: Lavatory	Facilities: Restaurant/Cafe	Facilities: Lodging	Facilities: Car parking	Facilities: Bus parking	Interpretation Panel	Vulnerability	Nº of publications
GS17	Caixaria	Paleogene marly sandstones, remains of an ancient lake inside a salt withdrawal minibasin.	High	Medium	High	Medium	Low	Local	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	0
GS24	Papôa	Volcanic breccia with large Paleozoic granites and gneisses xenoliths (from the basement) and Mesozoic limestones and sandstones, cutting Lower Jurassic dolomitic limestones.	Very high	Very high	Very high	High	Medium	Regional	Easy	×	✓	✓	×	×	×	×	✓	✓	Planned for the Current Year	High	47
GS26	Penedo Furado	An iconic large (20m) rocky block, isolated on the margin of a lagoon, made of Late Jurassic fluvial deposits, eroded by wind and wave action.	High	Medium	High	Medium	High	Local	Easy	×	✓	✓	×	×	×	×	×	✓	Planned	Medium	1
GS42	Freiria	Late Cretaceous magmatic dike (2 km long N-S), related to the Lisboa-Mafra Volcanic Complex, intruding Late Jurassic sandstones.	High	Medium	Medium	Medium	Low	Local	Easy	×	✓	×	×	×	✓	×	✓	×	Not Planned	Medium	1
GS44	Ponta do Trovão	The Global Boundary Stratotype Section and Point (GSSP) for the Torcian Stage, a IUGS stratigraphic "Golden Spike".	Very high	Very high	Very high	High	Medium	International	Medium	×	✓	✓	×	×	✓	×	✓	✓	Planned for the Current Year	High	66
GS46	Pico da Mota	Cretaceous fluvial conglomerates, with large siliceous clasts and appealing geometries and colour variety. These rocks are exposed on a cliff with active costal erosion.	High	High	High	Medium	Low	Regional	Easy	×	✓	×	×	×	×	×	✓	✓	Not Planned	Medium	0
GS56	Casais do Seixo	Lower Cretaceous continental fluvial sandstones with paleochannels and alluvial plains.	Medium	Medium	Medium	Medium	Low	Local	Easy	×	✓	✓	×	×	×	×	×	×	Not Planned	Medium	0
GS66	Consolação	Late Jurassic limestones and marls, showing a regressive sequence from coastal reef deposits to protected lagoons and fluvio-deltaic sedimentation. Dinossaur footprints and large in-situ colonial corals can be seen.	High	Very high	Very high	High	High	Regional	Easy	×	✓	✓	×	×	✓	×	✓	✓	Planned for the Current Year	Medium	11
GS71	Serra de Todo Mundo	Late Cretaceous 50 meters thick doleritic sill, originating a large (3 km long) horseshoe shapped plateau (250m high) dominating the surrounding lowlands (100m high).	High	High	High	Medium	Medium	Regional	Medium	×	✓	×	×	×	×	×	✓	×	Not Planned	Medium	1

INFOGRAPHIC MEANING

● Very high	● International	Hard	Planned
High	Regional	Medium	Not Planned
Medium	Local	Easy	Planned for the Current Year
Low			

record of the OAG, spanning from the Late Triassic to the Quaternary (Fig. 4). Its most ancient geological record is the Hettangian "sabkha" clays, with gypsum and halite, outcropping in several piercing diapirs. Lower Jurassic rocks are well exposed in uplifted sectors, close to diapiric structures as well. The best example is the *Peniche* peninsula, where continuous depositional sequences from the Pliensbachian to the Lower Aalenian (?) may be observed along coastal cliffs. It includes the Toarcian GSSP (Global Boundary Stratotype Section and Point), one of the highlights with international relevance in the OAG territory. The Middle Jurassic rocks are marine limestones uplifted by salt tectonics and exposed at the *Cesaredas* Plateau and the *Montejunto* anticline. The Late Jurassic is probably the most well represented and also the most important epoch in the OAG, occupying more than 50% of its area. The fluvial to coastal deposits of the Lourinhã Formation held an extraordinary array of palaeontological remains (*vd*. the Palaeontology theme).

The Cretaceous is represented by fluvial sands, spanning all the stages from the Berriasian to the Cenomanian. These continental units also present important palaeontological content (*vd*. the Palaeontology theme). The Late Cretaceous magmatic activity, related to the break-up of the North Atlantic, is evidenced throughout the territory by several dykes, sills, breccias and volcanic tuffs.

The Tertiary has a minor representation, restricted to the small *Runa* basin and to the East of the *Montejunto* anticline. Plio-Pleistocene sands cover most of the flattened depressions, related to ancient drainage systems towards the Atlantic, with occasional marine incursions. Some sands show clear signs of deformation, thus helping in Neotectonic studies and hazard assessment. The Holocene record is quite significant, both inland and in coastal areas. The main rivers present a large alluvial plain with a thick post-glacial infill (*vd*. the Coastal Dynamics theme). Some peri-glacial deposits such as limestone gelifacts, are also recorded in several places.

Ponta do Trovão geosite shows the transition between the Pliensbachian and the Toarcian Stages, which happened 182.7 Ma ago (Fig. 8A). Experts from around the world consider this site as the best record for this temporal boundary. In 2014, the International Union of Geological Sciences certified the importance of this site, signalling this recognition with the placement of a "Golden Spike" (GSSP—a site with geological heritage of international significance). The rocks below the "Golden Spike" are older, compact and calcareous, with abundant fossils of belemnites. These

Fig. 8 Geosites from the OAG territory, assigned to the six different themes. **A** *Ponta do Trovão* (GS44, geological record). **B** *Paimogo-Caniçal* (GS20, palaeontology). **C** *Vale de Maceira* (GS73, salt tectonics). **D** *Nossa Senhora das Neves* (GS8, geomorphology). **E Caldas da Rainha Thermal Complex** (GS9, geologic resources). **F** *Salir do Porto* (GS14, coastal dynamics)

animals, similar to current cuttlefish, were extinct by the end of the Cretaceous, at the same time as dinosaurs.

b) Palaeontology—Who Lived Here Before Us

Through several important geosites, it is possible to grasp the vast and diverse palaeontological record of the OAG, one of the major highlights of this territory (Table 2). Almost all outcropping geological units bear macro or microfossils, many of scientific relevance. Dozens of retrieved specimens led to the description of new species (holotypes). These important fossils were extracted from the geosites and are kept in museum collections, thus becoming ex situ palaeontological heritage (Brilha 2016; Henriques and Pena dos Reis 2015). Of note, the 11 sites where dinosaur holotypes were retrieved are here included (Fig. 8B), as well as dinosaur nests and tracks, fossil plants and invertebrate sites.

To fulfil international standards and practices on conservation and research, the most important vertebrate fossils were removed and stored in local museums or research collections, but the sites still hold information for further scientific studies. Those sites thus deserve the adoption of protection measures also because, in some cases, they can be used for educational and touristic activities.

At the *Paimogo-Caniçal* geosite, cliff outcrops show evidence that, in the Late Jurassic (about 152 Ma), meandering rivers flowed south-eastwards, bringing immense quantities of sediments in the region (Fig. 8B). In these sediments, there are several fossils of dinosaurs, turtles, crocodiles and even small mammals of those times. Among these findings, large dinosaur nests with preserved eggshells and embryos stand out (Mateus et al 1998; Fernandes et al 2021). Studies are currently underway to characterise these embryos and their ontogeny. Eggshells and embryo bones are very delicate, fossilising only in very special conditions and, therefore, these are very rare and important findings.

c) Salt Tectonics—Uprising Rocks and Crests

Salt tectonics, related to vertical movement of the Hettangian evaporitic clays, is a fundamental feature in the OAG region. Many OAG geosites are directly related to this geological phenomena (Table 3). This influence may be perceived not only from the surface presence of the piercing

Table 2 Geosites assigned to the palaeontology theme

Palaeontology

Ref.	Geosite Name	Main Highlight (Main Interests)	Values: Scientific	Values: Educational	Values: Scenic	Values: Ecology	Values: Cultural	Relevance	Accessibiliy: Walking difficulty	Accessibiliy: Reduced Mobility	Accessibiliy: Car	Accessibiliy: Bus	Facilities: Drinking fountain	Facilities: Lavatory	Facilities: Restaurant/Cafe	Facilities: Lodging	Facilities: Car parking	Facilities: Bus parking	Interpretation Panel	Vulnerability	N° of publications
GS1	Atalaia	Reference site for the holotype of dinosaur species *Lusotitan atalaensis*.	Very high	Medium	Low	High	Low	International	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	6
GS3	Praia da Peralta	Late Jurassic fluvio-deltaic deposits with hundreds of pterossaur footprints, unique in Portugal and and rare around the world. A well-preserved dinosaur nest was also found, probably from the species *Lourinhanossaurus*.	Very high	Medium	High	High	Low	International	Medium	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	18
GS7	Praia Assenta	Late Jurassic fluvio-deltaic depostis where several dinosaurs remains and footprints have been retrieved.	High	High	High	High	High	Regional	Medium	✓	✓	×	×	✓	✓	×	✓	×	Planned	High	3
GS11	Casaleiro	Place with outcropping Lower Jurassic marls, with fossils of brachiopods, crinoids and small ammonites.	Medium	Very high	Medium	Medium	Low	Local	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	0
GS12	Salir	Large gently dipping limestone layers, with more than 30 dinosaur footprints, from sauropods and theropods.	Very high	Very high	Very high	Medium	Low	Regional	Medium	×	×	×	×	×	×	×	×	×	Planned	Very high	2
GS15	Vale de Frades	Reference site for the holotypes of *Allosaurus europaeus*, a theropod dinosaur, and *Draconyx loureiroi* in Late Jurassic fluvio-deltaic deposits.	Very high	Medium	High	High	Low	International	Easy	×	✓	✓	×	×	×	×	×	✓	Not Planned	Medium	14
GS18	Zambujeiro	Important Cretaceous fossil flora, although relatively little diverse, formed by cryptogamic and gymnosperms.	Very high	Medium	Low	Medium	Low	International	Medium	×	✓	✓	×	×	×	×	×	×	Not Planned	Medium	2
GS20	Paimogo	Locality where a *Lourinhanosaurus* egg nest with dinosaur embryos was found, one of the largest and oldest known dinosaur nest.	Very high	High	Very high	High	Low	International	Medium	×	×	×	×	×	×	×	×	×	Not Planned	Medium	23
GS22	Cadriceira	One of the largest (20m long) *Araucaria* silicified Late Jurassic trunks known in the country is preserved here.	Very high	High	Low	Medium	Low	Regional	Easy	×	✓	✓	×	×	×	×	×	×	Not Planned	High	3
GS27	Casal do Cervantes	Site where one of the most complete dinosaur skeletons was found, belonging to the *Miragaia longicollum* species.	Very high	Medium	Low	Medium	Low	International	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	3
GS29	Praia de Porto Dinheiro	Reference site for the holotypes of *Pinheirodon pygmaeus* (a small fossil mammal) and *Supersaurus lourinhanensis* (a sauropod dinosaur) in Late Jurassic fluvio-deltaic deposits.	Very high	Very high	Very high	Very high	High	International	Medium	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	29
GS32	Valmitão	Place where the holotype of Oceanotitan dantesi (a sauropod dinosaur) was found, in Lated Jurassic fluvio-deltaic deposits.	Very high	Medium	High	High	Low	International	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	7
GS35	Cercal	Well preserved fossils of Aptian flower-plants, one of the oldest Dicotyledon Angiosperms records known in the world and studied since the XIX century (Saporta, 1894).	Very high	Low	Low	Medium	Low	International	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	9
GS39	Praia Azul	High cliff with Late Jurassic coastal deposits with large *Isognomon* shell banks and *Myophorella lusitanica* (Sharpe, 1850) holotype site. Fossil turtles, crocodilomorphs and dinosaurs were also retrived. To the South, the River Sizandro mouth presents a well-developed beach-dune system.	Very high	Very high	Very high	Very high	Medium	International	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	9
GS41	Pedras Negras	Sauropod hand and footprints (probably two trails) and Theropod footprints preserved on a Kimmeridgian limestone, with bivalve shells.	High	Very high	High	Medium	Low	Regional	Medium	×	×	×	×	×	×	×	×	×	Not Planned	High	3
GS45	Casal do Biqueirão	Theropod and sauropod tracksites, at least four trails, preserved in Kimmeridgian limestones.	High	Medium	Very high	Medium	Low	Regional	Medium	×	×	×	×	×	×	×	×	×	Not Planned	High	0
GS47	Casal do Borracho	Well preserved fossils of Aptian flower-plants, one of the oldest Dicotyledon Angiosperms records known in the world.	Very high	Medium	Low	Low	Low	International	Easy	✓	✓	✓	×	×	×	×	✓	✓	Not Planned	Medium	12
GS55	Praia da Vermelha	Reference site for the holotype of *Torvosaurus gurneyi*, the largest Late Jurassic carnivorous dinossaur in Europe, collected in Late Jurassic fluvio-deltaic sands.	Very high	Low	Medium	Medium	Low	International	Hard	×	×	×	×	×	×	×	×	×	Not Planned	Medium	10
GS57	Miragaia	Reference site for the holotype of *Miragaia longicollum*, a dinosaur from the Stegosaurus group.	Very high	Medium	Low	Low	Low	International	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	7
GS60	Vale de Pombas	Reference site for the holotype of *Zby atlanticus*, a sauropod dinosaur, both collected in Late Jurassic fluvio-deltaic sands.	Very high	Medium	High	High	Low	International	Medium	×	×	×	×	×	×	×	×	×	Not Planned	Medium	9
GS62	Peralta	Reference site for the holotype of *Lourinhanosaurus antunesi*, collected in Late Jurassic fluvio-deltaic sands.	Very high	Medium	Low	Low	Low	International	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	High	14
GS65	Praia de Cambelas	Only site in Portugal where more than 5 dinosaur species were retrieved, besides fossil vertebrates including a crocodile egg nest, in Late Jurassic fluvio-deltaic sands.	Very high	High	High	High	Low	Local	Medium	×	✓	✓	×	×	×	×	✓	×	Planned	Medium	16
GS67	Mugideira	Type locality (Catefica) for Upper Aptian - Lower Albian fossil flower species, collected in fluvial sandstones. These fossils play a key role in the understanding of early angiosperms' evolution.	Very high	Medium	Medium	Medium	Low	International	Easy	×	✓	✓	×	×	×	×	×	×	Planned	Medium	17
GS70	Porto de Barcas	Reference site for the holotype of *Eousdryosaurus nanohallucis* (dinosaur), collected in Late Jurassic fluvio-deltaic sands with a carbonate intercalation.	Very high	High	High	High	Medium	International	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	42
GS74	Paimogo-Caniçal	Upper Jurassic sequence, with excellent exposure of fluvial paleochannels and floodplains, where two very well preserved dinosaur egg nests were found, probably from *Lourinhanosaurus*.	Very high	Very high	Very high	High	Very high	International	Easy	✓	✓	✓	×	×	×	×	✓	✓	Planned	Medium	14
GS76	Quinta das Fontainhas	Sandstone layer with depressions interpreted as dinossaur footprints.	Medium	Medium	High	Medium	Low	Local	Medium	×	✓	✓	×	×	×	×	×	×	Not Planned	Medium	0
GS79	Zimbral	Important Upper Jurassic microvertebrate fossil site, with remains of small lizards, turtles, amphibians and mammals.	Very high	Medium	Medium	Low	Low	Regional	Easy	×	×	×	×	×	×	×	×	×	Not Planned	High	13
GS80	Murteiras	Late Jurassic fluvio-deltaic sands where several partial dinosaur skeletons have been retrieved.	High	Medium	High	Medium	Low	Regional	Easy	✓	✓	✓	×	×	×	×	✓	×	Not Planned	Medium	4

INFOGRAPHIC MEANING

Values	Relevance	Walking difficulty	Interpretation Panel
Very high	International	Hard	Planned
High	Regional	Medium	Not Planned
Medium	Local	Easy	Planned for the Current Year
Low			

Table 3 Geosites assigned to the salt tectonics theme

Salt Tectonics

			Values						Accessibility				Facilities								
Ref.	Geosite Name	Main Highlight (Main Interests)	Scientific	Educational	Scenic	Ecology	Cultural	Relevance	Walking difficulty	Reduced Mobility	Car	Bus	Drinking fountain	Lavatory	Restaurant/Cafe	Lodging	Car parking	Bus parking	Interpretation Panel	Vulnerability	N° of publications
GS4	Santa Cruz	Costal section showing the effects of a piercing diapir, from upturned Cretaceous units on the North side, to the almost vertical Late Jurassic units in the South side. Iconic rocky block on the beach ("Penedo do Guincho"), a Late Jurassic submarine canyon with granitic pebbles from the Berlengas islands.	Very high	Very high	Very high	High	High	Regional	Easy	✓	✓	✓	×	✓	✓	✓	✓	×	Planned	High	12
GS16	Pena Seca viewpoint	A viewpoint of the Bolhos diapir, where the erosion processes formed an elongated valley ("typhonic valley"), partially covered by Plio-Quaternary deposits.	High	High	Very high	Medium	Low	Local	Medium	×	✓	×	×	×	×	×	×	×	Planned	Medium	5
GS31	São Mamede	Diapiric "raft", with a small Lower Jurassic dolomitic plateau surrounded by older Hettangian red marly clays, in the nucleous of the Caldas da Rainha diapir.	High	Medium	High	Medium	High	Local	Medium	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	1
GS49	Pedras Muitas	Late Jurassic dipping layers, affected by regional diapiric movements. Place of the first Portuguese trench made to study neotectonic movements and risk assessment for a nuclear plant installation.	High	Medium	High	High	Medium	Local	Medium	×	✓	×	×	×	✓	✓	✓	×	Not Planned	High	11
GS52	Baleal	Middle Jurassic limestone layers dipping 45° to the North, due to the uplift caused by a nearby diapir.	High	High	Very high	High	High	Regional	Medium	×	✓	×	×	×	×	✓	✓	×	Planned for the Current Year	Medium	10
GS59	Santuário do Calvário	Diapiric "raft", with dolomitic layers suporting a small christian sanctuary, standing above the lowlands of the piercing diapir.	High	Medium	Very high	Medium	High	Local	Medium	×	✓	×	×	×	×	×	×	×	Not Planned	Medium	0
GS73	Vale de Maceira	Long and narrow piercing diapir, with eroded Hettangian salt-rich clays, originating a "typhonic valley" (with a thermal spring), surrounded by almost vertical uplifted Late Jurassic limestones.	Very high	Very high	Very high	Very high	High	Regional	Easy	✓	✓	×	×	×	×	×	✓	×	Planned	Medium	3
GS78	Santa Ana	Viewpoint to the western flank of the Caldas da Rainha diapir. The erosion processes cut a narrow opening, allowing for the entrance of the sea-water and diffracted waves, forming a unique shell-shaped bay.	High	High	Very high	Medium	High	Regional	Hard	×	×	×	×	×	×	×	×	×	Planned	High	5

INFOGRAPHIC MEANING

Very high; High; Medium; Low — International; Regional; Local — Hard; Medium; Easy — Planned; Not Planned; Planned for the Current Year

diapirs, but also from the intense deformation of the thick Jurassic/Cretaceous cover.

The exhumed piercing diapirs are a very important and noticeable feature of this region. The easy erosion of those clays originates from extensive flattened inland areas, very favourable to traditional agriculture practices. Moreover, salt tectonics is also responsible for bringing upwards several dolomitic rafts, which appear to be floating on top of the Dagorda Formation clays, defining isolated crests. On both sides of these flat areas, the rectilinear abrupt slopes mark the diapirs' border faults; therefore, it is possible to see the intense uplift and deformation of the sedimentary layers (with dips up to 70°), usually composed of Upper Jurassic limestones (Montejunto Formation).

Besides piercing diapirs, it is possible to detect the influence of salt tectonics by looking at the intense uplift, deformation and tilting of the Mesozoic sedimentary layers. These situations are associated with the movement of underground salt-pillows, which did not reach the surface but affected the Jurassic/Cretaceous cover, bringing to the surface Middle and even Lower Jurassic carbonate units, such as at *Cesaredas* Plateau or *Montejunto* hill.

Vale da Maceira geosite is a narrow diapiric valley, a flat lowland with steep slopes on both sides (Fig. 8C). This piercing diapir resulted from the pressure of the Jurassic rocks over evaporites and clays formed around 200 million years ago, by strong evaporation of shallow sea waters. These low density rocks have been squeezed to the surface and then eroded, whereas the hard limestones persisted as steep crests. Inside the valley there is a thermal spa and a few kilometres inland an active bottling industry of thermal waters (*Águas do Vimeiro*).

d) Geomorphology—Shaping Our Landscape

The landscape of the OAG territory includes different kinds of geomorphological features, seen on several geosites (Table 4). The overall topography and landscape forms are controlled mainly by the alpine compression and uplift, frequently with a strong influence of salt tectonics, and also of the recent fluvial drainage systems. This is the case for the higher parts of the OAG territory, such as the large Montejunto anticline (666-m height), topographically dominating the eastern border of the OAG area, and also the extended *Cesaredas* plateau (201 m high), on the southern tip of the Caldas da Rainha diapir. Contrasting with these uplifted areas, the exhumed piercing diapirs correspond to topographic depressions, either as flat extensive areas (such as *Bolhos* or *Caldas da Rainha*) or narrow elongated depressions (such as the *Maceira* or *Pena Seca* valleys).

At a local scale, the Jurassic uplifted carbonate units show much evidence of chemical and physical weathering

Table 4 Geosites assigned to the geomorphology theme

Geomorphology

Ref.	Geosite Name	Main Highlight (Main Interests)	Values: Scientific	Values: Educational	Values: Scenic	Values: Ecology	Values: Cultural	Relevance	Accessibiliy: Walking difficulty	Accessibiliy: Reduced Mobility	Accessibiliy: Car	Accessibiliy: Bus	Facilities: Drinking fountain	Facilities: Lavatory	Facilities: Restaurant/Cafe	Facilities: Lodging	Facilities: Car parking	Facilities: Bus parking	Interpretation Panel	Vulnerability	N° of publications
GS6	Pinhôa	Small elevated area with broad landscape views, used for the installation of five traditional windmills.	Medium	High	Very high	Medium	High	Local	Easy	✓	✓	✓	×	×	×	×	✓	×	Planned	Low	0
GS8	Nossa Senhora das Neves	Viewpoint from the Serra de Montejunto (666m high), with Middle Jurassic hard limestones, contrasting with the western and costal lowlands (around 200m high) with Late Jurassic terrigeneous rocks. Medieval abandoned monastery and XVI century chapel.	High	High	Very high	Very high	Very high	Regional	Easy	✓	✓	✓	×	×	×	×	✓	✓	Planned	Medium	3
GS19	Charca das Cesaredas	Small karstic doline on Middle Jurassic limestones, anthropically modified.	Medium	Very high	Medium	Medium	Medium	Local	Easy	✓	✓	✓	×	✓	×	×	✓	✓	Not Planned	Medium	0
GS30	Vale Cornaga	Narrow fluvial valley incised in Upper Jurassic limestones. Today it is seasonal river, with some interesting historical watermills.	Medium	High	Very high	High	High	Local	Medium	×	×	×	×	×	×	×	✓	×	Planned	Medium	1
GS37	Castro de Pragança	Small relief on the Montejunto hillfoot, dominating the western lowland plains, with a longlived prehistoric occupation, form Neoithic to Roman times.	High	High	Very high	High	Very high	Regional	Medium	×	✓	×	×	×	×	×	×	×	Planned	High	2
GS43	Gruta da Feteira	Karstic cave in Upper Jurassic limestones, occupied as a funeral ground, in prehistoric times.	Very high	Medium	Low	Medium	Very high	Local	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	High	0
GS50	Ereira	Panoramic viewpoint to the different surrounding Jurassic and Cretaceous reliefs with distinct tectonic features.	Medium	Medium	Very high	Medium	Low	Local	Easy	×	×	×	×	×	×	×	✓	×	Planned	Medium	0
GS54	Cabo Carvoeiro	Rich karstic features, including the iconic "Nau dos Corvos" (Raven's Ship) and many other zoomorphic forms. Well preserved marine abrasion platform and deposits. Karstic cave (Furninha) with very important archaeological findings. Type locality of *Pentacrinus penichensis* (Loriol, 1890).	Very high	High	Very high	Very high	High	International	Easy	✓	✓	✓	×	×	×	×	✓	✓	Planned for the Current Year	Medium	25
GS58	Castro do Zambujal	Large plateau on Late Jurassic limestones dominating the fluvial valleys, occupied by an important Calcolithic defensive wall ("castro") built-up with local rocks.	Very high	Medium	High	Medium	Very high	Regional	Easy	✓	✓	×	×	✓	×	×	✓	✓	Planned	Medium	3
GS64	Serra do Socorro	Conic flat topped relief, associated with a partially eroded volcanic chimney, related to the Late Cretaceous Lisbon-Mafra Volcanic Complex.	High	High	Very high	High	Very high	Regional	Medium	×	✓	×	×	×	×	×	✓	✓	Planned	Medium	0
GS68	Vale do Rôto	Deep fluvial valley, incised in Upper Jurassic limestones and draining into the Caldas da Rainha diapiric plain. More than 10 large karstic caves are identified, some with very important prehistoric artifacts.	High	Very high	Very high	Medium	Very high	Regional	Medium	×	✓	✓	×	×	×	✓	✓	×	Planned	Medium	4

INFOGRAPHIC MEANING

Very high · High · Medium · Low

International · Regional · Local

Hard · Medium · Easy

Planned · Not Planned · Planned for the Current Year

and erosion, with interesting karstic features. These include well-developed lapiés surfaces and holes, both inland (e.g. *Cesaredas* plateau) and on coastal cliffs (e.g. *Cabo Carvoeiro*, *Peniche*). Geomorphological features such as karstic dolines or sinkholes and water exsurgences, also testify the role of karstic dissolution in these areas. In deeply incised fracture valleys, mid-slope karstic caves have been used by prehistoric communities for a few thousand years since the Neolithic, while some tabular sub-horizontal limestone plateaus dominating incised fluvial lowlands, provided good situations to install fortified Chalcolithic settlements (e.g. *Castro do Zambujal, Torres Vedras).*

Besides these diapir-related morphologies, most of the OAG territory corresponds to a broad, smoothly undulated morphology, with interfluves or plateaus around 120 to 150 m. These areas are intensely occupied by agriculture, with good clayey soils developed on Upper Jurassic continental units mainly used for orchards and vineyards, whereas poorer sandy soils on Cretaceous units are used for eucalyptus and pine tree forestry.

Nossa Senhora das Neves geosite is located near the highest point of *Serra de Montejunto*, from where you can see the whole of the OAG to the sea (Fig. 8D). This mountain, a protected area with important cultural values, is made up of Middle and Upper Jurassic limestones, formed 170 to 150 Ma ago, when there was a tropical sea in this region. These rocks contain fossil ammonites, an extinct animal similar to today's squid, with a rolled shell. About 100 Ma ago, the tectonic movements caused the folding and lifting of these layers, giving rise to this majestic mountain in the shape of a whale's back (Curtis 1999).

e) Geologic Resources—Gifts from Our Land

The thick and complex infill and evolution of the LB generated different geological resources within its sedimentary rocks (Table 5). Salt-related resources have been explored since ancient times, namely the thermal waters in Roman times. Thermal baths, using the salt-rich and warm natural spring waters, are present in several places, and the world's oldest thermal hospital (founded by Queen Leonor in the fifteenth century) still exists at *Caldas da Rainha* (literally "Queens' spas"). At *Vimeiro* (*Torres Vedras*), a nationally well-known thermal drinking water is explored

Table 5 Geosites assigned to the geologic resources theme

Geologic Resources

Ref.	Geosite Name	Main Highlight (Main Interests)	Values: Scientific	Educational	Scenic	Ecology	Cultural	Relevance	Accessibiliy: Walking difficulty	Reduced Mobility	Car	Bus	Facilities: Drinking fountain	Lavatory	Restaurant/Cafe	Lodging	Car parking	Bus parking	Interpretation Panel	Vulnerability	Nº of publications
GS2	Serra d'El Rei	Abandoned limestone quarries, providing an excellent opportunity to observe Lower and Middle Jurassic limestones.	Medium	High	Medium	Low	Medium	Local	Medium	×	×	×	×	×	×	×	×	×	Not Planned	Medium	1
GS5	Vimeiro	Natural thermal water spring associated the nearby piercing diapir (Maceira), with the bottling comercail brand "Águas do Vimeiro".	High	Very high	High	Medium	Very high	Regional	Easy	✓	✓	✓	×	×	✓	×	✓	✓	Planned	Medium	2
GS9	Caldas da Rainha Thermal Complex	A five centuries old thermal hospital is present at this site, using natural thermal waters. Nowadays, it is one of the most important thermal resort (medical spa) in Portugal.	High	Very high	Very high	High	Very high	International	Easy	✓	✓	×	×	✓	✓	✓	✓	×	Planned	Medium	4
GS13	Quinta do Rol	A XIX century estate, where clay-sandy soils are here used for the growth of vineyards, providing unique characteristics to the grapes and its wines.	Medium	Medium	High	Medium	High	Local	Easy	✓	✓	✓	×	✓	×	×	✓	×	Not Planned	Medium	0
GS23	Adega da Lourinhã	Late Jurassic sands and clays provide specific soil conditions which, associated with the local atlantic climate, produce particular grapes used as the primary ingredient for "Aguardente DOC Lourinhã", a local brandy.	Medium	High	Low	Low	Very high	Regional	Easy	×	✓	✓	×	×	✓	×	✓	✓	Planned	Medium	0
GS34	Barranca	A large active quarry of Late Jurassic limestones, explored for gravel and ornamental stone, with interesting fossil content.	Medium	High	Low	Low	Medium	Local	Easy	×	✓	×	×	×	×	×	✓	✓	Not Planned	High	0
GS36	Cucos Thermal Complex	Natural springs of hydrothermal waters, enriched by underground circulation in salt-rich rocks, used for medicinal treatments. Historical XIX century hydrotherapy spa and chalets.	High	High	Very high	High	Very high	Regional	Easy	✓	✓	✓	×	×	×	×	✓	✓	Not Planned	Medium	2
GS38	Real Fábrica do Gelo	A unique XVIII century "Ice Factory", installed in a karstic doline (520m high), produced ice from underground water poored every Winter nights in large tanks, then stored and preserved, providing it to the Lisbon aristocracy during summertime, for over a century.	Medium	Very high	High	Very high	Very high	International	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Planned	Medium	0
GS48	Quinta do Sanguinhal	A XIX century vineyard and cellars, using the clay-sandy soils and the local climatic conditions to produce different kinds of grapes and wines.	Medium	Medium	High	Medium	Very high	Local	Easy	✓	✓	✓	×	✓	×	×	✓	×	Not Planned	Medium	0
GS51	Ventosa	A well-preserved old stone oven, traditionally used to transform the local limestone into lime for traditional construction and painting.	Medium	High	Low	Low	Very high	Local	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	High	0
GS61	Almagreira	Upper Jurassic to Lower Cretaceous stratigraphic transiction. Freshwater spring, very close to the atlantic beach, reaching the surface through a system of diaclases.	High	High	High	High	Medium	Local	Easy	×	✓	✓	×	×	×	×	✓	×	Planned for the Current Year	Medium	9
GS63	Cabaços	Abandoned quarry, with Late Jurassic fractured exhibiting natural extrusion of asphaltic hydrocarbons. This place relates to the historical (20th century) exploration of oil in this region, with many deep wells and oil-shows.	Very high	High	Medium	Low	Medium	Regional	Medium	×	×	×	×	×	×	×	×	×	Not Planned	Medium	6
GS69	Lagoa do Falcão	A large abandoned Late Jurassic clay pit, explored to produce bricks, roof tiles and pottery, now converted into and aquatic leisure centre.	Medium	High	High	Medium	Medium	Local	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Not Planned	Medium	0
GS72	Morraçal da Luz	An important archaeological roman site (I-III century), where the clay was cooked to make amphora to preserve local fish and "export" it through the whole Roman Empire.	High	Medium	Medium	Low	High	Local	Easy	✓	✓	✓	×	×	×	×	✓	×	Not Planned	High	0
GS75	Matacães	A unique exemple of underground salt extraction in this territory, pumping out salt-enriched water (previously injected up to 500 m deep) and then transported by pipeline for industrial and (nowadays) biotech uses.	High	High	High	Medium	High	Regional	Easy	✓	✓	✓	×	×	×	×	✓	✓	Not Planned	Medium	1
GS77	Currais do Mato	Old stone oven used to transform the local Late Jurassic limestone into lime for traditional construction and painting.	Medium	High	Medium	Medium	Very high	Local	Easy	×	✓	×	×	×	×	×	×	×	Not Planned	High	0

INFOGRAPHIC MEANING

- Values: Very high; High; Medium; Low
- Relevance: International; Regional; Local
- Walking difficulty: Hard; Medium; Easy
- Interpretation Panel: Planned; Not Planned; Planned for the Current Year

and commercialised, side-by-side with old thermal baths. The salt itself is also explored from a piercing diapir at *Matacães* (*Torres Vedras*), where water is injected underground, dissolving salt rocks, and then pumped out and sent by a 30-km long pipeline to industrial and biotechnological facilities close to Lisbon.

Jurassic limestones are another important resource, as gravel and rockfill, but also locally as ornamental stone. In the past, there were several small quarries that explored these limestones for small constructions. Nowadays, just a few still remain active. Another large quarry is located at *Serra de Todo o Mundo*, extracting Upper Cretaceous igneous mafic rocks.

Upper Jurassic clays are also an important geological resource, traditionally explored in this region. These clays were, and are, used for the production of tiles and also the very famous *Caldas da Rainha* faience tradition. On a totally different plan, Late Jurassic carbonates and siliciclastics have historically been the main targeted reservoirs for oil and gas in this region, with several deep exploration wells, attaining depths over 3 km, in most cases with significant oil and gas shows (Pimentel and Pena dos Reis 2016).

Rich and productive soils are also a crucial geological resource in this region, providing the base for a prolific agricultural activity. The best soils result from the Upper Jurassic siliciclastic rocks, used for extensive apple and pear orchards, as well as horticultural farms and important vineyards with very specific terroirs.

Finally, another important geological resource in the territory, essential for the survival of all biological communities, is water. Groundwater occurs naturally across the OAG territory, with dozens of natural water springs. Traditionally used for many human activities, these were important places for local communities, serving also as spots for socialisation. Due to the effect of climate change and increasingly drier weather, many of these natural springs are drying out, implying changes in the habits of local populations and also affecting biological communities dependent on them.

Caldas da Rainha Thermal Complex geosite is a thermal spa related to a large piercing diapir, used for therapeutic purposes for more than five centuries (Fig. 8E). These waters result from the infiltration of rainwater in the limestone rocks of *Serras d'Aire e Candeeiros*, 15 km to the East. As water infiltrates underground, it reacts with the salt-rich rocks of the Dagorda formation and gets enriched with certain elements, getting warmer as well. Due to warming, it becomes less dense and ascends to the surface, in a long route that takes more than 2000 years. According to legend, in 1484, Queen Leonor, on her way to *Batalha*, saw some people bathing in muddy waters, and they told her that those waters had healing properties. After trying it herself, the Queen ordered the construction of the thermal hospital. Founded in 1485, it is the oldest still operational thermal hospital in the world.

f) Coastal Dynamics—Shaped by the Sea

The ocean, rivers and all their dynamic processes are a very important aspect of the OAG territory, since the Atlantic Ocean limits a large part of its West boundary. These processes are well documented on coastal geosites (Table 6). The present-day coastline marks the dynamic limit between the continental areas and the millennial action of the sea-waves and tides, with all its energy and erosion or deposition capacity. The coastline of the OAG territory includes two types of shores: (i) high cliffs, up to 80 m, with active erosion, falling blocks, etc. and (ii) sandy beaches, which may be either small pocket beaches (related to the main fluvial outlets) or long beaches with sandy dunes. These coastal forms result from a long-lived evolution, mostly over the last 20,000 years, which is also well documented on the main rivers' valleys.

At the last glacial event, the sea-level was over 100 m below the present-day hydrographic zero. The coastline was, at that time, some tenths of kilometres to the West, and a good part of the continental platform was exposed. As a consequence, the main rivers developed deeply incised valleys, and river mouths were far away to the West, as testified by several submarine valleys. Since then, the sea-level rose until its actual height, attained about 5000 years ago, thus promoting the post-glacial alluvial infill of those

Table 6 Geosites assigned to the coastal dynamics theme.

Coastal Dynamics

Ref.	Geosite Name	Main Highlight (Main Interests)	Values: Scientific	Educational	Scenic	Ecology	Cultural	Relevance	Accessibiliy: Walking difficulty	Reduced Mobility	Car	Bus	Facilities: Drinking fountain	Lavatory	Restaurant/Cafe	Lodging	Car parking	Bus parking	Interpretation Panel	Vulnerability	Nº of publications
GS10	Paúl da Tornada	Swampy remains of the ancient broad and navigable river Tornada, gradually silted up for the last hundreds years. These lowlands correspond to the "typhonic valley" of the Caldas da Raína diapir.	High	Very high	Very high	Very high	Medium	Regional	Easy	×	✓	✓	×	✓	✓	×	✓	×	Planned	High	3
GS14	Salir do Porto	The highest dunar system in Portugal (up to 50m), resulting from strong wind-transport of loose beach sands against a steep limestone diapiric crest. Laggonal sandy beach and marshes.	High	High	High	High	Medium	Local	Medium	✓	✓	✓	×	✓	✓	✓	✓	✓	Planned	Medium	0
GS21	Praia da Areia Branca	Large sandy beach at the Grande River mouth, gradually silted up, with a a well-developed dunar system, including moving and fixed dunes, currently under human stress and sea level rise influence.	Medium	Medium	High	Very high	Medium	Local	Easy	✓	✓	✓	×	✓	✓	✓	✓	✓	Planned for the Current Year	High	2
GS25	Santa Rita	Old convent destroyed by the tsunami associated to the big 1755 Lisbon earthquake. The coastall geomorphology, with rocky cliffs defininf a narrow NW-SE entrance, channelized and amplified the tsunami waves into this valley, where they attained a hight of 16m, documented by historical descriptions.	High	High	Medium	High	Very high	Regional	Easy	✓	✓	✓	×	✓	✓	×	✓	✓	Planned for the Current Year	High	16
GS28	Lagoa de Óbidos	Lagoonal system with shallow waters and natural tendency to silting, due to deforestation and sea-level rise. Iimportant habitat for aquatic organisms (fishes and bivalves) and birds. A large dune system, periodically opened to renew waters, separates it from the open sea.	Very high	Very high	Very high	Very high	Medium	Regional	Easy	✓	✓	✓	×	✓	✓	✓	✓	✓	Planned	Very high	8
GS33	Atouguia da Baleia	Acting as an important fishing port in the Middle Ages, the estuaries of several waterstreams naturally siltedup, connecting the sofar island of Peniche (and Baleal) to the mainland, this promoting the shifting of all the fishing-related activities to this new location.	Very high	Very high	High	Very high	High	Regional	Easy	✓	✓	✓	×	✓	✓	✓	✓	×	Planned	High	3
GS40	Lourinhã	Floodplain of the Grande river, navigable untill a few centuries ago, now silted up due to sea-level rise and presenting flooding risk for local population.	Medium	High	High	Low	High	Local	Easy	✓	✓	×	×	✓	×	×	✓	×	Planned for the Current Year	Low	0
GS53	Nossa Senhora da Luz	Strong costal erosion affecting Lower Jurassic cliffs and destroying the historical fort (XVII century), close to the littoral crest.	Low	Medium	Very high	Very high	High	Local	Easy	×	✓	×	×	×	×	×	✓	×	Not Planned	Medium	0

INFOGRAPHIC MEANING

Very high · High · Medium · Low — International · Regional · Local — Hard · Medium · Easy — Planned · Not Planned · Planned for the Current Year valleys. However, this was a very slow process, and many present-day coastal lowlands were, up until a few centuries ago, still open to the coastal water table, becoming gradually filled by alluvial sediments (e.g. *Óbidos* lagoon). A good example is the commercial, fishing and whale port of *Atouguia da Baleia* ("Baleia" meaning "Whale"), which was abandoned in the eighteenth century and moved to *Peniche*. This happened also because a developing tombolo connected, by then, the previous island of *Peniche* to the mainland (Azevêdo and Nunes 2010).

In land, the main rivers also record those sea-level changes and valley silting. Just a few centuries ago, fishing, navigation and commerce were possible a few kilometres upstream, reaching the towns of *Lourinhã* or *Torres Vedras*, for example. Present-day river mouths are almost filled up; present flat areas have meandering channels and frequently give way to large sandy beaches. This may be observed at *Praia Azul*, *Praia da Areia Branca* or *Praia de Santa Rita,* where sand dunes and even swampy depressions developed behind the active present-day foreshore.

Therefore, this territory is an excellent place to show how the sea-level rose, due to climate change, and how it shaped and changed the landscape. This variation will have impacts on the local communities, which will have to adapt, in short time-scales.

Salir do Porto geosite is located at the *Tornada* river mouth, where the biggest dune in Portugal was formed, about 200 m long and 50 m high (Fig. 8F). In the twelfth century, there was an important maritime port in *Alfeizerão*, but gradually, due to wood exploitation and the use of the fields for agriculture, *Alfeizerão* lagoon began to silt up. Due to this geologic process, by the beginning of the sixteenth century, navigation became impossible, and it was necessary to move the maritime port to *Salir do Porto*, over 3 km away. A similar situation occurred in other mediaeval ports in the region, such as *Atouguia da Baleia*, where the port and all its activity have been shifted to *Peniche*, 4 km away.

Geosites Diversity

As mentioned, the OAG geosites were assigned to six themes, according to their most relevant geodiversity element. From a brief visual inspection of Tables 1, 2, 3, 4, 5 and 6, it stands out that the number of geosites assigned to each theme differs. The theme with more geosites is, by far, palaeontology (28), while the second one is geological resources (16), followed by geomorphology (11), geological resources (9), coastal dynamics (8) and salt tectonics (8) (Fig. 9).

The geosites identified in the OAG are important to the scientific community but also, many of them, to the local communities. Therefore, the geosites have been assessed

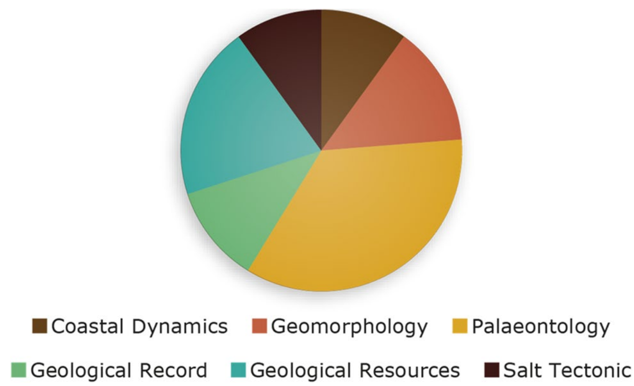

Fig. 9 Percentage representation of the geosites by thematic designation

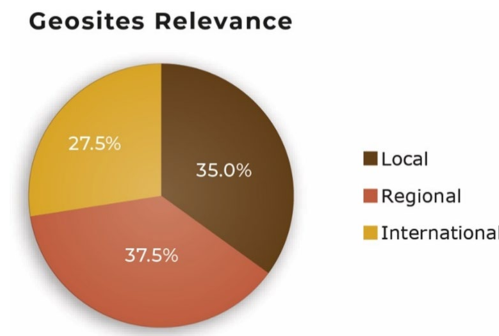

Fig. 10 Percentage representation of the geosites, according to their local, regional or international relevance

based on their scientific value, but also considering its geoeducational and geotouristic potential. Based on these three values, the importance of each geosite has been defined with simple qualitative scales. We used these results to discuss internally, as well as with the scientific and institutional partners, the potential and strategies for the different geosites.

From the 80 geosites identified in the OAG territory (Tables 1, 2, 3, 4, 5 and 6), 35% (28 geosites) were considered to bear geodiversity elements with local relevance, 37.5% (30 geosites) with regional relevance and 27.5% (22 geosites) with international relevance (Fig. 10).

From the geosites with international relevance, one belongs to the geological record theme (GS44—the Torcian GSSP), 18 to the palaeontology theme, two to the geologic resources theme, and one to the geomorphology theme. In the palaeontology theme, it is important to mention that 11 geosites represent places where dinosaur holotypes were discovered (GS1; GS3; GS15; GS29; GS32; GS39; GS55; GS57; GS60; GS62; GS70), three are sites where angiosperm remains have been found (GS18; GS35; GS47) and two correspond to the places where old dinosaur nests with eggs and embryos were discovered (GS20; GS74). All the 22 international relevant geosites have been checked and approved by the IUGS, supporting the application process to become a UNESCO Global Geopark.

Geoconservation

Current or Potential Vulnerabilities

The geosites identified in the OAG territory were also assessed according to the vulnerability of the existing geoheritage. In this territory, the current or potential threats to geosites can be divided into two main groups: natural and anthropogenic. For the OAG, the natural pressure on geosites encompasses natural erosion caused by weather factors (wind and rain) and coastal erosion. As natural factors, their impact is often hard to mitigate. The predictable impacts of climate changes over the geosites were also considered, namely, the impact of sea level and global temperature rises.

For palaeontological heritage, it is often only after ex situ preparation and study that its scientific value is properly recognised. This type of heritage is therefore safeguarded in museum collections, to be available for the community (both visitors and scientists), and the original excavation sites are therefore not so critical anymore.

On the other hand, the anthropogenic impact on the OAG geosites includes threats related to agriculture activities, human constructions, indiscriminate fossil collection and tourism. For the first two potential impacts, these activities are regulated by the municipalities master plan (municipal plan that regulates the land uses) and also by national laws. The other two potential impacts have been permanently accessed by the OAG team. Strategies have been implemented to disperse visitors through the territory, and geosites monitoring projects are being set in place, such as the geosites local ambassadors programme.

Tables 1, 2, 3, 4, 5 and 6 indicate the level of pressure for each geosite. Only two geosites were considered as very vulnerable, 20 geosites with moderate or low vulnerability and 58 geosites with minor vulnerability. Such analysis is important for the establishment of protection measures for the endangered heritage. For example, the conservation status evaluation of the dinosaur footprints of *Salir* (GS12 in Table 2) was classified as "high vulnerability", with potential for the disappearance of its heritage in the next few years. This important geosite got the highest vulnerability classification, leading to the establishment of a multidisciplinary team dedicated to the development of a geoconservation plan for that site.

Protection Status

From the 80 geosites present in the OAG, 34 are located in classified or protected areas. This classification confers legal protection to these geosites, in terms of territorial management, besides being under the specific norms of sustainable use of these areas. Table 7 summarises the protective mechanisms present in the territory, as well as the geosites with such classification. All of these areas represent

Table 7 Protective mechanisms in the Oeste Aspiring Geopark territory and geosites located within classified areas (AGEO 2022; Dias et al 2022)

Protective Mechanism	Name	Geosites	Legal Diploma / Regulatory Mechanism / Conservation status
Internationally Designated Area	1. Berlengas-Peniche Biosphere Reserve (Transition Zone)	GS33 (partially), GS54, GS24, GS44, GS72	UNESCO Program "Man and the Biosphere - MAB" / Portuguese Netork of Biosphere Reserves
Nature 2000	2. Peniche-Santa Cruz Special Areas of Conservation	GS73 (partially), GS33 (partially), GS54, GS24, GS44, GS53, GS21, GS25, GS1, GS20, GS62, GS29, GS3, GS55, GS74, GS70, GS60, GS32, GS15, GS66, GS46, GS61, GS52, GS49	Natura 2000 Network Directive 2009/147 / EC / Directive 92/43 / EEC
	3. Serra de Montejunto Special Areas of Conservation	GS8, GS37, GS38	
	4. Sintra-Cascais Special Areas of Conservation	GS39 (partially), GS65, GS7	
Protected Area	5. Serra de Montejunto Regional Protected Landscape	GS8	Regulatory Decree nº 11 July 22, 1999
	6. Serras do Socorro e Archeira Local Protected Landscape	GS64, GS67	Resolution of the Torres Vedras Municipal Assembly of May 4, 2012
	7. Paul da Tornada Local Nature Reserve	GS10	Resolution of the Municipal Assembly of Caldas da Rainha

around 7% of the OAG territory, thus contributing to the conservation of natural heritage (Dias et al. 2022).

The OAG management team is a partner of the management entities of these protected areas, having developed in recent years about 20 activities in partnership, as a way of promoting and enhancing the value of geosites and their respective areas of influence.

Other geosites do not have clear legal protection, under national laws. Therefore, the OAG management team is actively working with the local municipalities to create local protected areas that can effectively protect those sites, such as the "Jurassic Coastal Cliffs Local Natural Monument", for its important palaeontological record, and the classification of the "Cesaredas Plateau Local Protected Area", for its special karstic landscape and biodiversity. Meanwhile, the OAG municipalities have signed a "Letter of Commitment for the Defence of Geological Heritage" demonstrating, with this public act, their willingness to preserve and protect this heritage, and establishing the premises for future interventions and geoconservation activities.

Conclusions

The initial definition of geosites for the OAG was based on the knowledge and experience of its technical team, and later on discussed with different partners and entities. Besides the scientific value of the sites, other aspects were also considered, such as its potential to develop educational and outreach activities. Although some quantitative assessments have been previously proposed and successfully applied in different places around the world, a simpler qualitative assessment has been applied to this territory, looking at it mostly as a future geopark.

This approach took into account the holistic UNESCO Global Geopark concept of protection, education and sustainable development, through its three main pillars—geoconservation, geoeducation and geotourism. Both intrinsic and extrinsic values have been considered, looking at the present-day value of the geosites, including scientific publications, the existing biodiversity and the presence of cultural features, but also at its potential to be used in different geopark activities, namely scientific research, educational activities and geotouristic visits or tours.

The Jurassic rocks predominate at the OAG territory, containing most of the internationally relevant geosites, including its two main highlights: (i) the very rich diversity and abundance of Late Jurassic dinosaur remains and (ii) the stratigraphic GSSP for the Toarcian stage. Moreover, the geodiversity of the territory led us to broaden the scope broadening of the geosites list, as well as its organisation into six different themes.

Each theme leads us a to specific story about the evolution of the territory, since the Mesozoic opening of the North Atlantic to the Cenozoic alpine inversion and Quaternary landscape evolution: (i) "geological record—the story of our land"; (ii) "palaeontology—who lived here before us"; (iii) "salt and tectonics—uprising rocks and crests"; (iv) "geomorpholgy—shaping our landscape"; (v) "geological resources—gifts from our land" and (vi) "Coastal dynamics—shaped by the sea".

Combining the existing qualitative assessment with the regular visit by our staff and educational and touristic activities, helps the definition of a realistic geoconservation strategy, prioritising investments and funding application.

Acknowledgements This paper is the result of a collaborative work developed by the AGEO team, namely its President (João Serra) and Technical Staff (the authors and Rute Torres, Inês Cabau, Inês Lucas, Ana Rita Pereira, Inês Marques and Aline Dias). We also thank to the two anonymous reviewers and the Editor-in-Chief for the critical revision of the paper.

Author Contribution All authors made substantial contributions to the acquisition and analysis of data, as well as to the conception and writing of the work.

Funding Open access funding provided by FCT|FCCN (b-on). Financial resources for this work have been provided by AGEO (Associação Geoparque Oeste).

Data Availability This manuscript has no associated data, other than those presented on the inserted tables.

Declarations

Conflict of Interest The authors declare no competing interests.

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