THE GEOLOGICAL HERITAGE OF THE LOWER JURASSIC OF CENTRAL PORTUGAL: SELECTED SITES, INVENTORY AND MAIN SCIENTIFIC ARGUMENTS

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Abstract. The Lower Jurassic is well represented in west-central Portugal (Lusitanian Basin), where several outcrops with exceptional exposures exist. Among these, three sites have a major interest for Geological Heritage: S. Pedro de Moel, Rabagal and Peniche. These localities display important sections for the study of the Liassic carbonate successions, whose scientific and educational value, for the domains of Palaeontology, Stratigraphy, Sedimentology and Geomorphology is widely known. The aim of this work is to enumerate the main scientific arguments for considering these Portuguese Liassic localities with national and international relevance and important heritage value (Geosite).

Introduction

In Portugal, the Lower Jurassic successions crop out in two different geo-structural settings, both bounded by the Iberian Hercynian Massif: the Algarve Basin, in the south of Portugal (Rocha 1976) and in the Lusitanian Basin in west-central Portugal (Fig. 1). Whereas the Liassic deposits in the south are restricted to few and small outcrops, in west-central Portugal they are particularly well represented, showing sections with exceptional exposures and great scientific interest.

In the Lusitanian Basin, several outcrops are of major importance for the scientific knowledge and study of the Lower Jurassic. However, only three sites seem to have a large potential in terms of Geological and Natural Heritage: S. Pedro de Moel, Rabagal and Peniche (Fig. 1). These sites display important sections for the study of the Liassic carbonate successions, and their scientific value is well known among the national geological community and foreigner Jurassic researchers. The aim of this work is to present the main scientific arguments for considering these outcrops as part of the World Jurassic Heritage. Besides their national and international scientific value, other important aspects with local or regional relevance can also be recognized, namely educational (didactic-pedagogic), cultural and touristic values. In fact, the high touristic potential (natural scenery, cultural heritage) is also an important factor to be considered at each locality. Two of these sites are located at the seaside (Peniche and S. Pedro de Moel). The Rabagal region is located near the Iberian Massif border, and is integrated in a countryside calcareous landscape.

The Lower Jurassic in the Lusitanian Basin

In the Lusitanian Basin, the Lower Jurassic is mainly composed of shallow to deep-marine carbonate deposits. The continental (fluvial) siliciclastic facies of the Upper Triassic (Silves Formation) (Palain 1976; Soares et al. 1993), is overlaid by an argillaceous-evapor-
L. Duarte

Fig. 1 - Main Lower Jurassic outcrops in the Lusitanian Basin, to the north of Lisbon. Location of the proposed geosites.

Fig. 2 - Map showing the location of the proposed geosites.

The stratigraphy of the S. Pedro de Moel outcrop ranges in age from Hettangian (?) to Middle Toarcian. However, the section is discontinuous, because the uppermost Pliensbachian (upper Domerian) fold is not present.

S. Pedro de Moel proposed Geosite

S. Pedro de Moel is a small town located at the seaside (Fig. 1). The Jurassic outcrop is restricted to about 5 km in the coastline, and comprises a thick succession (more than 200 m thick) of bioclastic limestones, marlstones, marl/limestone alternations and bituminous shales. The succession is mostly dipping towards the west, though locally affected by tectonics (faults and large folds), due to a meridian diapiric alignment located in the region. In the northern part of S. Pedro de Moel, and as a consequence of this structure, the bedding surfaces are sub-vertical, exposed in cliffs of a unique scenery value (Fig. 3). The stratigraphy of the S. Pedro de Moel outcrop ranges in age from Hettangian (?) to Middle Toarcian. However, the section is discontinuous, because the uppermost Pliensbachian (upper Domerian)
and the lower Toarcian (Polymorphum and lowermost Levisoni zones) are missing (Fig. 2).

**National relevance:** Several reasons point out the S. Pedro de Moel sector as an important scientific value. The main arguments, all of them exclusive of this outcrop, are:

- the occurrence of the oldest known ammonites in the Mesozoic basins of Portugal (*Asteroceras obtusum* (Sow.), Obtusum Zone, upper Sinemurian; Mouterde 1967; Mouterde & Rocha 1981);
- the record of interesting and unique stromatolite buildups which are found at the base of the section (Hettangian?); as a consequence of the geological structure, these constructions are only observed over an area of 15/18 m², which shows their large vulnerability;
- the outcrop shows one of the most complete sections of the Sinemurian of the basin, being the type-section for the Agua de Madeiros Formation; L Fm - Leme de Mede Formation; 3 - Without biostratigraphic data; 4 - Anoxic facies; 5 - Siliciclastic and/or oolitic facies; 6 - Highly fossiliferous levels (high vulnerability).

**Rabaçal proposed GeoSite**

One of the most remarkable features of this proposed geoite is the continuity of the sedimentary record, in a monoclinal structure, which is exposed in the eastern part of the Rabaçal-Sicó calcareous hills (Fig. 4). This section (also known as the Maria Pares section) is Early Pliensbachian to Late Aalenian (Fig. 2) in age, and displays more than 300 m thick of fossiliferous marl/limestone alternating succession.

**National relevance:** Several palaeontological and sedimentological aspects can be observed along this section. However, three main scientific reasons must be emphasized:

- this section is considered as one of the main field references for the Toarcian of Portugal, due to the available high biostratigraphic control (Mouterde et al. 1964-65; Rocha et al. 1987; Henriques 1992), corresponding to the type-section of the S. Giao Formation (lowermost Polymorphum Zone to Meneghini Zone; Duarte & Soares 2002). For this reason and as a consequence of the high quality of the exposure, several works of integrated stratigraphy have been developed (micropalaeontology, geochemistry (stable isotopes and organic matter), clay minerals, cyclostratigraphy), so that currently it is the most studied section of the Upper Liassic of Portugal (Exton 1979; Exton & Gradstein 1984; Baudin 1989; Chamley et al. 1992; Duarte 1991, 1994, 1995, 1998; Almeras 1994).
- the Middle-Upper Toarcian comprises several mud-mounds with a singular assemblage of siliceous sponges (mainly hexactinellids) and other benthic organisms (Duarte & Krautter 1998; Duarte et al. 2001).
- the Rabaçal region is included in a wide and beautiful calcareous landscape (Sicó calcareous hills). This area is dominated by carbonate sediments of Early to Late Jurassic age, including very rich representation of different karstic features. Cunha (1990) provided a very accurate geomorphological map for the area and he has inventorized the main karstic features of this region. Some of them (dolines, lapies, scarpas, etc.) make spectacular pictures in the landscape.

**Peniche proposed GeoSite**

Around the cliffs of Cabo Carvoeiro (Fig. 5), the most representative Liassic succession for the Lusitanian Basin crops out. This succession, with more than 450 m thick, ranges in age from the early Sinemurian (dolomitic limestones and limestones) to the early Middle Jurassic (Aalenian; oepel spiders/ grainstones).

**National relevance:** Besides other possible features which may justify the proposition of this locality as a GeoSite, the main aspects to be considered are the following:

- the continuity of the section allows the vertical facies variation (lithofacies, biofacies and ichnofacies) to be known and the main discontinuities identified in the Sinemurian/Toarcian over the basin to be recognized. This section corresponds to the type-locality of three formations: Vale das Fontes, Leme and Cabo Carvoeiro (Duarte & Soares 2002); the rich ammonite assemblages recorded along the section (from the uppermost Sinemurian to the middle Toarcian) allowed several studies concerning biostratigraphy, taxonomy and palaeobiology domains (Mouterde 1955; Dommergues et al. 1981; Philips 1985; Dommergues 1987; Elmi et al. 1996; Fernandez Lopez et al. 2000); when compared with the whole of the basin, the Toarcian of Peniche, in particular, shows different facies patterns which include siliciclastic and reworked shallow-water limestones (peloidal-oolitic grainstones). This succession is interpreted as a regressive submarine fan (Wright & Wilson 1984), representing a highly intuitive depositional model. These carbonate facies correspond to allogenic sediments fed from the uplifted Hercynian block located to the northwest of Peniche (Wright & Wilson 1984; Duarte 1995, 1997);
- a beautiful karstic morphology has developed on this shoreline succession. This karstic landscape is one of the only two examples of litoral karsts in Portugal.
International relevance:
This section was recently proposed as a good and important reference for the choice of the Toarcian Global Boundary Stratotype Section and Point (GSSP: Elmi et al. 1996; Elmi 2002).

Socio-cultural and Educational Values
As shown above, the scientific impact of these three sites is unequivocal, but their potential for educational (didactic) and public science communication activities is also evident. All of the mentioned sections are frequently visited by senior research groups (for example, those who attended the 2nd International Symposium on Jurassic Stratigraphy, held in Lisbon: Rocha et al. 1987), both foreigner and national researchers, geology graduation students and High-school teachers (training actions), whose interest outlined the very high didactic and pedagogic potential of these sites. Visits include mainly fieldtrips and/or specific practical works in general geology, geological mapping, geomorphology, stratigraphy, palaeontology, sedimentology and/or basin analysis. Good examples can be given by the experience gathered in the last years, with the geology graduation and master students of several Portuguese universities. However, the different activities with students confirm that each site matches different educational (level) rank, if we want to take the best of the scientific potential (with diversified knowledge) and the natural laboratory of each place. The ranking assigned to each outcrop, presented in the Tab. I, shows the major potential of S. Pedro de Moel for Palaeontology (richness and diversity of invertebrate macrofossils and ichnofossils, ichthyofauna and microbial structures), Rabacal for Stratigraphy (unit differentiation based on different stratigraphic methods) and, finally, Peniche for Sedimentology (marked vertical changes of lithofacies and sedimentary structures).

On the other hand, the cultural potential of these geosites is quite high, due to their intense public use, especially since three years ago in the programme “Geology in the Summer”, sponsored by the Ministry of Sciences and Technology. These experiences confirm the cultural interest of these sites relative to Geology and Natural History, justifying, in the quantification model of Muñoz (1988), their local and regional interest. Moreover, the single scientific and educational features of all these Jurassic geosites can be profiled by the regional authorities and the local communities. The divulgation and the creation of small structures of conservation could further promote the touristic potential of each site. However, this has to be done very carefully, because of the increasing risk of negative impacts on the natural units that tourism also carries.

Vulnerabilities
One of the most serious problems related with this geological sites is the risk of destruction. Several factors can be measured in terms of natural and anthropic vulnerabilities (Tab. I). However, the main risks are located in the coastline, either through natural hazards like erosion and landslides, or through urban and touristic pressure. In fact, in the cases of Peniche and S. Pedro de Moel, the outcrops have a high level of vulnerability, as they show stratigraphic horizons with restricted lateral extension. On one side, the management of the coastal zone by Portuguese entities has been done without taking into consideration the scientific and educational values of these sites. The cliffs of some sectors of S. Pedro de Moel and Peniche are very unstable, showing strong risks to landslides (Tab. I). On the other hand, these classical palaeontological sites are particularly rich in fossils, which has attracted the uncontrolled interest of fossil dealers and amateur collectors. The absence
of legal geoconservation laws (Henriques 2002), has increased the risk of damage of these geosites.

Conclusions

The knowledge of the Lower Jurassic outcrops in the Lusitanian Basin allows the election of three sites as special geological heritage value (geosites): S. Pedro de Moel, Rabacal and Peniche. This work presents an inventory of the main scientific reasons for each site, in terms of national and international relevance. Besides, it demonstrates the socio-cultural (educational, touristic,...) value of those sites and their potential for wide public use, from a general public to graduation students and researchers.

This analysis claims to constitute a useful tool for the definition of the geological heritage of the Portuguese Jurassic in the world context. In such context, this inventory follows the recommendations of the Geosites Project, supervised by the IUGS Global Geosites Working Group. In addition, this evaluation can be taken into account by the regional decision-makers in the land-use planning.

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### Outcrop Conditions

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<th>S. Pedro de Moel</th>
<th>Rabacal</th>
<th>Peniche</th>
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<tr>
<td><strong>Location</strong></td>
<td>Seaside</td>
<td>Countryside</td>
<td>Seaside</td>
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<tr>
<td><strong>Extension</strong></td>
<td>Lateral, 5km long</td>
<td>Vertical, with good lateral continuity</td>
<td>Lateral, 5km long</td>
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<tr>
<td><strong>Accessibility</strong></td>
<td>Good</td>
<td>Very Good</td>
<td>Good</td>
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<tr>
<td><strong>Landscape/Scenery Interest</strong></td>
<td>High</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td><strong>Educational/Scientific Use</strong></td>
<td>High Potential</td>
<td>High Potential</td>
<td>Very High Potential</td>
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<tr>
<th><strong>Development (Hierarchy) of Scientific Domains</strong></th>
<th>1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt;</th>
<th>4&lt;sup&gt;th&lt;/sup&gt;</th>
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<td>Sedimentology</td>
<td>Stratigraphy</td>
<td>Palaeontology</td>
<td>Geomorphology</td>
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<tr>
<td>Sedimentology</td>
<td>Stratigraphy</td>
<td>Natural Hazards</td>
<td>Sedimentology</td>
<td>Geomorphology</td>
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### Social/Economic Interest

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<tr>
<th></th>
<th>Local Touristic Development</th>
<th>Natural Touristic Potential</th>
<th>Local Cultural Attractions</th>
<th>Vulnerability</th>
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<tr>
<td></td>
<td>Moderate (National)</td>
<td>Low (National/international)</td>
<td>High</td>
<td>Very High</td>
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<td>Low</td>
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### References
