Tectonostratigraphy of Middle and Upper Palaeozoic black shales
from the Porto-Tomar-Ferreira do Alentejo shear zone (W Portugal):
new perspectives on the Iberian Massif

H.I. Chaminé a,*, L.C. Gama Pereira b, P.E. Fonseca c, L.P. Moço d, J.P. Fernandes d,
F.T. Rocha a, D. Flores d, A. Pinto de Jesus d, C. Gomes a, A.A. Soares de Andrade e, A. Araújo f

a Centro de Minerais Industriais e Argilas (MIA) and Departamento de Geociências da Universidade de Aveiro,
Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
b Grupo de Modelagem de Sistemas Geológicos (CGUC) and Departamento de Ciências da Terra da Universidade de Coimbra,
3000-272 Coimbra, Portugal
c Laboratório de Tectonofísica e Tectônica Experimental (LATTEX) and Departamento de Geologia da Faculdade de Ciências da Universidade
de Lisboa, Ed. C2, 5º Piso, 1749-016 Lisboa, Portugal
d Grupo de Investigação de Petrologia e Geoquímica Orgânicas (CGUP) and Departamento de Geologia da Universidade do Porto,
Praça de Gomes Teixeira, 4099-002 Porto, Portugal
e Grupo de Evolução Litosférica (ELMAS) and Departamento de Geociências da Universidade de Aveiro, 3810-193 Aveiro, Portugal
f Centro de Geofísica da Universidade de Évora and Departamento de Geociências da Universidade de Évora, Apt. 94, 7002-554 Évora, Portugal

Received 2 October 2002; accepted 6 March 2003

Abstract

Middle/late Devonian and early Carboniferous metasedimentary sequences in the northernmost region (Porto-Espinho-Tomar) of the
Ossa-Morena Zone (Portuguese Iberian Variscan Massif) contain black shales of very low to low-grade metamorphism. These metasedimen-
tary rocks form a discrete NNW-SSE structure within a major shear zone (Porto-Tomar-Ferreira do Alentejo) and remain subparallel to the
observed regional major structures (folding, thrusts or overthrusts). These black shales are overhanged and then imbricated in an upper
Proterozoic metamorphic substratum. A multi-disciplinary study of these metasedimentary rocks from the Espinho-Tomar region has
tectonostratigraphy, palynology, organic petrology and clay mineralogy combined methods. This approach provides new insights into the
tectonic evolution and geological framework of Palaeozoic basement of the Iberian Variscides. Palaeoenvironmental and tectonostratigraphic
implications on the Iberian geodynamic framework are discussed.

© 2003 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

Résumé

À l’extrême Nord (Porto-Espinho-Tomar) de la Zone d’Ossa-Morena (Massif Ibérique des Variscides au Portugal), des successions d’âge
Dévonien moyen/supérieur et Carbonifère inférieur renferment des shales noirs à métamorphisme de faible à très faible degré. Ces
métasédiments forment un panneau structural NNO-SSE à l’intérieur de l’importante bande de cisaillement de Porto-Tomar-Ferreira do
Alentejo, tout en demeurant sub-parallèles aux structures majeures régionales (plis, chevauchements, charriages). Ces shales noirs sont
aujourd’hui imbriqués dans un substratum métamorphique d’âge Protérozoïque supérieur. L’étude multidisciplinaire (tectonostratigraphie,
palynologie, pétrologie organique, minéralogie des argiles, et pétrographie métamorphique) ouvre de nouvelles perspectives sur le cadre géologique et l’évolution tectonique du socle paléozoïque des Variscides Ibériques.

© 2003 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

**Keywords:** Devonian; Carboniferous; Tectonostratigraphy; Palynomorphs; Porto-Tomar-Ferreira do Alentejo Shear Zone; Iberian Variscides; Western Portugal

**Mots clés :** Dévonien ; Carbonifère ; Tectonostratigraphie ; Palynomorphes ; Bande de cisaillement de Porto-Tomar-Ferreira do Alentejo ; Variscides Ibériques ; Ouest du Portugal

### 1. Introduction

Integrated studies making use of techniques from different geological disciplines (e.g., geological mapping, tectonostratigraphy, structural geology, geological petrology, palynology, clay mineralogy, and organic petrology) constitute a powerful tool for understanding the geodynamic evolution of inner zones of orogens. To establish the late diagenetic to high-anthozoon processes of mineral formation (ca. 200°C–300°C, cf. Kisch, 1987, 1990; Merriman and Frey, 1999; Robinson and Merriman, 1999; Merriman and Peacor, 1999; Arkai et al., 2002) from metapelitic rocks is a complex task because of intergrowths of metamorphic phases (slices), of the small grain-size, and of microstructural defects as well. Consequently, it is often very difficult to establish the relationships between the growth of metamorphic minerals and all the deformation history. Despite these difficulties, attempts have nevertheless been made to study very-low to low-grade metamorphic belts (e.g., Munhá, 1983; Lee et al., 1986; Merriman et al., 1995; López-Munguira and Nieto, 2000; Abad et al., 2001), particularly in high-strain zones (e.g., Merriman et al., 1995; Taylor et al., 1998; Merriman and Frey, 1999, and references therein).

Variscan very-low-metamorphism was reported for the first time on the Porto-Coimbra-Tomar metamorphic belt (northernmost domain of Portuguese part of the Ossa-Morena Zone) by Chaminé (2000), as indicated by the observation of monotonous black pelitic sequences. The probable age of this metamorphism is middle Palaeozoic (Fernandes et al., 2000, 2001). Chaminé et al. (2000) have presented a preliminary geological overview from mid-Palaeozoic metasediments in Albergaria-a-Velha region. The present work reviews the available geological data on metasedimentary rocks from Albergaria-a-Velha, extends their study up to Coimbra-Tomar (central Portugal), and improves it through the use of a multidisciplinary approach. Aiming at this, black shale and phyllite samples were systematically collected along a Porto-Tomar geotraverse, passing through Espinho-Ovar-Albergaria-a-Velha and Meallhada-Coimbra-Espinhal. The works by Gama Pereira (1987) and Chaminé (2000) stand an updated regional mapping and tectonostratigraphic background. The tectonostratigraphic nomenclature for the Porto-Coimbra-Tomar shear zone follows this authors. The Palaeozoic time scale of Gradstein and Ogg (1996), with updated divisions for the Devonian after Tucker et al. (1998), and Remane (2000) was used.

### 2. Geological and tectonic framework

In southwestern Europe, the Variscan Belt (*sensu stricto*) is recognised as a Palaeozoic orogen formed by collision of Gondwana and Laurussia in the late Devonian-early Carboniferous (e.g., Matte and Ribeiro, 1975; Badham, 1982; Lefort, 1989; Eden and Andrews, 1990; Dias and Ribeiro, 1993, 1995; Fonseca and Ribeiro, 1993; Ribeiro et al., 1995; Krohe, 1996; Martínez-Catalán et al., 1997; Matte, 1998; Fonseca et al., 1999; Matte, 2001; Gibbons and Moreno, 2002; Fernández et al., 2003). The Iberian Massif corresponds to one of the widest exposures of the SW European Variscan basement.

The western branch of the Porto-Coimbra-Tomar shear mega-domain (Gama Pereira, 1987, 1998; Chaminé, 2000), is part of a narrow NNW-SSE strip, which belongs to the Portuguese northernmost domain of the so-called Ossa-Morena Zone (OMZ) of the Iberian Massif (Lotze, 1945; Schneider, 1947; Julivert et al., 1974; Ribeiro et al., 1990). This zone has been interpreted as a tectonostratigraphic terrane that collided and was amalgamated with the Central-Iberian Zone (CIZ), either during the Variscan Orogeny (e.g., Lefort and Ribeiro, 1980; Lefort, 1989; Ribeiro et al., 1990), or during the Cadomian Orogeny (Gama Pereira, 1987, 1998). In both cases, it was juxtaposed on an earlier Cadomian structure that resulted from the merging of an arc and marginal basin complex across a dextral strike-slip shear zone. OMZ bounds to the South Portuguese Zone (SPZ) in a typical suture-zone exposed along the entire length of a belt of mid-Palaeozoic oceanic rocks, the so-called Beja-Acebuches Ophiolitic Complex (Soares de Andrade, 1972, 1978, 1983, 1985; Fonseca and Ribeiro, 1993; Quesada et al., 1994; Fonseca, 1995; Fonseca et al., 1999). This mega-domain is located alongside the western border of the Porto-Tomar-Ferreira do Alentejo [PTFA] dextral major shear zone (Chaminé, 2000; Chaminé et al., 2000; Ribeiro et al., 2001; Fernández et al., 2003). So, the PTFA major shear zone most probably connects the SW Iberian suture (Fonseca and Ribeiro, 1993; Fonseca et al., 1999) to the W-NW Iberian suture (Ribeiro et al., 1990; Dias and Ribeiro, 1995). This latter suture may represent the root zone of the NW ophiolite complexes, footwall high-pressure assemblages, and superposed Continental Allochthonous Terranes of possible Avalonian origin (Martinez-Catalán et al., 1997). The PTFA geodynamic framework is analogous, in the present, to the Pacific-North American plate boundary system of San An-
dreas dextral transform (e.g., Crowell, 1974; Davison, 1994), to the North Chugoku shear zone of SW Japan (Gutscher and Lallemand, 1999), and also to the late Cenozoic dextral strike-slip Alpine Fault of New Zealand orocline (Little and Mortimer, 2001).

The Porto-Coimbra-Tomar metamorphic belt (Fig. 1, Oliveira et al., 1992) comprises relative autochthonous and parautochthonous tectonostratigraphic units of low- to high-grade metamorphic rocks, as well as allochthonous units, of middle- to high-grade, assumed of upper Proterozoic times (e.g., Gama Pereira, 1987; Beetsma, 1995; Chaminé et al., 1998; Noronha and Leterrier, 2000; Chaminé, 2000; Fernández et al., 2003; and references therein). Recently, we reported for the first time in this region, mid-upper Palaeozoic black shales underlining discrete and scattered structures, N–S, parallel to major regional shear thrusts (Chaminé, 2000; Chaminé et al., 2000; Moço et al., 2001; Fernandes et al., 2001). These internal scattered basins constitute a NNW-SSE trending structure located at the Western border of the Portuguese part of the Ossa-Morena Zone, about 25-50 km from the Atlantic shoreline.

3. Multi-disciplinary overview

For our study, the pre-Permian region, comprised between Porto and Tomar (Western Portugal), was subdivided into three major areas (Fig. 1): i) Espinho-Albergaria-a-Velha (Area I); ii) Mealhada-Coimbra (Area II); iii) Espinhal-Tomar (Area III). For laboratory analyses, 134 unaltered samples of shales, slates (phyllites) and micaschists were carefully collected in order to minimize the effects of weathering along a general W-E cross-section. The samples, representative of different metamorphic grades in the sequence, were studied by various methods, such as metamorphic petrology, palynology, organic petrology, geochemistry and clay mineralogy. The term “black shale” has been applied to shales having a broad range of shades of grey, i.e., containing varying amounts of organic matter.

4. Tectonostratigraphy


The tectonostratigraphic framework (see Gama Pereira, 1987, 1998; Chaminé, 2000; Chaminé et al., 2000; Fig. 2) comprises a well-structured substratum composed of extremely monotonous garnetiferous black-greenish phyllites with interlayered amphibolite and lydite lenses (Area I: Arada Unit, ArU; Area II: Vale de Canas Unit, VcU; Area III: Ribeira do Brás Unit, RbU; all related to the pre-Silurian “Série Negra” [s.l.] metasedimentary rocks). The total substratum ranges approximately 6 to 12 km wide. Radiometric dating indicated an upper Proterozoic age (Beetsma, 1995) for the Arada unit. This substratum is tectono-sedimentary imbricated with middle-upper Palaeozoic black shales (Area I: Albergaria-a-Velha Unit, AvU; Area II: Portela do Ceira

---

**Fig. 1. Regional geotectonic framework of the Porto-Coimbra-Tomar shear zone, in Espinho-Penela sector (W Portugal).**

---
Unit, PcU; Area III: Ponte de Penela Unit, PeU) that are interbedded in laminated siltstones with interlayered metacarbonates and black metagreywackes (1-50 cm). These imbricated structures present variable thickness, ranging between 50 to 500 m. The newly mapped black shales yielded spores attributed to the middle/late Devonian and early Carboniferous (see below).

Deformation and metamorphism in the Porto-Coimbra-Tomar shear zone (OMZ) have different characteristics in each tectonostructural domain. The general features for the region point out for the existence of two regional tectonometamorphic main stages of Variscan deformation (e.g., Severo Gonçalves, 1974; Ribeiro et al., 1980; Gama Pereira, 1987; Chaminé, 2000) sometimes overprinting an earlier Cadomian blastomylonitic fabric (e.g., Gama Pereira, 1987; Chaminé, 2000; Noronha and Leterrier, 2000). The first Variscan stage produced important folding and thrusts, as well as the dominant regional schistosity. The second regional stage (related to CIZ Variscan-D3, Dias and Ribeiro, 1995), also associated with mega-shear zones, produced a typical C-S deformation criteria and a non-coplanar cleavage schistosity with mylonitic or blastomylonitic foliation and crenulation. The metamorphic recrystallisation coincided with the first stage, and continued in the second stage, where the major event of deformation resulted in metamorphic blastesis and metasomatism (e.g., Severo Gonçalves, 1974; Gama Pereira, 1987; Chaminé, 2000).

The pre-Permian metapelitic basement is obscured mainly by Meso-Cenozoic cover deposits of the Lusitanian Basin, and bounded tectonically by medium- to high-grade metamorphic rocks of the PTFA metamorphic belt.

5. Palynology

Samples were prepared for palynological study (Fernandes et al., 2000, 2001) using standard treatment techniques involving maceration with HCl and HF, followed by oxidation of the residues with dry Schulze mixture (short oxidation times, of about 1 to 5 minutes were required, except for Ovar-Estarreja materials, which required about 30 minutes). Organic residues were systematically cleaned and concentrated during maceration procedures, thereafter strew mounts and permanent glass slides were prepared for transmitted light microscopic examination, subsequently studied and photographed. Samples, residues, and slides are stored in the archives of GIPEGO Laboratories (Department of Geology of University of Porto).

Albergaria-a-Velha (Area I) black shales provided palynomorph assemblages of late Givetian to early Frasnian age, whereas some samples from Sernada do Vouga-Serém (Area I) contained spores from the early Carboniferous (with a very large proportion of reworked Devonian palynomorphs). Black shale outcrops from Mealhada-Coimbra (Area II) provided a palynomorph association of late Famennian age, together with reworked Givetian/Frasnian forms. In the Penela-Espinhal sector (Area III) black shales yielded sporomorphs suggesting a Givetian age. A description of these assemblages follows (Fig. 3).

In the generally scarce organic residues obtained from Albergaria-a-Velha samples (Area I), a good number of palynomorphs can be found, the sporomorphs being clearly dominant over the acritarchs. Fragments of vegetal tissues are common. As a rule, palynomorphs are badly preserved,
the larger forms being almost invariably broken (e.g., palynomorphs with elongated ornamentation, belonging to the genus Ancyrospora or Hystricosporites, usually lack their termination). The palynomorph assemblage is characterised by the presence, among other spores, of Cristatisporites triangulatus, Geminospora micromanifesta and Ancyrospora.
Vegetal tissues and debris are less common than in samples from Area II outcrops. The close vicinity of Triassic red sandstones and evaporites could explain the presence of gypsum as a secondary mineral resistate in the residues, creating a supplementary difficulty for sample treatment. Nevertheless, the association found, with Cristatisporites triangulatus, is clearly dominated by Geminospora spp., indicating a probable Givetian age (Richardson and McGregor, 1986). Acritarchs are very rare.

6. Organic petrology

The petrographic characterisation of the samples was performed on whole rock and light fraction (organic concentrates obtained by heavy liquid separation) polished blocks and slides, prepared according to the techniques described in Alpern et al. (1993). Microscopic examination was carried out using a microscope equipped with both reflected white and fluorescent blue light. The terminology used to identify and describe the organoclasts is the one proposed by the International Committee for Coal and Organic Petrology (ICCP). Hydrocarbons were recognised and classified following Alpern et al. (1992, 1993).

The total amount of organic matter, measured on whole rock from middle/late Devonian materials (Fig. 4), is poor. The dominant organoclasts, often-small particles, are sporinite and vitrinite with minor amounts of inertinite. The sporinites, with orange-brown fluorescence, often show their original form. Vitrinite appears as particles totally gelified, homogeneous, with small inclusions of mineral matter. Inertinite is observed mainly as debris (inertodetrinite). Zooclasts are also observed interstratified within the rock matrix. Free viscous hydrocarbons (HC) were identified, under ultraviolet light, mainly as exsudates and HC extracted by resin with no regular form. Mineral matrices are in general strongly impregnated, sometimes filling fractures and cavities. HC fluorescence colour is usually yellow, corresponding to the heavy and viscous fraction. The maturation, measured by mean random vitrinite reflectance ($R_v$, %), is at the level of catagenesis (ranged 1.0% and 1.3%), which is compatible with HC generation. The fluorescence colour of sporinite also agrees with this maturity level. Further studies, namely geochemical characterisation, are in progress in order to determine the correlation between the solid organic matter and HC.

The most abundant macerals of the organic assemblage from early Carboniferous materials (Fig. 5) are sporinite, followed in decreasing order of importance by inertinite and vitrinite. This suggests a very important continental contribution. Sporinites are often well preserved. We also observed rare zooclasts, probably remains of marine organisms. The organic matter observed can be classified in type II-III. Maturation was measured by distinct methods. The observation of the fluorescence colour of sporinites in organic concentrates, using transmitted white light, permitted to determine the Thermal Alteration Index (Staplin, 1969) as 3+. Mean ran-
dom vitrinite reflectance is ranged 1.3% and 1.5%. Matura-

tion is at the level of catagenesis. Following Alpern et al.

(1992, 1993) methodology, we observed free HC mainly as

matrix impregnations and fracture and cavity fillings.

The above results are particularly interesting. Indeed, if

one considers that the west sector of PTFA major shear zone

is mainly covered by Meso-Cenozoic deposits (Lusitanian

Basin), with relative coarse lithology permitting migration

and trapping of HC’s, some Palaeozoic HC’s could have been

accumulated, the black shales described here acting as poten-

tial source rocks (Moço et al., 2001). These would constitute

possible areas for oil or gas exploration in the Mesozoic

basins as suggested in the past by Bless et al. (1977) and

more recently by Uphoff et al. (2002).

Organic petrology analysis from the upper Proterozoic

substratum shows a very poor organic content, lower than

that of the middle/upper Palaeozoic. The organic particles,

always very small, are thermally affected and consequently

their classification is very difficult. They may be classified as

“vitrinite-like” organoclasts. The coalification degree is al-

ways very high, corresponding to the upper epizone (low-

grade metamorphism). Organic petrology data clearly indi-

cate a distinct thermal evolution for the mid-upper

Palaeozoic rocks and the basement materials. These conclu-

sions are in agreement with previous metamorphic petrology

studies, which place these materials in lower- to middle-
greenschist facies, i.e., white micas + quartz + chlo-

rite ± chloritoid ± garnet ± tourmaline ± apatite ± zircon

(Severo Gonçalves, 1974; Chaminé, 2000).

7. Clay mineralogy

The mineralogical study of the samples, particularly of

clay minerals, was based mainly on X-ray diffraction (XRD)
analyses, carried out using a Philips X’Pert PW3040/60 powder diffractometer with CuKa radiation at the Aveiro University Laboratories. The terminology and recommendations suggested mainly by Kübler (1968), Thorez (1976), Kisch (1990, 1991) and Árkay et al. (2002) are followed. Several data (Rr, %) were compared with mineralogical data, namely Palaeozoic materials were studied, and organic petrology samples from Ovar-Tomar late Proterozoic and mid-upper sert (Carboniferous, middle/late Devonian and upper Proterozoic metapelitic materials).

Middle/upper Palaeozoic materials were studied, and organic petrology (Carboniferous, middle/late Devonian and upper Proterozoic metapelitic materials).

Fig. 6. KI/EI scatter diagram from the three main age groups studied (early Carboniferous, middle/late Devonian and upper Proterozoic metapelitic materials).

The results presented herein indicate the occurrence, in the region, of fault wedge and/or pull-apart like-basins formed at right stepping dextral of the PTFA major shear zone. Discrete metapelitic materials, with distinctive characteristics, have been observed along a strip subparallel to this shear zone, filling ancient small troughs. A large moderate to
high-angle normal fault borders each basin. These NNW-SSE middle/late Palaeozoic internal basins, of low- to high-anchizone metamorphism, have been interpreted as remnants of overlaying units; deposition would have occurred essentially on pre-early Palaeozoic OMZ deformed substratum of greenschist facies (Chaminé, 2000). The observed basins may thus be considered as key structures for tectonic modelling of the Portuguese northern branch of the OMZ along the PTFA major shear zone. Interestingly, Devonian-Carboniferous pull-apart basins have been recognised in Brittany in dextral major shear zones (Rolet et al., 1994; Paris and Robardet, 1994a; Matte, 2001) associated with great lithospheric depths (Judenherc et al., 2002), namely, the North-Armorican Shear Zone (Châteaulin and Laval Basins) and the South-Armorican Shear Zone (Ancenis Basin).

The geometry of an elongated trough between two tectonostratigraphic mega-domains, with a long tectonic history of activity, explains the general present pattern of the Portuguese northern branch of the OMZ along the PTFA major shear zone. Interestingly, Devonian-Carboniferous pull-apart basins have been recognised in Brittany in dextral major shear zones (Rolet et al., 1994; Paris and Robardet, 1994a; Matte, 2001) associated with great lithospheric depths (Judenherc et al., 2002), namely, the North-Armorican Shear Zone (Châteaulin and Laval Basins) and the South-Armorican Shear Zone (Ancenis Basin).

The geometry of an elongated trough between two tectonostratigraphic mega-domains, with a long tectonic history of activity, explains the general present pattern of the Portuguese northern branch of the OMZ along the PTFA major shear zone. Interestingly, Devonian-Carboniferous pull-apart basins have been recognised in Brittany in dextral major shear zones (Rolet et al., 1994; Paris and Robardet, 1994a; Matte, 2001) associated with great lithospheric depths (Judenherc et al., 2002), namely, the North-Armorican Shear Zone (Châteaulin and Laval Basins) and the South-Armorican Shear Zone (Ancenis Basin).

The geometry of an elongated trough between two tectonostratigraphic mega-domains, with a long tectonic history of activity, explains the general present pattern of the Portuguese northern branch of the OMZ along the PTFA major shear zone. Interestingly, Devonian-Carboniferous pull-apart basins have been recognised in Brittany in dextral major shear zones (Rolet et al., 1994; Paris and Robardet, 1994a; Matte, 2001) associated with great lithospheric depths (Judenherc et al., 2002), namely, the North-Armorican Shear Zone (Châteaulin and Laval Basins) and the South-Armorican Shear Zone (Ancenis Basin).

The geometry of an elongated trough between two tectonostratigraphic mega-domains, with a long tectonic history of activity, explains the general present pattern of the Portuguese northern branch of the OMZ along the PTFA major shear zone. Interestingly, Devonian-Carboniferous pull-apart basins have been recognised in Brittany in dextral major shear zones (Rolet et al., 1994; Paris and Robardet, 1994a; Matte, 2001) associated with great lithospheric depths (Judenherc et al., 2002), namely, the North-Armorican Shear Zone (Châteaulin and Laval Basins) and the South-Armorican Shear Zone (Ancenis Basin).
Portuguese sector of the OMZ (see Ribeiro et al., 1990, 1995; Matte, 1998; Fonseca et al., 1999; Franke, 2000). Devonian formations have already been described in early studies of regional geology and on the palaeontological (macro and/or microfossils) record, by Pruvost (1914), van den Boogaard (1963, 1972), Conde and Soares de Andrade (1974), Soares de Andrade (1983, 1985), Ribeiro (1983), Soares de Andrade and V. Oliveira (1983) and Moutinho da Silva (1988). More recently, palynostratigraphic preliminary reports by Pereira and Oliveira (2001a, b) also point out late Devonian/early Carboniferous ages for metapelitic units (e.g., Cabrera-Vendas Novas and Toca da Moura outcrops) of the Southern domain of the OMZ (Vendas Novas-Ferreira do Alentejo-Ficalho shear zone; e.g., Soares de Andrade, 1983, 1985; Fonseca and Ribeiro, 1993; Almeida et al., 2001). An integrated geological framework requires, however, more detailed descriptions of these units. These would allow precise interpretations of the relationships between Devonian and Carboniferous internal basins and main units of similar age from the OMZ and the South Portuguese Zone (SPZ).

The continental margins of Laurusia, N-Gondwana and the mosaic of widespread intermediary microplates are
known to have reached collisional stages during the latest Devonian throughout early Carboniferous times (e.g., Badham, 1982; Ribeiro et al., 1990; Rolet et al., 1994; Matte, 1998; Shelley and Bossière, 2000). It is therefore crucial, in order to understand the overall geological history, to establish the Variscan palaeogeographic position of Iberia (e.g., Paproth, 1982; Gama Pereira, 1987; Paris and Robardet, 1994b; Korn et al., 2000; Shelley and Bossière, 2000; McKerrow et al., 2000) and to identify the intervening Iberian terranes (e.g., Gama Pereira, 1987; Ribeiro et al., 1990; Martínez Catalán et al., 1997). The PTFA major shear zone stands as an essential research target to such an endeavour.

The overall skeleton structure, in the core of the emerging Variscan orogen, materialises marine pathways that intermittently connected the remaining marine like Rhen-Hercynian – South Portuguese basins adjacent to the Laurussian landmass, in the North, with the Ibero-Armorican – and Mediterranean basins juxtaposed to the main Gondwanaland coast-line (Korn and Horn, 1997; Korn et al., 2000; McKerrow et al., 2000; Franke, 2000). These linkages were maintained at least until the latest Viséan (ca. 340 Ma). Regarding that connection, Korn and Horn (1997) and Korn et al. (2000) present significant evidence based on goniometric biogeo graphical trends. Those faunal assemblages allow for the establishment of a general control about the timing and rate of the orogenic uplift of the Variscan belt. Korn et al. (2000) propose that a continuous transeuropean mountain barrier separated southern marine basins from northern basins at least in late Viséan times (ca. 325 Ma). Interestingly, in southwestern Iberia the miosepiration and accretionary assemblages previously recorded (e.g., Cunha and Oliveira, 1989; Pereira et al., 1994; Pereira, 1999; Fernandes et al., 2001, and references therein) are very similar in composition to those observed from the same stratigraphic interval in other areas of southern EuroAmerica (e.g., Streele et al., 1987; Higgs et al., 1988; Higgs et al., 1993; Clayton, 1996; Streele and Loboziaik, 1996; McKerrow et al., 2000).

Somehow, when a new paradigm emerges, one must give further attention to what was previously taken as being soundly established. The clear differentiation into North and South realms, in the classical OMZ (Julivert et al., 1974; Ribeiro et al., 1990), and its relationships with the northwestern prolongation of OMZ lithologies along the PTFA major shear zone (Chaminé, 2000), should considered if one hopes to understand the substratum structure. In fact, it appears as if a N–S narrow (15-35 km wide) high-deformation corridor exists, running parallel to the Galician-Portuguese shoreline for over 520 km, which bears medium- to high-metamorphic rocks and shear granitic plutons (Fig. 8). This corridor may extend from Finisterra to Tomar, passing through Muros, Vigo, La Guardia, Caminha, Apúlia, Porto, Espinho, Albergaria-a-Velha and Espinal. In our work, this high-strain zone has been named Western Iberian Line (WIL). This westernmost deformation corridor of lithostructural out-of-sequence sheets with Ossa-Morena Zone affinity, would be subparallel to the northern portion of the Malpica-

Lamego Line (Llana-Fúnez and Marcos, 2001). The WIL presents different types of micro- to macro-scale structure exposures formed at mid-crustal levels in a tectonic dextral strike-slip regime, therefore constituting a prolific imprinting of the complex tectonometamorphic events that occurred in the shoreline of West Galicia (e.g., Arps, 1970; Buiskool Toxopeus et al., 1978; Martínez et al., 1990; Martínez-Catalán et al., 1997; Llana-Fúnez and Marcos, 2001, and references therein) and/or West Portugal (e.g., Souza-Brandão, 1914; Soen, 1970; Severo Gonçalves, 1974; Ribeiro et al., 1980; Gama Pereira, 1987, 1998; Serrano Pinto and Soares de Andrade, 1987; Fernandes et al., 1998; Chaminé et al., 1998; Noronha and Leterrier, 2000; Chaminé 2000, and references therein).

9. Concluding remarks

In summary, given the complex geotectonic boundaries observed in the Porto-Coimbra-Tomar Shear Zone (Gama Pereira, 1987; Chaminé, 2000), it is natural that, at a regional scale, a single method of survey, be it geological, palynological, petrological or mineralogical, cannot yield a clear and straightforward result. Accordingly, we understand that the overall picture of this geological paradigm should be built-up on a systematic process of complementary data syntheses and croscheck as a patchwork (e.g., Bard et al., 1980; Ribeiro et al., 1990; Krohe, 1996; McNoleg, 1996; Franke, 2000; Llana-Fúnez and Marcos, 2001; Fernández et al., 2003). Moreover, the results of such multi-disciplinary approaches may deeply significantly influence future investigations on the Iberian Variscides, especially those related to basin analysis, regional tectonostratigraphy, geodynamics, mineral resources, and hydrocarbon potential. In an even more general view, a detailed terrane analysis, as those that have been carried out along the East coasts of U.S.A. and Canada (e.g., Haworth and Lefort, 1979; Williams, 1984; Mueller et al., 1996), must be pursued, as a long term goal, on this mirror side of the North-Atlantic Ocean (e.g., Ribeiro et al., 1990, 1995; Martínez-Catalán et al., 1997). Furthermore, concerning this latter issue, one must always bear in mind a fundamental question: how can our improved knowledge of the Porto-Tomar-Ferreira do Alentejo shear zone help to the correlation between some major suture lineaments of the European Variscides, namely those of Beja-Lizard-Harz and Cordoba-Baie d’Audierne—“Massif Central” (e.g., Bernard, 1974; Bard et al., 1980; Krohe, 1996; Zeh et al., 2001) ?

Acknowledgements

This research was funded by post-doctoral and doctoral scholarships from “Fundação para a Ciência e a Tecnologia” (FCT, PRAXIS XXI) to HIC (SFRH/BPD/3641/2000, Aveiro) and to LPM (BD/2767/96, Porto), respectively. This study was supported by a grant from the MODELIB/FCT project (POCTI/35630/CTA/2000 FEDER). Thanks are also
due to M.A. Marques da Silva (Aveiro) for providing deep borehole samples, and to C. Regêncio Macedo (Coimbra) for sharing unpublished results of a radiometric study in the Caramulo region. We benefited from discussions with R. Rodríguez-Gonzaléz (León), A. Ribeiro (Lisbon), A. Marcos (Oviedo), J.M. Munhá (Lisbon), F. Sodré Borges (Porto), M.J. Lemos de Sousa (Porto), M. Serrano Pinto (Aveiro), R. Baptista (Petrogal Exploration, Lisbon), G. Gutiérrez-Alonso (Salamanca), and other colleagues for critical comments provided during this investigation. Thanks are also due to Ricky Pinheiro (AfriOre, South Africa) for helpful discussions and improvements of the text. We acknowledge Michel Robardet and Alain Le Hérissé for detailed reviews that helped to improve the clarity of the manuscript.

References


Arps, C.E.S., 1970. Petrology of a part of the Western Galician basin between the Rio Jallas and the Ria de Arosa (NW Spain) with emphasis on zircon investigations. Leidsche Geologische Mededelingen 46 (1), 57–155 (PhD thesis).


Matte, Ph., 2001. The Variscan collage and orogeny (480–290 Ma) and the tectonic definition of the Armorican microplate: a review. Terra Nova 13, 122–128.


