Comunicações Geológicas, 2006, t. 93, pp. 23-38

The Upper Devonian Palynostratigraphy and Organic Matter Maturation of the Pulo do Lobo Domain, South Portuguese Zone, Portugal

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Key-words: Miospores, palynostratigraphy, organic matter maturation, Upper Devonian, Pulo do Lobo Domain, Pyrite Belt, South Portuguese Zone.

Abstract: Palynostratigraphic research in the Pulo do Lobo Domain, South Portuguese Zone, Iberian Variscides, allows the age revision and the following correlations among the composing stratigraphic units: the Pulo do Lobo and Atalaia Formations exhibit lithological and deformational affinities, and no age determination was achieved; the Ribeira de Limas and Gafo formations are of early Frasnian and the Santa Iria, Horta da Torre and Represa formations. yielded palynomorphs of late Famennian age. Vitrinite reflectance values of the organic matter indicate that the Pulo do Lobo and Atalaia formations reach the higher greenschist facies of metamorphism while all the overlying units belong to the upper epizone. The metamorphic and structural contrasts suggest that the Pulo do Lobo/Atalaia formations were once part of a pre-Famennian accretionary prism related to a northward subduction while all the other overlying units were laid down in a sedimentary basin, discordant over that paleoprism. From all these data, it is inferred that this basin and the Iberian Pyrite Belt basin were part of the same paleogeographic realm during the late Devonian.

Palavras-chave: Miosporos, palinoestratigrafia, maturação da matéria orgânica, Devónico Superior, Domínio do Pulo do Lobo, Faixa Piritosa, Zona Sul Portuguesa.

Resumo: Investigações palinoestratigráficas efectuadas na parte portuguesa do Domínio do Pulo do Lobo, Zona Sul Portuguesa, permitiram rever as datações das suas unidades constituintes e estabelecer as seguintes correlações: as Formações de Pulo do Lobo e Atalaia exibem afinidade litológica e de deformação e não permitiram obtenção de datações; as Formações de Ribeira de Limas e Gafo possuem miosporos de idade Frasniano inferior e as Formações Santa Iria, Horta da Torre e Represa foram datadas do Fameniano superior. Os índices de maturação da matéria orgânica das unidades Pulo do Lobo e Atalaia indicam condições de metamorfismo da fácies xistos verdes alta, enquanto os das restantes unidades indicam a parte alta da epizona. Os contrastes metamórficos e estruturais sugerem que o par Formação Pulo do Lobo/ Formação Atalaia foi parte integrante do paleoprisma acrecionário, de idade pré-Fameniano, associado a uma zona de subducção para Norte, enquanto que as restantes unidades depositaram-se numa bacia sedimentar, discordante sobre aquele paleoprisma. É sugerido que esta bacia e a da Faixa Piritosa estiveram em continuidade e pertenceram à mesma área paleogeográfica durante o Devónico superior.

INTRODUCTION

The Pulo do Lobo Domain is situated between the Ossa Morena Zone and the Iberian Pyrite Belt of the Iberian Variscides (Fig. 1). In the core of the structure, marking the base of the stratigraphic sequence, is the Pulo do Lobo Formation which is composed of highly sheared phyllites and quartzites, and intercalations of amphibolites with MORB-type geochemical affinity at the lower levels (MUNHÁ, 1983; EDEN, 1991; QUESADA *et al.*, 1994). A common feature of this unit is the widespread occurrence of exudation quartz veinlets which are related to a strong tectonic deformation. The north limb of the structure is represented by the Ferreira-Ficalho Group which in ascending stratigraphic order comprises the following units (CARVALHO *et al.*, 1977; OLIVEIRA *et al.*, 1986; GIESE *et al.*, 1988; OLIVEIRA, 1990; EDEN, 1991; QUESADA *et al.*, 1994): the Ribeira de Limas Formation is composed of phyllites, quartzwackes and minor intercalations of tuffites, in apparent transition to the Pulo do Lobo Formation; the Santa Iria Formation consists of greywackes, siltstones and shales, forming a flysch like

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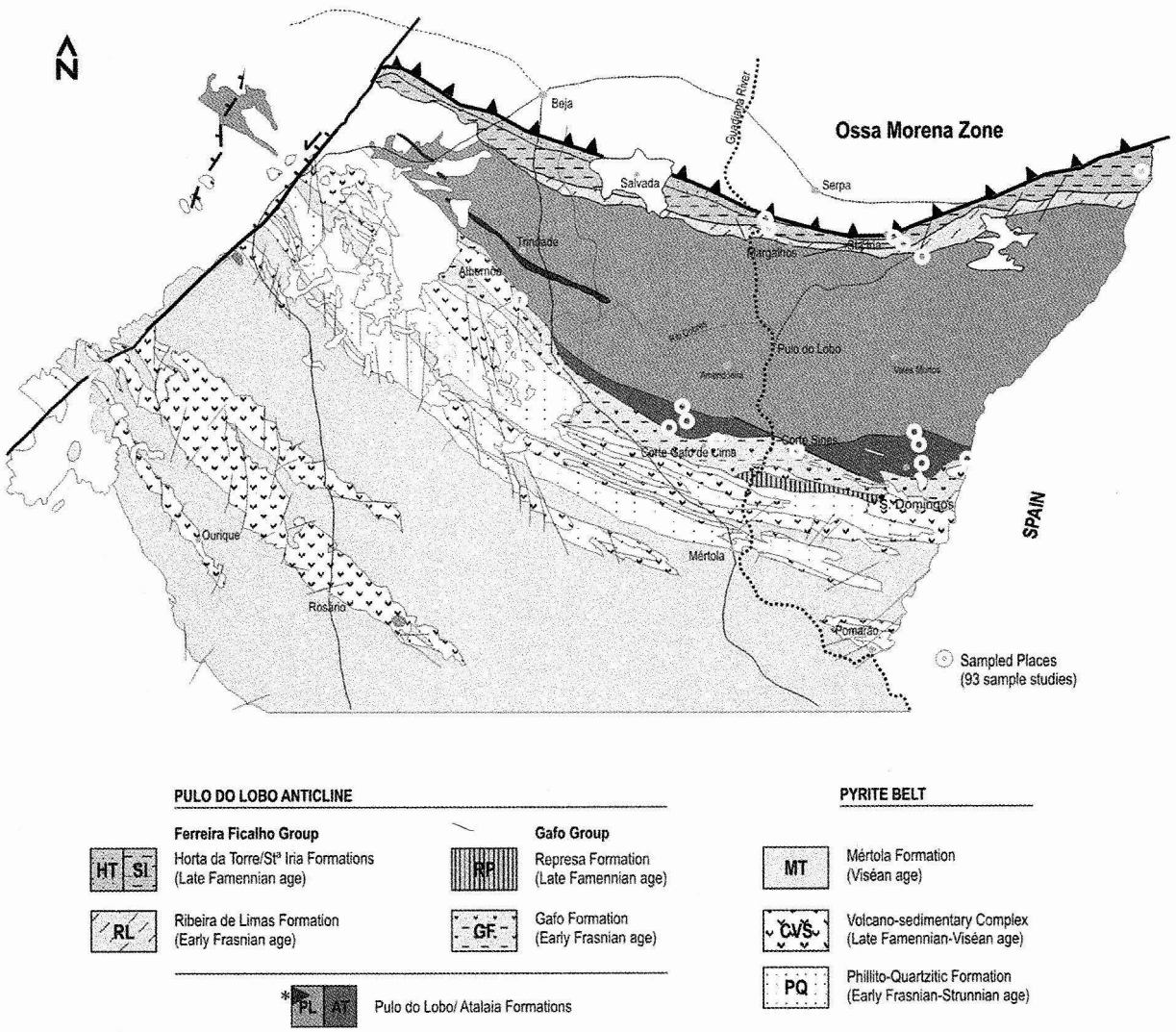

Fig. 1 – Geological sketch map of the South Portuguese Zone (adapted from OLIVEIRA (1990); Geological Map of Portugal 1/500 000).

succession; the Horta da Torre Formation is composed of dark shales, impure sandstones, siltstones and quartzite beds with bioturbation. The latter grades downward and laterally into the Santa Iria formation and both are affected by a single main cleavage, while the Ribeira de Limas and the Pulo do Lobo formations show two main episodes of cleavage. The group thickness is estimated at 500 m.

In the south limb of the structure are the units of the Chança Group, from base to top, as follows (PFEFFERKORN, 1968; SILVA, 1988; CUNHA & OLIVEIRA, 1989; OLIVEIRA, 1990; SILVA *et al.*, 1990): the Atalaia Formation, composed mostly of phyllites, quartzites and quartzwackes; the Gafo Formation with greywackes, siltstones and shales forming a turbidite succession, with intercalations of acidic and mafic volcanics and basic and acidic dikes; the Represa Formation consists of siliceous siltstones, shales and greywackes. The group thickness is estimated at 1100 m. According to MUNHÁ (1983; 1990), the regional metamorphism varies from the upper epizone to the upper greenschist facies.

The overall structure has been interpreted as an anticline (SCHERMERHORN, 1971; CARVALHO *et al*, 1976; OLIVEIRA *et al.*, 2006; PEREIRA *et al.*, 2006), as an accretionary prism related to a northward dipping subduction (SILVA *et al.*, 1990; QUESADA *et al.*, 1994; SILVA, 1998) and as a suspect terrain (RIBEIRO *et al.*, 1990).

This paper describes in detail the most recent advances on the palynostratigraphy and organic matter

maturation of the Portuguese part of the Pulo do Lobo Domain and discusses their implications in terms of the regional geodynamic model.

PREVIOUS PALYNOLOGICAL STUDIES ON THE PULO DO LOBO DOMAIN

The history of palynological studies of the Pulo do Lobo Domain extends back to the 1980s. In 1986, T. CUNHA (OLIVEIRA *et al.*, 1986) developed a palynostratigraphic project as part of a mapping programme carried out by the Portuguese Geological Survey and recorded for the first time a fairly well preserved palynomorph assemblage of mid Famennian age in the Horta da Torre Formation. Three localities were sampled near Corte Condessa, west of the Guadiana River. Miospore species identified include *Aneurospora greggsii*, *Ancyrospora langii*, *Diducites mucronatus*, *D. poljessicus*, *D. plicabilis*, *Pustulatisporites rugulatus*, *Retusotriletes planus, Samarisporites* sp. A and *Samarisporites* sp. cf. *Acanthotriletes hirtus*. Acritarch species recovered include *Ephelopalla* cf. *gorkae*, *Unellidium piriforme* and *U. winslowae*.

GIESE *et al.* (1988), working further east in the Almonaster la Real region, northern limb of the Pulo do Lobo Domain, in Spain, have subsequently determined a late Famennian to Tournaisian age for a sequence of greywackes, possible correlatives of Santa Iria Formation. In this work, the Horta da Torre Formation was considered to stratigraphically underlie the Santa Iria Formation. Due to the high thermal maturity of the assemblages, reflected light microscopy was used, allowing the identification of the miospore species, *Grandispora gracilis*, *Vallatisporites pusillites*, *Retusotriletes incohatus* and *Retispora lepidophyta*.

CUNHA & OLIVEIRA (1989), studied the palynostratigraphy of the Mina de São Domingos region e. g. Represa Formation and other units of the Pyrite Belt. The Represa Formation, north of Tapada Grande, provided three productive samples indicating an early late Famennian age. The poorly preserved miospore assemblage contains *Aneurospora greggsii*, *Auroraspora asperella*, *A. solisorta*, *Pustulatisporites rugulatus*, *Retusotriletes incohatus*, *R. planus* and *Rugospora flexuosa*.

In an unpublished PhD thesis, LAKE (1991) studied the palynology of the Pulo do Lobo Domain succession in Spain. The Aroche road section, in the north limb of the antiform, yielded a palynoflora comprising *Aneurospora greggsii*, *Cristatisporites inusitatus*, *C. triangulatus*, *Diducites mucronatus*, *Geminospora lemurata* and *Retusotriletes rugulatus*, indicating a Givetian to early Famennian age. The studied section was compared and correlated with the lithostratigraphic sequence of the Santa Iria Formation in Portugal. In the south limb of the antiform, LAKE (1991) studied three samples from the Chança section, located 8 km southwest of Paymogo. The miospore assemblage recovered indicated a late Givetian to early Famennian age, based on the presence of *Aneurospora greggsii*, *Cristatisporites inusitatus*, *Geminospora lemurata* and *Rugospora flexuosa*. The suited section was correlated with the Gafo Formation in Portugal.

Recent research on all the units of the domain allowed preliminary age determinations (PEREIRA & OLIVEIRA, 2006; OLIVEIRA *et al.*, 2006) which are here described in detail.

PALYNOSTRATIGRAPHY

The present study is based on 93 rock samples collected from all units of the Pulo do Lobo Domain, exposed in roads and river cuts (Fig. 1). Standard palynological laboratory procedures were employed in the extraction and concentration of the palynomorphs (WOOD *et al.*, 1996). The slides were examined with transmitted light, with a BX40 Olympus microscope equipped with an Olympus C5050 digital camera. All samples, residues and slides are stored in the Geological Survey of Portugal/INETI, S. Mamede Infesta, Portugal.

The miospore biozonal scheme used follows the standard Western Europe Miospore Zonation (after: CLAYTON *et al.*, 1977; STREEL *et al.*, 1987; HIGGS *et al.*, 1988; CLAYTON, 1996; PEREIRA, 1999; MAZIANE *et al.*, 2002). Ranges of selected spore taxa recovered and the zonal scheme used are presented in Fig. 2. Stratigraphically important and typical taxa are illustrated in Plate I.

Pulo do Lobo Formation

The unit is very well exposed along the Guadiana river and in road cuts from Corte Gafo to Amendoeira and from Corte Pinto to Serpa. The black phyllites sampled contain no organic matter, probably due to metamorphism destruction.

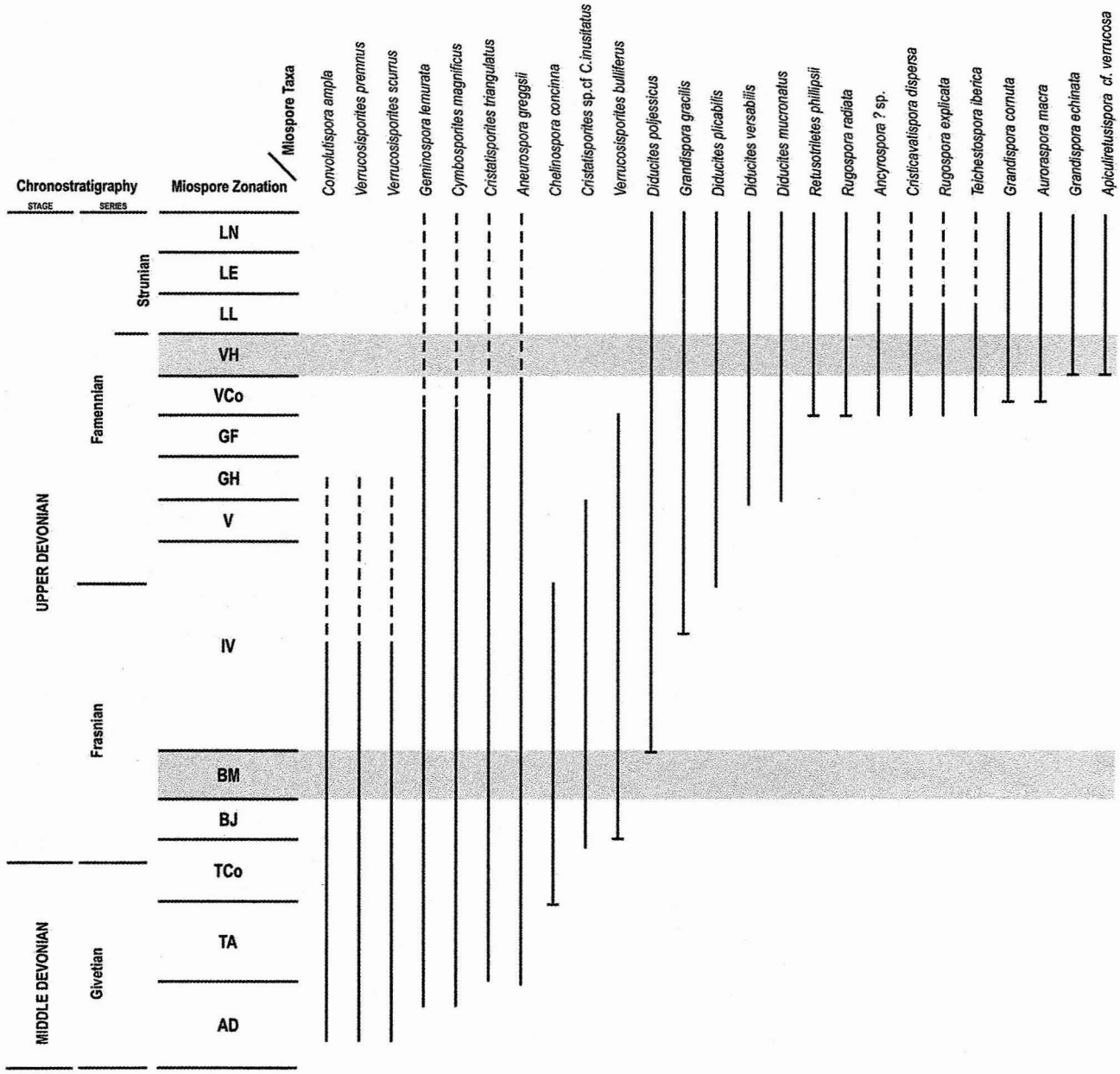

Fig. 2 – Ranges of selected miospore species found in relation to the spore biozonal scheme.

Ferreira – Ficalho Group

Ribeira de Limas Formation

This unit was sampled in a road cut section, located 100 m north of the Ribeira de Limas bridge. This section, the type section for the Ribeira de Limas Formation, is composed of black shales and phyllites, interbedded in quartzwakes. Black shales provided 5 productive samples. The assemblages are composed of poorly preserved miospores assigned to the upper part of the BM Biozone of early Frasnian age. The assemblage

includes *Aneurospora greggsii*, *Chelinospora concinna*, *Cristatisporites triangulatus*, *Cristatisporites* sp. cf. *C. inusitatus*, *Cymbosporites* sp., *Emphanisporites rotatus*, *Geminospora lemurata*, *Lophozonotriletes* sp., *Verrucosisporites bulliferus*, *V. premnus* and *V. scurrus*. All samples contain rare acritarchs and prasinophytes.

Santa Iria Formation

The Santa Iria Formation was sampled in several sections: Moinho da Vargem (Chança River) section, road cut section near Santa Iria village and Moinho da Misericórdia section, Guadiana River. In this last section the most typical facies are composed of dark laminated shales and greywackes. The dark shales revealed well preserved spore assemblages assigned to the VH Biozone of late Famennian age. The assemblages include *Grandispora echinata* that indicates the base of the biozone, together with *Ancyrospora* sp., *Apiculiretusispora* sp., *Auroraspora macra*, *Cristicavatispora dispersa*, *Diducites versabilis*, *D. poljessicus*, *Emphanisporites annulatus*, *Grandispora cornuta*, *G. famenensis*, *G. gracilis*, *Plicatispora* sp., *Punctatisporites* spp., *Retusotriletes planus*, *R. triangulatus*, *R. rugulatus*, *Rugospora explicata*, *R. radiata* and *Teichertospora iberica*. All samples contain very rich assemblages of acritarchs and prasinophytes.

Horta da Torre Formation

This unit was sampled in several road cuts, near Santa Iria village and in the Moinho da Ordem section, Guadiana River. Black shales interbedded in centimetric thick quartzite beds provided several productive samples with well preserved assemblages of miospores assigned to the basal VH Biozone of late Famennian age. The assemblages contain *Grandispora echinata* together with *Ancyrospora* sp., *Apiculiretusispora verrucosa*, *Auroraspora macra*, *Cristicavatispora dispersa*, *Diducites* spp., *Emphanisporites annulatus*, *Grandispora cornuta*, *G. famenensis*, *G. gracilis*, *Rugospora explicata*, *R. radiata* and *Teichertospora iberica*. All samples showed very rich assemblages of acritarchs and prasinophytes.

Chança Group

Atalaia Formation

The Atalaia Formation was sampled near the boundary between the Atalaia and the Pulo do Lobo formations in road cuts north of Corte Gafo de Cima and in a road section between Corte Pinto and Serpa, near Santa Luzia. This unit is characterized by alternating layers of highly deformed phyllites and quartzites. The black phyllite samples provided residual but highly mature organic matter, possibly due to the high grade of metamorphism. No palynomorph was identified.

Gafo Formation

This unit was sampled in several road sections, from Mértola to Corte Gafo de Cima, in the region north of Corte Sines (Cemetery section) and along the Chança River, in the Volta Falsa section. The dark shales provided several productive samples which yielded poorly preserved miospores assigned to the upper part of the BM Biozone of early Frasnian age. The assemblage includes *Aneurospora greggsii*, *Auroraspora* sp., *Chelinospora* sp., *Convolutispora ampla*, *Cristatisporites triangulatus*, *Cristatisporites* sp. cf. *C. inusitatus*, *Cymbosporites* sp., *Emphanisporites rotatus*, *Grandispora* sp., *Retusotriletes* sp., *Verrucosisporites bulliferus*, *V. premnus* and *V. scurrus*. All samples contain rich assemblages of acritarchs and prasinophytes.

Represa Formation

The Represa Formation was sampled along the section of the Ribeira de Vale Travessos (west of Tapada Grande, Mina de S. Domingos), where dark shales, siltstones and quartzwackes are the dominant lithologies, with rare intercalations of green and purple shales. The dark shale samples showed a rather poor miospore content. Complementary sampling was done in the MP 3 borehole, situated on the west margin of Tapada Grande, Mina de S. Domingos. This borehole cuts, among other units, the Represa Formation, for the first 80 meters, and the boundary with felsic rocks is at 88,4 m depth. Black shales interbedded in quarztwackes revealed the pres-

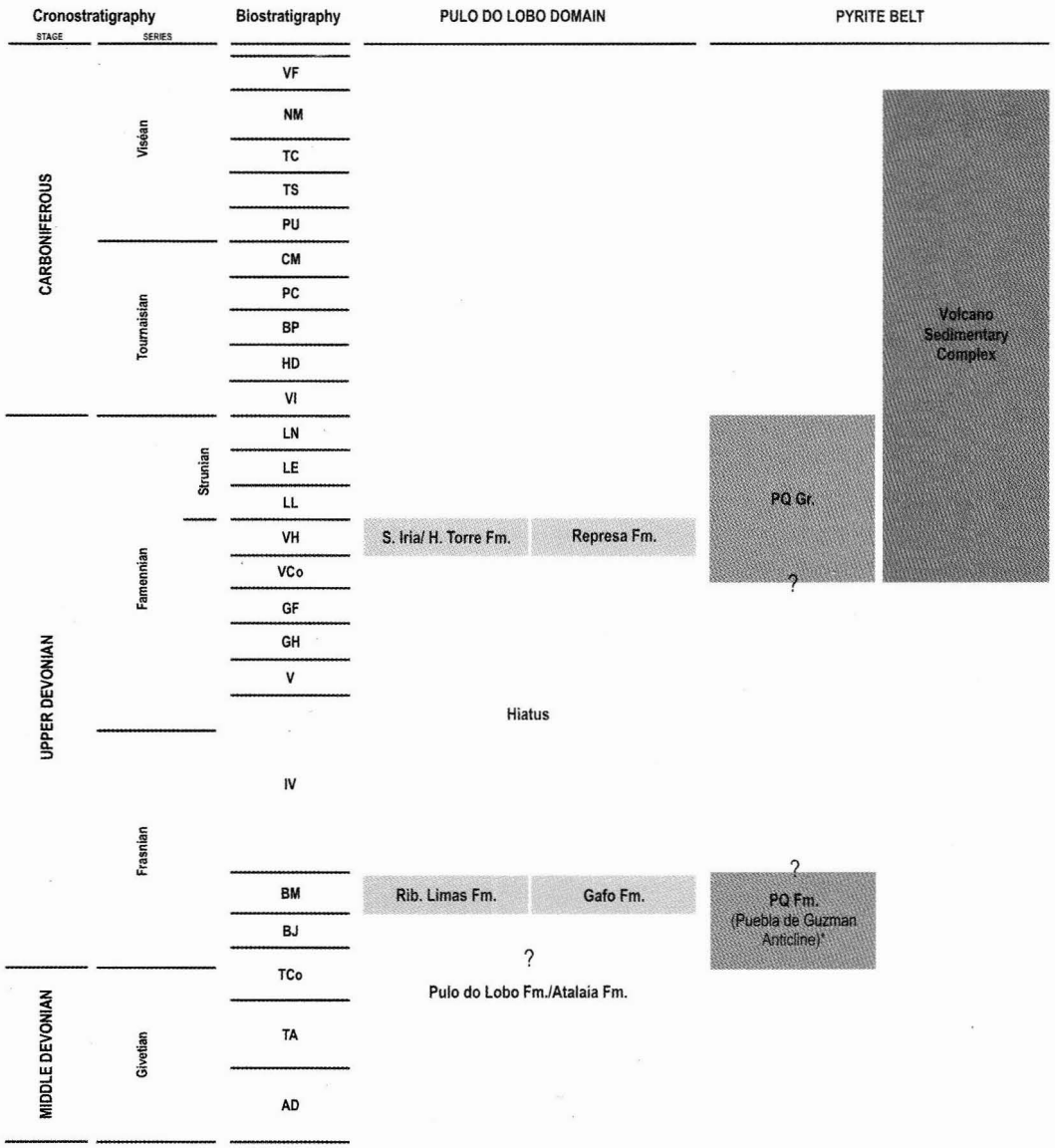

Fig. 3 – Comparison of the palynostratigraphic results obtained from the Pulo do Lobo Domain and the Pyrite Belt.

ence of well preserved miospores assigned to the basal VH Biozone of late Famennian age. The assemblage showed the presence of *Ancyrospora* sp., *Aneurospora greggsii, Apiculiretusispora* cf. *verrucosa*, *Auroraspora* sp., *A. solisorta*, *Crassispora* sp., *Cristicavatispora dispersa*, *Cymbosporites* sp., *C. triangulatus, Diducites* spp., *Emphanisporites* spp., *Geminospora lemurata*, *Grandispora cornuta, G. echinata*, *Rugospora explicata, R. radiata* and *Teichertospora iberica*. All samples contain very rich assemblages of acritarchs and prasinophytes.

Comments on the miospore assemblages

Comparison between the palynostratigraphic results obtained in the Pulo do Lobo Domain and those from the Pyrite Belt in Portugal (OLIVEIRA *et al.*, 1997; OLIVEIRA *et al.*, 2004; 2005; 2006; PEREIRA, 1999; PEREIRA *et al.*, 2006; 2007; PEREIRA & OLIVEIRA, 2006) and Spain (LAKE, 1991; GONZALEZ *et al.*, 2004; GONZALEZ, 2005) indicates a number of similarities (Fig. 3).

The age of the Phyllite-Quartzite Group, based on miospores, ranges from the early Frasnian, dated in the

Puebla de Guzman Anticline, SW Spain (GONZALEZ *et al.*, 2004), to late Strunian in Portugal (CUNHA & OLIVEIRA, 1989; OLIVEIRA *et al.*, 2004; OLIVEIRA *et al*, 2005; MATOS *et al.*, 2006).

The Puebla de Guzman Frasnian assemblage was recovered from the lower levels of the Phyllite-Quartzite Group and contains *Aneurospora greggsii, Chelinospora concinna, Cristatisporites triangulatus, Geminospora lemurata, Retusotriletes rugulatus* and *Verrucosisporites scurrus*. It is worth noting that this assemblage is similar to that found in the Ribeira de Limas and Gafo Formations.

The Volcano-Sedimentary Complex of the Pyrite Belt yielded miospores of late Famennian to mid/late Visean age (OLIVEIRA *et al.*, 1986; OLIVEIRA et *al.*, 2004; 2005; 2006; PEREIRA *et al.*, 2006; 2007). The late Famennian assemblage contains *Ancyrospora* sp., *Aneurospora greggsii, Auroraspora* spp., *Cristatisporites triangulatus, Diducites* spp., *Emphanisporites* spp., *Geminospora lemurata, Grandispora cornuta, G. echinata, G. famenensis*, and *R. radiata.* These taxa are also common presence at the late Famennian assemblages of the Iberian Pyrite Belt detrital basal unit (Phyllite-Quartzite Group) and in the Horta da Torre/Santa Iria/Represa Formations of the Pulo do Lobo Domain.

Another characteristic is the consistent presence, in both the Pyrite Belt and Pulo do Lobo domains, of the miospore species *Cristicavatispora dispersa, Rugospora explicata* and *Teichertospora iberica* lately described by GONZALEZ (2005). These species are presently only documented in the South Portuguese Zone.

The evidence clearly shows that sedimentation in the Pulo do Lobo Domain and in the Pyrite Belt was coeval, at least during the Upper Devonian.

ORGANIC MATURATION

From the palynostratigraphic samples, 17 from outcrops of the Pulo do Lobo Domain, 7 from borehole MP3 and 2 from borehole MSD1 (Fig. 1), were selected for vitrinite reflectance (VR) study in order to determine the regional maturity and to elucidate the thermal history of the area. The lithologies sampled were black to grey schists and dark phyllites from the lithostratigraphic units of the north and south limbs of the Pulo do Lobo Antiform.

Organic residues were extracted from the samples using standard cold hydrofluoric acid (HF) techniques. All the post-HF residues were mounted and polished using a method adapted from that described by HILLIER & MARSHALL (1988). Mean random vitrinite reflectance (*%Rr*) was determined using standard techniques for samples where sufficient well preserved vitrinite grains were present. Vitrinite reflectance measurements were taken using an Olympus BX51 microscope equipped with a black and white photographic camera. The black and white digital images (8-bit) of the vitrinite particles were analised using a MathLab® routine designed exclusively for vitrinite reflectance measurements. The routine calibrates a scale of 256 grey levels with standards of known reflectivity. The reflectance values of the standards used in this work were: 0.595%, 1.715%, 3.15% and 5.37%. These reflection values are for an incident light with a wavelength of 546 nm and oil immersion with a refractive index of 1.518.

Results

The vitrinite reflectance results obtained are summarised in Table 1. Palaeotemperatures for all the VR data compiled were also calculated using BARKER & GOLDSTEIN's (1990) empirical equations (Table 1). With the exception of the sample AT1, from the Atalaia Formation, there is no clear correlation between VR and the stratigraphic age of the samples. Most VR values fall between 4 - 5 *%Rr* coinciding with the onset and the lower field of a meta-anthracite coal rank and the lower epizone (Fig. 4). Standard deviations are relatively higher resulting in part from significant bireflectance at these higher maturity levels and possibly from some misidentification of some smaller organic particles in the residues. This was probably the case for some samples of the Santa Iria, Ribeira de Limas and Gafo Formations, which are rich in amorphous organic matter and the vitrinite particles are, in general, very small. Comparing the highest VR values from the data set, the measurements from the Chança Group in the south limb of the Pulo do Lobo Anticline seem slightly higher than those of the Ferreira – Ficalho Group in the northern limb, although more data are needed to ascertain this. With a value of 11.2 *%Rr*, sample AT1 is in clear contrast with VR values from the other samples, falling within the upper greenschist facies of metamorphism.

VR values measured from samples of the Pyrite Belt domain in boreholes MP3 and MDS1 are consistent with VR values measured from the Pulo do Lobo Domain (Fig. 4), especially from those measured in the Gafo and Represa units of the Chança Group.

TABLE 1

Vitrinite reflectance and palaeotemperature results. Abbreviations used: %Rr = Mean random vitrinite reflectance and STD = standard deviation. Numbers in brackets next borehole references (MP3 and MSD1) correspond to depth of the samples in meters.

Sample Reference	Formation	Age	*%Rr*	STD	No. Grains	Palaeo-temperature (°C)
HT5	Horta da Torre	Late Fammenian	4.32	0.37	100	336.1
HT9	Horta da Torre	Late Fammenian	4.39	0.5	50	338
MM1	Santa Iria	Late Fammenian	3.26	0.53	60	302.6
MM5	Santa Iria	Late Fammenian	4.95	0.65	53	352.3
MM9	Santa Iria	Late Fammenian	3.52	0.59	100	311.8
MM13	Santa Iria	Late Fammenian	3.87	0.39	55	323
RL1	Ribeira de Limas	Early Frasnian	4.47	0.62	86	340,2
RL2	Ribeira de Limas	Early Frasnian	3.98	0.51	50	326.4
EM1	Represa	Late Fammenian	5.06	0.56	67	355
EM3	Represa	Late Fammenian	4.77	0.4	100	347.9
EM8	Represa	Late Fammenian	5.1	0.5	100	353.8
MP3(75.3)	Represa	Late Fammenian	5.1	0.4	100	353.8
MP3(83.6)	Represa	Late Fammenian	5.58	0.46	100	366.6
MP3(86.8)	Represa	Late Fammenian	5.09	0.48	100	355.7
GF13	Gafo	Early Frasnian	5.12	0.59	100	356.4
GF14	Gafo	Early Frasnian	4.92	0.82	21	351.6
GF18	Gafo	Early Frasnian	3.92	0.64	51	324.6
VF6	Gafo	Early Frasnian	5.2	0.5	80	358.2
VF7	Gafo	Early Frasnian	4.59	0.6	78	343.4
AT1	Atalaia	Mid Devonian(?)	11.2	0.22	70	449.4
MSD1(55.8)	Phyllite-Quartzite	Strunian – Latest Fammenian	4.66	0.27	100	345.2
MSD1(216)	Phyllite-Quartzite	Strunian – Latest Fammenian	5.27	0.37	100	359.8
MP3(140)	VSC	Early Visean	4.94	0.34	100	352.1
MP3(295.8)	VSC	Early Visean	4.67	0.31	100	345.4
MP3(313.5)	VSC	Early Visean	4.77	0.26	100	347.9
MP3(321.1)	VSC	Early Visean	4.62	0.22	100	344.1

VR values obtained from the units of the southern part of Pulo do Lobo Domain are consistent with the metamorphic zones of MUNHÁ (1983; 1990) for the same region.

The units of the Ferreira – Ficalho Group in the north, have VR values similar to those at Gafo and Represa Formations of the Chança Group in the south. This fact, together with the age agreement of the Formations, strongly suggests that the Pulo do Lobo Domain is an anticline structure.

The high VR values observed in the Atalaia Formation, together with the absence of preserved organic matter in the Pulo do Lobo Formation suggest that both units were subjected to the same high grade of metamorphism. Due to the similarity of VR values, the time hiatus between the Ribeira de Limas/Gafo and Santa Iria-Horta da Torre/Represa Formations suggested by PEREIRA *et al.* (2006) was not detected.

The similarities of the VR values measured in the stratigraphic units of the north and south limb of the Pulo do Lobo Anticline were produced by the same maturation event that occurred in post-Late Devonian

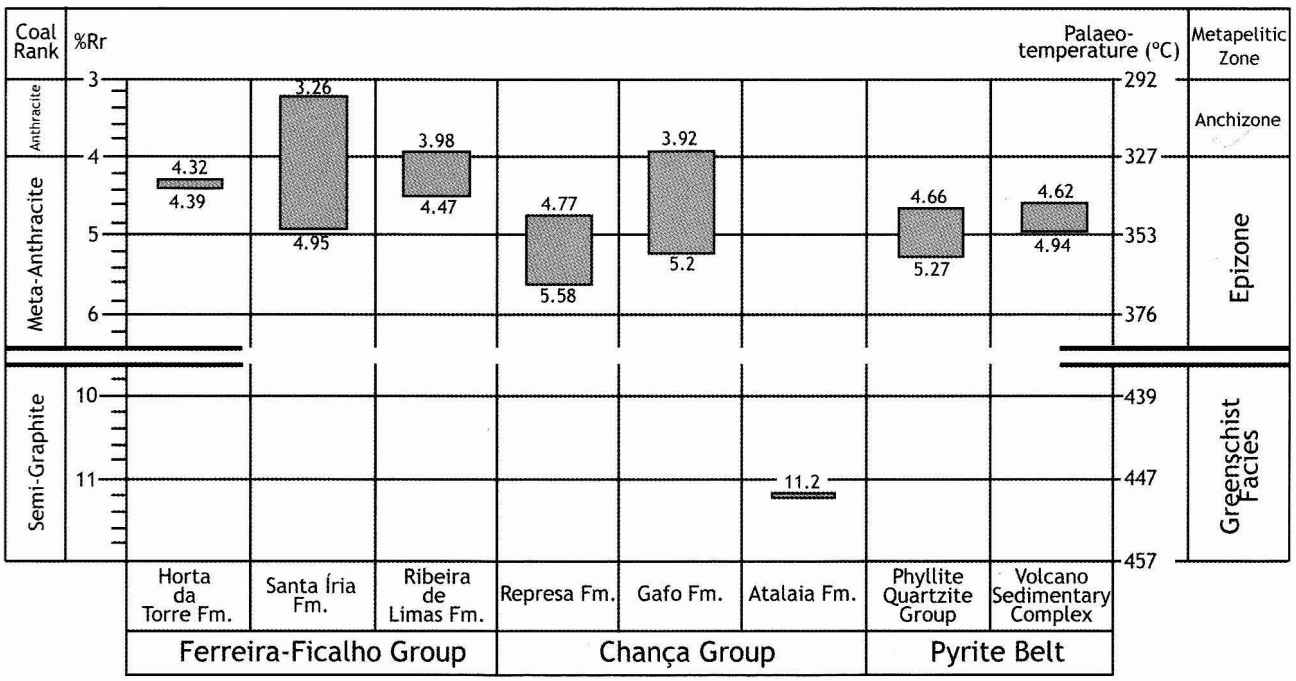

Fig. 4 – Vitrinite reflectance results from the different units of the Pulo do Lobo Domain and Pyrite Belt studied. Shaded areas indicate the range of values observed showing the highest and lowest values measured.

times. Since peak temperatures attained by the Atalaia Formation are *ca.* 100° C higher than the highest palaeotemperatures calculated from the other units, the upper greenschist facies conditions that characterise this formation could have been reached prior to the deposition of the Ribeira de Limas/Gafo Formations of Frasnian age, therefore recording an earlier thermal event, pre-Frasnian in age. However, the possibility that maturation was caused by the same thermal event everywhere in the Pulo do Lobo domain cannot be totally ruled out.

The results obtained for the Phyllite-Quartzite Formation and the Volcano Sedimentary Complex in the MP3 and MDS1 drill cores, although still very preliminary indicate that both were also affected by the same post-Upper Devonian metamorphic event.

CONCLUSIONS

The present study allows the following main conclusions:

1. No age determination was achieved for the Pulo do Lobo and Atalaia Formations, probably due to the high grade of metamorphism that affected these units. The units are surely older than early Frasnian age.

2. The Ribeira de Limas and Gafo Formations revealed the presence of moderately preserved miospore assemblages assigned to the BM Biozone of early Frasnian age.

3. The Santa Iria, Horta da Torre and Represa Formations yielded well-preserved assemblages of miospores assigned to the VH Biozone of late Famennian age.

4. The ages of Ribeira de Limas/Gafo and Santa Iria-Horta da Torre/Represa units are separated of about 14 My. This hiatus could be due to an unconformity, as suggested by previous structural interpretations, which, however, was not detected in terms of organic matter maturation.

5. VR results suggest that the Atalaia Formation (and possibly the Pulo do Lobo Formation) records an initial pre-Frasnian thermal event that reached the greenschist metamorphic facies prior to the deposition of the Gafo/Atalaia and Santa Iria-Horta da Torre /Represa Formations. These conditions were never reached by the other units of the Pulo do Lobo Domain, since maturation grades measured are lower and consistent to the meta-anthracite coal rank. The timing of this later maturation event cannot be fully constrained, however, it probably occurred in post late Devonian times (the age of the younger units of the Pulo do Lobo Domain).

6. Although restricted to the São Domingos mine area, VR values measured from the Phyllite-Quartzite and the lower units of the Volcano Sedimentary Complex of the Pyrite Belt are similar in magnitude to the VR values of the upper units of the Pulo do Lobo Domain. This indicates that the Pulo do Lobo Domain and the Pyrite Belt, in this region, have a similar thermal history, at least in post-late Devonian time.

7. The units of the Pulo do Lobo Domain have been interpreted as an accretionary prism in close relation with a northward directed (present coordinates) subduction zone. The clear contrast in terms of organic matter maturation and structural style between the Pulo do Lobo/ Atalaia Formations and the overlying units led to the conclusion that only these units incorporated in the accretionary prism (PEREIRA *et al*, 2006; OLIVEIRA *et al*. 2006). The upper units, much less metamorphosed and tectonically deformed were laid down in a basin superimposed over the accretionary prism and contemporaneous of the Iberian Pyrite Belt detritic substrate (Phyllite-Quartzite Group) and the overlying first volcanic episodes.

It is suggested that this superimposed sedimentary basin and the Pyrite Belt basin were part of the same paleogeographic realm during the Late Devonian.

ACKNOWLEDGEMENTS

This work was sponsored by the project POCI/CTE-GIN/56450/2004 (PYBE) and POCI/CTE-GEX/60278/2004 (PROVENANCE) of Fundação para a Ciência e Tecnologia, Portugal. Thanks are due to Filipe Barreira (INETI) for drawing the figures. The authors acknowledge to two anonymous referees for their helpful reviews of the manuscript.

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Artigo recebido em Maio de 2007
Aceite em Junho de 2007

PLATES

PLATE I

Miospores

Plate captions list the taxonomic name of the figured specimen, followed by the formation, sample number, slide number, microscopic coordinates and INETI/SG collection number of the specimen.

Photo 1 – *Verrucosisporites bulliferus* RICHARDSON & MCGREGOR, 1986, RL3-1, 1190-218, INETI 0701.

Photo 2 – *Cristatisporites triangulatus* (Allen) MCGREGOR & CAMFIELD, 1982, GF 13-2, 1315-165, INETI 0702.

Photo 3 – *Cristatisporites* sp. cf. *C. inusitatus* (Allen) MCGREGOR & CAMFIELD, 1982, RL3-3, 1260-228, INETI 0703.

Photo 4 – *Aneurospora greggsii* (McGregor) STREEL IN BECKER, BLESS, STREEL & THOREZ, 1974, GF13-3, 1290-100, INETI 0704.

Photo 5 – *Chelinospora concinna* ALLEN, 1965, RL1-1, 1320-205, INETI 0705.

Photo 6 – *Emphanisporites rotatus* MCGREGOR EMEND. MCGREGOR, 1973, RL2-3-1285-230, INETI 0706.

Photo 7 – *Verrucosisporites scurrus* (Naumova) MCGREGOR & CAMFIELD, 1982, GF13-4, 1275-90, INETI 0707.

Photo 8 – *Auroraspora macra* SULLIVAN, 1968, HT8-1, 1445-245, INETI 0708.

Photo 9 – *Ancyrospora* sp., HT8-1, 1440-120, INETI 0709.

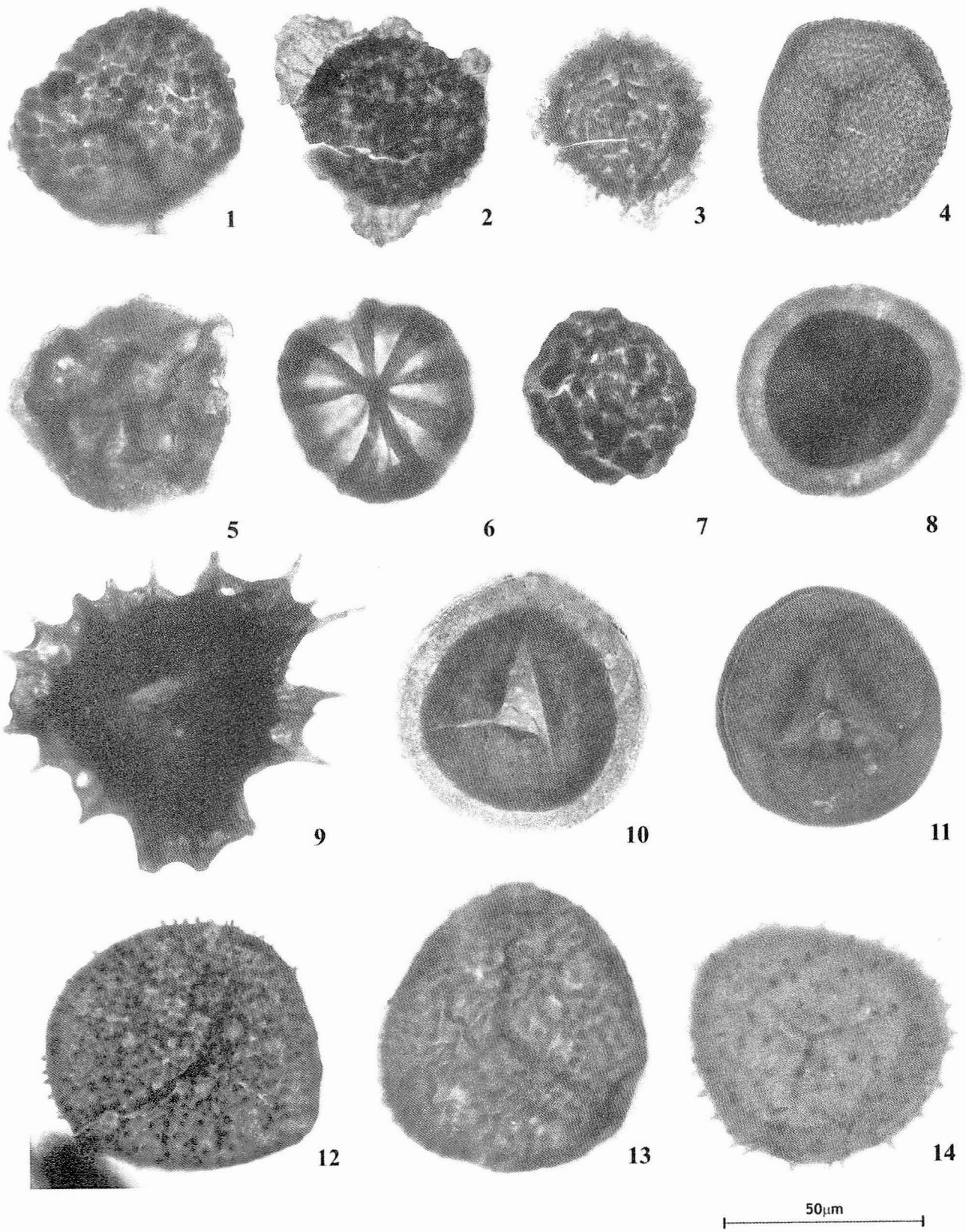
Photo 10 – *Teichertospora iberica* Gonzalez, PLAYFORD & MORENO, 2005, HT7-2b-1450-185, INETI 0710.

Photo 11 – *Retusotriletes phillipsii* Clendening, EAMES & WOOD, 1980, HT7-2a, 1395-50, INETI 0711.

Photo 12 – *Rugospora explicata* Gonzalez, PLAYFORD & MORENO, 2005, HT7-3, 1505-200, INETI 0712.

Photo 13 – *Rugospora flexuosa* (Jushko) STREEL, 1974, HT7-1a, 1390-105, INETI 0713.

Photo 14 – *Grandispora echinata* Hacquebard emend. UTTING, 1987, HT8-2, 1015-246, INETI 0714.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