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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, Rabaçal 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).

Riassunto. Il Giurassico inferiore è ben rappresentato nel Portogallo centro-occidentale (Bacino Lusitanico), dove esistono molti affioramenti con eccezionali esposizioni. Tra questi, tre sono i siti di maggior interesse per il Patrimonio Geologico: S. Pedro de Moel, Rabaçal e Peniche. Queste località mostrano sezioni importanti per lo studio delle successioni carbonatiche liassiche, il cui valore scientifico e didattico, per i campi di Paleontologia, Stratigrafia, Sedimentologia e Geomorfologia è ampiamente noto. Lo scopo di questo lavoro è di enumerare i principali argomenti scientifici per considerare queste località del Lias portoghese come di rilevanza nazionale ed internazionale e come un valore di patrimonio importante (Geosito).

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, Rabaçal 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 Rabaçal 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-

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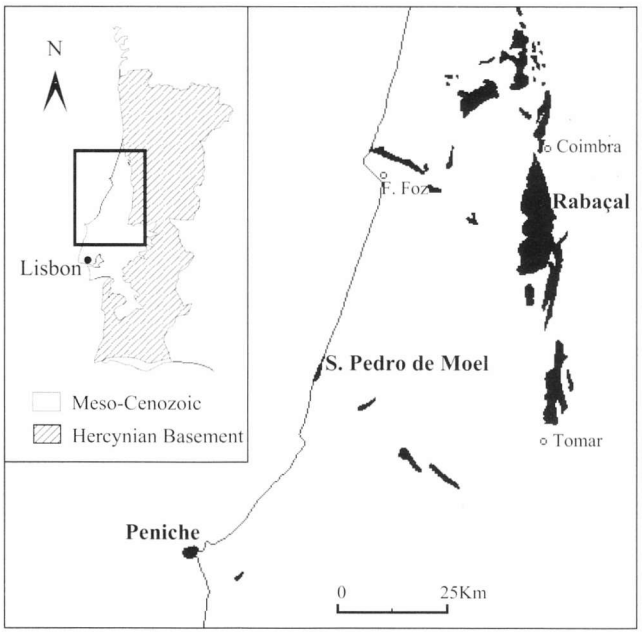

Fig. 1 - Main Lower Jurassic outcrops in the Lusitanian Basin, to the north of Lisbon. Location of the proposed geosites.

itic complex, detrital at the base (Pereiros and Dagorda Formations), capped by dolomitic and dolomitic limestone facies (Coimbra Formation), all of them of Hettangian/Sinemurian age (Soares et al. 1993). The Lower Pliensbachian (Carixian) succession records the opening of the basin to marine influence, with basinwide occurrence of ammonoids. In fact, the Middle-Upper Liassic (early Pliensbachian to early Aalenian) is characterized by significant marly limestone deposition, locally with a clear rhythmic pattern and very rich on benthic (bivalves, brachiopods, crinoids and siliceous sponges) and necktonic (ammonites and belemnites) macrofossils. The weak lateral facies variation observed all over the basin, suggests that these sediments were deposited in a homoclinal carbonate ramp system, dipping towards the west/northwest and controlled by N-S and NE-SW tectonic trends (Duarte 1995, 1997, 2000). Despite this general hemipelagic character, some particular and differentiated sedimentary aspects can be recognized at several locations in the southern half of the Lusitanian Basin, like Arrábida, Tomar and Peniche (Duarte 1995, 1997; Manuppella & Azerêdo 1996) (Fig. 1). During Toarcian times, the deposition of siliciclastic and resedimented oolitic sediments, observed in this last region, confirm a palaeogeography controlled by the uplift of western igneous blocks (Berlengas island) (Wright & Wilson 1984; Duarte 1995, 1997).

Geological Heritage

In this paper, the geological heritage value of the Lower Jurassic of the Lusitanian Basin is argued on a two fold basis: scientific and socio-cultural (educational) significance. However, this analysis is especially intended to emphasize the scientific value of each geosite, in terms of its national and international relevance. This inventory follows the recommendations of the Geosites Project, supervised by the IUGS Global Geosites Working Group (Wimbledon 1996).

Scientific Value

Data on the Jurassic of Portugal are known since the middle of the nineteenth century (Sharpe 1850). However, Paul Choffat (1880) was the first author to study the three sites here described, presenting the first stratigraphic chart for the Jurassic of Portugal. Several national and international researchers have contributed to the study of the Lower Jurassic of the Lusitanian Basin, and most of them have based their studies on those three sites. Among the most important authors, Abbey Mouterde (and his research team) was the responsible for the first complete biostratigraphical study of the Lower Jurassic of the basin, including the Peniche, S. Pedro de Moel and Rabaçal sections (Mouterde 1955, 1967; Mouterde et al. 1964-65). Recently, in the last three decades, the main stratigraphical and sedimentological contributions were developed by researchers integrating Portuguese and French universities (Coimbra, Nova de Lisboa and Lyon) (Dommergues et al. 1981; Dommergues 1987; Rocha et al. 1987; 1996; Elmi et al. 1988, 1989; Soares et al. 1993; Almeras 1994; Duarte & Soares 1993; Duarte 1995, 1997, 1998, 2000; Duarte et al. 2001), or working in other institutions (e.g. Wright & Wilson 1984; Guery 1985; Phelps 1985; Watkinson 1989).

The scientific relevance of these three sites is widely accepted as far as Jurassic stratigraphy and palaeontology is concerned (they are classical palaeontological sections), and also as regards to sedimentology, basin analysis and geomorphology. The quality of S. Pedro de Moel, Rabaçal and Peniche sections/outcrops (good exposure, lateral and vertical continuity, and deep level of current knowledge) has allowed the definition of the type-section of some lithostratigraphic units for the late Sinemurian-late Toarcian of the Lusitanian Basin (Duarte & Soares 2002) (Fig. 2). The scientific criteria for each site are presented in terms of national and international relevance.

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)

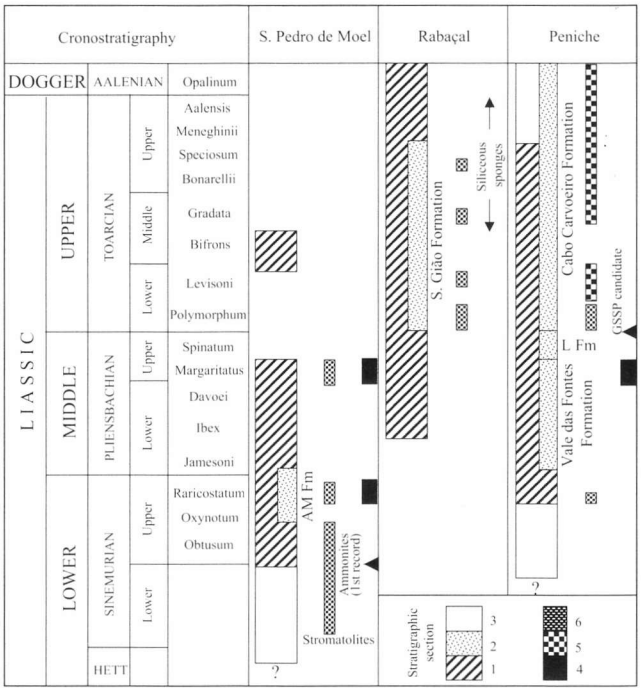

Fig. 2 - Stratigraphic range and main features of S. Pedro de Moel, Rabaçal and Peniche sections. Legend: 1 - High biostratigraphic control; 2 - Formation type-section (AM Fm - Água de Madeiros Formation; L Fm - Lemede Formation); 3 - Without biostratigraphic data; 4 - Anoxic facies; 5 - Siliciclastic and/or oolitic facies; 6 - Highly fossiliferous levels (high vulnerability).

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 m^2, 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 Água de Madeiros Formation (uppermost Sinemurian; Duarte & Soares 2002). This succession comprises an unusual benthic fossil record (vide Mouterde & Rocha 1981), with levels very rich in bivalves (*Gryphaea obliqua*, *Ceratomya* cf. *petricosa*), brachiopods (*Terebratula ribeiroi*) and gastropods (*Nerinella ficalhoi*). Diverse invertebrate ichnofossils are also recorded, including unique occurrences of the ichnogenera *Rhyzocorallium* and *Thalassinoides*;
- the Late Sinemurian-Early Domerian corresponds to a thick succession of marl/limestone alternations, with strong development of bituminous facies and rich necktonic fossil assemblage (belemnites and ammonites). Most of the ictyological record (actinopterigians) from the Portuguese Lower Jurassic was found in these stratigraphic levels (Antunes et al. 1981).

Rabaçal proposed Geosite

One of the most remarkable features of this proposed geosite 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. Gião Formation (lowermost Polymorphum Zone to Meneghinii 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 aspects. 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, lapias, uvala, scarps, etc...) make spectacular pictures in the landscape.

International Relevance: The Toarcian marly limestones of Rabaçal region show a strong development of siliceous sponge bioherms (Duarte 1997; Duarte & Krautter 1998; Duarte et al. 2001). These occurrences constitute the first references of such structures for the Upper Liassic of the Tethys northern sector (Duarte & Krautter 1998), and most species were up to now completely unknown (Krautter & Duarte in prep.). Considering the intermediate position of the Lusitanian Basin relative to Tethyan and Atlantic realms, these occurrences constitute an important and significant information to be included in global palaeobiological (ecological) and palaeogeographical reconstructions.

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; oopelsparites/ 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, Lemede 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, taphonomy and palaeobiology domains (Mouterde 1955; Dommergues et al. 1981; Phelps 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 resedimented 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 allodapic 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 littoral karsts in Portugal.

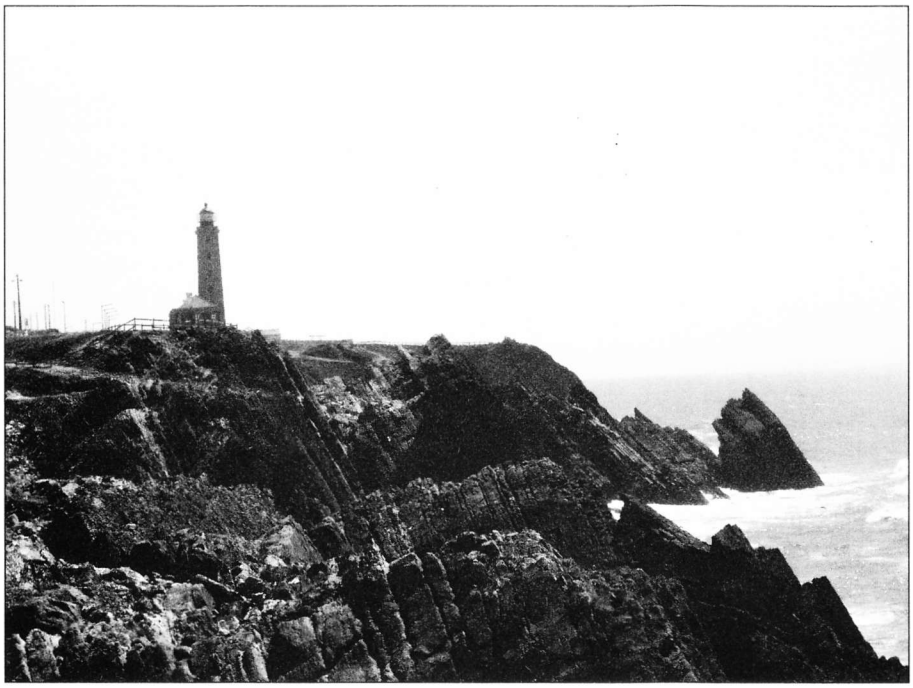

Fig. 3 - Panoramic view of Sinemurian carbonate succession in S. Pedro de Moel. Lighthouse is 32 m high.

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 field-trips 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), Rabaçal 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 profited 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

Fig. 4 - General view of Lower-Middle Toarcian marl-limestone alternations (S. Gião Formation) in the Rabaçal region.

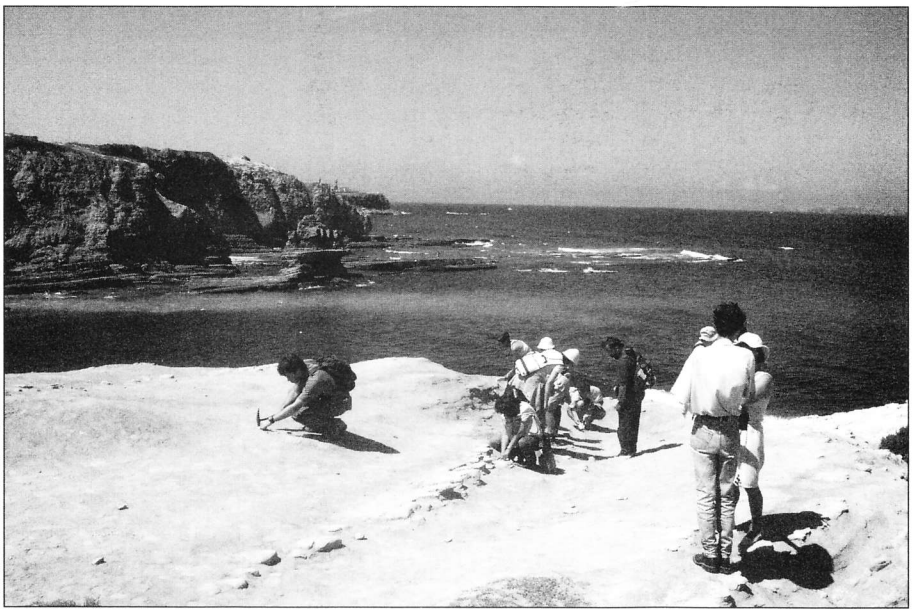

Fig. 5 - Partial view of Lower Toarcian succession in the Peniche Peninsula.

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, Rabaçal 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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	S. Pedro de Moel	Rabaçal	Peniche
Outcrop Conditions			
Location	Seaside	Countryside	Seaside
Extension	Lateral, 5km long	Vertical, with good lateral continuity	Lateral, 5km long
Accessibility	Good	Very Good	Good
Landscape/Scenery Interest	High	High	Very High
Educational/Scientific Use			
General Public Activities	High Potential	High Potential	Very High Potential
High-school Teachers/ Geology Students Activities	Very High Potential	Very High Potential	Very High Potential
Development (Hierarchy) of Scientific Domains 1st 2nd 3rd 4th	 Palaeontology Sedimentology Stratigraphy Natural Hazards	 Stratigraphy Palaeontology Geomorphology Sedimentology	 Sedimentology Stratigraphy Palaeontology Geomorphology
Social/Economic Interest			
Local Touristic Development	Moderate (National)	Low	High (National/International)
Natural Touristic Potential	High	High	High
Local Cultural Attractions	Low	High (Roman ruines at 5km)	Moderate/High (archaeological sites, museum)
Vulnerability			
Palaeontological record	Very High	High	High
Urban Occupation	Moderate/High	Low	Moderate
Human Pressure	High	Low	Moderate/High
Erosion Hazards	Moderate/High	Low	High
Landslide Hazards	High	Low	High

Tab. 1 - Social, educational and vulnerability evaluation of the three proposed Liassic geosites.

REFERENCES

Almeras Y. (1994) - Le genre *Soaresirhynchia* nov. (Brachiopoda, Rhynchonellacea, Wellerellidæ) dans le Toarcien du Sous-Bassin Nord-Lusitanien (Portugal). *Docum. Lab. Géol., Lyon*, 130: 135 pp., Lyon.

Antunes M. T., Rocha R. B. & Wenz, S. (1981) - Faunule ichthyologique du Lias inférieur de S. Pedro de Moel, Portugal. *Ciências da Terra*, 6: 101-116, Lisboa.

Baudin F. (1989) - Caracterisation géochimique et sédimentologique de la matière organique du Toarcien tethysien (Méditerranée, Moyen-Orient). Significations paleogeographiques. Thèse, Université Pierre et Marie Curie, Paris, 246 pp., Paris.

Chamley H., Baudin F., Foucarde E. & Galbrun B. (1992) - Stratigraphie mineralogique des argiles du Toarcien d'Iberie meridionale et occidentale. *Ann. Soc. Géol. du Nord*, 1 (2éme série): 109-117, Lille.

Choffat P. (1880) - Étude stratigraphique et paléontologique des terrains jurassiques du Portugal. Première livrasion - Le Lias et le Dogger au Nord du Tage. *Mem. Sec. Trab. Géol. Portugal*, 22: 72 pp., Lisboa.

Cunha L. (1990) - As Serras Calcárias de Condeixa-Sicó-Alvaiázere. *Estudo de Geomorfologia. Série Geografia Física*, 1, INIC, 329 pp., Lisboa.

Dommergues J.-L. (1987) - L'evolution chez les Ammonitina du Lias Moyen (Carixien, Domerien Basal) en Europe Occidentale. *Docum. Lab. Géol. Lyon*, 98, 297 pp., Lyon.

Dommergues J.-L., Elmi S., Mouterde R. & Rocha R.B. (1981) - Calcaire grumeleux du Carixien portugais. In Farinacci A. & Elmi S. (eds.), Rosso Ammonitico Symposium Proceedings, Edizioni Tecnoscienza, 199-206, Roma.

Duarte L. V. (1991) - Os Margo-Calcários do Toarciano na Região de Rabaçal-Condeixa (Sul de Coimbra): Caracterização Sedimentológica e Evolução Sequencial. *Memórias e Notícias, Publ. Mus. Lab. Min. Geol. Univ. Coimbra*, 112: 15-36, Coimbra.

Duarte L. V. (1994) - La sédimentation cyclique marne-calcaire dans le Toarcien du Bassin Lusitanien (Portugal Central). *Geobios*, M.S. 17: 663-669, Lyon.

Duarte L. V. (1995) - O Toarciano da Bacia Lusitaniana. Estratigrafia e Evolução Sedimentogenética. PhD Thesis, University of Coimbra, 349 pp., Coimbra.

Duarte L. V. (1997) - Facies analysis and sequential evolution of the Toarcian-Lower Aalenian series in the Lusitanian Basin (Portugal). *Com. Inst. Geol. Mineiro*, 83: 65-94, Lisboa.

Duarte L. V. (1998) - Clay minerals and geochemical evolution in the Toarcian Lower Aalenian of the Lusitanian Basin. *Cuad. Geol. Iberica*, 24: 69-98, Madrid.

Duarte L. V. (2000) - Sequence stratigraphy applied to homoclinal ramps: example of the Lower Jurassic of Portugal. 31st International Geological Congress, Abstract Vol. (CDRom), Rio de Janeiro.

Duarte L. V. & Krautter M. (1998) - Siliceous sponge mud mounds from the Toarcian of the Lusitanian basin, Portugal: Facies, stratigraphy and sequential evolution. 5th International Symposium on the Jurassic System, Abstract Vol., 23-24, Vancouver.

Duarte L. V., Krautter M. & Soares A. F. (2001) - Bioconstructions à spongiaires siliceux dans le Lias terminal du Bassin lusitanien (Portugal): stratigraphie, sédimentologie et signification paléogéographique. *Bull. Soc. Géol. France*, 172 (5): 637-646, Paris.

Duarte L. V. & Soares A. F. (1993) - Eventos de natureza tempestítica e turbidítica no Toarciano inferior da Bacia Lusitaniana (Sector Norte). *Cad. Geografia, F.L.U.C.*, 12: 89-95, Coimbra.

Duarte L. V. & Soares A. F. (2002) - Litostratigrafia das séries margo-calcárias do Jurássico inferior da Bacia Lusitânica (Portugal). *Comun. Inst. Geol. Mineiro*, 89: 135-154, Lisboa.

Elmi S. (2002) - Some general data on the Pliensbachian-Toarcian boundary (problems of biostratigraphic correlations). 6th International Symposium on the Jurassic System, Abstract Vol.: 56-57, Palermo.

Elmi S., Goy A., Mouterde R., Rivas P. & Rocha R. (1989) - Correlaciones bioestratigraficas en el Toarciense de la Peninsula Iberica. *Cuad. Geol. Ibérica*, 13: 265-277, Madrid.

Elmi S., Rocha R. & Mouterde R. (1988) - Sédimentation pélagique et encroûtements cryptalgaires: les calcaires grumeleux du Carixien portugais. *Ciências da Terra*, 9: 69-90, Lisboa.

Elmi S., Mouterde R., Rocha R. B. & Duarte L. V. (1996) - La limite Pliensbachien-Toarcien au Portugal: intérêt de la coupe de Peniche. Meeting on Toarcian and Aalenian Stratigraphy. *I.S.J.S., Aalenews*, 6: 33-35, Roma.

Exton J. (1979) - Pliensbachian and Toarcian microfauna of Zambujal, Portugal: Systematic Paleontology. *Carleton University, Geol. Paper*, 79: 1-104, Ottawa.

Exton J. & Gradstein F. M. (1984) - Early Jurassic stratigraphy and micropaleontology of the Grand Banks and Portugal. In: Westerman, G. E. (ed.) - Jurassic-Cretaceous Biochronology and Paleogeography of North America. *Geol. Assoc. Canada, Special Paper*, 27: 13-30.

Fernández-López S., Duarte L. V. & Henriques M. H. (2000) - Ammonites from lumpy limestones in the Lower Pliensbachian of Portugal: taphonomic analysis and palaeoenvironmental implications. *Rev. Soc. Geol. España*, 13 (1): 3-15, Madrid.

Guery F. C. (1985) - Évolution sédimentaire et dynamique du bassin marginal ouest-portugais au Jurassique (Province d'Estremadure, secteur de Caldas da Rainha, Montejunto). Thèse Doctorat. University Claude Bernard , 478pp., Lyon.

Henriques M. H. (1992) - Biostratigrafia e Paleontologia (Ammonoidea) do Aaleniano em Portugal (Sector Setentrional da Bacia Lusitaniana). PhD Thesis, University of Coimbra, 301 pp., Coimbra.

Henriques M. H. (2002) - Jurassic heritage of Portugal: state of the art and open problems. 6th International Symposium on the Jurassic System, Abstract Vol.: 89, Palermo.

Manuppella G. & Azerêdo A. C. (1996) - Contribuição para o conhecimento da geologia da região de Sesimbra. *Comun. Inst. Geol. Mineiro*, 82: 37-50, Lisboa.

Mouterde R. (1955) - Le Lias de Peniche. *Comun. Serv. Geol. Portugal*, 36: 87-115, Lisboa.

Mouterde R. (1967) - Le Lias moyen de São Pedro de Moel (Portugal). *Comun. Serv. Geol. Portugal* , 52: 185-208, Lisboa.

Mouterde R. & Rocha R. B. (1981) - Atlas des fossiles caractéristiques du Lias portugais. I. - Lias inférieur. *Ciências da Terra*, 6: 49-76, Lisboa.

Mouterde R. , Ruget Ch. & Moitinho de Almeida F. (1964-65) - Coupe du Lias au Sud de Condeixa. Comun. *Serv. Geol. Portugal*, 48: 61-91, Lisboa.

Muñoz E. (1988) - Georrecursos culturales. *Geologia Ambiental, I.T.G.E.*, 85-100, Madrid.

Palain C. (1976) - Une série détritique terrigène. Les "Grés de Silves": Trias et Lias inférieur du Portugal. *Serv. Geol. Portugal, Mem. N.S.*, 25: 377 pp., Lisboa.

Phelps R. (1985) - A refined ammonite biostratigraphy for the Middle and Upper Carixian (Ibex and Davoei zones, Lower Jurassic) in North-West Europe and stratigraphical details of the Carixian-Domerian boundary. *Geobios*, 18: 321-362, Lyon.

Rocha R. B. (1976) - Estudo estratigráfico e paleontológico do Jurássico do Algarve Ocidental. *Ciências da Terra*, 2: 178 pp., Lisboa.

Rocha, R. B., coord (1996) - The 1st and 2nd rifting phases of the Lusitanian Basin: stratigraphy, sequence analysis and sedimentary evolution. Final report, CEC, Project MILUPOBAS, 4 vols, Lisboa.

Rocha R. B., Mouterde R., Soares A. F. & Elmi S. (1987) - Excursion A- Biostratigraphie et évolution séquentielle du Bassin au Nord du Tage au cours du Lias et du Dogger. 2nd International Symposium on Jurassic Stratigraphy, 84 pp. , Lisboa.

Sharpe D. (1850) - On the secondary district of Portugal which lies on the north of the Tagus. *Quart. Jour. Geol. Soc. London*, 6: 135-200, London.

Soares A. F., Rocha R., Elmi S., Henriques M. H. P., Mouterde R., Almeras Y., Ruget C., Marques J., Duarte L. V., Carapito M.C. & Kullberg C. (1993) - Le sous-bassin nord lusitanien (Portugal) du Trias au Jurassique moyen: histoire d´un «rift avorté». *C. R. Ac. Sc. Paris*, Sér. II, 317: 1659-1666, Paris.

Watkinson M. (1989) - Triassic to Middle Jurassic sequences from the Lusitanian Basin Portugal, and their equivalents in other North Atlantic margin basins. Thesis, Open University U.K., 390 pp., Milton Keynes.

Wimbledon W. A. P. (1996) – GEOSITES – a new IUGS initiative to compile a global comparative site inventory, an aid to international and national conservation activity. *Episodes*, 19: 87-88, Beijing.

Wright V. P & Wilson R.C.L. (1984) - A carbonate submarine-fan sequence from the Jurassic of Portugal. *J. Sed. Petrol.*, 54: 394-412, Tulsa.