Devonian and Carboniferous palynostratigraphy of the South Portuguese Zone, Portugal – An overview.

Z. PEREIRA*, J. MATOS**, P. FERNANDES*** & J. T. OLIVEIRA****

Keywords: Devonian, Carboniferous, Palynostratigraphy, South Portuguese Zone.

Abstract: The South Portuguese Zone (SPZ) represents the southern branch of the Iberian Variscides and comprehends the following geologic domains: the Pulo do Lobo Antiform, the Iberian Pyrite Belt, the Baixo Alentejo Flysch Group and the Southwest Portugal (Aljezur and Bordeira Anticlines). An overview of all the results recently achieved in palynostratigraphic research of selected sections all over the SPZ is presented. A chronostratigraphic correlation of the stratigraphic units recognized across the ZPZ and its geodynamic and palaeogeographic implications is attempted.

Palavras-chave: Devônico, Carbonífero, Palinostratigrafa, Zona Sul Portuguesa.

Resumo: A Zona Sul Portuguesa (ZSP) representa o ramo sul do Orógeno Varisco Ibérico e compreende os seguintes domínios, de norte para sul: o Antiforma do Pulo do Lobo, a Faixa Piritosa Ibérica, o Grupo do Flysch do Baixo Alentejo e o Sector Sudoeste (Anticlinais da Bordeira e Aljezur). No presente trabalho apresenta-se uma síntese dos conhecimentos palinoestratigráficos obtidos em secções seleccionadas dos vários domínios da ZSP. Os dados obtidos permitem estabelecer correlações cronooestratigráficas em toda a Zona Sul Portuguesa, contribuindo assim para o melhor conhecimento da sua evolução paleogeográfica e geodinâmica.

1. INTRODUCTION

The South Portuguese Zone (SPZ) represents the southern branch of the Iberian Variscides (Figure 1). It is almost entirely composed of Upper Palaeozoic sedimentary rocks of late Devonian to the Moscovian (Late Carboniferous) age. The following geological domains are recognized in the SPZ (OLIVEIRA, 1990): the Pulo do Lobo Antiform, the Iberian Pyrite Belt, the Baixo Alentejo Flysch Group and the Southwest Portugal (Bordeira and Aljezur Anticlines).

The boundary between the Pulo do Lobo Antiform and the Ossa Morena Zone, a major shear zone, is in several places underlined by the Beja-Acebuches Ophiolite, a remnant of an oceanic realm closure. The Pulo do Lobo Antiform is currently interpreted as a Variscan palaeo-accretionary prism (OLIVEIRA, 1990). The Iberian Pyrite Belt (IPB) was part of a late Devonian shallow siliciclastic sea that underwent crustal extention during the late Devonian (Strunian) and the lower Carboniferous giving rise to an impressive bimodal volcanism. Related with this volcanism near 90 massive sulphide deposits were formed. The Baixo Alentejo Flysch Group (BAFG) is composed of southwestward prograding sandy turbidites of Late Viséan to Moscovian age that filled a foreland basin. Finally, the Southwest Portugal Sector (SWPS) still part of the siliciclastic sea during the late Devonian, evolved to a distal carbonate/shale platform that only during the Moscovian became part of the Variscan orogeny.

The rock succession of the SPZ attracted researchers, particularly exploration companies, because of its famous IPB polymetallie massive sulphides ore deposits (e.g., the world class Neves Corvo deposit). Geological research was mainly concentrated on lithostratigraphy, petrology and geochemistry. More recently, biostratigraphy, sedi-
Fig. 1 – Geological sketch map of the South Portuguese Zone (adapted after OLIVEIRA, 1990; Geological Map of Portugal 1/500 000, Oliveira et al. 1996).
mentary geology, physical volcanism and sediment geochemistry deserved more attention and are now current fields of research.

Palynological studies of the SPZ extend back to 1980s. Palynostratigraphy was for the first time tested in several units of the SPZ as part of a mapping programme carried out by the Portuguese Geological Survey (Oliveira et al., 1986; Cunha & Oliveira, 1989). At that time palynostratigraphic work was also undertaken in the Spanish sector of the Pulo do Lobo Antiform (Giese et al., 1988; Lake, 1991). In the following years more focussed projects on the biostratigraphy were developed.

Palynostratigraphy represents the best tool to date the SPZ lithostratigraphic units, allowing reliable stratigraphic correlations across the basins and giving support to structural, palaeogeographic and geodynamic interpretations. This paper presents an overview of all results recently achieved in palynostratigraphic research of selected sections all over the SPZ. The palynology data has allowed the establishment of the general chronostratigraphic correlation chart for all the domains of the SPZ (Figure 2).

2. METHODS

The studied samples were collected in complete outcrop sections, boreholes and occasionally spot samples. In the IPB, where a large number of boreholes are available, drilled by mining and exploration companies and by the Portuguese Geological Survey. Samples were preferably collected from cores and in a few cases samples were also collected from the mine addits (e.g., Neves Corvo and Aljustrel). In the SW Sector samples were mainly collected along the costal sections of the area.

Biostratigraphic research is based on palynomorphs and standard palynological laboratory procedures were employed in the extraction and concentration of the palynomorphs from the host sediments (Wood et al., 1996). The slides were examined with transmitted light, per BX40 Olympus microscope equipped with an Olympus C5050 digital camera facility. All samples, residues and slides are stored in the Geological Survey of Portugal (LNEG – LGM). The miospore biozonal scheme used follows the standard Western Europe Miospore Zonations (after: Clayton et al., 1977; Clayton 1996; Clayton et al., 2003; Higgs et al., 1988; Higgs et al., 2000; Maziane et al., 2002; Owens, 1996; Owens et al., 2004; Stree et al., 1987; Stree, 1996). The choice of alternative schemes was stated by the presence of very consistent local miospore assemblages in South Portugal. The defined zonal taxa used for the latest Devonian and Carboniferous of the South Portuguese Zone are presented in Figure 2. Stratigraphically important and typical taxa are illustrated in Plates I and II.

3. GEOLOGICAL SETTING AND PALYNOSTRATIGRAPHIC FRAMEWORK OF SPZ

This section deals with the stratigraphic palynology of all sections, boreholes and spot samples studied by the authors. Description of the new palynological data is presented here. In case of previously published data only a brief review is presented.

3.1. Pulo do Lobo Antiform

The Pulo do Lobo Domain is an antiformal structure located in the northern part of the SPZ, when it is in direct contact with the Ossa Morena Zone (OMZ). In the core of the structure crops out the Pulo do Lobo Fm. and is composed of phyllites, quartzites, minor felsic volcanics and amphibolites (former basalts) with MORB-type geochemical affinity at the lower part (Munha, 1983; Eden, 1991; Quesada et al., 1994).

In the north limb of the structure, the Ferreira-Ficalho Group (Figure 3) includes from base to top the following units (Carvalho et al., 1976; Oliveira et al., 1986; Giese et al., 1988; Oliveira, 1990; Eden, 1991; Quesada et al., 1994): the Ribeira de Limas Fm. is composed of phyllites, quartzwakes and minor intercalations of tuffites with a tectonic deformation similar to that of the Pulo do Lobo Fm.; the Santa Iria Fm. is made up of greywackes, siltstones and shales, forming a flysch-like succession; and the Horta da Torre Fm. is composed of dark shales, impure sandstones, siltstones and quartzite beds with strong bioturbation. The Santa Iria and Horta da Torre Fms. are affected by a main folding phase with associated cleavage. The group thickness is unknow, but estimated at 500 m.

The south limb of the structure is represented by the Chanca Group (Figure 3), which comprises the following units (Pfefferkorn, 1968; Silva, 1989; Cunha & Oliveira, 1989; Oliveira, 1990; Silva et al., 1990): the
Fig. 2 – Latest Devonian and Carboniferous of SPZ. (1. Western European Miospore Zonation (CLAYTON et al., 1977; CLAYTON 1996; CLAYTON et al., 2003, HIGGS et al., 1988; HIGGS et al., 2000; MAZANE et al., 1999; OWENS, 1996; OWENS et al., 2004; STREEL et al., 1987; STREEL, 1996); 2. South Portugal miospore Zonation (PEREIRA, 1999); 3. Defined guide taxa used for the latest Devonian and Carboniferous of the South Portuguese Zone (PEREIRA et al., 2007; Present work)).
Atalaia Fm. composed mostly of phyllites and quartzites, sharing with the Pulo do Lobo Fm. the same type of tectonic deformation; the Gafo Fm. made up of a thick pile of greywackes siltstones and shales forming a flysch succession, with intercalations and intrusions of felsic and mafic volcanics showing two main episodes of NW trending folds and related cleavages; and the Represa Fm. which is composed of siliceous siltstones, shales, greywackes and minor intercalations of fine volcanogenic sediments. The group thickness is estimated at 1100 m.

The overall structure has been interpreted as an anticline (SCHERMERHORN, 1971; CARVALHO et al., 1976; OLIVEIRA et al., 2006; PEREIRA & OLIVEIRA, 2006; PEREIRA et al., 2006a, b) 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).

3.1.1. Pulo do Lobo palynostratigraphy

The Pulo do Lobo Antiform units were recently investigated for palynostratigraphy (PEREIRA et al., 2006, Figure 2, 3). No age determinations were achieved for the Pulo do Lobo and Atalaia Fms., probably due to the high grade of metamorphism that affected these units, however the sequence is older than early Frasnian. The
Ribeira de Limas and Gafo Fms. revealed the presence of moderately preserved miospore assemblages assigned to the BM Biozone of lower Frasnian age. The assemblage includes Aneurospora greggsii, Chelinospora concinna, Cristatisporites triangularis, 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.

The Santa Iria, Horta da Torre and Represa Fms. yielded well-preserved assemblages of miospores assigned to the VH Biozone of late Famennian age (PEREIRA et al., 2006a,b). The assemblages include abundant Grandispora echinata which indicates the base of the biozone, together with Ancyrospora sp., Ancyrospora? implicata, Apiculiretusispora sp., Auroraspora macra, Cricicavatispora dispersa, Diducites versabilis, D. poljessicus, Emphanisporites annulatus, Grandispora cornuta, G. farnenensis, G. gracilis, Plicatispora sp., Punctatisporites spp., Retusotritelites planus, R. triangularis, R. rugulatus, Rugospora explicata, R. radiata and Teichertospora iberica. All samples contain very rich assemblages of acritarchs and prasinophytes.

The early Frasnian and late Famennian ages of the Ribeira de Limas/Gafo sequence and Santa Iria-Horta da Torre/Represa sequences indicate they are separated of about 14 My. This fact reinforces previous structural interpretations that suggested the existence of an unconformity between the Santa Iria/Horta da Torre Fms. and sediments. The South branch refers to the rooted anticlines and extends from the Pomarão Anticline (west) to Mina de São Domingos mine (at the east) (V. OLIVEIRA et al., 1998a, b; MATOS et al., 1998, 2000, 2003). This branch incorporates both autochthon sections, where it is possible to identify the VSC sequence over lain by the Freixial Fm. turbidites, and allochthon sections composed of several tectonic sheets that include PQG sediments and VSC volcanics and sediments. The South branch refers to the rooted anticlines and extends from the Pomarão Anticline (west termination of the Puebla de Guzmán Anticline in Spain) through the Neves Corvo-Rosário Anticline to the Lousal Region (Figure 4). Conformably above the VSC is a turbidite succession, known as Mértola Fm. which is the lower unit of the Baixo Alentejo Flysch Group (BAFG).

3.2. Iberian Pyrite Belt

In general terms, the stratigraphy of the Iberian Pyrite Belt (Figure 4) consists of two major units, the Phyllite Quartzite Fm. (PQG) and the Volcanic-Sedimentary Complex (VSC). The PQG is dated as late Devonian age by ammonoids, conodonts and palynomorphs (BOOGAARD, 1967, FANTINET et al., 1976; CUNHA & OLIVEIRA, 1989; OLIVEIRA et al., 1997; OLIVEIRA et al., 2004, PEREIRA et al., 2004). The PQG forms the detritic basement and is composed mostly of phyllites, quartzites, quartzwackes and shales with intercalations of limestone lenses and nodules at the upper part of this unit, which as a whole were laid down in a marine siliciclastic platform. The thickness is in excess of 200m (base not known). The VSC is dated as late Devonian to late Viséan age principally on palynomorphs and rare conodonts (OLIVEIRA, 1990; OLIVEIRA et al., 1997, OLIVEIRA et al., 2004; PEREIRA et al., 2004). The VSC incorporates several episodes of intrusive and extrusive volcanism, with dominant rhyolites, dacites, basalts and minor andesites, and intercalations of black shales, siltstones, minor quartzwackes, siliceous shales, jaspers and cherts and a purple shale member at the upper part of the complex. The thickness is variable, from few tens of meters to more than 1000m. The VSC was laid down in a deep submarine environment.

Regionally the belt is divided into two branches (OLIVEIRA, 1990): the North and the South branch (Figure 4). The North branch extends from Palma (Alcácer do Sal), below the Cenozoic sediments of the Sado Basin (at the west), to Mina de São Domingos mine (at the east) (V. OLIVEIRA et al., 1998a, b; MATOS et al., 1998, 2000, 2003). This branch incorporates both autochthon sections, where it is possible to identify the VSC sequence overlain by the Freixial Fm. turbidites, and allochthon sections composed of several tectonic sheets that include PQG sediments and VSC volcanics and sediments. The South branch refers to the rooted anticlines and extends from the Pomarão Anticline (west termination of the Puebla de Guzmán Anticline in Spain) through the Neves Corvo-Rosário Anticline to the Lousal Region (Figure 4). Conformably above the VSC is a turbidite succession, known as Mértola Fm. which is the lower unit of the Baixo Alentejo Flysch Group (BAFG).

3.2.1. Iberian Pyrite Belt palynostratigraphy

The selected lithostratigraphic sections investigated for palynostratigraphic purposes are depicted in Figure 4. In the North branch three sections were studied, i.e., Albernôa, Serra Branca and Mina de São Domingos. The palynomorph assemblages were recovered mostly from drill cores, complemented with outcrop samples. Within the autochthon successions, moderately preserved miospore assemblages were identified in shales interbedded in the lower part of the VSC and doubtly in shales of the PQG (Albernôa). These assemblages are assigned to the VCo and VH Bizones of late Famennian
Fig. 4 – Synthetic stratigraphic columns selected from the Pyrite Belt (adapt. OLIVEIRA et al., 2006).
age. The VCo assemblage contain the zonal species *Grandispora cornuta* and *Auroraspora sp.*, *Diducites sp.*, *Emphanisporites rotatus*, *Geminospora lemurata*, *Punctatisporites sp.*, *Retusotriletes planus*, *R. rugulatus* and *Rugospora radiata*. The VH assemblage is defined by the presence of the key specie, *Grandispora echinata* and includes the taxa *Auroraspora sp.*, *Diducites poljessicus*, *D. versabilis*, *Emphanisporites rotatus*, *Geminospora lemurata*, *Grandispora cornuta*, *Punctatisporites sp.*, *Retusotriletes phillipsii*, *R. planus*, *R. triangulatus*, *Rugospora expilcata* and *R. radiata*. All assemblages contain abundant acritarchs and prasinophytes.

Higher in the VSC, palynomorph assemblages obtained from black shales are assigned to the Pu Biozone and comprises the zonal species *Lycospora pusilla* in association with *Auroraspora macra*, *Convoluitisporites sp.*, *Densosporites sp.*, *D. spitsbergensis*, *D. brevispinosum, Dicryotriletes castaneiformis*, *Discernisporites micromanifestus*, *Knoxiosporites cf. triradiatus*, *Vallatisporites pusillites*, *V. galearis*, *V. verrucosus*.

At the top of the autochthon grey shales, siltstones and thin bedded greywackes of the Freixial Fm. yielded moderately preserved miospore miospores of the NM Biozone of mid late Viséan. The NM biozone assemblage is defined by the presence of the zonal specie *Raistrickia nigra* and abundant taxa such as *Ahrensosporites sp.*, *Anaplanisporites sp.*, *Crassispora trychera*, *Densosporites sp.*, *D. brevispinosum, D. intermedius*, *Knoxiosporites triradiatus*, *Leiotriletes tumidus*, *Lycospora pusilla*, *Microreticulatisporites sp.*, *Vallatisporites vallatus* and *Waltispora sp.* In Serra Branca the NM assemblage recovered from the Freixial Fm. also contains taxa such as *Emphanisporites rotatus*, *Geminospora sp.*, *Retispora lepidophyta*, *Rugospora radiata* and *Vallatisporites verrucosus*, which are interpreted as reworked miospores of late Famennian age.

In the allochthon, shales ascribed to the PQG yielded moderately to well preserved miospore assemblages assigned to the VCo and VH Miospore Biozones. The VCo Biozone assemblage includes the type species *Grandispora cornuta* and abundant specimens of *Auroraspora macra*, *Cristatisporites triangulatus*, *Diducites versabilis*, *D. poljessicus*, *Emphanisporites annulatus*, *Geminospora lemurata*, *Retusotriletes planus*, *R. triangulatus, R. rugulatus* and *Rugospora radiata*. Reworked Frasnian miospores (*Cristatisporites sp.*, *Contagiosporites optivus*, *Aneurospora greggsii*, *Verrucosisporites premnus* and *V. scurrus*) are well represented in the VCo assemblages. The VH Biozone is marked by the abundant presence of *Grandispora echinata* together with *Ancyrospora sp.*, *Auroraspora macra*, *Cristatisporites triangulatus*, *Grandispora cornuta*, *Emphanisporites annulatus*, *Geminospora lemurata*, *Retusotriletes planus*, *R. triangulatus, Raistrickia variabilis*, *Rugospora radiata*, *Spelaeotriletes sp.* and *Vallatisporites pusillites*. Acritarchs and prasinophytes are well represented in the assemblages. Reworked Frasnian miospores are also documented in the VH assemblages.
(2) The age of the VSC ranges from the late Strunian to early late Viséan. The LN, TS and NL Miospore Biozones are identified. The LN Biozone is marked by the presence of well preserved and abundant specimens of Auroraspora macra, Densosporites spitsbergensis, Geminospora spongianta, Grandispora cornuta, G. echinata, Knoxiosporites literatus, Leiotritiles struniensis, Retispora lepidophyta, Retusotriletes incohatu, Rugospora radiata, Tumulispora malevkensis, Vallatisporites pusillites and Vallatisporites verrucosus together with the index species Verrucosisporites nitidus. Rare specimens of Aratrisporites saharaensis also occur. Acritarchs and prasinophytes are very common in the assemblage. The TS Biozone is defined by the presence of the key species Knoxiosporites triradiatus and K. stephanephorus. Other taxa present include Anapiculatisporites sp., Convoluitispora nigrata, Densosporites rarispinosus, Diatomsomonzonotrites sp., Dictyotriletes propius, Hymenozonotriletes caperatus, Knoxiosporites hederatus, Microreticulatisporites concavus, Proprisporites sp., Spelaeotriletes pretiosus, S. arenaceus, Vallatisporites pusillites and V. galearis. Reworked Tournaisian palynomorphs are present. The NL Biozone, a local biozone defined by the fist occurrence of Raistrickia nigra (see the details described in the SSP below). Other taxa include Convoluitispora sp., Densosporites rarispinosus, D. annulatus, Diatomozonotrites sp., Knoxiosporites hederatus, K. triradiatus, K. stephanephorus, Leiotritiles sp., Lycospora pusilla, Microreticulatisporites concavus, Proprisporites sp. and Vallatisporites ciliaris;

(3) The Mértola Fm. flysch sediments yielded poorly to moderately preserved miospores assemblages assignable to the Biozones NL, SN and NC Miospore Biozones of the late Viséan. The NL Biozone includes the guide species Raistrickia nigra and also common specimens of Densosporites rarispinosus, D. annulatus, Diatomozonotrites sp., Knoxiosporites hederatus, K. triradiatus, K. stephanephorus, Leiotritiles sp., Lycospora pusilla, Microreticulatisporites concavus and Proprisporites laevigatus. Reworked Viséan and Tournaisian palynomorphs were also determined. The SN Biozone, a local zone, was defined by the presence of abundant Anaplanisporites baccatus, Densosporites intermedius, D. brevispinosus, Lycospora pusilla, Knoxiosporites triradiatus, K. stephanephorus; Raistrickia nigra, Savitisporites nux and rare Rotaspora fracta, Diatomozonotrites sp. and Triquitriles marginatus. The NC Biozone is characterized by the first occurrence of Bellisporites nitidus together with abundant species of Crassispora maculosa, Convoluitispora venustana, Diatomozonotrites sp., Dictyotriletes sp., Leiotritiles tumidus, Rotaspora fracta and Savitisporites nux. In the entire studied NC assemblages reworked Strunian and Tournaisian miospores are common. The Mértola Fm. also yielded the goniatites Goniatites hudsoni and G.? globostriatus of late Viséan A age and Arnsbergites arnsbergensis, Arnsbergites falcatus and Hibernicoceras, which indicate the late Viséan B confirming the results provided by the palynomorphs in the Neves Corvo mine region (Oliveira et al., 2004);

(4) Three stratigraphic hiatuses are recognized, embracing the early to middle Strunian, the Tournaisian and the early Viséan. These hiatuses appear related to a southwestward progressive unconformity;

(5) Precision of the biostratigraphic dating of the massive sulphide orebodies that are intercalated in latest Famennian (late Strunian) black shales. These age determinations proved that all of the lithostratigraphic units are involved in a pile of tectonic sheets (Figure 4).

The Pomarão anticline exposes a complete lithostratigraphic section of the Portugueses Pyrite Belt (Figure 4). Here, only shales of the lower part of the sequence (Nascedios Member of the PQG) yielded miospores assigned the LL Biozone of late Strunian age (Oliveira et al., 2006). Assemblage comprises moderately preserved specimens of Auroraspora sp., Diducites sp., Emphanisporites rotatus, Knoxiosporites literatus, Retispora lepidophyta and Retusotriletes sp., rare acritarchs and prasinophytes are also present. The overlying VSC is composed of three volcanic episodes and interbedded sediments. Until now no biostratigraphic age was obtained for VSC succession.

In the Lousal/Azinheira de Barros/Mina da Caveira region the Pyrite Belt develops complex antiformal structures. The age of the lithostratigraphic units is still poorly constrained. Only shales of the PQG, recovered from a road cut north of Azinheira de Barros village provided a moderately preserved miospore assemblage that contains Verrucosisporites nitidus, the index species and the following taxa Crassispora sp., Densosporites spitsbergensis, Geminospora lemurata, G. spongianta, Punctatisporites sp., Retispora lepidophyta, Rugospora radiata and Vallatisporites sp. that indicate the LN Biozone. The VSC shows two main volcanic
suites: one dominated by felsic volcanics, shales and intrusive diabases; the other composed mostly of basic volcanics and intrusives. The VSC suite is followed by the Mértola Fm. turbidites that yielded a moderately preserved miospore association *Crassispora* sp., *Densosporites* sp., *Lycospora pusilla*, *Microreticulatisporites concavus*, *Proprisporites* sp. and *Waltzispora planiangulata*, in association to the nominal species *Raistrickia nigra*. This assemblage is assigned to the NL Biozone of mid late Viséan.

Palynostratigraphic research in the Cercal anticline (westernmost Iberian Pyrite Belt) is currently being studied. The lithostratigraphic sequence is still poorly constrained in terms of lithology and age, and only very recent and limited data is available. The investigated Elf Aquitaine boreholes, located in the antiform central sector, SW of Salgadinho, revealed the VSC Cercal felsic volcanics, a large sequence (>250m) of dark grey shales, with siltitic intercalations and minor quartzwakes and quartzites. These shales yielded very well preserved specimens of *Grandispora echinata* together with *Ancyrospora* sp., *Apiculiretusispora* sp., *Auroraspora macra*, *Cristicavatispora dispersa*, *Diducites poljessicus*, *D. mucronatus*, *D. versabilis*, *Emphanisporites annulatus*, *Grandispora cornuta*, *Punctatisporites* sp., *Retispora macroreticulata*, *Retusotriletes phillipsii*, *R. planus*, *R. triangulatus*, *R. radiata*. This assemblage indicates the VH Biozone of late Famennian age. All samples studied contain rich assemblages of acritarchs and prasinophytes. This assemblage is similar to those described for the Neves Corvo and Mina de São Domingos mines (Pereira 2006a,b inc. ref.). No Carboniferous palynomorph assemblages have been identified here, only at the Neves Corvo mine region) based on the first occurrence of the index species *Retusotriletes rugulatus* and *Bellispores nitidus*. This assemblage indicates the VH Biozone of late Famennian age. All samples studied contain rich assemblages of acritarchs and prasinophytes. This assemblage is similar to those described for the Neves Corvo and Mina de São Domingos mines (Pereira 2006a,b ref.). No Carboniferous palynomorph assemblages have been identified until now. This data confirm the antiform Cercal structure and will be compared with the upper sequences of the VSC, located in the eastern and western antiform sectors.

In the Spanish region of Gerena, in the eastern part of the Val Verde del Camino anticline, the PQG was dated early Frasnian base on a moderate preserved assemblage of miospores that includes *Chelinospora concinna*, *Cristatisporites triangulatus*, *Geminospora lemurata*, *Retusotriletes rugulatus*, *Aneurospora greggsii* and *Verrucosisporites scurrus* (Lake, 1991; Gonzalez et al., 2004; Gonzalez, 2005). These assemblages are analogous to those recovered in the Pulo do Lobo Antiform (Ribeira de Limas and Gafo Fms.) and also the reworked assemblage recovered in the upper part of the PQG in the Neves Corvo mine region.

### 3.3. The Baixo Alentejo Flysch Group

The Baixo Alentejo Flysch Group (BAFG) comprises mostly gravity flow sediments that form a continuous and southward prograding unit (Figure 1). Sedimentological and palaeontological data of the GFBA indicate it consists of three formations, the Mértola, Mira, and Brejeira Formations (Oliveira et al., 1979; Oliveira, 1983; Oliveira & Wagner-Gentis 1983). The stratigraphic palynology of the Baixo Alentejo Flysch Group, although still very incomplete, has been provisionally established. The miospore ages are consistent with ammonoid data recovered from all the BAFG units (Korn, 1997).

### Mértola Formation

The Mértola Fm. was studied for palynomorphs in several regions: such as the Neves Corvo mine, Mértola town, Azenhas section in Guadiana River, Bens Farm, and are give a late Viséan age (Oliveira et al., 2007; Pereira et al., 2007). Three miospores biozones of late Viséan age are identified: the NL and SN Biozones, defined as local Miospore Biozones (see the details described in the SWSP below) based respectively on the first occurrence of the index species *Raistrickia nigra* and *Savitrisporites nux*, and the NC Biozone (recognized only at the Neves Corvo mine region) based on the first appearance of the key species *Bellispores nitidus*.

### Mira Formation

The age of Mira Fm. is late Viséan to early Bashkirian, based on the ammonoids *Dombarites*, *Lyrogoniatites* and *Cravenoceras* (Oliveira et al., 1979; Korn, 1997). Palynostratigraphic data are scarce at the present time and are only restricted to black shale samples obtained in the Castro Marim region. These samples yielded late Viséan NC miospore Biozone assemblages that contain the key species *Bellispores nitidus*.

### Brejeira Formation

The youngest unit of the BFGA is the Brejeira Fm. The palynostratigraphic study of this unit revealed 6 miospore biozones, ranging from the Bashkirian to late Moscovian (Pereira 1997; 1999; Figure 5, 6). These miospore ages are consistent with the local ammonoid biozonation (Korn, 1997).
Fig. 5 – Selected stratigraphic section from Brejeira Fm. (Adapt. PEREIRA, 1999).
The base of the Brejeira Fm., in the north part of its outcrop area indicates the FR miospore Biozone of the mid Bashkirian age, which contains the index specie *Reticulatisporites reticulatus* and the *Dyctiotritetes probireticulatus* in the upper part of the zone. Further south, miospore assemblages are successively assigned to the following: SS Biozone characterized by the index specie *Cirratriradites saturni*; Ra Biozone assemblage containing *Radiizonates aligerens*; Ra/NJ biozonal boundary was only identified in Pincho Road section and is marked by the first occurrence of *Florinites junior*; the SL Biozone was identified based on the first appearance of *Torispora securis*, the presence of *Cadiospora magna* and upper in the series by the incoming of the index taxa *Raistrickia aculeata*; the OT Biozone is marked by the occurrence of *Thysmospora psedothiessenii*, and the common presence of *T. obscura* and *T. thiessenii*. This distribution of the palynological assemblages, confirms the southwestward progradation of the turbidites. The Variscan tectonic deformation in this sector is Kasimovian in age.

### 3.4. Southwest Portugal Sector (SPS) (Bordeira and Aljezur Anticlines)

The stratigraphic succession of this sector was given in Oliveira et al. (1985), Oliveira et al. (1986), Ribeiro et al. (1987), Pereira (1997, 1999) and Korn (1997). Four successive formations were identified in SPS, from

![Geological Map of Aljezur and Bordeira Antiforms in SWPS](http://example.com/map.png)
base to top, the Tercenas, Bordalete, Murração and Quebradas Formations, of which the latter three are combined to form the Carrapateira Group (Figure 6). Detailed palynostratigraphic research has allowed the establishment of 12 miospore biozones, with 47 late Devonian and more than 200 Carboniferous miospore species documented (PEREIRA et al., 1994; PEREIRA et al., 1995; PEREIRA, 1997; 1999). These palynostratigraphic results correlate well with the local ammonoids biozonation (KORN, 1997).

**Tercenas Formation**

The Tercenas Fm. (base unknown) comprises dark marine shales with interbedded thin sandy tempestites which grades upward to a 10m thick tidal sandstone body. Rare clymenids, brachiopods and corals suggest a late Famennian to early Tournaisian age for this unit (OLIVEIRA, 1990). The palynological study reveals a diverse well preserved miospore assemblages assignable to the LN miospore Biozone of late Strunian age and VI miospore Biozone of early Tournaisian age (Figure 7). The LN Biozone is characterized by the common presence of Densosporites spitsbergensis, Dictyotriletes fimbriatus, Knoxiosporites concentricus, Retusotriletes crassus, Retispora lepidophyta, Rugospora radiata, Vallatisporites pusillites, Vallatisporites verrucosus, Tumulispora rarituberculata and the key specie Verrucosisporites nitidus. All samples suited contain rich assemblages of acritarchs and prasinophytes.

**Bordalete Formation**

The Bordalete Fm. is a monotonous succession of dark grey to black shales and siltstones, which frequently contain phosphatic nodules. Goniatites are randomly distributed within the Bordalete Fm., and being concentrated at certain horizons and where they belong to only one species, Becanites algarbiensis (PRUVOST 1914; KORN, 1998). In terms of palynostratigraphy, the Bordalete Fm. allowed the identification of the VI, HD and PC Miospore Biozones of Tournaisian age (Figure 7). The VI miospore Biozone (recognized in the Eirinhas-Rizada-Penedo Road section, Monte do Penedo and Pedra Ruiva sections) is marked by the presence of the index specie Vallatisporites verrucosus together with the common presence of Cyrtospora cristifera, Puctatisporites irrasus, Retusotriletes incohatus, Secarispores sp. and Tumulispora malevicensis. The base of HD biozone, marked by the first incoming of the index taxa Cristatisporites hibernicus, identified in the Eirinhas-Rizada-Penedo Road section, is also characterized by the first appearance of the distinctive species Umbona-tisporites distinctus and Neoraistrickia cymosa. A typical, diverse and very well preserved PC miospore Biozone assemblage was recovered from several sections of the Bordalete Fm. The zone is defined by the presence of the guide specie Spelaeotriletes pretiosus together with Auroraspora macra, K. cf. triradiatus, Granulatisporites microgranifer, Neoraistrickia cymosa, N. logani, Rais-trickia clavata, Spelaeotriletes balteatus, Vallatisporites microspinus, V. vallatus, V. verrucosus, Verrucosispo-rites congestus, V. irregularis and V. nitidus (Figure 7). At the top of this unit the CM miospore Biozone of late Tournaisian age is missing, probably due to the presence of a hiatus. These palynostratigraphic data exclude the existence of a basal hiatus as previously suggested (OLIVEIRA et al., 1985).

**Murração Formation**

The Murração Fm. is composed of two members. The lower Pedra das Safias Member, has a thickness of 25 metres and is composed of grey shales with rhythmic marly carbonate and dolomitic intercalations. The member has yielded a few fragmentary macrofossils of corals and trilobites, including large but poorly preserved specimens of Merocanites sp., indicating an early to middle Viséan age. The upper Vale Figueira Member has a thickness of 32 metres and is best exposed at the Atlantic coast, near Carrapateira village. Strongly weathered successions of the formation also occur in the area of Aljezur and Bordeira. However in the Quebradas beach section, the Vale Figueira Member is well exposed and in non-weathered conditions. Here, it is composed of dark-grey or black shales, and nodular and sometimes dolomitic limestones. The succession contains scarce benthic faunas, restricted to certain levels characterized by rare trilobites, brachiopods, echinoderms and rugose corals. The section is also extremely rich in goniatites and bivalves such as Posidonia becheri BRÖNN, 1828, of late Viséan age. The following goniatite zones were identified (KORN, 1997): hudsoni Zone (fauna with Goniatites hudsoni), crenistia Zone (fauna with Beyrichoceras sp.),
Fig. 7 – Selected stratigraphic sections from Aljezur and Bordeira Anticlines, Southwest Portugal Sector (SWPS).
Tripartites stratigraphically useful taxa such as *Goniatites spinifer* and *Goniatites fimbriatus*, gracilis Zone (fauna with *Hiberniceras carraunense*) and postriatum Zone (fauna with *Lusitanoceras algarviense*). The Murração Fm. has been interpreted as a deep open-marine, pelagic carbonate platform in front (to the south) of the flysch basin (OLIVEIRA et al., 1985; HERBIG et al., 1999).

The palynostratigraphic study of the Murração Fm. has recognized 5 miospore biozones of Viséan age (PEREIRA, 1999; Figure 2, 7). The study of the Pedra das Safias Member proved to be very difficult due to the strong dolomitization. Only in the Aljezur Anticline, in the Marianos and Corte da Velha sections (Figure 7), where the unit has a more shaly character, it has been possible to identify the base of the Pu miospore Biozone, based in the first appearance of *Lycospora pusilla* and the base of TS Biozone, by the first appearance of *Knoxisporites triradiatus* and *K. stephanephorus*. These two miospore biozones indicate an early Viséan age for the Pedra das Safias Member.

The Vale Figueira Member, in Praia das Quebradas section (Figure 7) has yielded moderately preserved miospore assemblages assignable to the NL, SN, and NC Biozones of late Viséan age. Two zones were defined as local miospore Biozones, the NL (*Raistrikia nigra* – Propisporites laevigatus) and SN (*Savitrisporites nux*) based respectively, on the first occurrence of *Raistrikia nigra* and *Savitrisporites nux* guide taxa (Figure 2). These biozones were defined due to the absence of stratigraphically useful taxa such as *Rotaspora* spp., *Tripartites* spp. and *Triquiritites* spp. Nevertheless, the NL biozone can be correlated with the *Raistrikia nigra* – *Triquiritites marginatus* Miospore Biozone of Western Europe based in the first appearance of *Raistrikia nigra* that occurs at the same level. *Propisporites laevigatus* appears together with the first *R. nigra* in southwest Portugal, but in Western Europe the first record of this specie is much higher, at the top of NC Biozone of late Viséan to early Serpukhovian (CLAYTON et al., 1977, CLAYTON, 1996). The SN local biozone can be correlated with the VF miospore Biozone of Western Europe, based in the first occurrence of *Savitrisporites nux*. In Western Europe, in addition to *S. nux*, the *Tripartites vetustus* Biozone is defined by the first appearance of a group of new species which includes *Tripartites vetustus*, *Tripartites nonguerikei*, *Rotaspora fracta* and *R. knoxi*, which are not represented in the late Viséan of southwest Portugal (CLAYTON et al., 1977; CLAYTON 1996).

The basal part of the NC Biozone is marked by the presence of the guide species *Bellispores nitidus*, which was recognized in the Quebradas Beach section. The assemblage also contains the species *Crassispora maculosa*, *Mircoreticulatus concavus*, *Propisporites laevigatus*, *Raistrikia nigra* and *S. nux*.

The palynostratigraphical evidence indicates that the entire Viséan may be represented in the Murração Fm. (PEREIRA 1997, 1999).

**Quebradas Formation**

The Quebradas Fm. has a thickness of approximately 70 metres and is mainly composed of black shales with intercalated carbonate and phosphoritic layers, lenses and nodules (Figure 7). This unit is rich in fossils, and several carbonatic horizons contain distinctive ammonoid assemblages (OLIVEIRA et al., 1985; KORN, 1997).


The moderately preserved miospore assemblages recovered from Quebradas Fm. are assigned to the Bashkirian KV and FR miospore Biozones. The KV Biozone is marked by the presence of *Crassispora kosankei*. The basal pat of the FR Biozone is defined on the first occurrence of *Reticulatisporites reticulatus* together with common specimens of *Crassispora kosankei*, *Raistrikia fulva* and *S. nux* (Figure 2). These results fit well, in terms of age, with the local ammonoid biozonation (KORN, 1997).

**CONCLUSIONS**

Devonian and Carboniferous palynomorphs are documented from all the geological domains recognized in the SPZ. For the first time, an assessment of all of the palynostratigraphic records obtained in the SPZ are compared (Figure 2). Twenty three miospore biozones are identified in the SPZ comprising the identification of
more than 150 Devonian miospores and acritarchs species and more than 200 Carboniferous miospore species (Pereira et al., 2007). Selection of the index species used for the SPZ is based upon the consistent occurrence of each taxon in several sections and boreholes.

A number of palynological events recognized in the Western Europe were identified in the SPZ. These events, generally defined as the appearance or disappearance of a single genus or whole complexes of forms, providing important indicators in the establishment of global zonations (Clayton, 1985; Clayton, 1996; Clayton et al., 2003; Owens, 1996; Owens et al., 2004; Streel, 1996). One event has local importance at the scale of SPZ (in Portugal and Spain) and two events are locally distinct and are correlated with goniatites control points in the BAGF and SPS (see figures 2 and 7).

The most important events identified in the Western Europe and recognized in SPZ are:

(1) The first appearance of Grandispora cornuta, together with other taxa that typically occur at this level in SPZ, that includes Retisotriletes phillipsii, Diducites versabilis and Rugospora radiata. This event, with the same type assemblage is recognized in Western Europe and marks the basal part of the VCo Biozone of late Famennian age (Maziane et al., 1999);

(2) First appearance of Grandispora echinata. Assemblages in the SPZ also typically contain consistently Ancyrospora sp., Cristicavatispora dispersa, Rugospora explicata and Teichertospora iberica at this level. It is worth noting that this assemblage is currently only documented in the SPZ and could represent a local event. In addition, the appearance of Grandispora echinata occurs immediately before the first inception of Retispora lepidophyta in SPZ and Western Europe, at the late Famennian age;

(3) Extinction of Retispora lepidophyta. In Western Europe this event is approximately at the Devonian/Carboniferous boundary (Paproth & Streel, 1972; Higgs & Streel, 1984);

(4) First appearance of Spelaeotriletes pretiosus, marking the middle Tourainian age, in Western Europe;

(5) First appearance of Lygospora pusilla. In Western Europe it is approximately coincident with the Tourainian/Viséan boundary;

(6) First appearance of Raistrickia nigra, together with other taxa that typically occur at this level in the SPZ is Propisporites laevigatus and Densosporites spp. This event marks the mid late Viséan in SPZ. This data is confirmed with goniatites;

(7) First appearance of Savitrisporites nux. This local event is equivalent to the Western Europe first appearance of Tripartites vetustus Schemel. In the SPZ, the other taxa that typically occur with the S. nux are Rotaspora spp. and Grandispora spinosa of late Viséan age;

(8) Extinction of the characteristic Viséan miospore species, Raistrickia nigra, Grandispora spinosa, Rotaspora spp. and Crassispora maculosa, analogous to the Viséan/Serpukovian bondary of the Western Europe;

(9) Appearance of the distinctive Bashkirian genus Reinschospora and increase on Crassispora kosankei, representative of the early Bashkirian assemblages, similar to the Western Europe;

(10) First appearance of Radizones aligerens, a type event for the late Westphalian A, in Western Europe. It is also characterized by the increase of Laevigatosporites and Cirratiradites saturni;

(11) First appearance of Torispora genus, marking the basal Westphalian C, as documented for Western Europe;

(12) First appearance of Thymospora spp. which in Western Europe marks the basal part of the Westphalian D.

The synopsis of the SPZ palynostratigraphy obtained from all the geological domains recognized allow the following conclusions (Figure 2):

1. Early Frasnian miospores assemblages were recovered from the PQG of the IPB, in Valverde del Camino Anticline, SW Spain (Lake, 1991; Gonzalez et al., 2004; Gonzalez, 2005) and appear as reworked assemblages at the top of this same Group. These Frasnian assemblages are also comparable to those found in the Ribeira de Limas and Gafo Fms. of the Pulo do Lobo Antiform (Pereira et al., 2006).

2. Late Famennian assemblages in SPZ have a consistent presence of the miospore species Ancyrospora sp., Cristicavatispora dispersa, Rugospora explicata and Teichertospora iberica. These assemblages were recovered from the PQG and the VSC (IPB) (Gonzalez et al., 2004; Pereira et al., 2004; 2007) and from the upper units of the Pulo do Lobo Antiform (Horta da Torre, Santa Iria and Represa Fms; Pereira et al., 2006a, b).
3. Analogous late Strunian miospore assemblages were recovered from the IPB, the upper part of the PQG (CUNHA and OLIVEIRA, 1989; OLIVEIRA et al., 2004; OLIVEIRA et al., 2005; MATOS et al., 2006), and the VSC in Spain (GONZALEZ, 2005) and also from the Tercenas Fm. in Southwest Portugal (Bordeira and Aljezur Anticlines).

4. Similarities in Upper Devonian miospore assemblages, strongly suggest that the Pulo do Lobo, the IPB basin and the Tercenas Fm. (Southwest Portugal), were part of the same palaeogeographic realm during the late Devonian.

5. Records of Tournaisian palynomorphs from the Bordalete Fm. in Southwest Portugal and reworked Tournaisian associations in the VSC of the IPB show the presence of the same taxa.

6. The VSC of the IPB yield miospores of late Famennian to mid/late Viséan age (OLIVEIRA et al., 1986; OLIVEIRA et al., 2004; 2005; 2006; PEREIRA et al., 2006; 2007). Mid/late Viséan assemblages appear to be very consistent along the SPZ as the same assemblages are recorded from the BAFG.

ACKNOWLEDGEMENTS

This work was presented at the CIMPLISBON’07 meeting and was sponsored by the project POCI/CTE-GIN/56450/2004 (PROVENANCE) of Fundação para a Ciência e Tecnologia, Portugal.

The authors express sincere thanks to the referees, Prof. Ken Higgs (UNIVERSITY College Cork, Ireland) and Prof. Geoff Clayton (Trinity College, Dublin, Ireland) that improved the manuscript.

REFERENCES


Devonian and Carboniferous palynostratigraphy of the South Portuguese Zone, Portugal – An overview


Artigo recebido em Dezembro de 2007
Aceite em Dezembro de 2007
PLATES
Plate captions list the taxonomic name of the figured specimen, followed by the formation, sample number, slide number and microscopic coordinates.


5 – *Chelinospora concinna* Allen, 1965, Ribeira de Limas Formation, Sample 1-1, 1320-205.

6 – *Teichertospora iberica* Gonzalez, Playford & Moreno, 2005, Horta da Torre Formation, Sample 7-2b-1450-185.


8 – *Grandispora cornuta* Higgs, 1975; MP3 Borehole, Represa Formation, Sample 36,60-1, 1305-225.

9 – *Cristicavatispora dispersa* Gonzalez, Playford & Moreno, 2005; Open pit Mina de São Domingos mine, Represa Formation, Sample EM4-1, 1225-185.

10 – *Ancyrospora* sp., Horta da Torre Formation, Sample 8-1, 1440-120.

11 – *Rugospora explicata* Gonzalez, Playford & Moreno, 2005, Horta da Torre Formation, Sample 7-3, 1505-200, INETI 0712.

12 – *Rugospora flexuosa* (Jushko) Streel, 1974, Horta da Torre Formation, Sample 7-1a, 1390-105, INETI 0713.

13 – *Retispora lepidophyta* (Kedo) Playford, 1976; Tercenas Formation, Sample 105,1, 1350-210.

14 – *Indotrirradites explanatus* (Luber) Kedo, 1963; Tercenas Formation, Sample 106,b,2, 1391-165.

15 – *Verrucosisporites nitidus* (Naumova) Playford, 1964; Tercenas Formation, Sample 338,1, 1110-110.
Plate II

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

1 – *Cyrtospora cristifera* (Luber) emend. **VAN DER ZWAN**, 1979; Bordalete Formation, Sample 147,c,3, 1155-120.

2 – *Cyrtospora cristifera* (Luber) emend. **VAN DER ZWAN**, 1979; Bordalete Formation, Sample 147,c,2, 1198-120, equatorial.


4 – *Granulatisporites microgranifer* **IBRAHIM**, 1933; Bordalete Formation, Sample 226,1, 1053-215.

5 – *Tumulispora rarituberculata* (Luber) **PLAYFORD**, 1991; Bordalete Formation, Sample 324,1, 1465-138

6 – *Spelaeotriletes balteatus* (Playford) **HIGGS**, 1975; Bordalete Formation, Sample 147,4, 1345-195.


8 – *Lycospora pusilla* (Ibrahim) **SCHOPE, WILSON & BENTALL**, 1944; Murração Formation, Sample 280,1,1220-175.

9 – *Lycospora pusilla* (Ibrahim) **SCHOPE, WILSON & BENTALL**, 1944; MDS1 Borehole, VSC, Sample 255, 30-1, 1155-75.

10 – *Densosporites* sp.; MDS1 Borehole, VSC, Sample 255, 30-1, 1095-135.


13 – *Knoxisporites triradiatus* **HOFFMEISTER, STAPLIN & MALLOY** sensu **SULLIVAN**, 1964; Murração Formation, Sample 147,2, 1145-120.

PLATE III

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

1 – *Savitrisporites nux* (Butterworth & Williams) Smith & Butterworth, 1967; Murração Formation, Sample 387.2, 1160-255.


3 – *Crassispora kosankei* Potonié & Kremp emend Bharadwaj, 1957; Quebradas Formation, Sample 387.2, 1230-95.

4 – *Reticulatisporites reticulatus* (Ibrahim) Ibrahim, 1933; Quebradas Formation, Sample 195.1, 1364-35.

5 – *Raistrickia fulva* Artuz, 1957; Quebradas Formation, Sample 200.1, 1430-205.

6 – *Cirratriradites saturni* (Ibrahim) Schöpf, Wilson & Benton, 1944; Brejeira Formation, Sample 266.1, 1260-87.

7 – *Dictyotrilites probireticulatus* (Ibrahim) Butterworth & Mahdi, 1981; Brejeira Formation, Sample 238.b.1, 1350-110.


9 – *Florinites junior* Potonié & Kremp, 1954; Brejeira Formation, Sample 229.3, 1145-100.

10 – *Torispora securis* Balme, 1952; Brejeira Formation, Sample 63.1, 1135-185.

11 – *Raistrickia aculeata* Kosanke, 1950; Brejeira Formation, Sample 63.1 – 1385-200.

12 – *Cadiospora magna* Kosanke, 1950; Brejeira Formation, Sample 62.1,1254-175.


Devonian and Carboniferous palynostratigraphy of the South Portuguese Zone, Portugal – An overview

Pl. III

[Images of various fossils with labels 1 to 14]

50 μm