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UPPER JURASSIC OUTCROPS ALONG THE CALDAS DA RAINHA DIAPIR, WEST CENTRAL PORTUGAL: A REGIONAL GEOHERITAGE OVERVIEW

JORGE DINIS' & CRISTINA BERNARDES-

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Abstract. The Mesozoic Portuguese geological heritage is very rich and varied, a legacy of the position in the western margin of Iberia and its relationship with its evolution of the North Atlantic, with an interesting tectonic history since the Late Triassic. Regarding the Upperjurassic several connections can he established between the tectonics and the stratigraphic record in the area surrounding the Caldas da Rainha structure: the basement and salt pillow control on deposition; the beginning of a diapine and magmatic cycle associated to the onset of sea-floor; the exhumation of both Jurassic deposits and the core of their controlling diapirs. The nature of the outcrops and richness in sedimentary environments, related with the different phases of rifting, is a remarkable case for extensional basin studies.

Geological sites can be of regional, national or international importance due to scientific, educational, economical, social or historical reasons. The present proposal can be considered as a model for the establishment of tourist/educational routes with a strong component in communication on Karth Sciences, integrating social and historical aspects at a regional level. The recognition of those sites as geoheritage may contribute to a more sustainable management, in particular because it allows the achievement of a critical dimension for the investment in human resources and marketing. In Portugal, recent legal evolution can be considered promising. Nevertheless, since implementation of the concept of protected site depends on the approval of detailed management programs, there are frequent delays, misinterpretations and disrespect for legislation. The strategy to he adopted in project with economic and social interest must integrate conservation aspects, scientific studies and science communication.

Riassutilo. Il patrimonio geologico mesozoico del Portogallo e molto ricco e vario, conscguenza della sua posizione sul margine occidental di Iberia e dei suoi rapporii con l'evoluzione del Nord Atlantico, con un'interessante storia tettonica sin dal Triassico supcriore. Riguardo al Giurassico superiore, si possono stabilire moke connessioni fra la tettonica e la documentazione stratigrafica ncll'area che circonda la struttura di Caldas da Rainha: il controllo del basamento e dei pillow salini sulla deposizione; l'inizio di un ciclo diapirico e magmatico associato alia messa in posto del fondo marino ed all'esumazione sia di deposit! giurassici che del nucleo dei diapiri che li controllavano. La natura degli affioramenti e la ricchezza di ambienti sedimentari, legati alle differenti fasi di rifting, e un caso notevole per gli studi sui bacilli esiensionali.

I siti geologic! possono essere d'importanza regionale, nazionale od internazionale, a seconda di motivazioni scientifiche, didattiche, economiche, social! o storiche. La presente proposta puo essere considerata un modello per 1'istituzione di itinerari turistici/didattici con una forte componente di comunicazione sulle Scienza della Terra, che integra aspetti sociali e storici a livello regionale. Il riconoscimento di quei siti come geopatrimonio puo contribuire ad una gestionc piii sostenibile, in particolare perche permette il raggiungimento di una dimensione critica per l'investimento in risorse umane e marketing. In Portogallo, la recentc evoluzione legislativa puo essere considerata promettente. Ciononditneno, visto che l'applicazione del concetto di sito protetto dipende dall'approvazione di dettagliati programmi di gestione, ci sono frequenti ritardi, fraintendimenti e mancato rispetto della legislazione. La strategia da adottare deve integrare conservazione, studi scicntifici e comunicazione scicntifica in progetti d'interesse economico e sociale.

Introduction

Why preserve and promote?

Most of the issues of the United Nations World Summit on Sustainable Development agenda (Johannesburg, summer 2002) are related with Earth Sciences/ Geology, such as depletion of fresh-water reserves, (ab)use of fossil energy sources, land use for food security, ecological degradation and habitat loss, and global (human) health. A major role of Earth Sciences and, ultimately, of Earth scientists is to promote a healthy and more intelligent use of resources extracted from our live

1 Earth Sciences Department/Geosciences Centre, University of Coimbra, 3000-272 Coimbra, (Portugal). E-mail: jdinis@dct.uc.pt
2 Geoscienccs Department, University of Aveiro, 3810-193 Aveiro (Portugal). E-mail: cbernardes@geo.ua.pt

support system (Cook 1998), as well as understand the natural processes that erected and shaped the earth's surface in the past and will continue to do so in the future, but considering also the increasing perturbation by human activity.

Therefore, it must be recognised that rocks and fossils are an important part of our natural heritage. Geodiversity is the whole range of Earth natural past and present features and processes: geological, geomorphologic and soil features, assemblages, systems and processes. Geoheritage refers to those elements of the geodiversity we want to keep on account of their natural significance. In a broad sense, any site suitable for illustrating a significant aspect of geology is part of our geoheritage.

To the achievement of the aforementioned goals, it is essential the preservation of entities that act as references, paradigms, examples (either as exceptions or rules in nature) and, last but not the least, as persuasive links between mankind and environment. In particular, geosites are outstanding earth features, or key elements of our geoheritage, that worth identification, protection, management and interpretation to provide information for the science and for the public. Different categories can be established, according the international to local, scientific and educational significance and, thus, it is quite probable that a given region possesses a particular geoheritage.

It must be stressed that the public understanding of science can change the general practices of the society, through the change of attitude of each individual, but they will only become effective in a wide scale if exerted in the promotion of the above-mentioned attitudes, pressing authorities and politicians in the context of democratic structures.

The geoheritage of a region can be better preserved and promoted if included in a network of sites of several scales and/or importance with a connecting logic, an approach similar to the "UNESCO Geoparks" initiative (Eder 1999). The ProGEO (The European Association for the Conservation of Geological Heritage) objectives also have implicit such approach.

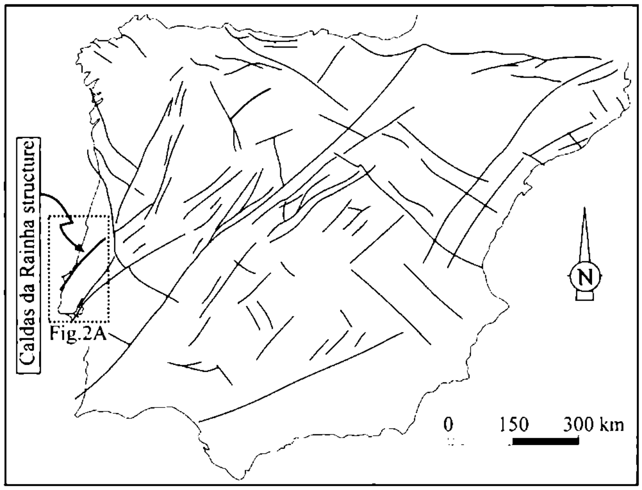


Fig. 1 - Simplified scheme of late Hercynian strike-slip faults network (modified after Capote 1983), with location of the Caldas in Iberia da Rainha structure and Fig. 2A.

Society and Law

As no specific law for geological values exists in Portugal, the general law on Natural Conservation must support geoconservation. However, this legal instrument designed for Natural Heritage in a broad sense is clearly focused on the Biological Heritage (Henriques, this volume). Even so, efforts from the scientific and academic community has achieved the protection of several geosites of national relevance as Natural Monuments, all of them corresponding to small areas including dinosaur tracksites of Jurassic and Cretaceous age. When geosites can be considered of regional relevance, due to its important public use, cases of success have been also developed under municipal laws or related to museums. Some sites or institutions have also created schedules of educational activities related to geoheritage.

The use of a strictly scientific logic should be per se enough to convince policy makers about the convenience of protection and study of main geological sites. A related question is the Public policy for promoting popular understanding of science. However, probably all scientists trying to promote Conservation in nature have experienced some kind of resistance which is not exclusive to geological matters. In the particular case of Portugal, recent legal evolution might be considered very promising, although the reality shows a darker picture. In fact, even the so-called "civil society" starts to be aware of delays, misinterpretations and disrespect of legislation. For instance, a reference newspaper in Portugal ("O Público", July 12, 2002) has recently presented a large report describing the legal void in which ten natural heritage areas fall: the implementation of the whole concept of protected site depends on the approval until a legal deadline, already expired, of detailed management programs.

In such circumstances, the main concern must be to include conservation, scientific studies and communication in science in projects with economic and social interest – a sustainable project to sustainable development. The first step is a preliminary inventory of sites with geological relevance, emphasising the relation between history, ethnological particularities, landscape and geology. The aim of this paper is to present a preliminary proposal for the establishment of tourist/educational routes with a special attention on communication in Earth Sciences, integrating local aspects at a regional level. Even if the puzzling and controversial nature of (this) science is also a value to transmit, the public exposure of scientific questions should avoid, for clearness, hermetic discussions and present the knowledge that is more up-to-date, consensual and filtered by the specific scientific community.

Regional Geology

The Caldas da Rainha structure: origin and functioning

We label as Caldas da Rainha structure a main fault (from Pombal to Santa Cruz), presumably a late Hercynian strike-slip (Fig. 1). Throughout most of its surface representation it has a clear morphological effect, mainly due to associated diapiric movements affecting the Meso-Cenozoic cover. It is consensual that the major faults and sutures of the Hercynian basement (e.g. Capote 1983) were reactivated by the Mesozoic Atlantic rifting in the western margin of Iberia (Wilson et al. 1989), whose central part constitutes the Lusitanian Basin. Within this framework, a set of NNE to NE major faults acts as a pervasive tectonic control in the evolution of the basin. The halokinetic structures were developed where normal reactivated faults allowed the deposition of thick Upper Triassic/Lower Jurassic evaporites and marls (Dagorda Formation), including the so-called Leiria-Parceiros, Caldas da Rainha, Bolhos, Vimeiro and Santa Cruz diapirs (Fig. 2). As a typical case of the tectonic style and development of the basin, the Caldas da Rainha structure functioned essentially during the Late Jurassic/Early Cretaceous rifting phase and during the Late Miocene Betic transpression. For the purposes of the present paper, several relations can be established between the structure and the Upper Jurassic, namely: i) the basement block and salt pillow control on deposition (Oxfordian to Berriasian); ii) the beginning of a diapiric and magmatic cycle related to the on-set of sea-floor; and iii) the later exhumation of both Upper Jurassic deposits and the core of their controlling diapirs.

Late Jurassic Rifting (pre, syn, and post)

During the Late Jurassic rifting phase the Lusitanian Basin was re-organized in sub-basins (Wilson et al. 1989; Canérot et al. 1995; Pena dos Reis et al. 1996; Ravnås et al. 1997; Rasmussen et al. 1998) by reactivation of several faults (Fig. 2); the Caldas da Rainha fault separated the blocks of Bombarral (east) and Peniche, both tilted towards the east (Fig. 3). Extensional tectonics and long-term sea level rise led to onlapping deposition of middle to upper Oxfordian over Callovian. The middle Oxfordian is characterised by lacustrine and marginal marine carbonates (Stage I in Fig. 4). Fully marine carbonate deposition occurred in the late Oxfordian, during which apparent subsidence rates increased steeply, and records the extensional climax; a sudden influx of siliciclastics sediments at the end of the Oxfordian was accompanied by a further increase

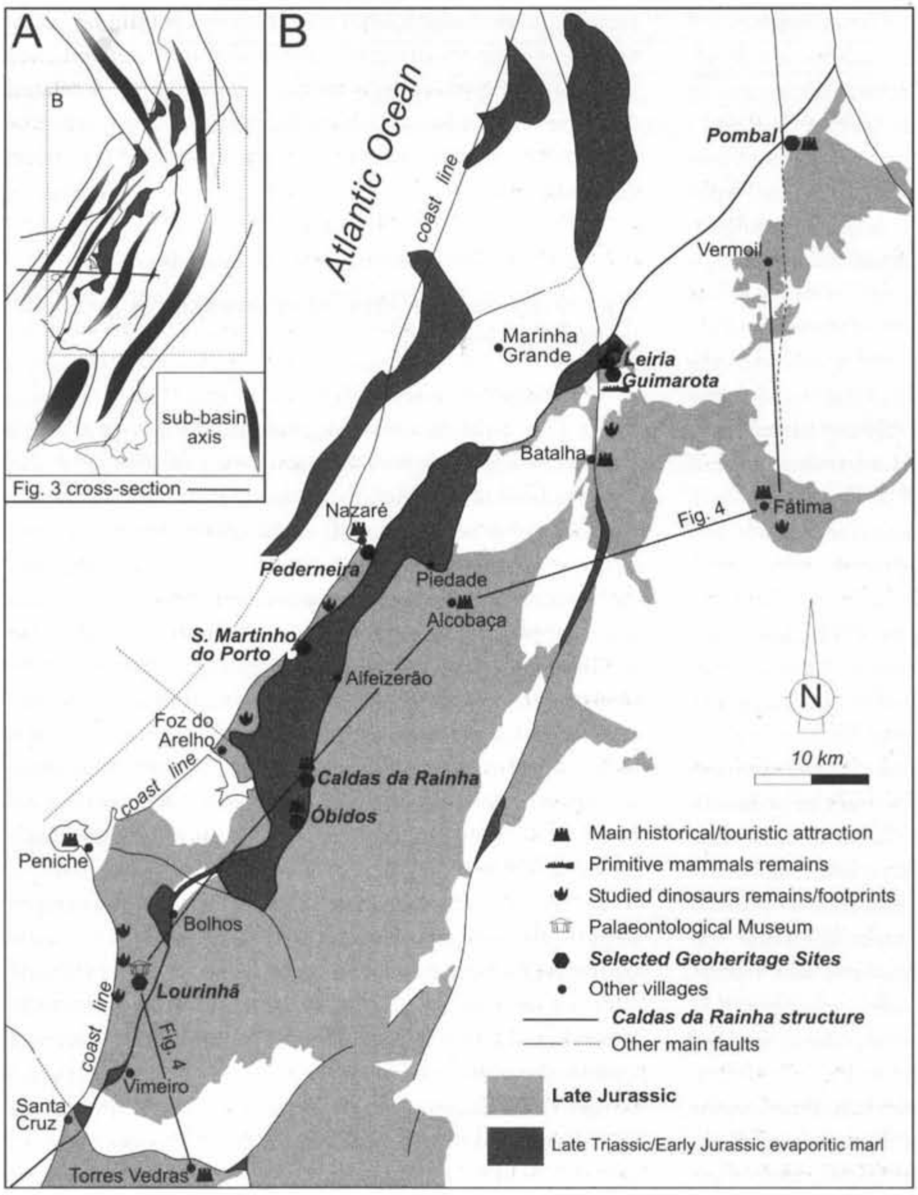


Fig. 2 - A - Location of the main Lusitanian Basin sub-basins and respective axis (not necessarily the depocenter). B - Upper Jurassic outcrops, main faults and diapirs in Central Portugal, around the Caldas da Rainha structure; selected geoheritage sites and settlements positioned; location of Figs. 3 and 4.

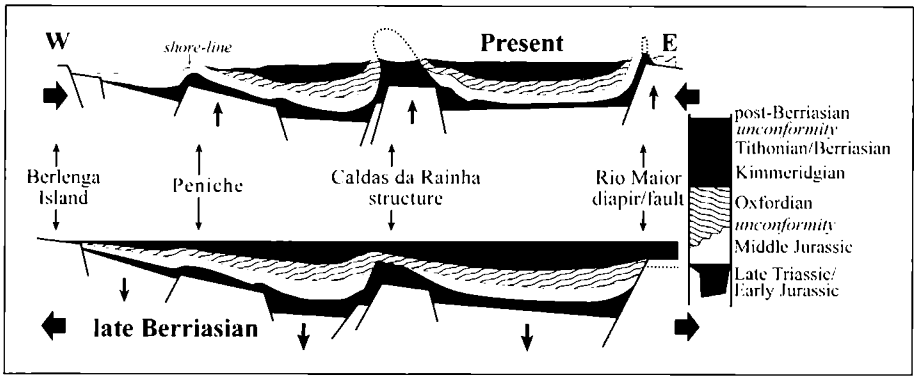


Fig. 3 - Schematic cross-sections of several sub-basins of the central sector of the Lusitanian Basin (located in Fig. 2; modified after Canérot et al. 1995). Oxfordian to Berriasian syn to immediate post-rifting infill was controlled by fault generated subsidence and salt pillow development. The present situation reflects the late Miocene inversion that led to folding Upper Triassic/Lower Jurassic evaporitic marls that acted as a detachment level in an essentially thin-skinned tectonic process; the folding was concentrated over basement horsts due to its interference with lateral salt movements.

of the subsidence and creation of salt pillows over several main faults. This effect created several sub-basins developed as half-graben basins, salt-withdrawal structures or between halokinetic structures. In the Caldas da Rainha area the salt pillow was growing at this time and had a major effect on facies distribution, separating different depositional environments. This event is recorded by marginal siliciclastic deposits of deltaic and marsh environments, and mixed marginal to marine carbonates in depocentric areas, corresponding to the Montejunto Formation.

The Kimmeridgian deposits correspond to the syn and immediate post-rift basin fill. High subsidence rates and the complex distribution pattern of lower Kimmeridgian deposits indicate an important transtensional rifting phase (Wilson et al. 1989; Stage II in Fig. 4). In the considered region (Fig. 2), the fine sandstones and siltstones with subsidiary coarse sandstones represent a braided delta system prograding towards the east, affected by minor transgressions (Bernardes et al. 1991). Those deposits comprise the Alcobaça formation and are covered by marginal to shallow marine carbonates (Pl. 1, fig. D), equivalent in other zones to the Amaral beds.

From the Late Kimmeridgian onwards the environmental pattern was simplified, as shown in the sedimentary record (Stage III in Fig. 4) by the upward and southward gradation to fluviatile siliciclastics with subsidiary deltaic clastics and marginal marine shales of the Lourinhã Formation (upper Kimmeridgian to upper Berriasian). It records short ang long-term transgressions, but the regressive trend of the stratigraphic record is attributed to a decreasing thermal subsidence and long-term sea level fall (Pena dos Reis et al. 2000).

Several gabbroic injections in the considered region belong to the late Tithonian to early Hauterivian magmatic transitional cycle (145±2 to 133±3 Ma; Ferreira & Macedo 1983), and are interpreted as resulting from both the mantellic melting due to the slowdown of the Late Jurassic rifting phase (Martins 1991) and the marginal doming created by the break-up of the western margin of Iberia (Dinis & Rey 2001). Later, the same structure acted as an inverse fault under the Cenozoic NNW-SSE Betic compression, which reached a maximum by the Late Miocene. The crest of the basement block interacted with the mobile Upper Triassic/Lower Jurassic evaporites, marls and mudstones that acted as a detachment level and folded the cover rocks (Fig. 4). The erosion of the resulting elongated diapir created a valley with narrow connections to the sea in which, until four centuries ago, several fishing harbours existed, some of them with an important role in the Portuguese Discoveries saga.

Preliminary and non-exhaustive inventory of geological interesting sites.

Selection criteria

The conservation of geological sites is often a choice taking between different uses of the land and the availability and use of limited public financial resources, in a reasoning of costs versus benefits. Such options are problems of valuing nature, something very difficult to quantify and dependent on philosophic attitudes of people and organisations (Goulder & Kennedy 2000). Therefore, in a society keeping an anthropocentric view of nature and with short-term economic logics, it is useful, to justify environmental conservation, to invoke some categories of intrinsic, scientific, cultural and recreational values, in order to "capture the active support of the human spirit" (Goulder & Kennedy 2000, p. 493).

Intrinsic value refers to the importance and uniqueness that a component of nature has by itself. It does not concern the human use value, although it is a useful concept for man in developing an ethics for management of natural landforms or ecosystems and provides a safeguard against manipulation of environmental meanings (Nordstrom 1993). The concept can play an important role in environmental debate and carry weight in pragmatic decisions in planning actions.

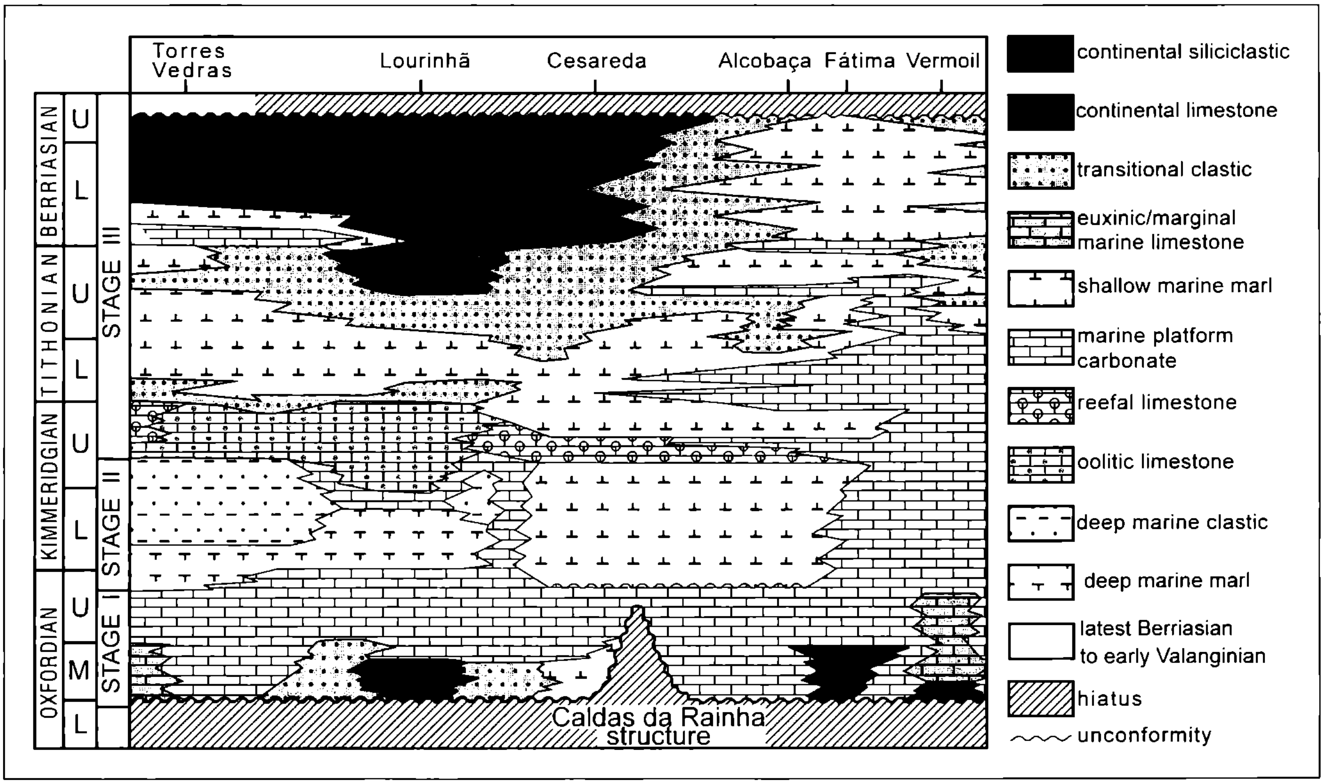


Fig. 4 - Chronostratigraphic distribution of Upper Jurassic facies associations in the region of the Caldas da Rainha structure; basin evolution stages indicated (location of selected sections in Fig. 2; modified after Pena dos Reis et al. 1996).

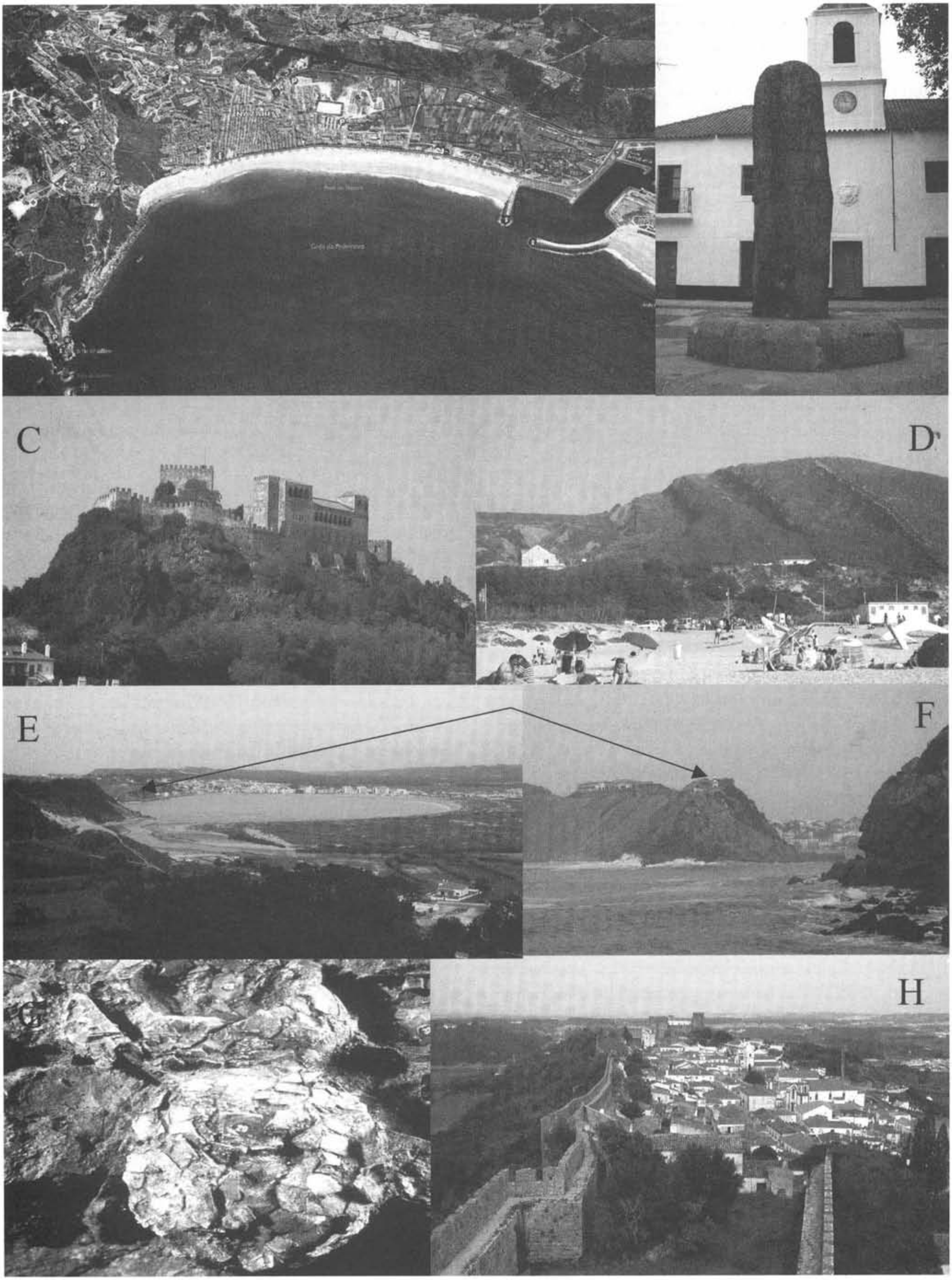
For purely geological scientific purposes, considering that the access to materials is crucial for the advancement of the science, the region (Fig. 2) is very interesting for basin analysis. This is mainly due to the favourable outcrop of deposits and their relationships with the different phases of tectonic evolution. Mesozoic rocks of this area hold a large variety in sedimentary environments, displaying large spectra from marine to continental deposits. It also includes several stratotypes of lithostratigraphic units. It is often put forward the argument that once sampled and measured, the outcrop is no longer needed, but the science is continually developing. Insight into geological materials and processes provided by the application of new techniques, methods and approaches is greatly increased if the access to the original exposures is granted. Cycles of re-discovery and re-assessment can occur if the preservation of the geological sites such as Lourinhã and Guimarota areas, important at world level, is possible. These are also a part of our species heritage, where the origins are recorded (Martini & Pagès 1994).

Science is a cultural exercise too, and the strong links between geological aspects and the development of the science raises sites reputed as noteworthy in the history of the geology to a status of cultural importance. Geological sites include features with a long cultural significance. Several sites were selected because their location typifies a particular geological aspect (namely the geometry of a diapiric fault structure, including the peripheral uplift, deep-seated hot springs and igneous injections) but also by their historical richness. Historically, such sites comprise a history of human use due to their geological context. This can be either for recreative purposes like the Caldas da Rainha Spa or by their economic importance such as the Guimarota coalmine. Remains of fishing and commercial activities, in the areas of Óbidos, Pederneira and S. Martinho do Porto, are witnesses of the past economic and social development of the region, closely linked to the geomorphology.

Regional history

In the geological literature of the western central Portugal, the valleys corresponding to the eroded cores of diapir anticlines are known as "Vallées typhoniques" (Choffat 1882), from Typhoeus, a serpent-like monster whose eyes shot forth flames, son of Gaea – the Earth, and Tartarus - the lowest abyss beneath the Earth surface where all waters originate; defeated by Zeus was buried beneath Mount Aetna, where he still expels fire. The western uplifted border of the Caldas da Rainha diapir between Nazaré and Foz do Arelho (Fig. 2), mainly Upper Jurassic outcrops, acted during the Holocene as a wall separating the open ocean from the inundated valley, a very shallow nearshore marine embayment or lagoon.

Narration by the historian Plinius (I Century) of the Roman conquest of Óbidos throughout a naval landing indicates that the present valley was at that time a wide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lagoon. Following the conquest of the region by the first King of Portugal (Afonso Henriques) from the Muslims, a large Cistercian Abbey was established in Alcobaça in 1153 (currently a UNESCO Cultural World Heritage) owning vast domains of territory. Agriculture replaced large areas of forest, and the consequent erosion led to the silting up of the lagoon. The black plague (pest), particularly in 1348, delayed this process, but prosperity was high in the region from mid XIV to mid XV centuries, a period of accelerated infill. In this century, the commercial harbours were located up to 6 km inland in Alfeizerão, Valado, Arelho, etc., locations with famous salt and naval industries.

The region was a frontier between the northern Christian kingdoms (initially the Kingdom of León and later the Kingdom of Portugal) and the Muslim kingdoms during several centuries (X to XIII). This is the reason why several castles were built, restored or improved during that period, including a settlement by the knights of the Temple Order (the Templars). The successive feudal and royal succession conflicts, as well as the successive wars with Castille and Spain in later times justified its maintenance.

Geoheritage sites

Guimarota coalmine - "... the most important fossil locality in the world for Late Jurassic mammals and other small vertebrates..." (Martin & Krebs 2000). The primitive mammals include several extinct side branches of the stem-lineage, but also some of the first representatives of the branches leading to modern mammals. Even if the precise stratigraphic dating is problematic, a Kimmeridgian age is proved. The rich and diverse fossil content of the Guimarota beds allows depicting a detailed image of a terrestrial ecosystem in a sub-tropical forest swamp with open bodies of brackish to freshwater. It is also a remarkable site to present the industrial archaeology of a small-scale mining, and 40 years of palaeontological research (since 1959), one of the largest projects in the history of palaeontology all over the world.

Lourinhã area - One of the most productive European Upper Jurassic areas for dinosaur remains, including several locations with large number of recovered (many of them studied) bones (skeletons and isolated), extremely rare eggs and embryos, and foot-prints (Pai Mogo, Areia Branca, Zambujal, Porto das Barcas and Ponta da Corva). It must refered in particular the therapods embryos found in clutches with a total of more than 100 closely grouped eggs, one of them containing 34 eggs. As stated by Ricqles et al. (2001) "... exceptionally well preserved in ovo remains... allows to extend in time and to considerably supplement in great details our knowledge of early phases of growth... as well as shape modelling among carnivorous dinosaurs." (Pl. 1, fig. G). In the same area, the well exposed sea-cliffs between Peniche and Santa Cruz displays a beautiful and suggestive "natural architecture" and includes several Upper Jurassic litho-stratigraphic stratotypes (Praia da Amoreira, Porto Novo, Praia Azul and Santa Rita Members of the Lourinhã Formation, as well as the Consolação and Santa Cruz Units; Hill 1989; Manuppella et al. 1999).

S. Martinho do Porto lagoon - A perfect semi-circle (known as "the shell") separated from the open Atlantic by the western uplifted border of the Caldas da Rainha diapir (Pl. 1, fig. E, F), an excellent belvedere to the sea and the valley. It includes a lithostratigraphic stratotype (Upper Jurassic) and localities with dinosaur footprints (lagoon inlet, Serra da Pescaria and Serra do Bouro). The village was founded by the monks of the Alcobaça Abbey, and recently replaced the Alfeizerão harbour (see Fig. 2), a commercial and fishing harbour until the XVII century.

Óbidos fortified town - In the diapir nucleus, built on a Lower Jurassic limestone block, the village (Pl. 1, fig. H) follows the Roman town of Eburobrittium and is named after the Latin word "oppidum". The existing castle has a Muslim origin (VIII to XII centuries), and suffered main changes from 1186 (?) to circa 1370. The fortified palace of the governor was built in the beginning of the XVI century. The belvedere view allows the clear perception of the relation between the diapir borders and the drainage network that infilled the lagoon, contributing to the isolation from the sea. This evolution was responsible by the sudden decline of a rich town. However, even if "freezed" in time it was never abandoned, leading to the extraordinary preservation of this historic heritage.

PLATE 1

Fig. A - The Pederneira/Nazaré bay; arrow points the Pederneira centre (city hall, see Fig. B) and the solid line marks the Upper Jurassic (land side)/Aptian (sea side) limit; the old harbour should have been located around the upper right corner of the picture (© Editorial Geo-Planeta/ Barcelona).

Fig. B - Pederneira municipal symbol (the "pelourinho") in front of the city hall: a silicified late Jurassic or early Cretaceous trunk, probably once used as a menhir.

Fig. C - The Leiria castle (XII to XIII century), built on the top of a dolerite dome injecting the Caldas da Rainha structure, probably belonging to the late Tithonian to early Hauterivian magmatic cycle.

Fig. D - Depositional architecture of the Alcobaça formation (Upper Kimmeridgian to Berriasian) well exposed at the Salgados beach sea-cliffs (between Nazaré and S. Martinho do Porto).

Fig. E - The S. Martinho do Porto "shell", a perfect semi-circular lagoon, more than 10 km wide in the Holocene, separated from the Atlantic by the western uplifted border of the Caldas da Rainha diapir.

Fig. F - S. Martinho do Porto lagoon inlet; to the left the base of the S. Martinho do Porto formation stratotype (Upper Oxfordian to Upper Kimmeridgian); dinosaur footprints were found in the inlet shoulders.

Fig. G - Lourinhã palaeontological museum: clutch containing several dinosaur eggs (probably theropods *Lourinhanosaurus*, the left one is 12 cm long), some with in ovo remains (© Octávio Mateus/GEAL).

Fig. H - Óbidos fortified town, built on a Lower Jurassic limestone bloc in the Caldas da Rainha diapir nucleus; the castle has a Muslim origin (VIII to XII centuries) and suffered main changes during the XII to XIV centuries; the fortified palace (last plane in the town) was built in the beginning of the XVI century; in both sides, the agriculture fields covers the infilled lagoon.

Caldas da Rainha Spa - Literally the hot spring of the Queen. The first thermal Hospital (in the modern sense) in the world was established here in 1485 by the Queen Leonor, spouse of King João II, one of the main political figures in the Portuguese Discoveries epics. Just in the eastern limit of the diapiric structure, the sulphuric thermal spring is a proof of the deep root of the bounding fault and the water composition reveals that it crosses the Upper Triassic to Lower Jurassic evaporites. The Spa includes a part of the XV century bath, and the oldest preserved hospital dates from 1747. Other thermal springs exist in a similar location, namely in Piedade (Fig. 2), already known in the Roman period and used since the XV century by the monks of the nearby (4 km) Abbey of Alcobaça.

Leiria castle - Built on the top of a dolerite dome injecting the main fault. It probably belongs to the late Tithonian - early Hauterivian magmatic cycle linked with the late rifting and the beginning of sea-floor spreading in the Western Iberian Margin. The dome hill rises almost 100 m above the surrounding plane, which is formed by evaporitic marls of the Dagorda Formation and recent alluvium. The castle (Pl. 1, fig. C) was founded in the XII century (1135), but most of the structure dates from around 1325 (King D. Dinis) and was restored between 1898 and 1944 under a romantic logic, after a project of the Swiss architect Ernest Korrodi (Gomes 2001). The view from the castle is magnificent, in particular over the old town just at the base of the steep-side hill.

Pombal castle - Founded in 1147 by the Templars, was rebuilt in the beginning of the XVI century (Gomes 2001). The hill rises at the crossing of the eastern border of the diapir and the N-S Arunca River fault (Fig. 2). From the castle, the view over the region permits the perception of these (and other) structures in the landscape.

Pederneira village - Located just above the basin-wide Late Jurassic to Early Cretaceous (Aptian) unconformity (Dinis & Trincão 1995; Pl. 1, fig. A), this ancient fishing harbour is named after the municipal symbol (the "pelourinho"): a silicified late Jurassic or early Cretaceous trunk, probably once used as a menhir (Pl. 1, fig. B). In the western border of the diapir, the village is a belvedere over Nazaré (a traditional fishing village) and the "vallée thyphonique", facing a doleritic dome (S. Bartolomeu, a classified landscape feature), similar to the one of the Leiria castle.

Proposals and Conclusions

Strategy and public-targets for enhancing interest on regional geology

Many natural areas not protected by particular legislation or regulation can, nevertheless, represent an opportunity for the promotion of an holistic approach to the complex interplay of physical, biological and social phenomena. However, a political and/or economic decision to the effective use of that potential will arise only if the authorities admit the relevance of geoheritage conservation to modern society and/or a feasibility study, including some sort of marketing research, points to a positive economic budget. The following proposal can be considered as a model, and, if implemented, a case-study for enhancing interest on regional geology. It is based on the next premises: i) besides the intrinsic value and specific scientific interest, the geological knowledge is interesting ("marketable") for tourism (cultural and recreational); ii) the considered geoheritage sites are important for education (research and training); iii) the integration of sites in regional heritage routes or trails is a format adjusted to those activities; and iv) the integration of sites contributes to a more sustainable management, in particular because it allows the achievement of a critical dimension for the investment in human resources and promotion.

Tourism - Site interpretation, self-guided trails and heritage information centres are essential to attract people. The currently common public information on history, society and landscape of the selected sites/region should include some explanation of regional and local geology and must be incorporated in tourist "packages". Being the tourism the second largest economic sector of the country, it should be a partner and a financial support for the management of protected geosites. Portugal is 16th country in the world ranking of tourist regions. Besides domestic visitors, the foreign tourists come essentially from the European Union and are presumable consumers of scientific culture. Some situations have a particular potential: for instance, in the vicinity of the worldwide famous sanctuary of Fátima (Fig. 2) that attracts hundreds of thousands of pilgrims every year, important dinosaur footprint sites can be found less than 8 km away in Upper (Amoreira) and Middle Jurassic (Pedreira do Galinha) outcrops.

Education - The size of exposure, and the relative safety of most sites makes them highly suitable and attractive for educational studies. At present, the national curriculum at all levels requires students to be aware of some aspects of geological materials and processes. In this way, the access to in-situ materials and sites becomes increasingly important for scholar learning. At higher levels, the Lusitanian Basin, and in particular the region of the Caldas da Rainha structure is a remarkable case for extensional basin studies, because the syn, pre and post-rifting sequences are exposed by a gentle uplifting. Considering the Pombal - Santa Cruz axis (Fig. 2), within a range of 100 km (by road), there are 4 universities teaching geological matters, increasing to more than 10 if the range is enlarged to about 300 km (including some Spanish Universities). Similarly, 7 Polytechnic Institutes exist within the same 100 km range.

Regional effect - Besides the tourism implying travel, a structure such as the one proposed here must be seen as a field to promote public understanding of science for a general public, including the inhabitants of the region. Local residents are self-motivated as individuals or groups for anything that can be considered as its own "particular" values - the so-called parochialism. On the other hand, the economic input of visitors into the local economy can be significant, reinforcing the support to the project.

Final remarks

The natural landscape, castles, thermal springs, preserved ancient towns and the harbour history, can be used for geotourism as well as for educational purposes concerning the promotion of science and good environmental practices. Even activities and structures for recreation and tourism can be accommodated with minimal impact on natural environment, within a comprehensive regional assessment.

Let us remember the above stated importance of scientific knowledge, namely by a general increase of the so-called "scientific literacy": the basic level of knowledge about science and technology of the citizens of a scientific and technologic society in order to survive in and benefit from its social, cultural and physical environment (Durant 1992). Earth sciences should contribute to prove that environmental degradation does not have to be the price to pay for prosperity.

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