THERMAL MODELIZATION OF A COMPLEX EXTENSIONAL EVENT WITH TWO SIMULTANEOUS LOW-ANGLE NORMAL FAULTS (LORA DEL RÍO METAMORPHIC CORE, OSSA-MORENA ZONE)

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The Lora del Río metamorphic core (southern limb of the Monesterio antiform, Ossa-Morena Zone) is a particular core complex structure. The exhumation of the Lora del Río core is favoured by two simultaneous low-angle normal faults. This faults isolate three structural levels: the upper level (Los Miradores unit), the intermediate level (Hueznar succession) and the lower level (Lora del Río metamorphic core). The first and main low-angle normal fault control the structure of the region and the secondary low-angle normal fault controls the metamorphic evolution of the greater part of upper and intermediate structural levels.

A speculative unidirectional thermal model has been made, based in principally assumed parameters of the conventional literature. The special feature of this model is the thermal evolution related to the intermediate level (Hueznar succession; located between two low-angle normal faults). In a first stage only the main low-angle normal fault is active and the Hueznar succession play like a typical lower unit in a core complex structure (3.5-5 kbar, 400-500°C). Nevertheless, after the activation of the secondary low-angle normal fault the Hueznar succession acts as an upper unit but starts with a previous thermal evolution. During this second stage the Hueznar succession is affected by a LP-HT metamorphism (3-4 kbar, 700-750°C) and metamorphic isograds developed parallel to the secondary low-angle normal fault. Therefore the Hueznar succession show a two-stages relatively complex thermal evolution.

The theoretical P-T paths obtained by the unidimensional model for the Lora del Río core and the Hueznar succession are quite similar to the paths obtained by geothermobarometry.

The path of the lower unit (Lora del Río core) is composed by a first stage of 35 my (375-340 Ma) between the duplication of the crust and the beginning of the extension. At this time, the path of the Lora del Río core is defined by an isobaric heating related to the crustal thermal relaxation (12-14 kbar, 700-725°C). The second stage is decompressional with a small heating. The heating of this stage is generated because the exhumation of the Lora del Río core begin when the geotherm is still unstable. The interval of time (5-9 my) between the beginning of the extension and the thermal maximum (4-6 kbar, 750-800°C) decreases with the depth. After the temperature maximum the path shows a downward evolution for the temperature and pressure (<3 kbar, <400°C). First a drop in pressure conditions is more evident and later the temperature falls isobarically. Although the extension is still active during the drop in temperature conditions the exhumation rate decrease during this stage.

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GEOCHEMICAL CHARACTERIZATION OF THE GARROTAL CADOMIAN ANATECTIC GRANODIORITE

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The Garrotal granodiorite crops out in the southeastern area of the Monesterio antiform (central area of the Ossa-Morena Zone, Iberian Massif). It is the last granitic massif of the alignment of Cadomian anatectic granitoids that extends to the northwest for more than 200 km along the internal area of the Monesterio antiform. This alignment is composed by the Garrotal, Atalayuelas and Pintado granodiorites (Seville province), Monesterio granodiorite (Badajoz province) and some granodiorites cropping out around the Assumar village in Portugal. The origin of these granodiorites is the regional low-pressure metamorphic regime giving rise to development of anatectic domes around 530 Ma. They are composed by autochthonous to subautochthonous migmatite rich granite massifs and moderately allochthonous leucogranites.

The more differentiated levels of the Cadomian anatectic granodiorites alignment appear probably in the Garrotal massif. This massif is mainly composed by a porfidic granodiorite with prismatic plagioclase and k-feldspar porphyroblasts. The migmatites are scarce and crop out only in the northern area of the massif. Amphibolitic bands and sporadic black cherts have been mapped.

The granodioritic rocks of the Garrotal massif have a composition similar to the partial melts issued from metapelites and peraluminious metagreywackes. The comparison between the trace element contents of the Garrotal granodiorite and the average continental crust (e.g., post-Archean shales) shows striking similarity. The multi-elemental normalized diagram shows that the main composition of analyzed samples is similar of that to the reference materials, and indistinguishable from that of the Montemolín schists (lower member of the "Serie Negra").

The mass balance models imply low melting rates for leucogranites, lower than those attainable through qualitative reaction melting models (vapor absent muscovite melting). For the granodioritic samples, the mass balance models imply larger rates of melting, up 50%. This large melting rate allows the explanation of the chemical similarities between the Montemolín schists and the Garrotal granodiorite.

The Garrotal granodiorite, like the Monesterio granodiorite and probably the Atalayuelas and Pintado granitoids, originated by local melting of pelitic protholiths analogous to those of the upper Proterozoic Montemolín unit. They do not appear to have been affected by significative melt extraction. Geochemical data show striking similarities between metasedimentary protholiths and granodioritic rocks. Chemical models point to a vapor absent muscovite partial melting at low pressure as the main source for the granodiorite, which is in agreement with the LP/HT metamorphic evolution of the area.

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GEOCHEMICAL CHARACTERIZATION OF BASIC ROCKS RELATED WITH A POST-CADOMIAN EXTENSIONAL EVENT (NW SEVILLA, OSSA-MORENA ZONE)

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Volcanic rocks are frequent in the southern limb of the Monesterio antiform (central sector of the Ossa-Morena Zone, Iberian Massif) from upper Proterozoic until Cambrian times. In the southeastern sector of this limb (Lora del Río region) volcanic rocks have been affected by a variable metamorphism and the recognition and initial classification of this rocks is an arduous work. The gabbros, diorites, amphibolites and pillows analyzed in this sector allow the first geochemical characterization of these rocks and the comparison with other better exposed sectors of the southern limb of the Monesterio antiform.

The major and minor elements in analyzed amphibolites and gabbros show compositional resemblance and similar evolution trend in Harker diagrams, suggesting a genetic relation. The diorites and pillow-lavas analyses projected in quite different domains and with proper evolution trends suggesting that these rocks have an individual genetic evolution.

The normalized multi-elemental diagrams shows little but meaningful differences between the amphibolite and gabbro trends. The amphibolites show normalized trends (rare earth elements and Thompson's multi-elemental trends) similar to the ridge basalts with depletion in lithophile elements and light rare earths. The gabbros are more enriched in lithophile elements and the trends are not depleted in light rare earths. The pillow-lavas have an alkaline trend with high contents in minor elements and the rare earth model notably fractionated. The diorites geochemical features are quite different showing an alkaline trend with striking enrichment in minor and light rare earth elements.

The projection of analyzed rocks on tectonomagmatic discrimination diagrams suggests that the amphibolites are related with MORB basalts (with scarce dispersion or without dispersion). On the other hand, the gabbros show a transition between MORB basalts and basalts related with island-arc vulcanism.

Generally, the chemical features of amphibolites and gabbros are quite similar but it is difficult to ascertain if they have a common origin because there are scarce differences in composition and in the trends of the normalized multielemental diagrams. The affinity of amphibolites with MORB basalts and the transitional character of gabbros between MORB basalts and K-poor tholeiites has been often attributed to rocks originated in back-arc basins. These rocks are probably related to magmatic events associated with the beginning and later evolution of an oceanic basin in the southern sector of Ossa-Morena during Cambrian times.

The analyzed pillow-lavas are clearly related with intraplate basalts. Probably, the pillow-lavas are the youngest analyzed rocks and have originated later in a bigger ocean basin.

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GEOCHEMICAL CHARACTERIZATION OF THE CRUSTAL MELTING PRODUCTS IN THE LORA DEL RÍO METAMORPHIC CORE

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The Lora del Río metamorphic core is a hercynian gneissic dome located at the southeastern border of the Ossa-Morena Zone of the pre-Mesozoic Iberian Massif. It is overlain by unconformable Tertiary successions of the Guadalquivir basin. The evolution of the high grade metamorphism of this dome has been identified like a clockwise path with a first MP-MT event and a second LP-HT event. The processes of crustal melting developed during the isothermal decompression between the MP-MT and the LP-HT events. The age of the melting process deduced by U/Pb isotopic relations in zircons of the anatectic granitoids is 340 Ma (Lora del Río anatectic granodiorite), and this metamorphic cycle overlaps a previous Cadomian metamorphism dated as 590 Ma (Las Camachas granodiorite).

Analyzed migmatites, anatectic granodiorites and aplogranitic rocks have a peraluminic composition similar to the "S" type granites defined by White & Chapell (1983) and Chapell & White (1992). This rocks have originated by the partial melting of a crustal protolith [probably different to the metapelites and metagreywackes of the "Serie del Hueznar" (Hueznar succession)] following a differentiation process between the restitic material and the melt. The representation of the analyzed rocks on the tectonomagmatic discrimination diagrams and the spiders geometry in normalized multi-elemental diagrams clearly shows his relation with a syn-collisional environment.

The geochemical character of the analyzed rocks and the melts formed by biotite melting in high temperature water subsaturated conditions is similar. The similarity is more evident between the analyzed rocks and the melts generated by Patiño Douce & Johnston (1991) from pelitic protoliths. Likewise, the melts generated by Vielzeuf & Montel (1994) from metagreywackes are slightly Ca enriched.

The Lora del Río and Las Camachas granodiorites show a similar geochemical and mineralogical character suggesting a similar melting process during the Cadomian and Hercynian orogenies. The only meaningful difference is the absence of garnet in the Las Camachas granodiorite restitic material and the abundance of this mineral in the Lora del Río granodiorite. The iron fraction X_{Fe} [Fe/(Fe+Mg)] in the melts obtained experimentally by metapelites and metagreywackes partial melting depends on solid ferromagnesian minerals balanced with the melt. The solid ferromagnesian mineral rate is controlled by

physicochemical conditions of the system (X_{H_2O}, P_{O_2}, P, and T). The appearance or absence of garnet is probably related with the pressure of the partial melting process. The Cadomian melting happened below 5 kbar pressure conditions (without garnet growths) and the Hercynian garnet grow just above these pressure conditions.

The fractional crystallization rate of the two granodiorite rocks is very low. Likewise, the quartzfeldspathic differentiated products are probably related to melting leucosomes and not to fractional crystallization.

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Volcanoclastic series of the Obejo-Valsequillo-Puebla de la Reina Domain (Ossa-Morena Zone, Iberian Massif)

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In the Obejo-Valsequillo-Puebla de la Reina Domain (DOVPR), there is a succession corresponding to a Cadomian nucleus constituted by plutonics rocks, intruded in metasedimentary and volcanic materials, and structured during a long Variscan left shear process. The plutonic rocks are predominantly diorites, but it is possible to find variable proportions of mafic accumulates, leucotonalites, granodiorites and subvolcanic granites. The volcanoclastic rocks are found in two different series: Don Álvaro volcanoclastic succession and Oliva de Mérida vulcanites. Both successions have a bimodal vulcanism with an important volcanoclastic component, which increases to the top of the sequence. Those rocks grade laterally into metapelitic rocks which could be related with the "Serie Negra" of other parts of the Ossa-Morena Zone (OMZ). In the Peraleda antiform these rocks clearly present at least one more deformation phase than the materials of the lower Palaeozoic. Towards the top, the volcanic rocks grade gradually into the pelitic series of the Alange dam constituted by alternating sandstones, quartz schists and fine-grained quartzites.

The Volcanoclastic succession of Don Álvaro crops out in the Mérida area. It is a very tectonized succession, placed in the central sector of an asymmetric flower structure with a high transpressive component. This succession grades rapidly into the materials of the "Serie Negra". It is formed mainly by an alteration of porfidic rhyolites, vitric tuffs and greenish dacites, with few phenocrysts of quartz and feldespar, and with occasional beds of greywackic schists. This succession shows some intercalations of fine-grained amphibolites that show a planelineal fabric defined by green hornblende and plagioclase, and abundant decimetric to metric-wide intercalations of greenschists with a similar mineralogy to the amphibolite. It presents a lower middle grade Cadomian metamorphism that has been little studied, showing a garnet-hornblende-albite assemblage. There is a Hercynian low-grade metamorphic overprint.

The Oliva de Mérida volcanics are placed between the Mérida massif and the Palomas pluton, and can be related with those of Don Álvaro. They are vitric rhyolites; microlitic rhyolites with flame textures and dacites, which intercalated fine-grained quartzites, metagreywackes, rhyolitic tuffs, and cinerites, with occasional levels of fine-grained amphibolites. To the East, they present abundant intercalations of biotitic schists and metavolcanites. These present a middle grade metamorphism with garnet-staurolite assemblages. This series is unconformably overlain by Lower Cambrian siliciclastics (Torreárboles Formation) and carbonates with archaeocyaths. These two series show important differences on their metamorphism, and the pre-Cambrian presents a deformation which originates protomylonitic lineations (absent in the Cambrian) compatible with a left shear to N170E. This metamorphism has been dated as 500 Ma (Quesada & Dalmeyer, 1991). Those rocks are situated in an antiformal structure thrusting to the northeast and are intruded by rocks similar to those of the Mérida massif.

Both series define a calc-alkaline tronjhemitic series which represents a juvenile magmatic arc. Geochemical results, geological cartography, metamorphism and deformation do not permit the distinction of the presence of two or more volcanic arcs.

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Deformation of the Mérida Massif (Ossa-Morena Zone, Iberian Massif, Spain)

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The Mérida massif is located in the NW of the Obejo-Valsequillo-Puebla de la Reina Domain (DOVPR), between the Los Pedroches batolith and the Badajoz-Córdoba Shear Zone (CBSZ). In this Domain, a Central Iberian-type Palaeozoic succession overlies a pre-Ordovician sequence similar to those of Ossa-Morena, showing an angular unconformity which reflects the Cadomian orogeny. The SW boundary of the Mérida massif is marked by the Hornachos fault, while its NE boundary is more problematic but could be the Portalegre thrust in Portugal and the San Pedro de Mérida thrust in Spain. In this domain, the pre-Ordovician basement has a Cadomian deformation and metamorphism overprinted by a transpressive Hercynian deformation which generates a flower structure.

The Mérida Massif defines an asymmetric flower structure with a vergence to the NE. Although it shows a Hercynian evolution, it is possible to recognize pre-Hercynian deformation criteria which controlled the subsequent evolution of those rocks. Cadomian rocks are mylonitized in the northern part of this massif, with high deformation belts. In this sector it is possible to recognize an acussed thrust component related with the left trasncurrent process. This structure (San Pedro de Mérida thrust) is generated under transitional fragile-ductile conditions, typical of the middle crust levels, and caused the thrusting of the Cadomian igneous rocks over the Palaeozoic rocks which define a late antiform (Sierra Bermeja). The deformation increases towards the contact with the Palaeozoic rocks, where diorites are transformed into ultramylonites. In this sector there are kilometric-scale shear bands, formed by mylonites and ultramylonites which include masses of Tremadocian arkoses, diorites and Devonian materials. The Tremadocian arkoses are thrusted onto Middle and Lower Devonian materials. This sequence is similar to that of the Valle de la Serena massif.

In the less deformed central area, there is a protomylonitic foliation, but millimetric to centimetric levels of ultramylonites concordant with the foliation are present. Later centimetric bands of cataclastites superimposed to the dominant foliation are developed. A second cataclastic process generates verticalized North-dipping shear band structures. The lineations show average strikes N40E with dips to the SW, and it is possible to recognize numerous kinematic criteria in XZ sections (C-S structures, porphyroclastic systems,…) which indicate thrusting to the North, with a very important left lateral component. In the area where the vergence changes, two types of Carboniferous igneous rocks crop out: medium-grained, gneissified synkinematic rhyolitic porphyries, and postkinematic, mantled feldspar-bearing rhyolitic porphiries, fine-grained biotite-bearing granites and porphyric granites (Proserpina pluton).

In the shouthern sector of the Mérida massif, the flower structure is overlain by Palaeozoic rocks. Another sigmoidal structure appears more to the South, with rocks similar to those of the Mérida massif and complementary with it. All this massif is cut by later faults showing left lateral movements. Associated with these faults, an irregular vertical foliation N30E is developed which overprints previous foliation near to those accidents.

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Deformation in the Valle de la Serena massif

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The Valle de la Serena massif is placed in the Obejo-Valsequillo-Puebla de la Reina Domain (DOVPR), in northern Ossa-Morena Zone (OMZ). It is an igneous body formed by Cadomian acid and basic rocks, unconformably overlain by Tremadocian arkoses. It presents a long sigmoidal cartographic morfology (35x10 km). The massif is surrounded by post-Tremadocian Palaeozoic materials that show vergence to the NE opened folds. It shows a transcurrent hercynian deformation with thrust component to the NW marked by stretching lineations dipping 20-40° to N300-330E. Deformation takes place under greenschist conditions. The massif presents a very well developed strong dipping protomylonitic foliation trending N140-160E. In the most deformed areas, it shows mylonitic or gneissic textures. Anamostosed kilometric-scale shear bands cut the foliation at a low angle (10-20°). The cataclastic-protomylonitic textures of these rocks indicate that deformation has developed in the fragile-ductile transition with high content in fluids. In the SE, metasedimentary rocks show a typical imbricated thrust system in which the Tremadoc thrusts over the Devonian, with a left transpressive disposition and little internal deformation. Granitics rocks of NW area have developed little cataclastic foliation with centimetric bands of cataclastites parallel to poorly developed metric shear bands and conjugate fracture systems. Structuration of central and northern areas of the pluton take away in the transition between cataclastic flux and intercrystalline deformation. Igneous materials develop a very penetrative cataclastic foliation which evolves to protomylonitic-gneissic foliation and confers to the rocks an augengneiss or C-S textures close to the major faults.

Deformation of Valle de la Serena massif is typical of very rich feldspar rocks, with the generation of metric and anamostosed discrete shear zones, and submillimetric very heterogeneous shear bands which absorb moderate stress. It take away under greenschist facies, in fragile-ductile (between 300-450°C) to fragile conditions, defining shallower conditions to the SE. This body is placed inside a large shear zone with left transpressive kinematics which constitutes the boundary between the Ossa-Morena (OMZ) and Central Iberian Zones (CIZ) and whose septentrional edge thrusts OMZ basement materials onto the CIZ Palaeozoic cover. This process evolved during all Palaeozoic times, controlling the stratigraphy, palaeogeography and tectonics. This explains the large variations in thickness of the Armorican Quartzite (Arenig) and its occasional lack.

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The granitic belt of the northern area of the Ossa-Morena Zone. A major feature of the Iberian Cadomian Orogen

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The Obejo-Valsequillo-Puebla de la Reina Domain (DOVPR) is the northernmost domain of the Ossa-Morena Zone. Its northern boundary is a left transcurrent thrust, developed under fragile-ductile transition deformational conditions. This separates the DOVPR from the Palaeozoic materials of the Central Iberian Zone and from the Los Pedroches Carboniferous basin. The southern boundary is the shear belt of Hornachos, a left transcurrent accident which separates DOVPR from the materials of the Badajoz-Córdoba Blastomylonitic Belt.

The DOVPR is formed by a pre-Arenig basement with Ossa-Morena affinity, unconformably overlain by a Palaeozoic sequence very similar to that of the Central Iberian Zone. The pre-Arenig succession, similar to the "Serie Negra", is constituted by metagreywackes with black quartzites, a volcanoclastic series (Don Álvaro Series and Oliva de Mérida vulcanites), and on the top an alternating sequence (Pelitic Series of Alange dam). Different intermediate plutonic bodies (diorite-tonalite) intrude those rocks. Unconformably overlaying all the former appears the Malcocinado Formation, which includes poligenic conglomerates and some acid and basic volcanic levels. On top of this formation there are Tremadocian white arckoses that can be compared with those of the Urra Fomation and "Serie Intercalar" of the Portuguese authors.

The main massifs are: the Mérida massif, the Palomas pluton, the Oliva de Mérida and the Zarza de Alange intrusions, the Valle de la Serena massif and the Valsequillo and Escribano granites. The Mérida massif is constituted by accumulative rocks, formed by centimetric levels of hornblendites, plagioclastites and accumulative diorites and gabros with centimetric magmatic granites. These rocks

pass into coarse-grained diorites with accumulative textures and fine-grained diorites. The most differentiated facies correspond to granodiorites and leucotonalites. The other massifs present more evolved terms with quartzdiorites, granodiorites, microgranites and coarse-grained subvolcanic granites. These rocks are accompanied by some subvolcanic acid bodies, such as the Valle de la Serena massif dated as 574 Ma, which shows evidence of pre-Hercynian deformation, trending approximately N160E and overprinted during the Hercynian orogeny. In the Mina Afortunada area, the Cuartel amphibolites show lithotypes and geochemistry very similar to the Mérida massif. The same occurs in El Entredicho diorites, in the Badajoz-Córdoba shear belt, and in La Bomba and Mosquil granites, and in the Ahillones pluton in the south of the Azuaga fault.

Geochemically, these rocks show a calc-alkaline trondhjemitic evolution with an important mantle contribution. The rocks have a complex petrogenetic evolution, starting from the very hydrated mantle melt. This alignment, and all the products described above, correspond to the materials of a Cadomian volcanic arc.

Along the Hercynian orogeny, under a transpressive regime, the whole domain shows a left lateral movement and thrusting to the NE with the formation of transcurrent duplex, which incorporates the Cadomian and Palaeozoic materials.

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Reconstruction of the Cadomian foldbelt: Outer marginal setting of the Terminal Neoproterozoic to Early Cambrian at the NE of the Bohemian Massif and tectonostratigraphic relations to Central and Western European Cadomian terranes

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A crustal section composed of very low to low grade Cadomian basement and regional unmetamorphosed Lower to Middle Cambrian overlap sequences is preserved at the NE margin of the Bohemian Massif (Saxothuringian Zone, Torgau-Doberlug Syncline).

The Cadomian basement (Rothstein Formation, terminal Neoproterozoic) represents a fragment of a late Cadomian marine continental margin backarc basin, comparable to the modern Japan Sea backarc (Buschmann, 1996). Greywackes and conglomerates display a dissected continental arc provenance. Calc-alkaline tuff intercalations of extrabasinal provenance record synsedimentary magmatic activity at the continental arc source. Intrabasinal volcanic rocks display eruptional and trace element features attributed to a geotectonic determined basin evolution. Thinning out of a continental basin substratum resulted in eruptions of alkaline sea floor basalts, and culminated in voluminous eruptions of sea floor E-MORBs (formation of oceanic basin floor), accompanied by sea floor hydrothermal activity. The initial stage of basin closure is recorded by eruption of subduction influenced andesitic sills into unconsolidated mass flow deposits (sill-sediment complexes). Basin closure was accomplished by accretionary deformation of the basin infill in a second order wedge setting, as recorded by the penetrative formation of broken formation-type tectonic melanges. SHRIMP-U/Pb data of zircons from a tuff layer date the basinal sedimentation and the synsedimentary arc activity at 566 ± 10 Ma. SHRIMP-U/Pb data of detrital zircons from greywacke reveal a Cadomian arc source (~590 to 690 Ma), and a detrital contribution of a Palaeoproterozoic source (~ 1.8 to 2.0 Ga), as well as involvement of the Palaeoproterozoic basement in continental arc magmatism (idiomorphic zircon with 2.0 Ga core and 600 Ma rim). The Palaeoproterozoic components suggest a Cadomian marginal basinal setting at the periphery of the West African craton (Nance & Murphy, 1994).

The regional unmetamorphosed Lower Cambrian (Zwethau Formation) overlaps the Cadomian basement disconformably. Highly immature basal conglomerates are composed of reworked Cadomian basement material, comprising green schist clasts and greywacke clasts showing pressure-solution cleavage, thus evidencing a Cadomian regional overprint (Buschmann, 1996). The overlying Lower Cambrian succession displays the following facies development: deep subtidal carbonate ramp, shallow subtidal ramp, intertidal mixed siliciclastic-carbonate ramp, supratidal flat, intertidal mixed siliciclastic-carbonate ramp, subtidal siliciclastic shelf (Elicki, 1995). Fossils (archaeocyathans, small shelly fossils) from carbonates record a Lower Ovetian age and a Mediterranean setting (Elicki, 1995). Trace element patterns of high level intraformational intrusions of tholeiitic basalts of E-MORB affinity, and andesitic derivatives of tholeiitic and calc-alkaline composition reflect thinning of the continental basinal substratum, briefly after termination of the Cadomian convergence (Jonas, 1999).

The terminal Neoproterozoic continental margin backarc basin fragment reflects a NW-Pacific-type geotectonic setting of the Late Cadomian processes. The NW-Pacific-type setting, as characterized by closely spaced, highly dynamic, and short lived marginal basins and active margins (Taylor & Natland, 1995), appears to be common for the terminal Proterozoic development of the European Cadomides. Instead of voluminous juvenile arc and related volcanoclastic rocks characteristic of Andean-type settings, the bulk of the late Cadomian high crustal sequences preserved in the European Variscides is derived from marginal basin fragments composed of greywacke-bearing flyschoid sequences and intrabasinal erupted basaltic volcanics.

NW-Pacific-type Cadomian processes in Cadomian terranes of the Saxothuringian Zone postdate equivalent processes in the Armorican Massif (e.g. Chantraine *et al*., 1994) by ca. 30 Ma. First age data of the Cadomian history in the Teplá-Barrandean region (Zulauf *et al*., 1999) point to a contemporarity with Cadomian NW-Pacific-type processes in the Armorican Massif. The younger ages of Cadomian marginal basin fragments in the Saxothuringian Zone are interpreted to reflect an outer marginal setting with respect to the previously accreted Cadomian terranes of Armorican Massif, and probably of the Teplá-Barrandean as well.

Despite the diachronous active margin history of the European Cadomides, the termination of the Cadomian orogenic history occurred roughly synchronous at the Precambrian/Cambrian boundary interval. Marked by intrusions of voluminous S-type granitoids which are probably related to orogenic collapse melting of the Cadomian arc-composition crust, the termination is best attributed to transition to a transform margin (Murphy *et al*., 1991). The transform regime has been maintained during the Lower Cambrian, as indicated by local, fault-controlled formation of shallow marine transtension pull-apart basins in the framework of a counter-clockwise rotation of Gondwana (Courjault-Radé *et al*., 1992).

In terms of the palaeogeographic setting, the Lower Cambrian of the NE Bohemian Massif was situated at an outer marginal position too. This is indicated by geotectonic parameters of the intraformational volcanism and the marine sedimentary facies compared to the sedimentary and magmatic development of contemporaneous Lower Cambrian successions in European Cadomian terranes of the Teplá-Barrandean, the Armorican Massif, the Montagne Noir, and the Iberian Peninsula.

The Cadomian late-orogenic transitional/alkaline magmatism in the Ossa-Morena Zone (Iberian Massif)

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The alkaline granitic rocks (with sodic pyroxenes and/or amphiboles) are relatively abundant in the NW sector of the Olivenza-Monesterio antiform (Ossa-Morena Zone). Some plutons of this sector, located in the Badajoz province, define an alkaline/transitional association composed by gabbros, syenites and alkaline granites: (a) the circular complex of Barcarrota; (b) the Feria-Sierra Vieja massif; (c) the Almendral pluton. The geochemical characterization of the latter pluton is the aim of this paper for completing the information and locating this magmatism on its geodynamic setting.

The Almendral massif was emplaced into the Lower Cambrian limestones of the northern limb of the Olivenza-Monesterio antiform during the Upper Cambrian-Ordovician transition (K-Ar: 450±12 and 481±10 Ma). The materials forming this antiform have been affected by the Hercynian orogeny. However, the consequences of this orogeny in the normal limb, in which this pluton is located, were not very important and, consequently, the igneous rocks do not exhibit any deformation.

Gabbros, diorites, monzodiorites, alkaline and peralkaline syenites, quartz-syenites, alkaline and subalkaline granites are the more characteristics lithotypes of this pluton. The basic rocks exhibit amphibole±pyroxene. Sodic amphibole±pyroxene±biotite, with one or two feldspars, occur as mafic phases in the syenites. The granites exhibit biotite and sodic amphibole and they are commonly subsolvus although hypersolvus varieties are not uncommon. The pluton defines an essentially bimodal transitional/moderately alkaline magmatism.

The Almendral pluton is related to an intracontinental environment. The high content in Ba and Sr in the acid terms and their position in the WPG and VAG fields of the Rb vs Nb+Y diagram point out the compositional similarity with late-orogenic alkaline granitoids. The lack of an evolved rift reduced the environment to pre-rift environments, probably related to the late-orogenic continental epirogenic uplift or to the initial stages of the rifting. The petrologic and geochemical affinity of this pluton and Barcarrota pluton suggest that both massifs are part of the same late Cadomian tectonomagmatic event. This magmatism point out the end of the Cadomian orogenic regime and the transition to an intracontinental rift regime, starting the Hercynian Wilson cycle.

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The Valencia del Ventoso pluton. An example of late post-tectonic Hercynian I-type granitoid

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The Valencia del Ventoso massif (VVM) is placed in the meridional zone of Badajoz province (Spain). It is emplaced in the central part of the Monesterio antiform, an Hercynian structure which is cross-cut in NE-SW direction. Its northern and southern parts intruded the succession from the Malcocinado Formation through the Lower Cambrian (Toreárboles Formation and a detrital-carbonate formation) and the volcano-sedimentary materials of the Bodonal-Cala Complex respectively. The central part cuts the Precambrian materials of the “Serie Negra” and some different Palaeozoic granitic massifs.

This pluton produces a wide metamorphic aureole with migmatites and pyroxenic hornfels in its internal zone overprinting all the previous Cadomian foliation. It cuts the Monasterio thrust, a first phase Hercynian structure, but it is still posible to recognise a narrow band of hornfelsed and migmatized mylonitic rocks which marks the boundary betwen the Valencia del Ventoso and Cortijo del Pozuelo units. Consequently, this massif is posterior to the first Hercynian phase and possibly also to the second, since it has not any significant signs of deformation. However the intrusion is conditioned in part by the Monesterio thrust which would control its emplacement.

Recent works lead us to rewiew the scheme of a simple pluton proposed by Pons (1987), as explained below: the VVM is considered as formed by two principal units called

dioritic unit and granitic unit, plus two subvolcanic suites represented by rhyolites with aplitic affinities and mafic dykes trending E-W, which were emplaced later.

The dioritic unit occupies the meridional, septentrional and most part of oriental edges, as well as the inner part of the massif. It includes the outcrops of Medina de las Torres and Cortijo del Pozuelo, and so the central and intermediate units. It is mainly formed by two types of lithologies: gabbros, which are placed at the two extremes of the massif, and diorites and monzodiorites located in the south-east and northwest edges, and around Valencia del Ventoso where it defines a central mass with a circular cartographic pattern and accumulative facies.

The granitic unit, which occupies the more extensive outcrops, intrudes and cuts the facies of the dioritic unit. In the northeast and southwest areas, this unit is intrusive in the Precambrian materials of the host rocks.

The subvolcanic suite includes rhyolitic dykes with aplitic affinities and diferent diabasic rocks, presenting a dominant E-W trend.

Rewiew of structural evidences and a detailed analysis of the different planar structures have conducted to the conclusion that there are two different foliations, one related with a primary magmatic layering linked with the accumulative process, and a second due to the emplacement of related magmatic flow. The first one is present in the central gabbroic masses and defines two tabular bodies with a small dip.The second one is characteristic of the granitic facies, presenting northened directions and sinistral movement criteria, becoming more penetrative near to the edge of the main granitic bodie, which is posterior in time intruding previous facies.

Altogether, this is a massif with a inversal zoning and with the typical characteristics of the I type granitoids, whose origin can be related to the subduction of the South Iberian ocean to the North below the Aracena dome, whose materials conform the Beja-Acebuche ophiolite.

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The Cadomian block in North Brittany

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On the basis of numerous studies carried out since the 1970s, the Cadomian orogeny in the Armorican Massif has been interpreted as the result of a collision arc/continent. Several geodynamic models were proposed and discussed but many questions remained unanswered: influence of oceanic subduction?, compressive or transpressive deformation? During the 1990s new analytical data collected in the framework of two scientific projects (CADOMIAN and ARMOR projects associating geological mapping, magnetic/gravimetric models and seismic profile) have made it possible to update the scenario of the evolution of the Cadomian active margin.

In the Armorican Massif, the Cadomian block is constituted by Neoproterozoic formations (Brioverian) emplaced from 620 Ma to 540 Ma and lying on a disrupted gneissic basement (Icartian) that have yielded ages around 2,000 Ma.

The Cadomian block comprises two domains: a northern orogenic domain mainly contituted by volcanic and volcanoclastic formations and a southern continental domain with thick sedimentary successions and granitic bodies of crustal origin.

The orogenic domain comprises two units. The Tregor Unit is composed of a volcanic-plutonic complex of crustal affinity comprising the North Tregor Batholith (615 +13/-7 Ma) and volcanic formations making up and intermediate to acid suite (615 Ma). The Saint Brieuc Unit is made up of several formations affected by deformation and metamorphism increasing from North to South: (a) a volcano-sedimentary succession in which the volcanic rocks (610±9 Ma) are comparable to the present-day arc tholeiites; (b) a bimodal volcanic suite with continental tholeiite associated with leptynite (588±11 Ma) and covered by a sedimentary formation (turbidites). This volcanic suite emplaced in a marginal basin of which the basement is constituted by the Pentevrian orthogneiss (746±17 Ma). The Saint Brieuc Unit is cut by intrusive bodies emplaced in a narrow time span (from 595 Ma to 580 Ma). The orogenic domain is affected by intense tangential tectonics dated about 570 Ma (Ar/Ar ages).

The continental domain is mainly constituted by very thick sedimentary successions lying on an unknown basement. Several migmatite domes and granitic bodies of crustal origin emplaced in this domain around 540 Ma. Two metabasic and ultrabasic bodies have also been recognized of which the protolith is dated at 620±8 Ma. These bodies are tectonic slices of deep origin and underline the tectonic contact between the orogenic domain and the continental domain.

South of the North Armorican Shear Zone, in central Brittany, granitic intrusions are lacking and the age of the very thick and uninterupted Brioverian succession is very late Neoproterozoic to early Palaeozoic. The continental domain is affected by late stage tectonics of weak intensity.

On the basis of recent studies the following version of the geodynamic model of the evolution of the Cadomian active margin can be proposed:

(a) 800-750 Ma: an early arc formed on the border of the Icartian continent; this early evolution was sealed by the emplacement of the North Tregor Batholith.

(b) 620-610 Ma: emplacement of the Tregor volcanic arc linked to a northwards dipping subduction.

(c) 600-590 Ma: a local extension opened the Saint Brieuc basin in which a strong igneous activity developed.

(d) 580-570 Ma: the Cadomian shortening caused occlusion of the Saint Brieuc basin and its thrusting on the foreland.

(e) 560-540 Ma: the Cadomian tectonics migrated southwards and migmatite domes and granitic bodies were emplaced in the continental domain.

Transected folds in the Neoproterozoic rocks of the Central Iberian Zone: evidence for Cadomian deformation?

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The Neoproterozoic sedimentary Schist-Greywacke Complex, located in the Central Iberian Zone of the Iberian Variscan belt, was variously deformed and metamorphosed during the Variscan orogeny. One of the areas with less intense Variscan overprint is located in the southwestern part of the Salamanca Province close to the village of Monsagro, at the northern boundary of the Las Hurdes Dome within the Domain of Vertical Folds. In this area, in addition to the Variscan deformation, there is a record of Sardic deformation mainly manifested as an unconformity between Neoproterozoic and Ordovician rocks. The Variscan event produced folds with generally vertical axial plane cleavage and horizontal axes in the Palaeozoic rocks. In contrast to the deformation style in the Palaeozoic rocks, two sets of folds were found in the underlying Neoproterozoic conglomerates, sandstones and pelites: (a) Variscan folds with vertical axial plane cleavage and predominantly vertical axis and (b) pre-Variscan folds with both limbs transected by cleavage and variable plunging axis. The latter pre-Variscan folds occur at different scales (from outcrop to regional) and bear no associated cleavage or metamorphism. It is interpreted that the vertical axis of the folds are due to the initial steep position of bedding during the Variscan deformation. Furthermore, the steep position of bedding was caused by the cleavage-transected folds, which are interpreted to have been formed in relation to deformation activity during Cadomian times. The occurrence of this deformation event, not necessarily related to a collisional setting, and its tectonic implications are undoubtedly a key piece in the puzzling Precambrian picture of Iberia.

Contribution for the study of the early Ordovician bimodal volcanism from the Marão mountain, northern Portugal

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In the Marão mountain, northern Portugal, acid volcanism occurs associated with the volcano-sedimentary Vale de Bojas Formation, considered as lower Ordovician in age and being part of the Central Iberian Zone autochthon (Coke *et al*., 1995). This paper presents the geochemistry of these acid rocks (SiO_2 > 67.6). They are characterized by significant concentrations of trace elements compatible with K-feldspar (Rb: 228-157 ppm, Ba: 691-401) but by depletion on HFSE such as Y (16-4 ppm), Zr (94-50 ppm), Nb (29-14 ppm) and the rare earth elements (SREE: 50-142 ppm). These acid rocks show negative Eu anomaly (Eu/Eu*: 0.23-0.96), and moderate REE fractionation (Ce_N/Yb_N: 2.36-6.04). Sub-contemporaneous extrusions and intrusions of basic compositions (SiO_2=48.9%) also occur associated with Vale de Bojas Formation. They present now paragenesis typical of the amphibolite facies and show characteristics representative of basaltic tholeiitic magmas. This effusive volcanism was synchronous with conglomerate diagenesis. As is typical for tholeiitic magmas, the mafic rock is poor in incompatible elements (Rb=9 ppm, Ba=22 ppm, Y=32 ppm, Zr=70 ppm, Nb=18 ppm), and shows weak fractionation from light to heavy rare earth elements (Ce_N/Yb_N=2.78). Field evidence, the petrography and the similarity of trace element ratios existing between the basic rock and the conglomerates suggest that these sedimentary rocks were partially imbibed (and recrystallized) by mafic magmas. Although not very abundant, these manifestations of bimodal volcanic activity suggest an extensional setting, with crustal thinning and fracture development that allowed magma ascent. The bimodal association comprising tholeiitic basalts and rhyolites is characteristic of the initial stages of rifting, which is in agreement with the tectonic setting proposed by Ribeiro *et al.* (1990) for the beginning of the Ordovician. The pre-Variscan magmatism with basic-acid manifestations were also cited by Navidad & Carreras (1992) on the NE of Iberia.

Also other mafic veins crop out in the Marão mountain, cutting the schistose Landeilian Formation, cited by Coke *et al*. (1995) as having a Variscan age. The geochemistry of one of these rocks indicate significant REE fractionation (CeN/YbN=10.46) and high concentrations of Ti, P, Zr, Nb, Ba, and REE (TiO_2=1.2%, P_2O_5=1.6%, Zr=583 ppm, Nb=45 ppm, Ba=2,578 ppm, SREE=355 ppm), similar to that reported for alkaline mafic rocks.

The contrasting magmatic affinities of the two mafic volcanic episodes show significant differences in the magma genesis processes and/or mantle source compositions prevalent during the Palaeozoic history of the Marão region.

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The transition Cambrian/Ordovician in the Central Iberian Zone of the Trás-os-Montes region (NE Portugal); the acid volcanism as stratigraphic correlation element

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The transition of the Slate and Greywacke Complex into the Ordovician in the Central Iberian Zone of the Trás-os-Montes region has been referred as assuming distinct aspects: - gradual passage, apparently without unconformity in the Moncorvo region (Rebelo & Romano, 1986), in S. Gabriel, NW of Castelo Melhor (Silva & Ribeiro, 1991)

and in S limb of Poiares synclinal, SE of Freixo de Espada à Cinta (Silva & Ribeiro, 1994); - sudden passage with angular unconformity in the E of Marão (Ribeiro, 1992; Coke *et al*., 1993) and in the Sião riverside in NE of Pardelhas (Pereira, 1987). Recent field works in Marão, Eucísia, Moncorvo, Castelo Melhor and Poiares, in the petrography domain have revealed the occurrence of acid volcanism and, in some places, also bimodal [Marão (Coke *et al*., *in this volume*) and Eucísia] associated to the lower Ordovician units. The quartz-rhyolitic volcanism that occurred in the beginning of the Ordovician was the main responsible for the production of great quantities of ashes that were spread in a large area having been deposited in various sedimentary environments. The occurrence of acid tuffs proceeding from those ash accumulations either directly deposited or carried with the sediments, constituted an important time marker. Having in mind these aspects, it was possible to essay some correlations among the formations of Vale de Bojas (Marão), Qta. da Ventosa (Moncorvo), S. Gabriel (Castelo Melhor) and "Serrinha" (Eucísia). The simultaneous existence of an angular unconformity and a disconformity in Marão mountain associated to the presence, in the basal conglomerate, of lithic clasts with striped phyllites, probably from the Desejosa Fm. as well as the distinct enrichment of the siltitic component expressed in a substantial increase of the thickness of the siltstone beds, usually bioturbated, point out to the occurrence of some emerged areas. This situation was also observed in Qta. do Cuco (Moncorvo), although here it was only registered the presence of a disconformity. SW further, nearby S. Gabriel chapel (Castelo Melhor), it was observed the existence of a gradual passage at volcanic levels without conglomerates suggesting a more distal environment. In all these situations the televolcanism was always stratigraphically registered above the stratigraphic unconformity. The model proposed by Ribeiro *et al*. (1991) for the evolution of the Central Iberian Zone included the formation and filling up of an aulacogene in the Upper Proterozoic-Cambrian with active faults in the borders, followed by an early tectonic inversion in left transpression perpendicular to the trough axis responsible either for the occurrence of bimodal volcanism or for the development of folds with large wave length, without slate cleavage. This model fits with the field data. This syndepositional tectonics would be at the origin of the reactivation of the active folds with associated uplift isostatic movements which would control the sedimentation.

The structural model referred above would explain: (a) the sudden passage, through the angular unconformity or disconformity, with erosion of the emerged parts that would provide the striped clasts of unconsolidated sediments; (b) the mixture of coarse grain sediments with volcanic material; (c) the development of base-of-slope debris cone or fan into shallow water, marine fan delta deposits (fluvial-deltaic or submarine; Oliveira et al., 1992; McDougall et al., 1987).

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Age and relationships between the deep continental crust of South Portuguese and Ossa-Morena Zones in the Aracena metamorphic belt revealed by zircon inherited core

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Textural observations, trace elements analysis and U-Pb isotope analysis performed by LAM-ICP-MS of zircon inherited core of Gil Márquez granodiorite (South Portuguese Zone) and Almonaster nebulite (Ossa-Morena Zone) in the Aracena metamorphic belt show that deep continental crust of Ossa-Morena is older and different than the non-outcropping crust of the South Portuguese Zone.

This supports the exotic origin of the South Portuguese Zone with respect to the rest of the Iberian Massif, as the nature and age of magma sources of the Seville Range batholith (South Portuguese Zone) are different from the Ossa-Morena Zone magmatism.

Structure and deformation history of the continental domain of the Aracena metamorphic belt (SW Iberian Massif)

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The Aracena Metamorphic Belt (AMB), located in the southwestern part of the Iberian Massif, represents the contact between the Ossa-Morena and South Portuguese Zones (OMZ and SPZ). Therefore, describing the structure, the deformational history and its relationship with the main metamorphic and magmatic events in both continental and oceanic domains of the AMB turns out to be a key matter in understanding the tectonic evolution of this part of the European Variscan orogen. Since structure of the oceanic domain (OD) has already been described (Crespo-Blanc & Orozco, 1988; Crespo-Blanc, 1991; Eden, 1991; Castro, 1996), this paper deals with the poorly known structure of the continental domain (CD).

Three different deformational events affected the CD of the AMB. The first one (D1), coeval with a first high grade metamorphic event, generated kilometer-scale recumbent folds, as well as an axial plane foliation and related mineral lineations. A second deformational event (D2) gently folded the previous structures. Between D2 and the third deformation phase (D3), static HT/LP metamorphism, generalized migmatization and associated intrusions of diorites, gabbros and norites took place. Finally, crustal scale, NW-SE oriented thrust shear zones and geometrically associated large scale antiforms developed during D3 and generated a prominent mylonitic foliation and a stretching lineation. Interference between the three phases gave place to complex fold patterns that have been classified, based on angles *(alpha)*, *(beta)* and *(gamma)*, as C-E-G-F types of Thiessen & Means (1980), and 1(→ 2)-3 types of Ramsay (1977). Only the third deformational event affected the OD; it seems to be related with the overthrusting of the continental margin onto the oceanic crust.

Structural evidences for a pre-Variscan tectonothermal event in the Central Iberian Zone. Variscan Belt, NW Spain

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New mapping and structural analysis carried out in the northern part of the Ollo de Sapo, together with the already existing isotopic (Fernández Suárez, *et al*. 1999) and metamorphic information (Martínez *et al*. 1996; Reche *et al*. 1998), allow us to improve the arrangement and characterisation of the tectonothermal events of the relative autochthonous domain of the Variscan belt.

An older tectonothermal event recorded in this domain is Upper Silurian to Lower Devonian in age and consists of an HT-LP, And-bearing metamorphic event coeval with top to W shearing affecting Lower Ordovician metasediments and the Ollo de Sapo (OSA) megacrystic metagranite. The passive continental margin of Gondwana subjected to continuous extension would provide the favourable setting for the lower Ordovician intrusions (OSA protolith and minor gabbroic-related intrusions) as well as the development of this pre-Variscan HT-LP tectonothermal event.

This was followed by a D_{1+2} thrust-related tectonic event, (360 to 340 Ma in age, Dallmeyer *et al*., 1997) which developed mylonitic rocks in the OSA and one phase of east-facing folds in the metasediments situated above the OSA, but two phases of east-verging folding and a shear band system in the lower Palaeozoic metasedimentary sequence situated in the footwall of the OSA. This crustal thickening event triggered syn-D_2 Barrovian, Ky-bearing metamorphism restricted to the footwall of the OSA.

This was in turn followed by the intrusion of early granodiorites (325 Ma; Fernández Suárez *et al*. 1999) affected by an HT, top to NW, D_3, shearing event also localised below the Cabo Ortegal Allochthonous complexes where lower grade phyllonitic rocks developed.

Leucogranitic intrusions (313 ± 2 Ma, Fernández Suárez *et al*., 1999) postdate this event and were affected by steep normal faulting and dextral shearing, the most important being the Vivero normal fault, to which D_4 collapse folds (in the footwall) appear related. Open and upright folding affect to the whole. Late Variscan granodiorites were intruded along NW-SE left-lateral faults.

The orogenic late Cadomian vulcanism in the Ossa-Morena Zone (SW Iberian Massif)

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One of the characteristic features of the Ossa-Morena Zone is the existence of extensive volcano-sedimentary formations, which unconformably overlay the metapelitic materials of the "Serie Negra". Those are, in turn, overlain with a minor unconformity by trilobitic Lower Cambrian successions. The volcano-sedimentary rocks are divided into two main units: the Malcocinado Formation and the Bodonal-Cala Complex, which are considered of late pre-Cambrian age. Both have been formed through an orogenic event related to an active continental margin of the type found today in the Andes.

A cartographic study of the main outcrops and new geochemical and geochronological data make it possible to determinate the significance of these events. In recent datings, a Lower Cambrian age (ca. 520 Ma) has been established for these materials. Likewise, a systematic variation of the main lithological types has been found. The oldest materials relate to the Malcocinado Formation, constituted by andesites, trachytes, dacites and rhyolites, with a large quantity of volcanoclastic and conglomeratic facies, of which some boulders are structurated. These materials crop out mainly in the northern side of the Monesterio antiform, and the andesites become dominant toward the SE of the structure in the Córdoba sector. Here, the lavas that form the so-called San Jerónimo Formation are essentially andesites and basalts. Towards the top, these materials change into mainly rhyolitic rocks, including crystal tuffs, cinerites, rhyolites, etc., among which some scattered pebbles of quartz, lyddites, etc. can be found. These materials are common in the San Calixto area, but are represented in larger quantities in the southern limb of the Monesterio antiform, where they are known as the Bodonal-Cala Complex, and in the area of Aracena where they are called the Jabugo Series.

Different diagrams of geotectonic discrimination indicate that the studied volcano-sedimentary formations are late orogenic successions, related to a magmatic arc. Calc-alkaline trends *s. l.* (low, medium, high K and shoshonitic terms) can be found in the Malcocinado Formation, while from high K calc-alkaline to shoshonitic terms can be recognized in the Bodonal-Cala Complex and Jabugo Series.

According to the data presented above, it can be concluded that this vulcanism is related to a lithospheric convergence process, with the Benioff plane dipping to the South. Furthermore, it can be associated with the final stages of the Cadomian orogeny, when there is a thickened, unstable crust that begins to collapse and become thinner during an extensional event. Likewise, the distribution of different materials is compatible with an important oblique component during the subduction, producing an important lateral deformation.

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Alegrete-San Pedro de Mérida thrust: the boundary between the Ossa-Morena and Central Iberian Zones

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The boundary between the Ossa-Morena (OMZ) and Central Iberian Zones (CIZ) is one of the more controversial geological features of the Iberian Massif, and there is no consensus about its location neither its exact geodynamic significance. It had to be located at different accidents between the Malcocinado fault in the South and Los Pedroches batholith to the North. However, there is a consensus in that it is a transitional zone between the Ossa-Morena and Central Iberian Zones, because it has pre-Arenig materials of Ossa-Morena affinity and Palaeozoic materials of Central Iberian affinity. The SW boundary of the Obejo-Valsequillo-Puebla de la Reina Domain (DOVPR) is the Hornachos fault, which separates from the Badajoz-Córdoba Shear Zone (BCSZ). To the NE the contacts are more problematic, and while in Portugal the limit could correspond to the Portalegre thrust, in the Spanish area it has only been defined in Peñarroya area, where the Palaeozoic and the Proterozoic are thrusting onto the Los Pedroches Carboniferous basin.

In the SE area of DOVPR, between Peñarroya and Adamuz, the lower Palaeozoic materials (that correlate with the Hoyo and Albariza micaschist) and locally the Devonian thrust to the NE onto the Carboniferous Culm series of Los Pedroches basin. This accident, which can be identified up to near Montoro, constitutes a part of a thrust system, which allows the emplacement of the Escribano granite onto Palaeozoic materials.

In the NE area of the Portuguese Alentejo it has been proposed a major left shear zone, which controls the Ordovician palaeogeography and forms a flower structure which causes the basement materials thrust into the NE onto Palaeozoic materials of the CIZ. Regardless of this, it has associated a very marked left-lateral component. The Valle de la Serena area forms a similar sketch, where Cadomian igneous rocks show left transpressional deformation thrusting to the NE.

In the central area, near Mérida, a volcano-sedimentary sequence crops out, intruded by dioritic and tonalitic rocks that are part of a major Precambrian alignment. The northern border of this massif corresponds to a belt of mylonitic rocks of kilometric width, with levels of ultramylonites. These materials thrust over highly deformed Tremadocian rocks, which in turn thrusts over Devonian materials along the San Pedro de Mérida thrust. The deformation of the diorites has taken place with ductile mechanisms in amphibolitic facies in the deeper zones, and up to brittle conditions in the final phase.

The gathering and processing of gravimetric data available in the area have revealed a significant leap in the Bouguer anomaly throughout this structure. This can be interpreted as a border between crust blocks of different characteristics. In order to make this structure more clear and perceivable, a map of the horizontal gradient and the second derivation of the Bouguer anomaly has been made, with relief and slanting lighting. This technique makes it possible to trace precisely this accident. The structure, which runs over more than 300 km between Portugal and the Guadalquivir river, could be called the Alegrete-San Pedro de Mérida-Montoro thrust. It must be understood as the border separating the OMZ and the CIZ, while the village of San Pedro de Mérida is the point from which both of these two zones can be most clearly observed.

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Cadomian-Variscan orogenic evolution of the Ossa-Morena zone and related areas of the Iberian Massif

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Ductile deformation and plurifacial metamorphism in the Ossa-Morena Zone (OMZ) of the Iberian Massif are related to a poly-orogenic evolution including two major tectonothermal episodes of Cadomian (late Proterozoic to Early Cambrian) and Hercynian age (middle to late Palaeozoic). Petrological, structural and geochronological data attest a number of tectono-metamorphic and magmatic episodes in the 620-480 Ma interval, that would comprise a complete Cadomian Wilson cycle. Cadomian crustal thickening is indicated by high-grade metamophic cores as in Monesterio, Assumar, Mina Afortunada and other less known localities of the OMZ.

The geodynamic scenario was an Andean-type continental margin. A model evolution is presented for this orogeny comprising stages of volcanic arc generation, back-arc extension, tectonic inversion, crustal thickening, and cratonization. A correlation with comparable areas from pre-Mesozoic massifs elsewhere in Europe is attempted, in particular with the Armorican Massif (northern France) and the Bohemian Massif (Czech Republic).

The Hercynian Wilson cycle began in the early Palaeozoic with continental rifting episodes that produced abundant bimodal volcanics of Middle Cambrian age. Orogenic *s. s.* events occurred in the 390-300 Ma interval and affected both the Cadomian basement, which was heterogeneously reworked and overprinted, and the Palaeozoic cover. Hercynian regional metamorphism generally was of low-grade, though high-pressure assemblages and thermal domes developed locally in relation to marginal subduction zones and late extensional events. The geodynamic model proposed for the Cadomian and Hercynian orogenies have a continous left laterall component and accounts both for the geological evolution of the sector studied of the Iberian Massif and for the geodynamic scenario that drove the fate of Cadomian terranes in western Europe.

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Anatexis of quartz pellitic rocks during Cadomian orogeny in the Ossa-Morena Zone. Examples of Monesterio, Mina Afortunada and related cores

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Late Proterozoic metasediments of the "Serie Negra" crop out widely along the Ossa-Morena Zone of the southern Iberian Massif (SW Spain). The succession consists mainly of schists, amphibolites, greywackes and volcanic levels at the top, often with interbedded phtanite layers. This series was subject to a regional low-medium pressure, tectono-metamorphic regime that gave rise to a Cadomian metamorphic belt. This crops out along three main alignments, reactivated at variable degrees during the Hercynian orogeny: Mina Afortunada-Fuente Obejuna, Monesterio-Assumar and Aracena-Almadén de La Plata. Nevertheless, similar materials are probably also near Évora. Quartz, biotite, white mica, chlorite, K-feldspar and plagioclase are the more common minerals in metapelites of different metamorphic grades. Al-silicates (andalusite/sillimanite) and cordierite only occur in the higher-grade areas. Garnet is very rare or absent in metapelites from the Monesterio area, nevertheless minor amounts can be found in other areas (Mina Afortunada). Using standard petrochemical calculation in the area of Monesterio, maximal temperatures of 550-650°C and pressures of 1.5-2.5 kb have been established. This metamorphism shows a clockwise path that fit well with P-T-t trajectories undergone by a crust moderately overthickened by the thrusting of thinned sialic crust. The migmatization ages have been dated at ca. 530 Ma (Oschner, 1993; Ordóñez, 1998).

The inner cores are constituted by anatectic domes composed by migmatites, autochthonous to subautochthonous migmatite-rich granite massifs and moderately allochthonous leucogranites. High-grade amphibolitic levels, black cherts and limestones, like the host-rocks of "Serie de Montemolín", have been recognized The best known domes are those of Mina Afortunada, Monesterio, Fuente Obejuna and Pintado. The central sector (Monesterio sector) has a lesser Hercynian overprint. In addition to anatectic domes, it contains granodioritic bodies more or less unrooted and correlatables that define an alignment more than 250 km long, from Lora del Río (Seville) to Assumar (Portugal).

The migmatites and granitoids appear to have been generated through partial melting of lower members of the "Serie Negra" succession (Montemolín and related successions). Geochemical data and models are consistent with low-pressure partial melting of those rocks where ratios of ca. 60 and 10% can be admitted for the generation of the granodiorite and leucogranite massifs, respectively.

These processes are similar to those proposed for the Saint-Malo anatectic dome, also similar from a lithostratigraphic point of view. It is suggested that the anatectic cores studied herein might be correlated with the Saint-Malo and related migmatite domes of the North Armorican Massif (NW France).

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Cambrian palaeogeography of the Ossa-Morena Zone: preliminary data

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In the recent literature of the trilobitic Cambrian of the Ossa-Morena Zone (OMZ), a subdivision in Domains has settled down based mainly on stratigraphical differences (thicknesses and facies) among units tectonically individualised. The two first units were established in the area of Zafra (Badajoz province, Spain) by Liñán & Perejón (1981), namely the Alconera and Zafra units. They were interpreted as having important stratigraphic differences and formed in different environments, being later juxtaposed by Hercynian tectonics. With posteriority, this subdivision in units has been extended to several parts of the Spanish sector of the OMZ, including a number of nine units (Liñán & Quesada, 1990). Wide areas rest without any attribution to concrete units. This outline makes very difficult a comprehensible palaeogeographical reconstruction.

A detailed cartography of problematic areas and a general revision of the available information provide a simple model which allows a simple palaeogeographic reconstruction for the Cambrian to be to established. In this new model, two areas can be distinguished, one to the north and a second to the south of the Monesterio antiform.

In the northern limb of the Monesterio antiform, the Cambrian rocks lay in paraconformity on a mainly conglomeratic volcano-sedimentary sequence which, in turn, lays in angular unconformity over the structured Precambrian. The Alconera Unit has formal continuity with the Zafra Unit and these materials can be traced laterally from Córdoba up to the vicinities of Assumar in Portugal. In summary, the Cambrian consists of a Lower Cambrian sequence that include an arkosic interval, a mixed (detrital-carbonate) succession, a detrital succession culminated by a quartzitic interval and a Middle-Upper Cambrian (Palacios, 1993) detrital unit with bimodal vulcanites. Toward the NE the succession is similar, although the carbonate and volcanic units are less important.

In the southern limb of the Monesterio antiform, the Cambrian sequence shows lateral continuity from Alter do Chao (Portugal) to Lora del Río (Seville province, Spain).

The succession starts with a unit composed of calc-alkaline, acid volcanic rocks discordant above the Precambrian. This unit grades into a siliciclastic-carbonate unit with important volcanic contribution. Remarkably, the carbonate rocks contain numerous per-alkaline subvolcanic intrusions in the sector between Jerez de los Caballeros (southern Badajoz province) and Alter do Chao. The next succession consists of pelites and sandstones, strongly bioturbated toward the top, culminating with a quartzitic unit. The sequence ends with a volcanoclastic unit of Middle-Upper Cambrian age (Mette, 1989; Moczydowska, 1998), in which the basaltic rocks prevail. Toward the SW the sequence is similar (areas of Aracena, Serpa, etc.).

During the Cambrian times, the OMZ can be considered a simple basin located on a structured Cadomian basement whose main reliefs are located to the NE. A first transgressive cycle takes place on the area, during which transitional (fluvio-deltaic) facies deposited (lowermost detrital succession), followed by a mixed platform, possibly storm-influenced (carbonate succession). After a deepening episode, related with the beginning of the alkaline vulcanism, an important regression took place (Hawke Bay/Daroca regression) that culminates with the deposition of the quartzitic unit. The acceleration of the rifting allowed the deepening of the basin and gave place to the basaltic Middle-Upper Cambrian vulcanism. In the southern sector, the lowermost clastic materials are poorly represented, starting the sequence with the establishment of the carbonate platform.

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Experimental constraints on Aracena metamorphic belt anatexis

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The Aracena metamorphic belt (AMB) constitutes the boundary between Ossa-Morena and South Portuguese Zones (Crespo-Blanc & Orozco 1991). New data on experimental petrology of the AMB show that this is a subduction-related, low-pressure/high-temperature complex developed by plate convergence during the Palaeozoic. Various igneous rocks crop out in the AMB including granodiorite, trondhjemite, peraluminous granite and Mg-norite with boninite affinities.

In order to understand the petrogenetical context of this igneous rocks, two types of experiments have been carried out in solid-medium piston cylinder apparati at the University of Huelva (Spain): (a) Partial melting of "Fuente de Oro" tonalitic gneiss, Pl-Hbl amphibolite and Qtz-amphibolite; (b) near-liquidus phase relations of Mg-norite.

From one side, the experimental results show that under anhydrous conditions melting of tonalitic gneisses generates peraluminous granitic melts (<8 vol%), whereas the melting of the same material with 5 wt.% water generates granodioritic melts (>35 vol%). On the other hand, anhydrous melting of qtz-amphibolites produces trondhjemitic melts (>15 vol%), whereas anhydrous melting of Pl-Hbl amphibolites generates tonalitic melts (10-15 vol%). Finally, near-liquidus experiments of Mg-norites indicate that boninite-like magma may be derived at P=8 kbar from shallow pyroxenite mantle consisting predominantly of clinopyroxene, orthopyroxene and plagioclase.

The results of melting experiments suggest that the generation of granodioritic rocks in the AMB needs free H_2O in the system. The predominance of granodiorites over peraluminous granites indicates that H_2O is largely present in the system. It is very likely that the source of this water is related to subduction of an oceanic plate. The subsequent ridge subduction (Castro *et al*., 1996) and the associated thermal anomaly would generate the heat responsible for the partial melting of the "Fuente de Oro" tonalitic gneisses. The second type of experiments indicate that the presence of a hot shallow mantle is the cause of the thermal anomaly in the continental domain.

Alpine stress field evolution and fault kinematics in Mina Ratones area, Albalá granitic pluton, central Extremadura, Spain

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The Albalá granitic pluton is located in the SW sector of Iberian Massif (Central Iberian Zone). Petrographycally, it consists of a concentric zoned body, elongated in a N-S direction, with biotite porphyritic granites in the rim and fine-grained two-mica leucogranites in the core. Rb-Sr whole rock ages indicate intrusion ages of 302±14 Ma. The Alpine stress-field evolution of the granitic pluton has been established on the basis of fault kinematics and palaeostress analysis. This evolution has three phases of faulting related to different stress-field configuration, that are superposed to the ductile and ductile-brittle late-Variscan structures: (D1) a extensional phase, with a subhorizontal WNW-ESE to NW-SE oriented $(sigma)_3$, related to the intrusion of alignments of basic dykes; (D2) a compressive phase, characterized by the development of a system of conjugated strike-slip faults and a subhorizontal NNE-SSW to N-S oriented $(sigma)_1$, under a wrench stress regime; and (D3) a late extensional phase, that fundamentally causes the reactivation of part of the previous structures as normal and normal-slip faults, with a subhorizontal NNW-SSE to N-S oriented $(sigma)_3$.

The D1 structures form a group of basic intrusions forming subvertical dykes and trending NNE-SSW. In base of their petrologic characteristics these dykes are related to the basic dyke of Alentejo-Plasencia, intruded in Jurassic times under a WNW to NW-directed extensional stress field. The D2 structures are subvertical brittle faults grouped in two conjugate families of unequal development: the principal family is NNE to ENE-directed and sinistral; the subordinate is NW-directed and dextral. The NNE-SSW trend is also the direction of many dykes formed during the late Variscan evolution, as well as the basic dykes, and therefore they were frequently reactivated. The geometry of the fault system is compatible with a large-scale, ENE-directed sinistral wrench. The obtained NNE-directed compression is equivalent to the compression that structures the Plasencia pull-apart basin during the Miocene (Middle Aragonian). As a consequence of the most recent extensional stress-field, a new set of normal faults was developed, or reactivated the previous faults and dykes. These late normal faults are important from a morphogenetic point of view, since they have controlled the development of some characteristics of the current relief and the installation of the drainage network, with frequent capture processes, as well as the location of the areas where the lehm presents a more extension and deep. The age of these deformations is not known in detail. By correlation with the most recent deformations that affect gravel deposits with glacial geometry and terraces in the Cabeza de Araya graben, they are Plio-Pleistocene to Quaternary in age.

Magmatism associated with pre-Variscan crustal extension in the Tormes gneissic dome: geochemical evidence from orthogneisses and orthoamphibolites

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The Tormes gneissic dome (TGD) is located in the Central Iberian Zone of the Variscan Iberian Massif, to the NW of the town of Salamanca. It consists of two lithotectonics units, separated by an extensional tectonic contact. The Lower Unit comprises a high grade metamorphic complex mainly composed of augen-gneisses (618±9 Ma), under an upper metapelitic sequence with intercalations of tonalitic orthogneisses bodies, boudins of orthoamphibolites, lenses of marble and calc-silicate rocks. The detailed cartographic data indicate that the relationships between augen-gneisses and metapelites are those of a basement and their sedimentary cover. Orthogneisses and orthoamphibolites are the record of prevariscan magmatic episodes, since they never appear as intrusions in Tremadoc-Arenig younger rocks.

The mineral assemblage of basal augen-gneisses is composed of Qtz+Kfs+Pl+Bt±Grt±Sil, with minor Zr, Mon, Ap, Tur and Ilm. The geochemistry of augen-gneisses point to peraluminous granites derived from crustal melts, with contents of SiO_2=67-76%, Na_2O+K_2O=7-8% and Al_2O_3=13-16% (C_{nor}=1-4%), and low values in trace (Nb=8-11 ppm, Zr=77-129 ppm and Y=20-45 ppm) and REE elements (Σ_{REE}=40-160 ppm), suggesting a depleted source. Their chondrite-normalized REE patterns are typical of differentiated magmas and reflect a garnet balance melting ($[La/Lu]_{cn}$=1,3-5,7). The relations of the less mobile element and ORG patterns relates them to post-collisional magmas emplaced in an extensional setting.

Tonalitic orthogneisses consists of Pl+Qtz+Bt+Hbl+Cpx mineral assemblage, with minor Sph, Mon, Zr, Ilm and Ap. Their geochemical composition defines a quartz-monzonitic meta-aluminic association, with tonalite to granodiorite members, and differentiated leucogranites (SiO_2=53-63%, Na_2O+K_2O=5-6%, CaO=4-6%). Their trace elements patterns show a subduction-related Nb negative anomaly (Nb=12-16 ppm), and a crustal-related Sm and Ce high contents (9-20 ppm and 100-170 ppm, respectively), typical of contractive-extensional settings, analogous to a continental back-arc domain. The REE content is greater than those in augen-gneisses (Σ_{REE}=250-380 ppm) and their patterns show a low fractionation ($[La/Lu]_{cn}$=12-23). Hovewer, the LREE patterns are fractionated respect to HREE probably by the concentration of hornblende and monazite.

The orthoamphibolites present a mineral assemblage composed by Hbl+Pl+Gtr±Cpx±Qtz+Ilm. Their geochemical character is typical of transitional basalts ($SiO_2 \approx 47\%$, $TiO_2 \approx 2\%$ and $Fe_T \approx 2\%$), with values of $Mg' = 100x(Mg/Fe^{+2}) = 54$, and high contents of Cr and Ni (222 ppm and 323 ppm, respectively), that suggest an early differentiation. Their trace elements patterns are also characteristic of transitional magmas, with a crustal contribution (Nb=33-40 ppm, Zr=158-207 ppm). The REE content is heterogeneous owing to weatering (134 to 275 ppm, in the more transformed orthoamphibolites) and their chrondrite normalized REE patterns are fractionated ($[La/Lu]_{cn}$=11-14) and LREE enriched (LREE/HREE =8.26-6.70), with a light positive Eu anomaly (Eu/Eu* =1.14-1.21), typical of magmas emplaced in an extensional tectonic setting.

The emplacement of Albalá granitic pluton, central Extremadura: relative effects of intrusion and regional deformation

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The Albalá Granitic Pluton (AGP) is located in the SW sector of Iberian Massif (Central Iberian Zone), which represents the westernmost segment of the European Variscan Belt. Petrographycally, it consists of a concentric zoned body, elongated in a N-S direction, with biotite porphyritic granites in the rim and fine-grained two-mica leucogranites in the core. Major, trace and REE-elements suggest that magmatic rocks conform a continous sequence ranging from granodiorites through granites, monzogranites to leucogranites. Rb-Sr whole rock ages indicate intrusion ages of 302±14 Ma. In the AGP, the magmatic foliation trajectories present a concentric general pattern, elongated parallel to the longitudinal axis of the pluton. The high dips (>60°) are concentrated in the central sector, coinciding with the leucogranitic core. The zones with low dips (<30°) are developed in the NE, NW and S areas of the pluton, throughout a wide sector. These data suggest that the central sector is the feeding zone, where the pluton is rooted, and the peripheral sector the subhorizontal cupola zone where the pluton is laterally expanded. The magmatic lineation trajectories present a general radial trend, which the lineations converge toward the central feeding zone. The lineations are strongly inclined (>45°) toward the feeding zone and shallowing toward the external contact with the metasediments, indicating the predominance of a peripheral subhorizontal magmatic flow. On the other hand, the D3 structures developed in the host's metasediments during the emplacement of the pluton are compatible with a moderate N-S to NNE-SSW-directed regional shortening.

The asymmetry of sigmoidal inclusions trails in porphyroblats related to the contact metamorphism are regionally consistent with a WNW-ESE dextral wrench, associated with the N-directed regional shortening. In summary, the concentric pattern of the magmatic foliation trajectories and the radial trend of the magmatic lineation, indicate that during the emplacement of the pluton the body forces prevailed. The magmas ascended from their source along a central conduit zone to the site of final emplacement, where the pluton is laterally expanded by ballooning in the horizontal. The deformative effects of a contemporary phase of N-S regional shortening are very limited. However, this compression phase has had an important role in the opening of cracks in the brittle part of the crust, for where the magma ascend from the deep source zone.

GEOMETRY AND KINEMATICS OF THE VARISCAN EVOLUTION ON BOTH SIDES OF THE OSSA-MORENA / CENTRAL IBERIAN BOUNDARY

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The Ossa-Morena Zone (OMZ) and the Central Iberian Zone (CIZ) are two main tectonic units of the Variscan Iberian Massif. The contact between these two crustal portions is marked by a strongly deformed and metamorphosed, NW-SE trending and NE dipping, narrow band named Central Unit, where partially retrogressed eclogites crop out.

To the SW, in the Ossa-Morena Zone, the main structure consists of kilometer-scale recumbent folds and thrusts verging to the SW and kinematically indicating a decoupling between the upper and the lower crust**.** This structure, which date back to the Middle-Late Devonian, strongly suggests that the CIZ overthrust the OMZ at that time, with underplating of the OMZ lower crust under the Central Unit and the CIZ. The eclogites of the Central Unit are believed to come from the underplated OMZ lower crust. At the same time, in the hanging wall of this continental thrust an intense though nevertheless localized back- (NE vergent) folding and back- (top to the SE) shearing took place.

In the Early Carboniferous, an oblique extensional collapse came about. The concentration of the shearing on the Central Unit gave rise to a high-to-low-temperature, left lateral shear zone whose subordinate normal component sank the CIZ, easing the eclogites exhumation. The collapse originated a major basin on the southern border of the CIZ, as well as some spread out minor basins in the OMZ.

The subsequent upright kilometer-scale folding is the evidence of a new shortening event all along the OMZ and the CIZ which, together with Middle-Late Carboniferous fracturing greatly contributed to the final complex picture of this region.

The high-pressure metamorphism registered in rocks of the Central Unit and the geometry, size and kinematic pattern of the structures on both sides of the OMZ/CIZ contact unequivocally support the idea that this is one of the main tectonic boundaries of the Iberian Massif.

THE NEOPROTEROZOIC AND EARLY PALAEOZOIC EVOLUTION OF NW IBERIA: INFERENCES FROM DETRITAL ZIRCON LAM-ICP-MS U-Pb AGES

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Understanding the nature, age and distribution of basement terranes in orogenic zones provides constraints on the evolution of igneous and sedimentary rocks formed during subsequent orogenic cycles. For example, neodymium isotopic compositions and model ages of granitoids or detrital sedimentary rocks are often not uniquely interpretable without knowledge of the ages of crustal reservoirs that constituted sources for those granitoid melts or sedimentary detritus. Plate tectonic and palaeogeographic reconstructions are also greatly aided by evidence about the age and distribution of older terranes, particularly in orogenic belts or major crustal sections where an igneous/high grade metamorphic cratonic basement is not exposed. Such a situation is well illustrated in the northwestern Iberian Massif where thick Neoproterozoic successions of pelites and greywackes are the oldest exposed rocks, and there is great uncertainty about the nature and age of the basement upon which they were deposited. Constraints on the ages and nature of older basement can be acquired by: presence of inherited in zircons in magmatic rocks; detrital zircons in sedimentary rocks; and by neodymium isotopic studies.

Within the above context, we have undertaken a study of the U-Pb ages of detrital zircons obtained from Neoproterozoic, Cambrian and Ordovician sedimentary and volcano-sedimentary rocks from NW Spain. These data were obtained using the laser ablation microprobe-inductively coupled plasma-mass spectrometry (LAM-ICP-MS) technique. The primary aim of this study is to place new constraints on the Proterozoic-early Palaeozoic evolution of NW Iberia and to better integrate this area into palaeogeographic reconstructions of circum-Atlantic Gondwanan terranes.

The U-Pb ages of detrital zircons in Neoproterozoic Cambrian and Ordovician rocks, integrated with previous U-Pb and Sm-Nd studies (e.g Näggler *et al*., 1995; Beetsma, 1995; Ortega *et al*., 1996; Fernández-Suárez *et al*., 1998) and current palaeogeographic reconstructions of peri-Godwanan terranes (e.g. Nance & Murphy, 1996; Keppie *et al*., 1998; Fernández-Suárez *et al*., 1998) are consistent with the following sequence of events in NW Iberia:

(a) Early Cadomian-Avalonian subduction and arc construction (ca. 790-640 Ma). This magmatic episode created the main arc edifice (Avalonia).

(b) Full development of a back-arc basin upon which the Neoproterozoic sediments were deposited (ca. 640-600 Ma). The combined U-Pb ages of detrital zircons and Nd isotopic features of these sedimenary rocks suggest that they were mostly shed from the main magmatic arc. On the basis of the presence of Grenvillean age detrital zircons with short waterborne transport before incorporation into the sediment, we propose that the basin was possibly located in a peri-Amazonian realm close to West Avalonian terranes. Other evidences point to the possibility that these basins were developed upon a cratonic basement that involved both Grenvillean (ca. 0.9-1.2 Ga) and Transamazonian (ca. 1.9-2.1 Ga) igneous rocks. We also suggest that the genesis of the back-arc basin could be related to a change in the subduction regime (from ridge push to slab pull?) that might have started at ca. 640? Ma. The intrusion of ca. 580-600 Ma scarce granitoids (Fernández-Suárez *et al*., 1998) represents the terminal magmatic activity of the Cadomian-Avalonian subduction in this area. Therefore, the reported zircon ages indicate a long-lived andean-like (over 200 Ma) subduction, starting at ca. 790-780 Ma and terminated by ca. 580-570 Ma with no geological record of a final collision event.

(c) The continuation of extension gave rise to the undocking of Avalonia (main arc edifice) from the back-arc, the opening of the Rheic ocean and eventually, the genesis of the Iberian-Armorican and Meguma platforms at both sides of the ocean (Martínez Catalán *et al*., 1997). Detrital zircon ages in lowermost Cambrian strata indicate that the main arc edifice had drifted away by ca. 550-540 Ma and was no longer shedding detritus into the back-arc basin. During the lower Ordovician, further extension of an already thinned crust gave rise to the "Ollo de Sapo" magmatic event in NW Iberia (ca. 480 Ma), likely to have been triggered by mantle upwelling and concomitant upper mantle-lower crustal melting. Coeval vulcanism in neighbouring areas displaying within-plate geochemical signatures lends credence to the hypothesis of an extensional setting for the generation of the "Ollo de Sapo" complex igneous and sedimentary rocks. Detrital zircon ages and Nd isotopic features of the Ollo de Sapo greywackes reflect both an increase in the contribution from older crustal components and the addition of newly accreted crust. A progressively thinning crust is a likely scenario that would explain the simultaneous exhumation of lower crustal (Grenvillean+Transamazonian/Icartian) material and the generation of coeval magmatism (juvenile component). This latter scenario is consistent with models proposed for other circum-North Atlantic Avalonian-Cadomian terranes where repeated episodes of melting occurred in response to subduction and subsequent rifting events (e.g. Murphy *et al*., 1996). The proposed sequence of events is also compatible with the subsequent evolution of NW Iberia from Silurian to Late Carboniferous times (e.g. Martínez Catalán *et al*., 1997).

GOLD EXPLORATION IN THE PINO AREA (NW ZAMORA, SPAIN)

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The Pino area has been explored by the Instituto Tecnológico Geominero de España in order to assess the significance of the gold mineralization that had been previously defined by the Mineral Research Service of the Autonomous Government of Castilla y León.

In the mineralized zone, occupying an area of about 18 km^2, the following studies have been undertaken: regional structural research, geological mapping at 1/5,000 scale, soil and rock geochemistry, IP geophysical survey, and drilling.

The vein-type gold mineralization in the Pino area occurs within shear bands developed at the northwest end of the major Villalcampo shear zone. Average mineralized shear bands are subvertical, N068°E-trending and sinistral. Length ranges between tens to hundreds of metres and width between 1 and 5-6 metres. The ore bodies are hosted by granitic rocks belonging to the Ricobayo pluton, which was deformed by late events of the Variscan orogeny. Mineralization is also locally hosted by pre-Ordovician and early Ordovician metasedimentary rocks making the country-rock to the granites. Mineralization is associated to hydrothermal alteration, mainly involving K-feldspar, silica and sericite formation.

Ore mineralogy is composed of arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, magnetite, cassiterite, bornite and gold (free gold in quartz and gold inclusions in arsenopyrite). This mineralization is included in breccias, quartz veins (often mylonitized) and hydrothermally altered granite. 15 mineralized structures (shear bands) have been defined on the 1/5,000 scale mapping.

Shallow soil geochemistry (Au and As analysis on 2,639 samples) delineates the main mineralized area that enclose two ore structures: El Facho and La Ribera. Three anomaly thresholds are defined: 320, 220, 120 ppb Au and 145, 105, 65 ppm As. The Au-As correlation coefficient is 0.63 for normal values and 0.61 for log values.

Channel and trench sampling (608 samples) provides the geochemical signature of the ore structures at the surface. The best values correspond to a section in La Ribera with 8.17 ppm in 3.5 metres.

Drilling of 8 holes totalling 1,179 metres have been situated around the El Facho structure. This structure has been intercepted in five holes up to 50 metres depth as well as other structures and quartz veins unexposed at the surface. 691 samples, one metre each, from drill-cores have been analized. The best value corresponds to an 1 metre thick quartz vein with 65.75 ppm Au.

The Au-As correlation coefficient is lesser in rock geochemistry from channel, trench and holes than in soil geochemistry. This is, maybe, because the ore bodies for both sulphide and gold mineralizations are the same structures but in detail the internal mineral distribution within each structure is different because of different ore mineralization processes.

TIME CONSTRAINTS ON THE DURATION OF OROGENIC PROCESSES - FROM INITIAL SUBDUCTION TO LATE STAGES OF EXHUMATION

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The duration of mountain forming processes is often not well constrained and therefore vague or even wrong ideas frequently exist. For the European Alps for example, many models were constructed until recently that involve single

or multiple lithospheric subduction and collision processes in excess of 100 Ma. In the case of older orogens such processes are often taken to have lasted even longer. For decades, major reasons for these hypotheses were wrong interpretations of geochronological data. However, a better understanding of the behaviour of the applied isotopic systems as well as improved and/or new geochronological techniques allows these mistakes be to corrected.

Under this premise we examined young orogenic belts as the absolute age errors are minimized when compared to older orogens. Additionally, a lower age limit (0 Ma) is given by the present exposure of such orogens, which is more difficult or impossible to assess precisely for older mountain belts.

Apart from classical techniques of estimating cooling ages via mineral dating (mainly Rb-Sr, various Ar-techniques, Sm-Nd and fission track), cathodoluminescence (CL) based ion microprobe (SHRIMP) analyses of different types of zircon domains allowed dating of prograde, peak- and retrograde metamorphism.

(a) Dating of initial stages of prograde metamorphism: No reliable geochronometer was found so far, that gave information on the onset of orogenic activities in high-grade terranes. The detection of hydrothermal zircons in early, deformed quartz veins lying concordantly within metasediments (Rubatto *et al*., 1999; Liati & Gebauer, 1999; and unpublished data) is a major step forward to fill this gap. Such prograde quartz veins commonly form during initial subduction in a narrow T-interval of ca. 250-300°C. As the hydrothermal zircon domains can be shown to remain closed for U-Pb during highest grade metamorphic conditions of the quartz vein and its country-rock, an important age tag can be fixed on the prograde part of a PTt path.

(b) Dating of P- and T-peak: In many geological units petrological work argues that both P-and T-peak more or less coincide in the course of metamorphism or can not be differentiated. Thus metamorphic zircon domains or entire zircon crystals formed during partial melting in leucosomes would reflect peak-T conditions close to the P-peak. As it is known for a long time that U-Pb zircon systems can remain closed at T > 1,100°C (e.g. Gebauer, 1990), the blocking temperature concept can not be applied for zircons from metamorphic rocks. Recent CL-based SHRIMP-data allowed even to differentiate between the ages of the P- and T-peaks of eclogite facies rocks (Liati & Gebauer, 1999). This is due to the prograde release of fluids (breakdown of paragonite) at or shortly before the P-peak triggering a reorientation of zircon lattices and therefore resetting of ages. The T-peak follows with an analytically significant time gap of ca. 2 Ma and is based on the new formation of zircon in leucosomes within the *in situ* metamorphosed orthogneisses under granulite facies conditions (Liati & Gebauer, 1999). Dating the T-peak of ultramafic rocks (Gebauer, 1996; Ordóñez *et al*., submitted paper) may be done by dating of HP or UHP melts, e.g. pyroxenites or primary magmatic eclogites.

(c) Dating of retrograde metamorphism: This can be achieved by CL-based SHRIMP-dating of zircon domains, but it is usually restricted to metamorphic stages only at or above amphibolite facies conditions. At lower T, conventional cooling ages of mainly amphiboles and micas as well as fission track ages are used. However, retrograde zircons that formed newly at ca. 300°C by precipitation from late metamorphic fluids at the end of the tectono-metamorphic cycle can be also used to date late stages of retrograde metamorphism. This was successfully done for zircons from late, undeformed pegmatoids crosscutting the metamorphic rocks of the Rhodope HP terrain in N Greece (Gebauer & Liati, 1997; Liati & Gebauer, 1999). The arising ages were in very good agreement with K-Ar biotite ages (Liati & Kreuzer, 1990).

Taking published thermobarometric data as well as zircon domain SHRIMP-data, subduction speeds and heating rates were determined for the first time in geochronological research. Values of ca. 1-3 cm/y (10-30 km/Ma), resp. 30-94°C/Ma were found for the Sesia Zone, the Zermatt ophiolites (both Western Alps) and the Rhodope (N Greece).

Exhumation and cooling rates including rocks from Ronda (Spain; Sánchez-Rodríguez & Gebauer, in press), Rhodope (Liati & Gebauer, 1999), Dora Maira (Western Alps; Gebauer *et al*., 1997), Alpe Arami (Central Alps; Gebauer, 1996), Cima di Gagnone (Central Alps; Gebauer, 1994) and the Kaghan eclogites (Himalaya; Spencer & Gebauer, 1996) vary from 0.5-4.2 cm/y, resp. 50°C-130°C/Ma (with the exception of Ronda where cooling rates reach 340°C/Ma). Interestingly, exhumation rates are significantly higher for early exhumation of HP- and UHP rocks from mantle depths. This applies not only for felsic rocks, but also for mafic/ultramafic rocks arguing that the latter must have been attached to deeply subducted, buoyant continental crust.

For all rocks cited, the corresponding PTt-paths above 300°C were completed within ca. 9-30 Ma. Thus, mass transfer during subduction/exhumation closely follows typical speeds of plate motions. Together with the observed heating and cooling rates, existing models on the speed of mass and heat transfer need to be revised to fit the above age constraints.

Generally, it is much more likely that many orogens formed by one or more short lasting (ca. 10-30 Ma) rather than one or more prolonged subduction-collision cycles. This is also much better in tune with the presumed widths of oceans and presently observed speeds of plate motions.

Metamorphic evolution and origin of allocthonous complexes from the NW Iberian Massif: from continental Gondwana and ophiolitic basal units to Avalonian upper regional allochthon. Results and perspectives

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Allochthonous complexes from the NW Iberian massif comprise:

1. A composite upper regional allochthon with metasediments and orthogneisses, eclogites, HP granulites and garnet-bearing ultramafic rocks. High-pressure rocks formed during an episode at 390-400 Ma from protoliths of Cambrian age or older, except for some of the ultramafic protoliths which appear to be distinctly younger (395-400 Ma). The more reliable reconstructions suggest that this allochton represents fragments of the Avalonian plate including portions from different structural levels of an active margin together with parts of the subducted intervening ocean (Rheic).

2. Underlying ophiolitic units formed around ca. 395 Ma record prograde metamorphism and deformation at ca. 380-390 Ma. This might be related to the progressive closing of that ocean and associated obduction of overlying eclogitic/granulitic massifs.

Ophiolite and Avalonian units were incorporated subsequently into the Gondwana continent through processes related to the Hercynian collision.

3. Remnants of the former passive margin of Gondwana continent form the lowermost regional allochthon. These were affected by HP metamorphism from ca. 360 to 340 Ma. These events mark the beginning of the continental accretion and blocking of subduction/obduction processes that preceded intracontinental Hercynian activity s. str. within the Iberian massif. Diachronism of HP metamorphism and marked regional variations in PT conditions suggest subduction processes in relation to an oblique collision.

Earliest deformation phases occurred at different moments within each domain. Yet, deformation regimes operative in the deepest HP metamorphic units (eclogites, HP granulites, Grt-bearing ultramafites) are characterized by regionally consistent stretching lineations subparallel to the orogenic trend and to associated isoclinal and sheath folds. The observed structures are consistent with shear zone deformation under HP conditions in one or more subduction realms, and reflect tectonic amalgamation related to eo-Hercynian NNE-directed oblique collision. Earliest deformation phases in foreland tectostratigraphic units should relate to the more or less coeval latest deformation phases recorded in the hinterland (which also occurred in shallow structural levels), instead of to the much older and deeper seated earliest ones.

Middle Cambrian correlation in the Mediterranean Subprovince and its palaeogeographical consequences

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In the Middle Cambrian palaeobiogeography, the Mediterranean Subprovince (*sensu* Sdzuy, 1958, 1972) includes the outcrops of Germany, France, Italy, Spain, Morocco, Turkey, Egypt (Sdzuy *et al*., 1999) and probably Portugal and Israel. These two last countries, where Middle Cambrian fossils have not been found yet, are included in this subprovince because geological characteristics and inferred palaeogeographical positions.

In recent papers, the biostratigraphical nomenclature proposed for Spain by Liñán *et al.* (1993) has been widely applied to Germany, France, Turkey and Sardinia. The analysis of the Middle Cambrian trilobite assemblages, from different localities of the Mediterranean area, and their comparison with the Spanish data have permitted us to propose new lines of correlation, in order to study the palaeogeographical evolution of the Mediterranean subprovince during Middle Cambrian times. The main point of correlation are the FADs of *Eoparadoxides mureroensis*, *Eccaparadoxides sdzuyi*, *Eccaparadoxides asturianus*, *Badulesia tenera*, *Pardailhania hispida*, *Solenopleuropsis ribeiroi* and *Bailiella levyi*, all included in the Leonian and Caesaraugustan Stages.

From late Lower Cambrian (Bilbilian) to early Middle Cambrian (Leonian) times, important carbonate facies developed in a central area of the Mediterranean region (including the Cantabrian Mountains, Montagne Noire, Sardinia and Turkey). It was surrounded by a peripheral area mainly occupied by siliciclastic facies, which included the Anti Atlas, High Atlas, Ossa-Morena, and Germany (Sdzuy *et al*., 1999).

This carbonate sedimentation persisted in the Cantabrian Mountains, Sardinia and Turkey during most of the time of the Caesaraugustan Stage, and it was finally replaced by mainly siliciclastic facies from Upper Caesaraugustan to Upper Cambrian times. The lithostratigraphical boundaries are diachronous in most of the sequences considered herein.

Both Middle Cambrian trilobite faunas and facies of the Mediterranean Subprovince are analysed to propose a new palaeogeographical model.

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The Lusitanian-Marianic area as a new zone of the Hesperian Massif. Stratigraphic arguments

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The boundaries between the Central-Iberian Zone and the Ossa-Morena Zone of the Iberian Massif, were described either in Los Pedroches batholith or in the Badajoz-Córdoba shear zone using different arguments. Based on mainly stratigraphic and palaeogeographic criteria, the definition instead of a new zone of the Iberian Massif is here proposed. The fact is that a zone which northern boundary is at present concealed by the Hercynian Los Pedroches batholith, and which southern zone is the Malcocinado fault shows distinctive main geological features here summarized:

1) The Proterozoic-Middle Cambrian basement is characteristic from the Ossa-Morena Zone. This basement cannot be correlated using several arguments with the Precambrian

rocks outcropping towards the NE of Los Pedroches batholith, even if the higher Alcudian-type sedimentary layers may have a Central-Iberian equivalent.

2) The Palaeozoic sequences younger than Middle/Upper Cambrian, present between the Malcocinado fault and the Pedroches batholith, have clear Central-Iberian affinities, and do not have anything in common with those of SW Ossa-Morena. With the exception of the Silurian, a persistent palaeogeographic high is marking a boundary in the core of the proposed zone, migrating in a parallel mode through time.

3) The proposed new Lusitanian-Marianic Zone shows more distinctive properties to be recognised as an independent entity, than other traditionally distinguished zones i.e. the Cantabrian, West Asturian-Leonese or Central Iberian, whose boundaries do not correspond to such significant palaeogeographic features as those from the zone here proposed.

THE CADOMIAN UNCONFORMITY OF THURINGIA AND LUSATIA, GERMANY: SOME BIOSTRATIGRAPHICAL ASPECTS

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Schwarzburg anticline (Thuringia).
The Schwarzburg anticline constitutes the type section of the German lower Palaeozic (Ordovician-Lower Carboniferous) and consists of low grade metamorphic rocks overprinted by Variscan collision tectonics during the Early Carboniferous.

The Neoproterozoic successions (Cadomian basement) and the lower Palaeozoic sections of the Schwarzburg anticline were first described by von Gaertner (1932, 1934, 1944) and modified by Falk & Lützner (1991), Ellenberg *et al.* (1992), Lützner *et al.* (1986), and recently revised by Falk, Lützner and Mann in a stratigraphical compilation made by the German Commission on Stratigraphy (Stratigraphische Kommission Deutschlands, 1997).

Traditionally, and in comparison to the Barrandean sequences (Bohemia), the greywackes of the Katzhütte and Frohnberg Groups were lithostratigraphically correlated with the Precambrian, the Goldisthal Formation with the Cambrian and the Frauenbach Group with the Tremadoc. Von Gaertner (e.g. 1944) postulated an Assynthian (now Cadomian) unconformity between the Neoproterozoic greywackes and the overlying Goldisthal Formation whereas a concordant Proterozoic/lower Palaeozoic transition was favoured by Ellenberg, Falk and Lützner in the above mentioned publication.

The concept of concordant Proterozoic/lower Palaeozoic transition was first contradicted by the discovery of Upper Cambrian/lower Ordovician acritarchs in equivalents of the Goldisthal Formation on the northwest flank of the Schwarzburg anticline (Estrada *et al.*, 1994). Based on a comparison of relative sea level fluctuations of the lower Ordovician sequences from the Schwarzburg anticline and from the deep drilling 5507/77 near Gera, Linnemann & Buschmann (1995) opted for a Tremadoc age of the Goldisthal Formation.

Stratigraphy.
So far, no reliable biostratigraphical data exist from the Frohnberg Group. Lyddites from the underlying Katzhütte Group yielded poorly preserved acritarch assemblages considered to be indicative for a Late Vendian age (Heuse, 1989). This biostratigraphical date was recently confirmed by single zircon geochronology ($^{207}Pb/^{206}Pb$) of a granite pebble with an age of approximately 576 Ma by Linnemann *et al.*, (1998).

A poorly preserved Upper Cambrian to lower Ordovician acritarch association from the overlying Goldisthal Formation of the northwest flank of the Schwarzburg anticline was described by Heuse (*in* Estrada *et al.*, 1994). Recently, single zircon data were presented by Gehmlich *et al.* (1997, 1998). The age of the deformed Cadomian basement was fixed by granite intrusions at 538±3 Ma (Gehmlich *et al.*, 1997). The Blambach rhyolite at the base of the Goldisthal Formation was dated as 487±5 Ma. Thus the sedimentation of the Goldisthal Formation must be younger than 487±5 Ma and probably started in the Tremadoc.

Although significant palynodata are still missing from the underlying Frohnberg Group, and consequently this sequence may reach into the Early Cambrian, a stratigraphical hiatus between the Frohnberg Group and the overlaying Goldisthal Formation is obvious, probably covering the entire Cambrian Period (Cadomian unconformity).

The Goldisthal Formation is overlain by the Frauenbach Group. Inarticulate brachiopods from the Oberer Frauenbachquarzit Formation near Siegmundsburg reported by Loretz (1880), Koliha (1926), v. Gaertner (1944), Falk (1956) and Müller (1956) have been identified by I. Puura (pers. comm., 1998) as *Hyperobolus feistmanteli* (Barrande, 1879). In the Prague Basin this species occurs in the upper part of the Trenice Formation (Havlícek, 1982; Havlícek & Fatka, 1992). Recent single zircon data from the Bärentiegel-Porphyroid (Oberer Frauenbachquarzit Formation, 479±5 Ma; Gehmlich *et al.*, 1997) made a late Tremadoc age as very probable.

Lausitz Anticline (Lusatia).
The area of the Hohe Dubrau (Lausitz anticline) constitutes the type locality of the Cadomian unconformity in the Saxo-Thuringian Terrane (Linnemann & Buschmann, 1995). Tremadoc conglomerates, quartzites and silty shales are overlying tectonically folded Cadomian greywackes.

The sedimentation age of the Cadomian greywackes in Lusatia (Lausitz Group) has been under discussion for a long time. From thermally metamorphosed greywackes, Timofeev (1958) first described three new acritarch species which were reportedly indicative of an Early or Middle Cambrian age. Later the palynomorphs were regarded as laboratory contaminations by Burmann (1966, 1969). Succeeding investigations on the material originally studied by Timofeev led to a Precambrian (probably Vendian) age-determination (Burmann, 1966, 1969, 1972; Weber *et al.*, 1990).

The first single zircon evaporation ages from an ash layer (Wüsteberg tuff) with 564±4 Ma were published by Gehmlich *et al.* (1997) and interpreted as the sedimentation age of the Lausitz Group.

The first findings of inarticulate brachiopods from the superimposed Dubrauquarzit Formation by Geinitz (1873) were considered as unidentifiable by Koliha (quoted in Schwarzbach, 1934: 409). Recently, inarticulate brachiopods from the Dubrau quartzite have been identified by I. Puura (pers. comm., 1998) as *Westonisca arachne* (Barrande, 1879). This species has been described from the Bohemian Trenice Formation as *Lingulella arachne* and *L. variolata* by Barrande (1879) and Koliha (1924), and revised by Havlícek (1982) as *Westonisca arachne*.

Summary.
The biostratigraphical data, now confirmed by new geochronological informations corroborate the existence of a stratigraphical hiatus (Cadomian unconformity) above the Upper Proterozoic Thuringian and Lusatian greywackes, perhaps covering the entire Cambrian Period.

LARAMIDE-STYLE SUBDUCTION OF A RHEIC OCEAN PLUME: EVIDENCE FROM THE PALAEOZOIC EVOLUTION OF MARITIME CANADA

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Previous work has shown that the Iapetus Ocean closed during the Ordovician and its vestiges were covered by the late Ordovician-Early Silurian Appalachian overstep sequence which extended from the Laurentian miogeocline to the Avalon terrane (Chandler *et al.*, 1987). This interpretation is supported by faunal linkages (Williams *et al.*, 1995), the first appearance of Laurentian Nd signatures in earliest Silurian sediment of the Avalon terrane (Murphy *et al.*, 1995), and the age of accretionary deformation (Keppie, 1993). However, the location of the Meguma terrane at this time is controversial. The Meguma terrane represents a Palaeozoic passive margin sequence that bordered either the southern margin of Avalonia (e.g. Keppie & Dostal, 1991) or northwest Africa until it was accreted to eastern Laurentia during the Devonian (e.g. Schenk, 1981). This has important consequences for (a) the location of the Rheic Ocean suture: either south of the Meguma terrane or along the Minas Fault between Avalon and Meguma terranes, respectively; and (b) the tectonic interpretation of the Acadian orogeny as either a Pacific-type orogeny or a collisional event between eastern Laurentia and NW Africa. Siluro-Devonian palaeomagnetic data show three different apparent polar wander paths that allow either possibility (Van der Voo, 1993).

The Meguma terrane consists of Cambro-Ordovician turbidites (Meguma Group) overlain by Silurian-Early Devonian (White Rock and Torbrook Formations) and Carboniferous shallow marine and continental rocks that occur mainly along the northwestern margin of the Meguma terrane. Poor age constraints in the Silurian part of the sequence have hampered detailed correlations with other Appalachian units. A new U-Pb nearly concordant zircon age at the base of the White Rock Formation yielded an age of 442±4 Ma (Keppie & Krogh, in review) straddling the Ordovician-Silurian boundary (Tucker *et al.*, 1990). This allows a detailed comparison between Siluro-Devonian units in the Meguma and Avalon terranes, which shows the following close similarities: (a) both have latest Ordovician-earliest Silurian, bimodal, subaerial, alkalic-tholeiitic, volcanic rocks extruded in an extensional environment, and with Nd isotopic data indicating a similar source (Keppie *et al.*, 1997); (b) both have Siluro-Devonian shallow marine sequences that switch from deepening to shallowing in the Ludlow and become subaerial in the Pragian (Schenk, 1995; Boucot *et al.*, 1974); and (c) both contain Rhenish-Bohemian Lower Devonian fauna (Boucot, 1975). This suggests that the White Rock Formation formed part of the Appalachian overstep sequence. This is supported by the SE to NW transition from an offshore sandbar to a beach sand in the White Rock Formation (Lane, 1976), and the continental basement source for the White Rock volcanic rocks (Keppie *et al.*, 1997). It is concluded that the Meguma terrane is underalin by Avalonian basement and forms the passive margin on the southern side of the Avalon terrane and that the Rheic suture lies south of the Meguma terrane.

Following Devonian deformation (*400-377 Ma, $^{40}Ar/^{39}Ar$ plateau ages; Keppie & Dallmeyer, 1987, 1995) of the Meguma terrane, voluminous granitic magmatism occurred between 380 and 370 Ma (Keppie & Krogh, in review). An Avalonian source is suggested by U-Pb upper intercepts of *660 Ma and *732 Ma (Keppie & Krogh, in review) and Pb isotopic data (Ayuso *et al.*, 1996). This was accompanied by intrusion of lamprophyre dykes (Clarke *et al.*, 1997), regional low pressure metamorphism (Keppie & Dallmeyer, 1995), and gold mineralization (Kontak *et al.*, 1990), followed by rapid denudation of 5-10 km (Keppie & Dallmeyer, 1987, 1995). These observations may be interpreted as the overriding of a mantle plume by the Laurentian margin (including the Avalon and Meguma terrane). Thermal erosion and penetration of the subducted oceanic lithosphere by the plume leads to rapid melting of the continental lithosphere producing voluminous granitoid magmatism in the Meguma terrane, coeval high temperature/low pressure metamorphism and gold mineralization (Murphy *et al.*, 1998, in press). Northward migration of the plume explains the diachronous magmatism occurring in the Cobequid Highlands (Avalon terrane) at *360 Ma, and the mid-Carboniferous plume-related intrusions around the Magdalen Basin (Pe-Piper & Piper, 1998). The beheaded top of the plume may be recorded by the 10-20 km thick high density lens at the base of the crust beneath the Magdalen Basin (Marillier & Verhoef, 1989). Cooling of this lens provides a mechanism for the sinking of the Magdalen Basin. Subduction of a plume also provides a viable mechanism for the Siluro-Devonian Acadian orogeny by analogy with the Laramide orogeny in the western United States of America (Murphy *et al.*, 1998, in press). It is inferred that flattening of the Benioff zone related to subduction of a mantle plume led to termination of arc-related magmatism in the Avalon terrane followed by a period of relative magmatic quiescence, and diachronous migration of the Acadian deformation front across the Appalachian orogen from *415 Ma in the southeast to *370 Ma in the northeast (Keppie, 1995; Robinson *et al.*, 1998). Such a model for the Acadian orogeny suggests that the Rheic Ocean survived into the Carboniferous, outboard from the Meguma terrane.

POSTCOLLISIONAL GRANITOIDS EMPLACED IN A EXTENSIONAL SETTING: THE SANTA ELENA STOCK (CENTRAL IBERIAN ZONE, SPAIN)

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The Santa Elena stock, traditionally included in the Los Pedroches magmatic alignment, is an apical magmatic outcrop of another important late-orogenic magmatic event located in the southern sector of the Central Iberian Zone (Iberian Massif). The pluton is emplaced into detritic materials of Ordovician to Carboniferous age. The intrusion of the stock, with associated magmatic stooping phenomena is contemporary with the main extensional event after the main Hercynian deformation phase.

The field relationships, petrography and geochemical features display the spatial-time coincidence of the two contrasted magmatic bodies:

(a) Small size outcrops of basic rocks of probable mantellic origin. They exhibit a great mineralogical and chemical variations explained by the hybridization with the host rocks (granodiorite-tonalite). They constitute metaluminous terms of a cafemic association (Debon & Le Fort, 1983).

(b) Granodiorites-tonalites show a very important microstructural variability that contrast with the mineralogical and chemical homogeneity. Only an incipient fractional crystallization and /or local hybridization processes with the country rock change the common mineralogical features. They are peraluminous terms of a high K calc-alkaline aluminic or aluminic-cafemic association.

The isotopic dates (Rb-Sr system) show a good lineal correlation (R=0.99934) in the $^{87}Sr/^{86}Sr$ *vs*. $^{87}Rb/^{86}Sr$ diagram with a Sr_i of 0.70581. The partial melting or the fractional crystallization is excluded as the genetic relationship between the basic rocks and the host granitoid. The obtained results must been related with the development of isotopic homogenization processes associated to a simple mixing (at the emplacement level) between two magmas that characterizes the pluton.

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POSTCOLLISIONAL GRANITOIDS EMPLACED IN A TRANSTENSIONAL SETTING: THE CARDEÑA-VIRGEN DE LA CABEZA PLUTON (LOS PEDROCHES BATHOLITH, SPAIN)

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The Los Pedroches batholith is a late-orogenic magmatic alignment emplaced in a transtensional setting in the southern part of the Central Iberian Zone (Iberian Massif). Two plutonic units (granodiorites and granites) with an important acid-intermediate filonian complex constitute the main cartographic elements of this batholith.

The Cardeña-Virgen de la Cabeza pluton represents the easternmost magmatic event of the granitic unit of the batholith. It is constituted by lithologies similar to those of the other sectors of the magmatic alignment: granodiorites, biotitic adamellites *s. l.*, porphyritic biotitic granites *s. l.*, leucogranites and NW-SE striking acid dyke swarm. Besides, locally, there are important swarms of mafic microgranular enclaves (bt±amp) with mingling relations with the host rocks.

With respect to the petrography the main lithotypes display slight qualitative mineralogical variations: they are rocks with a simple granitic mineralogy with accesory cordierite, secondary muscovite, and apatite, zircon and ilmenite are the common accesories.

The main rock types define peraluminous terms of a aluminic-cafemic calc-alkaline association (Debon & Le Fort, 1983) or high potasium calc-alkaline one (Pecerillo & Taylor, 1976). The geochemical trends are characterized by a compatible behaviour of the Al_2O_3, FeO, MgO and CaO, and the increasing content of the Na_2O and K_2O during differentiation. These features with the linear and segment trends in some trace elements are characteristics of the fractional crystallization process. The participation of the plagioclase, biotite and K-feldspar, with some accesory minerals, during the fractionation could explain the observed chemical tendencies.

Only the mafic microgranular enclaves (bt±amp) are separated from the aforementioned petrographic and chemical characteristics, defining terms of a cafemic association (Debon & Le Fort, 1983). These rocks evolved by differentiation-mixing processes to less metaluminous lithologies.

The isotopic dates (Rb-Sr) show an 309±8 Ma (MSWD=1.98) emplacement age. Besides, they suggest the possible mantelic and crustal interaction in the magma genesis (Sr_i=0.705). The spatial and time coincidence of the mantelic basic magmas with the crustal melts in the formation of the magma/s is the suggested petrogenetic hypothesis.

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THE CADOMIAN OROGENY AND RELATED GEOTECTONIC EVENTS PRESERVED IN PERI-GONDWANAN CENTRAL EUROPE (SAXO-THURINGIAN TERRANE, GERMANY)

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The Neoproterozoic to Cambro-Ordovician units of the Saxo-Thuringian Terrane originated on the periphery of Gondwana (peri-Gondwana). The Neoproterozoic rock suites belong to the Avalonian-Cadomian Orogenic Belt. These units are preserved as basin fragments overprinted by the Cadomian orogeny. At some localities the Cadomian unconformity is preserved. The geotectonic setting of the peri-Gondwanan basement of the Saxo-Thuringian Terrane can be divided into six stages by use of sedimentology, sequence stratigraphy, geochronology and geochemistry:

(a) Island arcs and marginal basins during the late Neoproterozoic and the earliest Cambrian (575-540 Ma): Sedimentation, extra-basinal island arc magmatism culminating at 575 Ma and accretion of terranes within a system of island arcs and related marginal basins with an oblique vector of subduction on the margin of Gondwana.

(b) Cadomian orogeny during the earliest Cambrian (540 Ma): Deformation and accretion of the whole system with the Gondwanan basement (West African and sub-Saharan Cratons) and intrusion of post-deformative Cadomian plutons.

(c) Transform margin during the Lower and Middle Cambrian (540-505 Ma): Opening and closing of pull-apart basins developed on the consolidated basement of the Avalonian-Cadomian Orogen; filling with Lower to Middle Cambrian carbonates and siliciclastics.

(d) Uplift and chemical weathering during the Upper Cambrian (505-495 Ma): uplift and/or sea level lowstand and the origin of a chemical weathering crust under humid to subtropical conditions.

(e) Rift-controlled subsidence and shelf sedimentation in the Ordovician (495-445 Ma): Transgession on the peri-Gondwanan shelf during the Tremadoc with the recycling of the chemical weathering crust; opening of a rift basin with related magmatism starting at 490 Ma, control of subsidence, sedimentation and sea level fluctuations by rift tectonics; the maximum subsidence and sedimentation rate was reached during the Tremadoc.

(f) Separation from Gondwana and start of northward drift at 445 Ma: The rifting processes finally led to the separation of the Saxo-Thuringian Terrane during the late Ordovician. The separation overlaps with the Saharan glaciation (Ashgill).

The docking event with Baltica and amalgated Avalonia took place during Upper Devonian and Lower Carboniferous times. The old terrane boundaries were reactivated and overprinted by large strike-slip-faults during Variscan collision tectonics, which dominate the modern surface geology.

PARTIAL MELTING MANTLE PROCESSES RELATED TO CALC-ALKALINE AND SHOSHONITIC PLUTONISM FROM THE VARISCAN TORMES DOME (CENTRAL WESTERN SPAIN)

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Basic, intermediate and acid Variscan plutonic rocks from the Tormes Dome build up the following three associations: (a) Trondhjemitic association, with metadiorites and metatonalites, (b) monzonitic association, with monzodiorites, quartz-monzodiorites and related granites, and (c) granodioritic association, with vaugneritic rocks and other relatively abundant hybrid rocks. Besides, in this area there are two types of orto-amphibolitic rocks: (a) LREE and Nb,Ta,Ti-enriched type with within-plate affinity, and (b) Nb-poor type with flat chondrite normalized REE spectrum. Despite their petrographic diversity, their different emplacement and their wide time span, some geochemical criteria allow us to suggest certain cogenetism. A likely overall mantle derivation is masked by crustal processes as fractional crystallization, assimilation and contamination. However, amphibolites offer us a seemingly reliable clue in order to find a common mantle segregation mechanism. In this way, the Nb-poor amphibolites are consistent with relatively high degree partial melts compositionally quite close to mantle source. Inversion method modelling makes easy discrimination between mantle partial melting and the crustal processes. In this respect, some amphibolite, metadiorite and monzodiorite rocks which specifically record partial melting processes have been selected in order to obtain genetically meaningful parameters of the model. HRE elements reveal good correlations in La/element *vs.* La diagrams; so, a fertile mantle source with garnet as residual mineral phase can be proposed. Estimated modal proportion of the garnet from the mantle source ranges from 13 to 18%. This result rules out a eclogitic residue, as well as a mantle of exclusive peridotitic component. Moreover, intermediate Cr/Ni ratio suggests a hybrid source mantle made up of a peridotitic component mixed with adakitic melts. The Nb-rich amphibolites associated with the arc signature magmas could support a unique subduction geodynamic model, according to some recent vulcanism models (Sajona *et al*., 1996). Consistently, an old subduction event (Cadomian?) is suggested, predating the Variscan evolution of the Tormes Dome. The uncommon LREE enrichment of calc-alkaline and mainly shoshonitic magmas is consistent with an input of slab component. This additional process could yield an even more hybridized mantle, supposed to be reactivated up to late extensional Variscan evolution.

CONTEMPORARY CRUSTAL DEFORMATION MODELLING IN THE SOUTH PORTUGUESE AND OSSA-MORENA ZONES: PRELIMINARY RESULTS

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An attempt is made to study the main constraints in the evolution of the crustal deformation of the boundary between the South Portuguese Zone and Ossa-Morena Zone using a two-dimensional numerical model. The program allows the modelling of the present-day behaviour of tectonic structures considering kinetic boundary conditions. The algorithm used is based on the elastic behaviour (plane stress) of the geological materials, being applied the finite element method. Since realistic modelling of complex tectonics is a very difficult task, the methodology used gives us only a first approximation to the problem. For studying present-day state of stress distribution, the model included geological and geophysical data obtained mainly from seismic and magnetotelluric studies performed in the area. Narrow zones with elastic parameters lower than those in surrounding regions simulated the presence of the major discontinuities. The results obtained by numerical experiments are consistent with geological observations.

Life and Times of the Avalon Arc in the northern Appalachians

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The Avalon arc in the northern Appalachians appears to have been active from *763 Ma to *550 Ma. Its basement, athough not exposed, is inferred to have been built on juvenile Grenvillian, 1-1.2 Ga basement based upon (a) Nd isotopic data that show consistent TDM ages for Precambrian and Palaeozoic volcanic rocks (Keppie, 1997; Murphy *et al*., 1998), and (b) the *977-1,223 Ma U-Pb ages obtained on detrital zircons in Avalonian sedimentary rocks (Keppie *et al*., 1998).

The early magmatism lasted from *763 Ma to *630 Ma, and consisted of (a) calc-alkaline rocks: *734 Ma Economy River Gneiss (Doig *et al*., 1993) and 683-676 Ma Stirling and Connaigre Bay Groups and Roti granite (Bevier *et al*., 1993; Krogh *et al*., 1988; Swinden & Hunt, 1991; O'Brien *et al*., 1992), and (b) rift-related ophiolites and tholeiitic rocks: 763 Ma Burin Group and in the *700-630 Ma George River Metamorphic Suite (Keppie *et al*., 1998; Keppie & Dostal, 1998). The contemporaneity of these suites suggests that they formed in a rifted arc tectonic setting. Assuming limited Palaeozoic shuffling, spatial relationships imply NW-dipping subduction in Cape Breton Island.

The main magmatism occurred between *630 Ma and *590 Ma and is composed mainly of calc-alkaline plutonic and volcanic rocks and rift-related tholeiites overlain by turbidites (Keppie *et al*., 1998 and references therein). These rocks are inferred to have been formed in arcs and periarc basins. This was synchronous with greenschist-amphibolite facies metamorphism and transpressional ductile shear deformation that varies in space and time. Northwesterly subduction polarity is indicated various geochemical parameters including Nd isotopic data.

The terminal magmatism extended from *590 Ma to *550 Ma and shows diachronous along-strike changes from calc-alkaline to tholeiitic (Keppie *et al*., in press, and references therein): 590 Ma in southern New England, 560 Ma in southern New Brunswick, 550 Ma in Cape Breton Island, and 570 Ma in Newfoundland. The bi-directional diachronism is attributed to migration of two ridge-trench-transform triple points as the Merlin Plate was subducted beneath Avalonia, which caused a switch from arc to extensional magmatism. This is accompanied by a reversal in deformation from convergent to transtensional. Subduction terminates with complete subduction of the Merlin Plate which became stationary. Remnant mantle upwelling along the subducted ridges produces uplift, gravitational collapse and the high temperature/low pressure metamorphism observed in southern New Brunswick and central Cape Breton Island.

Pre *977 Ma detrital zircons show the following populations: *977-1,223 Ma, 1,332 Ma, *1,506-1,545 Ma, *1,606-1,630 Ma, *1,827-2,000 Ma, and *2,600-3,000 Ma (Keppie *et al*., 1998). The combination of 1.0-1.3 Ga ages in a Neoproterozoic arc favours provenance in the Amazon craton or Oaxaquia (Mexico-Honduras). The early, main, and late stages of Neoproterozoic magmatism are inferred to represent growth of the arc on the margin of Amazonia, separation by backarc rifting, and re-amalgamation with Amazonia. The northwestward migration of the arc magmatism through time suggests progressive shallowing of the Benioff zone.

Early Ordovician separation of Avalonia from Amazonia is indicated by subsidence curves (Prigmore *et al*., 1997), and late Ordovician-Early Silurian accretion to eastern Laurentia is recorded by an Appalachian overstep sequence (Chandler *et al*., 1987), accretionary deformation (Keppie, 1993), the first appearance of a Laurentian Nd signature (Murphy *et al*., 1995), and faunal linkages (Williams *et al*., 1995). If western Avalonia originated by >200 Ma of Neoproterozoic subduction beneath Amazonia, then the NW-dipping Benioff zone beneath Nova Scotia (present coordinates) requires a rotation of 180° before accretion to Laurentia.

Bimodal pre-Hercynian magmatism in the lower Palaeozoic of the Eastern Pyrenees. A magmatism representative of the Lower Cambrian

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The Hercynian massifs located northeastward of the Iberian Massif comprise the Pyrenees axial zone (Nuria, Canigó, Rock de Frausa, Alberes, and Cap de Creus massifs) and the Catalonian mediterranean coastal ranges (Guillerias massif). In all massifs, the pre-Hercynian magmatism is located at the basal part of an azoic metasedimentary succession, whose age is probably Lower Cambrian ("Canaveilles Formation", Laumonier, 1988; and "Cadaqués series", Carreras, 1988). Different sheets of peraluminous orthogneisses (Canigou, Roc de Frausa and Mas Blanc augen-gneisses) are included into the metasedimentary succession showing controversial relations of intrusivity (Guitard, 1970; Liesa & Carreras, 1989) and also metaluminous gneisses are presents in specified massifs ("Port de la Selva" and Casemí leucogneisses; Carreras & Ramírez, 1984; Guitard *op. cit.).*

The basic magmatism appear as doleritic sills, metagabbro domes, lava flows and pyroclastics ignimbrites tuffs generally in relationship with the marble beds or located near the augen-gneiss/metasediment contact or into the augen-gneiss bodies. At the bottom of the succession, this magmatism is formed by quartz-amphibolites derived by basalts and andesitic basalts of tholeiitic character (SiO_2=45-48%, Na_2O+K_2O=1,5-3%, Fe_T=10-12%) in the midle part, calc-alkaline affinity (SiO_2=52-54%, Na_2O+K_2O=3-5%, Fe_T=6-10%). In general, they show hight content of Cr and Ni (260-500 ppm, and 60-300 ppm respectively) and very low content of Nb (3-15 ppm), Th (1-12 ppm), Y (20-30 ppm) and Zr (70-80 ppm in Tol and 160-180 ppm in calcalk). The ORG toleiitic patterns are analogous to E-MORB and back-arc continental tholeiites, and their REE chondrite normalized patterns show a relatively flat profile with a low fractionation ($(La/Yb)_N$=1.5-2.8 in Tol and 5.8 in calcalk) and a variable anomaly in Eu (Eu/Eu*=0.55-1.12 in Tol and 0.72-0.86 in calcalk). The geochemical characteristics of these magmatic sequences suggest that they are derived from low fractionation mantle melting setting into a continental back-arc basin.

In several massifs (Canigou and Roc de Frausa Massifs) there are also Fe-rich orthoamphibolites, intruded as sills in the augen gneiss/metasediment contacts. They offer planar fabrics and represent transitional magmas with high contents of Nb (814-25 ppm), Y (23-60 ppm), Zr (150-340 ppm) and ∑REE (178-240). Their ORG patterns offer a convexity and a "M" shape, analogous to postcollisional crustal magmas. Their REE patterns normalized to chondrite are similar to calc-alkaline magmas, with a positive anomaly in Eu ($(La/Yb)_N$=4.5-7; Eu/Eu*=(0.539-0.780). These orthoamphibolites are interpreted as transitional magmas derived from crustal melts.

The acid magmatism is composed of metatuffs and rhyolitic porphyritic metarhyolites. They are interbedded in the middle and highest part of the Canaveilles succession. Their geochemical characteristics are calc-alkaline magmas derived from rhyodacites and rhyolites members. In the Canigou massif a fractionation appear betwen acid gneisses and the basic calc-alkaline ignimbrites tuffs but in the Cap de Creus and Albera massifs they represent aluminous magmas derived from crustal melts. As the tholeitic-calc-alkaline sequence, they have low content in Nb (5-11 ppm), Th (8-12 ppm), Y (20-42 ppm) and their ORG patterns are analogous to Chile granites with a significative crustal component. Their REE patterns are moderately fractionated $(La/Yb)_N$=5-9 with positive Eu anomaly (Eu/Eu*=0.48-0.68). Probably, different sources could be invoked for these acid magmas, fractionation and crustal melting processes during their tardiorogenic setting in a continental back-arc bassin.

Geochemistry of Precambrian igneous rocks from the northern sector of the Narcea Antiform (Cudillero, Asturias, Spain)

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A bimodal sequence of acid volcanic and volcaniclastic rocks and basic dykes crops out within Precambrian sediments of the Narcea antiform (West Asturian-Leonese Zone, N Spain) at the Cudillero harbour in the Asturias coast. A small body, several decameters in size, of gabbro-diorite occurs associated with the sequence.

Volcanic and volcanoclastic rocks, classically known as "porphyroids", show way up criteria towards the East. They crop out as layers less than 100 meters in total thickness showing sharp or gradual contacts and azimuths ca. 290/60. These are rhyolitic rocks with porphyritic texture made of a greenish aphanitic matrix containing medium- to fine-grained porphyroclasts of quartz, plagioclase and, less often, K-feldspar. There is evidence for these being in part coherent lavas barely transformed by deformation and/or metamorphism, while the rest corresponds to volcanoclastic (epi and pyroclastic) rocks.

These rocks are intruded by a minor body of medium-grained, dark coloured rock with intersertal texture. The only remnants of the primary, likely gabbroic, assemblage are albitized pseudomorphs of plagioclase, acicular apatite and opaques. Other minerals, like quartz, chlorite, biotite, Ti-rich phases and rare epidote, appear to be secondary in origin.

The porphyritic rocks and the gabbro/diorite intrusive are cross cut by less than 1 meter thick dykes with various orientations. The dykes are dark coloured and fine- to very fine-grained (slaty in appearance). Originally interpreted as basaltic dykes, they do have a basic composition but show mostly a secondary mineral assemblage of albite, chlorite, sericite, quartz and opaques; calcite and biotite are found less often. Petrographic features allow to distinguish two types of dykes: Type I, with microlitic texture, either intersertal (Ia) or nodular (Ib), and Type II typically with porphyritic texture.

The whole igneous association at Cudillero shows typical mineral assemblages of spilitic rocks with albitization of plagioclase, however, other hydrothermal processes of transformation related to late stages of the magmatic evolution cannot be excluded. The Hercynian metamorphic overprint occurred under greenschist-facies conditions at ca. 420°C, P < 3 kbar as indicated by the occurrence of iron-rich biotite. The microstructures suggest a mild and heterogeneous deformation coeval with this metamorphism under equally low-grade conditions of ca. 300-400°C.

The geochemistry of this igneous association reveals a bimodal magmatism: porphyritic rocks may be classified as rhyolites, whereas the basic dykes correspond to basaltic andesites. The chemical composition of the intrusive body appears to be that of a gabbro transformed into diorite. Besides that, there appears to exist a good correlation between petrographic types defined and major and trace element contents, with lavic porphyroids for instance being richer in Zr than the volcanoclastic varieties, both with relatively low Ti contents, and Type II dykes richer in K_2O (and associated trace elements) than those of Type Ia.

Major element composition of the basic dykes is similar to analogous rocks of calc-alkaline series, although with an enrichment in FeO.

Rhyolitic rocks show LREE continuously fractionated patterns [$(La/Sm)_n$=2.45-3.14] and important Eu negative anomalies (Eu/Eu*=0.06-0.52). These features suggest some degree of differentiation and compare also to those of acid rocks from calc-alkaline series. Basic rocks show likewise continuous fractionation of LREE [$(La/Sm)_n$=2.20-2.57] but distinctly separate Eu behavior, with marked negative anomalies in the case of the basaltic andesites (Eu/Eu*=0.29-0.47), and virtual absence for the dioritoid (Eu/Eu*=0.85). Overall, the patterns observed for the basic rocks are somewhat richer in REE although comparable to those of crustal basaltic andesites. It may be noted that REE contents of basic and acid rocks are rather similar, and except for the dioritoid, so are the Eu negative anomalies. On the contrary, fractionation of HREE is the less marked in basic rocks [$(Gd/Yb)_n$=1.48-1.62] and practically absent in the rhyolitic ones [$(Gd/Yb)_n$=1.09-1.40].

The whole association of igneous rocks at Cudillero suggest an evolution during late Precambrian times from crustal derived acid magmas of calc-alkaline affinity towards deeper products involving an increased participation of mantle derived magma.

THRUSTING AND WRENCHING IN THE PULO DO LOBO ANTIFORM (SOUTH PORTUGUESE ZONE, SPANISH AREA)

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Introduction.
The Pulo do Lobo antiform represents an intermediate segment of the Iberian Variscan fold belt. Together with the Beja-Acebuches ophiolitic complex, the Pulo do Lobo antiform separates the Ossa-Morena Zone (OMZ) from the South Portuguese Zone (SPZ). Its composition and its structural features appear very important to constrain the relationships between these two units. It thus represents a key point for the understanding of the geodynamic setting of the whole South Portuguese Zone and especially the Iberian Pyrite Belt. The aim of this work is to provide new structural and microstructural data recorded through the Pulo do Lobo antiform on its Spanish part, in order to improve the geodynamic model.

1. Pulo do Lobo antiform stratigraphy.
The Pulo do Lobo mainly consists of a terrigenous sequence with scarce acidic dykes and intercalations of amphibolites in its core showing MORB-type affinities. Several units have been distinguished (Pfefferkorn, 1968; Schermerhorn, 1971; Oliveira *et al*., 1986; Giese *et al*., 1988; Eden, 1991) but remain poorly detailed, from a cartographic point of view, in the Spanish sector. Besides, three main units can be distinguished from the bottom to the top, namely the Pulo do Lobo *s. s.*, wherein melange have been described, the Ribeira de Limas formation and the Santa Iria formation. The oldest unit (Givetian-Frasnian) consists of phyllite, quartzite and quartz micaschists. The overlying succession, the Ribeira de Limas formation, is mostly composed of phyllites and metagreywackes. Finally, the Famennian Santa Iria formation consists of metagreywackes and shales with turbiditic features (Quesada *et al*., 1994).

2. Structural features.
Field work across the Pulo do Lobo antiform allows us to divide this unit into three main domains with respect to their structural features.

2.a. Southern domain.
This sector corresponds to the contact between the Pulo do Lobo and the Iberian Pyrite Belt. These formations are separated by an undifferentiated Devonian-Dinantian unit which has been described in Portugal as the Gafo formation and partially recognized in Spain, where it is associated to the Phyllites and Quartzites formation. But there is no age constraint available. In agreement with Spanish maps, in this work we consider that the Gafo formation belongs to the Iberian Pyrite Belt (IPB).

Nevertheless, a significant structural obliquity exists between the IPB and the Pulo do Lobo unit in the Paymogo area. The southern side of the contact is affected by F1 folds of average unusual N010°-N030° trending axes and axial planar F1 dipping northwestward. On the northern side, the axes of the South-verging folds trend E-W. The associate north-deeping cleavage carries a N120° trending stretching lineation which pitch indicates a dextral thrusting towards the southeast to a simple dextral wrenching striking N120°. Eastward the conjugate N-S sinistral wrenching is also observed.

In the Santa Bárbara de Casa area, strike-slip tectonics seems to be absent while thrusting towards the south is clearly exposed. It is well represented by South-southwest-verging folds (F1), with sometimes thrusted inverted limbs, but also by shear planes and associated sigmoidal quartz lenses indicating a top-to-the-South sense of shearing.

Going eastward, on El Mustio road, south-verging structures can be observed. Very scarce North verging folds (F2) exist and appear similar to those cropping out in the IPB.

The easternmost observations, between the localities of Valdelamusa and Gil Márquez, show the transition from a single South-verging tectonics in the Pulo do Lobo (with the same shear criteria as exposed above) to a superimposed strike-slip tectonics in the volcano-sedimentary complex of the Iberian Pyrite Belt.

2.b. Central domain.
The most remarkable structural feature characterising the central domain concerns folds style. Indeed, the decameter scale folds appear here upright while they are overturned at the southern limb of the Pulo do Lobo. The question is to know if this style corresponds to a second folding phase or to the F1-related one. Field observations suggest that it corresponds to the same first episode affecting S_0. However an intermediate phase (F1, 2) affecting $S_{0\text{-}1}$ in the less competent lithologies (where folding is much more intense) seems to emerge.

Strike-slip tectonics is also present in this domain and is linked to the Gil Márquez granite emplacement. This intrusion presents a ductile deformation expressed by a E-W vertical foliation carrying a weakly East-dipping lineation. Shear criteria (pressure shadows around K-feldspar and sigmoidal enclaves) indicate a dextral wrenching.

The presence in the central domain of an ophiolitic detritism described in the Los Ciries antiform (Eden, 1991) remains a very important point for the description of the geodynamic evolution of the Pulo do Lobo.

2.c. Northern domain.
In the northwestern part of the studied area, to the south of Rosal de la Frontera locality, a general change in the vergence of the structures is observed. From South-verging in the meridional domain, through upright in the central domain, folds appear here overturned towards the north. The associated N120E striking cleavage is dipping South and is sometimes affected by North-verging F2 folds. These folds may be different from those observed in the southern domain and in the IPB, the latter being antithetic while the former have a synthetic behaviour.

In the Almonáster la Real area, this North-verging tectonics is not represented. There, criteria towards the southwest and their related northeast dipping schistosity are in contact with the Acebuches amphibolite. This unit, regarded as a "major" suture zone, corresponds to a ductile shear zone. Its mylonitic foliation and stretching lineation are associated to left-lateral wrenching towards the northwest (even if the lineation appears sometimes steep).

The North-verging tectonics is thus less obvious in the eastern extent of the Pulo do Lobo. However, to the South of Alajar, the Pulo do Lobo–Acebuches amphibolite contact provides new evidences of the North-directed tectonics. The block-bearing series of the PL (see Eden, 1991) is affected by gently dipping thrusts indicating a top-to-the-North kinematics. Coeval upright to South-verging F2 folds are developed.

Finally, strike-slip tectonics also appears in this domain, to the South of Aroche in the vicinity of the contact with the Acebuches amphibolite. Here, highly sheared phyllites striking N155E and carrying a horizontal lineation indicate a left-lateral wrenching.

Synthesis and geodynamic implications.
The Pulo do Lobo as a whole provides two main kinds of structures, one related to the N-S thrusting event and the second linked to strike-slip tectonics.

On a N-S section of the Pulo do Lobo, the thrust planes together with the associated folds (F1, F2) and cleavages (S1, S2) show a fan-like distribution of the structural criteria. From a southwest-verging tectonics exposed in the South, an opposite North-verging tectonics in the North is reached, through an upright folded central zone.

The thrusts–back-thrusts geometry has been modelled and described for imbricated thrusts (Malavieille, 1984) and accretionary prism (Mascle *et al*., 1986; Byrne *et al*., 1988, 1993; Charvet & Ogawa, 1990). It thus seems that these works support the accretionary prism model already proposed (Eden, 1991) for the Pulo do Lobo terrane. Ophiolitic detritism also described at the bottom of the sequence (Pulo do Lobo formation *s. s.*) suggests an early intraoceanic formation prior to accretion as olistolithes into the prism. On the other hand, OMZ-related blocks (Alajar melange of Eden) seems to be related to continental erosional process.

Finally, the Gil Márquez granite syntectonic intrusion is associated to the second kind of structures related to right and conjugate left-lateral wrenching, occurring throughout the Pulo do Lobo. Considering the style of the deformation and the age of the granite [ca. 330 Ma (Rb/Sr; Giese *et al*., 1993)], strike-slip tectonics may represent the late stage of the Variscan tectonics. Such a transcurrent tectonics is also described in present accretionary prisms (Lallemand, 1999) linked to oblique subduction. There it remains located at the rear part, at the prism–forearc basin transition. Nevertheless, wrenching should have been reworked during the late stage of the SPZ-OMZ collision, allowing granite emplacement.

A GEODYMAMIC MODEL FOR THE OSSA-MORENA ZONE (IBERIAN MASSIF) BASED ON GEOCHRONOLOGICAL DATA

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SHRIMP-data reported for zircons from a number of sedimentary, igneous and metamorphic rocks within the Ossa-Morena Zone allow to distinguish a sequence of distinct magmatic and metamorphic episodes. The model proposed here includes both the Cadomian and the Variscan cycle.

Inherited grains within the metasediments, gneisses and granitoids studied reveal several provenance ages. Pan African ages indicate derivation from Gondwana-type sources. In general, the inherited ages found fit well with the megacycles of crustal growth reported for the European Variscides but the detection of single detrital grains at 1.5, 2.4, 2.8, 3.3 and 3.4 Ga was so far uncommon for zircon dating in the European Variscides.

Dating of metasediments, granitoids, volcanics, basic rocks, and migmatites allows us to propose several stages of the Cadomian cycle: sedimentation of the Serie Negra in a stable platform (ca. 590 Ma ago), anorogenic rifting with bimodal magmatism at ca. 580-540 Ma, a syn- to post-collisional phase with the formation of anatectic granitoids (533-523 Ma), a post-collisional phase (525-498 Ma) with the intrusion of calc-alkaline granitoids and volcanism. At the end of this phase there is an episode of alkaline magmatism that represents the transition to an extensional episode.

Dating of granitoids and basic rocks indicate bimodal magmatism during anorogenic rifting (490-460 Ma). *(epsilon)*Nd values around +10 of one of the retrogressed eclogite protoliths indicate that rifting reached an oceanic stage.

Dating of retrogressed eclogites and migmatites within the Coimbra-Badajoz-Córdoba shear belt (CBCSB) reveal an age for the subduction-related eclogite facies metamorphism at 340±13 Ma and immediately following migmatization of the gneisses at 337±3 Ma. These ages are within limits of error identical and therefore we propose a single P-T loop reaching the P-T peak during subduction with subsequent decompressional melting during Tournaisian-Visean times.

Cooling and exhumation rates reported for the gneisses of the CBCSB are calculated at ca. 27-133°C/Ma and 1.3-7.7 mm/y, respectively. If we consider that the eclogites are *in situ* and therefore have the same cooling and exhumation history we can calculate exhumation rates of ca. 1.4 to 14.6 mm/y.

Regarding the whole European Variscides, we can state that migmatization ages around 530 Ma related to compressional episodes are also present in the Saint-Malo migmatite dome of the North Armorican Massif (NW France; Peucat, 1986). Thus, a similar geological evolution as the Ossa-Morena Zone and the North Armorican Massif is indicated, strongly arguing for palaeogeographic links.

The Variscan (Hercynian) orogeny, caused by the Carboniferous collision of the supercontinents Laurasia and Gondwana to form Pangea, was preceded by various orogenic episodes of varying extents (e.g. Gebauer & Grnenfelder, 1982). In the Cabo Ortegal complex such an orogenic cycle has now been found to have taken place in the Lower Devonian. In the Ossa-Morena Zone it has been found in Early Carboniferous times.

Similar ages for the subduction of distinct terranes are also found e.g. in the Bohemian massif and thus, the micro-continent or terrane model is the most plausible model to explain the multi-episodic nature of the Variscan orogen.

Acritarch assemblages at the Lower-Middle Cambrian boundary in the Iberian Peninsula and their utility in global correlations

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Cambrian acritarch assemblages are reported from continuous successions of Sierra Morena (southern Spain, Badajoz province) and Iberian Chains (northern Spain), embracing the Lower-Middle Cambrian boundary. The microfossil assemblages allow to recognize two acritarch zones, the uppermost Lower Cambrian (*Tubulosphaera perfecta-Heliosphaeridium notatum* Assemblage Zone and the lowermost Middle Cambrian (*Eliasum llaniscum-Celtiberium dedalinum* Assemblage Zone). In Ossa-Morena their faunal boundaries are coincident with an important volcanic episode, which may has contributed to the palaeoenvironmental changes that led to the extintion and radiation events at the Lower-Middle Cambrian boundary. These associations allow the first detailed biostratigraphical correlation between the transitional levels of the North and South of the Iberian Peninsula to be carried out .

The global stratotype section for the Lower-Middle Cambrian boundary has not yet been established and various stratigraphic levels were recognised and/or proposed as standard candidates in different palaeogeographic areas. The recognition of the regional boundaries is based on the occurrence of trilobite faunas that have mostly restricted geographic distribution and are often facies dependent. Another important problem is the presence of an important hiatus in the north of Europe and Laurentia, related with the late Lower Cambrian Hawke Way Regression and its equivalents. Thus, the chronostratigraphic interregional correlation of the Lower-Middle Cambrian boundary is uncertain.

The first appearance of Eliasum llaniscum, has been proposed to mark the Lower-Middle Cambrian boundary in the Iberian Peninsula. The clear diagnostic characters of this species and its cosmopolitan distribution eliminates the inherent problems to the use of trilobites faunas (affected by a marked provincialism) in global correlations. The data presented in this work reinforce this proposal and allow the establishment of the first Assemblage Acritarch Zone of the Middle Cambrian in the Iberian Peninsula.

The lowermost Cambrian in the Valdelacasa Anticline (central Spain): some new palaeontological data

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Successions straddling the Precambrian/Cambrian boundary in northern and southern Spain show important hiatuses, but this transition is recorded without important breaks in the central part of the country. The western part of the northern side of the Valdelacasa anticline (Toledo Mountains) is one of the most suitable areas to study the palaeontology of this transition in central Spain, and also one of the best in western Europe. Here, fine siliciclastics of the Río Huso Group (Pusa shale) crop out providing a fairly rich record of ichnofossils, small shelly fossils, trilobites and other groups. The stratigraphic succession is ca. 2,000 m thick and includes a lower unit of greenish shales, a middle unit including black, micro laminated shales, phosphate beds and conglomerates, and an upper unit of greenish shales, very fine sandstones and scarce calcareous sandstones.

Cambrian-diagnostic trace fossils appear from the base of the lower stratigraphic unit, including *Phycodes pedum*, *Monomorphichnus lineatus* and small specimens of *Psammichnites* ichnosp.

The middle unit contains phosphatized fossils, namely *Cloudina*, anabaritids, halkieriids, sponges and probably small arthropods.

The upper unit provided rich and diverse body fossils assemblages at several horizons, as well as abundant ichnofossils. A lower assemblage consists of small shelly fossils (aff. *Aldanella*, hyoliths and others, including forms of centimetric sizes) and trilobites of the Family Bigotinidae. Another assemblage, placed a few meters above in the column, contains more diverse small shelly fossils: monoplacophorans (aff. *Aldanella*), hyoliths (hyolithids, circothecids and orthothecids), possible protoconodonts (aff. *Mongolitubulus*) and coeloscleritophorans (chancelloriids). A recently found uppermost assemblage, placed about hundred meters above in the column and shortly below the base of the Azorejo Formation, has provided very abundant bigotinid trilobites, small shelly fossils (molluscs and others, including forms of centimetric sizes), trace fossils (*Sericichnus* and *Teichichnus*) and probably inarticulate brachiopods.

Trace fossils in the upper unit of the Pusa shale are, as a whole, of bigger size than in underlying units and include feeding burrows of several patterns, such as *Dactyloidites* ichnosp., *Treptichnus bifurcus* and big specimens of *Psammichnites gigas*. This succession is overlain by sandstones and shales of the Azorejo Formation containing *Rusophycus* ichnosp.

According to its palaeontological record, the age of the fine siliciclastics of the Río Huso Group (Pusa shale) in the studied sections ranges from the lowermost Cambrian (Nemakit-Daldynian) to the latest Tommotian or Atdabanian.

The southern boundary of the Central Iberian Zone (Spain), a new proposal: the Castuera-San Benito Fault

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Traditionally, the southern boundary of the Central Iberian Zone (CIZ) has been traced following the Los Pedroches batholith; however, and in spite of its lateral continuity, the batholith ends near Castuera village, so that it only covers the eastern half of that boundary. Some authors attempted to extend this boundary along to some other scattered batholiths, one of them (Valencia de Alcántara) goes into the Obejo-Valsequillo Domain (OVD), and it even reaches the Badajoz-Córdoba Shear Zone. However, this situation implies the emplacement of La Codosera-Portalegre and Sierra de San Pedro synclines in the same Zone (CIZ); these two synclines, which are today very close geographycally, are, however, very diferent from a stratigraphical point of view, at least with respect to their Devonian successions.

On the other hand, Los Pedroches batholith intrudes in the middle of the "Culm de Los Pedroches" series, a thick Carboniferous formation; successions on both sides of the batholith are very similar, and they belong to the same marine basin. Thus, the batholith does not represent a boundary between different stratigraphical successions and palaeogeographical conditions. On the contrary, there are differences between these Carboniferous rocks and those situated at the top of the Palaeozoic succession, which is inmediately located to the north of the "Culm" outcrops (Guadalmez and Santa Eufemia areas).

Moreover, the "Culm" itself is in tectonic contact with those northern Palaeozoic series, along the San Benito-Santa Eufemia-Castuera line. This important fault has traced seen between San Benito and Castuera areas and, along this major fracture, the top of the "Culm" is in contact with several Palaeozoic and even Precambrian rocks. Although more detailed research needs to be done, it seems that this fault reaches the region of Sierra Morena Oriental at the southeast; to the northwest, this fault would be placed between the aforementioned La Codosera-Portalegre and Sierra de San Pedro synclines, and it would extend to the East of the Dornes syncline (Portugal), whose Devonian succession is very similar to that of La Codosera-Portalegre.

The placement of the boundary in the Castuera-San Benito fault seems to fit better to the defining characteristics of other similar boundaries in the Iberian Massif (i.e., it must coincide with stratigraphic and tectonic changes, and be preferably placed in tectonic structures). Because of that, we propose the Castuera-San Benito fault as the boundary between the CIZ and the OVD.

Preliminary characterization of carbonated rocks from central sectors of the Central Iberian Zone

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A preliminar geochemical study of some limestones and marbles from the central-western part of the Central Iberian Zone (Iberian Massif) is presented Two domains are distinguished.

(a) Late Neoproterozoic low-grade metasedimentary rocks from the Upper Unit of the Schist-Greywacke Complex, in which limestone levels and some calc-silicate rocks are interbedded in a predominantly pelitic succession with several alternations of black mudstones, conglomeratic and sandstone bodies as well as some volcanoclastic interbeds. These materials, Upper Vendian in age, show a continuous transition into the Lower Cambrian shallow sequences (Tamames Sandstone and Tamames Limestone Formations).

(b) High grade metamorphosed rocks of the Tormes Dome domain, including some marble levels and calc-silicate rocks, amphibolites and metapelitic sequences associated with augengneisses and other deformed igneous rocks which had been intruded by abundant calc-alkaline Variscan plutonism.

In all cases the carbonated successions constitute discontinuous lenticular bodies of decametric to hectometric thickness and several kms in length. In addition, limestones and marbles always show a different degree of siliciclastic participation either as terrigenous components within the carbonated rock or as pelitic or sandstone interbeds.

Geochemical analyses have been made for some 30 samples, including major and trace elements from the following outcrop areas: (a) in Salamanca province: Tamames-Casafranca (Lower Cambrian) and Pastores-Fuenteguinaldo-North of Ciudad Rodrigo (Upper Vendian); (b) in Zamora province: Fermoselle-Pinilla (upper Precambrian?); and (c) in Ávila province: Urraca-Miguel (upper Precambrian?). The last two are associated to the augengneiss domain.

A wide range is shown by major element contents, which is independent of the age of the rocks. Specifically, CaO content range is 54.63-25.46 while MgO is 19.69-0.89; SiO_2: 29.21-0.16 and Al_2O_3: 10.93-0.07. These variations are largely caused by the existence of substantial proportions of non-carbonated components in the samples.

Regarding trace elements, specific content of Sr allows the whole outcrops to be discriminated according to their age as follows: higher values (778-2,109 ppm) for the upper Neoproterozoic outcrops and lower values (16-279 ppm) for the Cambrian. The high-grade metamorphic outcrop of the Fermoselle-Pinilla area is also included in the lowest range.

Besides Ti and K, rare earth elements such as V, Ba, Rb, Th, and Zr show good positive correlations with SiO_2 and Al_2O_3 for all the outcrops. These correlations are closely related to the presence of terrigenous phyllosilicate components, mainly biotite. Of particular relevance is the fact that LREE and HREE correlations define linear trends which tend to converge in the samples with higher rates of siliciclastic elements. These trends also allow us to clearly discriminate the Fermoselle-Pinilla area as the one with LREE highest values, which is consistent with the geochemical signature of the surrounding magmatic rocks. The calc-alkaline igneous provenance previously attributed to some volcanoclastic rocks from the Schist-Greywacke Complex strongly suggests that a (Cadomian?) igneous participation had also been partially involved in the genesis of some of the non-carbonated components of the carbonate-siliciclastic sequences described above.

DEVELOPMENT OF AN UPPER PALAEOZOIC COMPOSITE FLOWER STRUCTURE ON THE NORTHERN OSSA-MORENA CADOMIAN BASEMENT (IBERIAN MASSIF): THE MEGASTRUCTURE OF ASSUMAR (NORTHEAST ALENTEJO, PORTUGAL)

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The Megastructure of Assumar comprises an extensive and representative outcrop of the Ossa-Morena Cadomian basement characterized by a sedimentary and volcanic upper Proterozoic sucession ("Serie Negra") which is unconformably overlain by upper Proterozoic/Lower Cambrian felsic volcano-sedimentary series (Freixo-Segovia Volcano-Sedimentary Complex) and by Lower Cambrian platform sequences (Detritic-Carbonate Cambrian of Assumar). The upper Proterozoic "Serie Negra" were affected by a deformation event associated with intermediate to low-grade metamorphism which does not affect the overlying uppermost Proterozoic/lowermost Cambrian stratigraphic record and the pre-Variscan granitoids (Barreiros granitoid complex and Barquete-Bedanais-Aguilhão granitoid lineament).

The Variscan continuous deformation within the Megastructure of Assumar is characterized by composite flower structures built along sinistral strike-slip fault systems, consistent with a transpressional setting.

Despite the scarcity of geochronological and geochemical information, which inhibits the establishment of definitive correlations, one can recognize affinities between the tectonostratigraphic and metamorphic record of the Megastructure of Assumar and the Olivenza-Monesterio antiform (Spain), mainly based on field and petrographic studies.

UPPER DEVONIAN PALYNOMORPHS OF NE SECTOR OF TRÁS-OS-MONTES (CENTRAL IBERIAN ZONE)

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The lower parautochthonous variscan sequences occur in the NE sector of Trás-os-Montes, near the boundary with the subzone Galicia-Trás-os-Montes. The geology is characterized by the structuring and emplacement of a pile of thrust sheets, well exposed in the Morais and Bragança Massifs, which together with the Galicia Massif creates a sequence of sheets implanted on the autochthonous of the Central Iberian Zone (CIZ).

The bases of the lithostratigraphic succession of the autochthonous of the Bragança region was established by Ribeiro (1974) and then modified and reviewed by Meireles *et al*. (1995), Meireles (1997) and Ribeiro & Pereira (1997). The succession is mostly composed by Ordovician quartzites with iron bands and shales, followed by an amalgamated unit mainly of Silurian age composed, at the bottom, of black phyllites and greywackes with quartzites, lidites and limestone intercalations, and at the top, by a volcanosedimentary complex (purple shales and bimodal volcanics) interbedded in shales, quartzites and limestones. A poorly dated flysch unit of Upper Devonian age also occurs. It has been referred as the Gimonde Formation (Pereira *et al*., 1982).

The aim of the present work is to investigate the palynological contents of the Gimonde Formation, located in the transition autochthonous-lower parautochthonous sequences of the Bragança Massif. This unit is characterized by shales and greywackes, rich in plant debris, of Upper Devonian to Lower Carboniferous age (Teixeira & Pais, 1973; Pérez Estaun, 1974).

The recovered assemblages of spores are assigned to the *Archaeoperisaccus ovalis-Verrucosisporites* bulliferus (OB) Biozone, of Frasnian age (Upper Devonian).

A detailed sampling through the Gimonde Formation in the Gimonde road and Quintanilha road sections yielded spores of the species *Aneurospora greggsii*, *Densosporites devonicus*?, *Geminospora lemurata* and *Verrucosisporites scurrus*. Spores are very badly preserved but are assigned to the Givetian/Frasnian boundary.

The Rio de Onor road section provided a rich spore assemblage that includes *Aneurospora greggsii*, *Auroraspora* sp., *Archaeoperisacus* cf. *ovalis*, *Contagisporites optivus*, *Hymenozonotriletes deliquescens*, *Lophozonotriletes* sp., *L. media*, *Retispora archaeolepidophyta*, *Samarisporites* sp., *Retusotriletes* sp., *Verrucosisporites bulliferus*, *V. scurrus*, *V. premnus* and *V. tumulentus* assigned to the *ovalis-bulliferus* Biozone of Frasnian age. The assemblage is complemented by Lower Devonian reworked spores, that include the species, *Brochotriletes* sp., *Dictyotriletes subgranifer*, *Emphanisporites microornatus*, *E. rotatus*, *Knoxisporites riondae*, *Retusotriletes* sp. and *Synorisporites verrucatus*, typical of Lochkovian and Praguian age. New investigations are been carried out in the sense of identifying the Lower Devonian in the lithostratigraphic sequence of the NE of Trás-os-Montes.

The palynomorph assemblages have proved to be an useful tool for precise dating of the Devonian formations in the Bragança region. These results allow the previous datings based on plants remains (Teixeira & Pais, 1973; Pérez Estaun, 1974) to be refined and prove to be very important for structural and geodynamic reconstructions.

Thus, spore assemblages recovered from the Gimonde Formation indicates an age close to the Givetian/Frasnian boundary. Further north in the Rio de Onor section, data from spores indicates a Frasnian age. Reworked spores of Lochkovian to Praguian age are also present in the assemblages.

PRELIMINARY NOTE ON THE ORDOVICIAN-SILURIAN STRATIGRAPHIC SEQUENCE OF THE SERRA DE SÃO MAMEDE REGION, SOUTHERN BORDER OF THE CENTRAL IBERIAN ZONE, PORTUGAL

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The Serra de São Mamede, in the NE region of the Alentejo province, Portugal, defines a 30 km long topographic ridge situated at the southern border of the Central Iberian Zone (CIZ). Besides Ordovician granites occurring along its southern flank, the region is also known for the Palaeozoic siliciclastic sequence of which the Ordovician to Silurian component is here synthetically examined.

A revision of the regional geological map sheets in progress has allowed the identificatin of several composite stratigraphic sections in the northern and southern flanks of the São Mamede syncline and across the Alegrete-Esperança ridge, which taken as a whole lead to the following preliminary conclusions:

1. The Ordovician is represented, from the bottom to the top, by: (a) the so-called Armorican Quartzite (quartzites with *Cruziana*), a succession of quartzites and interbedded conglomerate layers of Arenig age, whose thickness changes from 10 to 100 m; (b) a 100 m thick interval composed of shales and siltstones which yielded graptolites of Oretanian age; (c) a sandstone packet (10 m) followed by 20-30 m of dark grey shales; (d) a succession of bioturbated and lenticular sandstones of about 30 m in thickness, that ressembles the Cabeço do Pião Formation of the Amêndoa-Mação Syncline (Young, 1990), of Caradoc age; (e) a thin bedded silty/shale suite, with some fine sandstone intercalations, of about 60 m in thicknesss, whose lower part shows spheroidal weathering affecting the shales, a lithological characteristic that is quite common in the Casal Carvalhal Formation (Young, 1990) of late Ashgill age, that crops out in the Buçaco, Dornes and Amêndoa-Mação synclines.

2. The Silurian comprises the following main units: (a) a 10-20 m thick unit of dark and pyrite-rich quartzites showing strong affinities with the Vale da Ursa Formation (Cooper, 1980) of the Dornes and Amêndoa-Mação synclines; (b) a 30-40 m thick succession of black shales, locally micaceous and rich in fossiliferous nodules, lithologically similar to the Aboboreira Formation of the Mação-Amêndoa syncline (Romão *et al.*, 1998), that provided graptolites from Llandovery to late Wenlock age; (c) a lithological sequence composed of unfossiliferous shales and siltstones, with a thickness in excess of 80 m, that becomes more rich in sandstone beds upwards; (d) the Silurian-Devonian boundary is not exactly known, being probably situated elsewhere in the upper sandstones which bear faunas (trilobites, brachiopods, etc.) of Lower Devonian age.

The Ordovician and Silurian sequences of the Serra de São Mamede region have many stratigraphic and sedimentological characteristics in common with those of several other regions situated at the southern border of the CIZ, both in Portugal (Valongo, Buçaco, Dornes, Amêndoa-Mação) and Spain (Sierra de San Pedro, Soldevila, 1992; Almadén, El Centenillo, etc., Gutiérrez-Marco *et al.*, 1998). This indicates that all these regions were part of the same major sedimentary basin, in this case a huge epicontinental sea (Oliveira *et al*., 1992).

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THE UPPER ALCUDIAN FROM THE ALCUDIA ANTICLINE REVISITED (CIUDAD REAL, CENTRAL SPAIN)

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A very low-grade metasedimentary succession crops out forming the 120 km long pre-Ordovician core of the Alcudia river anticline in the south of the Central Iberian Zone. The presence of an angular unconformity was reported by a student of Prof. Lotze, Redlin (1955) separating what he considered a Lower Cambrian with limestones from an underlying turbiditic Precambrian sequence. These results were not following Lotze's ideas and thus the results were almost forgotten. An important mining evaluation project carried out in this anticline during the 70's rediscovered the unconformity and made popular the name Alcudian, which became a definitive reference for the correlations in the upper Proterozoic from the southern half of the Iberian Massif.

Later, the names Lower Alcudian and Upper Alcudian were used with a chronostratigraphic purpose, and they are found throughout the geological papers, but surprisingly, there is nothing like a formal definition of its units or a description of the sedimentology of the corresponding sequences. In addition to this, the late Precambrian age used by most of the recent authors is different from the age that can be deduced from recent palaeontological findings.

The lower unit (Lower Alcudian or Extremenian Dome Group), which base has never been found in the Central Iberian Zone, is Proterozoic (Riphean or Lower Vendian) and shows turbiditic characteristics. Above, the Upper Alcudian lies on an angular unconformity, locally with associated palaeoalteration. It is here subdivided into five lithostratigraphic units with range of Formation, which are from the base towards the top: (a) Tamujar Formation, formed by graywackes and arkoses; (b) Hinojosas Formation, with characteristic banded shales, graywackes, conglomerates and dolostone lenses, rich in trace fossils; (c) Lower shaley Formation formed mainly by shales; (d) the impressive conglomeratic San Lorenzo Formation; and (e) Upper shaley Formation where the shales predominate, but the base is formed by sandstones and graywackes, containing small shelly fossils.

The age of the Upper Alcudian, based on its trace fossil and microfossil content is Lower Cambrian (the basal four formations are Nemakit-Daldynian and the fifth formation is Tommotian). The Upper Alcudian is thus younger than the typical rocks from the Ibor Group, and therefore the attribution to this unit should be abandoned. The name Alcudian was taken from this locality; so if we maintain it for local materials, the units forming the rest of the materials lying above the intra-Alcudian unconformity in the Central Iberian Zone, many of which are still Proterozoic (Upper Vendian), should be redefined or revised.

This also implies a revision of many of the correlations made by different research teams, which therefore may be no longer accurate. Thus, some of the correlations made for the Upper Alcudian by San José *et al*. (1990) and the presence of the sedimentary cycles described by these authors are no longer correct, because some were supposed to be much older than they are.

On the other hand, the correlation of all the uppermost Proterozoic platform facies, considered as an unique level, and the related existence of a basal unconformity between the Domo Extremenian Group (Lower Alcudian) and the Ibor Group (Upper Alcudian) as pointed by Álvarez-Nava *et al*. (1988), is not correct either, because the pre-Ordovician rocks from the Ibor anticline are older (Upper Vendian) than those from Alcudia anticline (Cambrian). Therefore both ensembles cannot be included together within the Ibor Group.

Late Proterozoic crustal growth in Ossa-Morena: Nd isotope and trace element evidence from the Sierra de Córdoba volcanics

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Several calc-alkaline volcanic rocks from the Precambrian basement of the Ossa-Morena Zone (San Jerónimo Formation) have been analysed for the Sm-Nd isotopic system and REE, Rb, Sr, Zr, Nb and Ni content. These rocks are generally porphyritic to microporphyritic andesites, with abundant plagioclase (±amphibole) phenocrysts. With the exception of two samples, they display positive *(epsilon)*Nd values, ranging from +2.9 to +7.4. Most of them, with +4 < *(epsilon)*Nd < +6, exhibit LREE enrichment (La_N/Lu_N=2.3-4.9), strong negative Nb anomalies and Zr/Nb ratios range from 21 to 32. There is no obvious correlation between the shape of REE patterns, La/Nb ratios and *(epsilon)*Nd values, precluding simple models of late-stage interaction with typical crustal components with low *(epsilon)*Nd and large LREE/HREE and La/Nb ratios.

Based on their enriched, crustal trace element characteristics, combined with distinctly positive *(epsilon)*Nd values, the Sierra de Córdoba andesites are interpreted to document an episode of crustal growth through addition of calc-alkaline magma, extracted from a depleted mantle reservoir. The occurrence of subordinate amounts of rocks with negative *(epsilon)*Nd values does not favour a purely ensimatic arc setting for this subduction-related magmatisn, although assimilation of sediments during magma fractionation might also account for the isotopic data. Overall, these suggest that an active continental margin environment, involving concomitant crustal growth, prevailed in the latest Proterozoic of southern Iberia.

350 Ma (U-Pb zircon) igneous emplacement age and Sr-Nd isotopic study of the Beja gabbroic complex (S. Portugal)

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The boundary between the highly contrasting Ossa-Morena and South Portuguese Zones of the Iberian Variscan orogen is interpreted as a major suture zone (Andrade, 1977). In Spain and Portugal, this is represented by discontinuous strips of mafic rocks with broadly oceanic geochemical affinities, regarded to represent an extremely disrupted ophiolite (the so-called Beja-Acebuches Ophiolitic Complex; Munhá *et al.*, 1986, 1989), and by mélange deposits of Middle to Late Devonian age (Eden & Andrew, 1990, 1991) in the Pulo do Lobo Accretionary Terrane (Quesada *et al.*, 1994, and references therein). Based on the palaeontologically documented age of the overlying Horta da Torre Formation, the ophiolite/mélange emplacement occurred earlier than the Famennian (Oliveira *et al.*, 1986). After accretion-related deformation in a thrust regime, tentatively interpreted in terms of north-eastward obduction (Fonseca & Ribeiro, 1993), the suture zone was affected by SW-directed thrusting evolving to left-lateral ductile shearing movements (Crespo-Blanc & Orozco, 1988; Quesada *et al.*, 1994), interpreted as a result of oblique collision between the South Portuguese Terrane and the Iberian Autochthon.

The large Beja gabbroic complex was interpreted either as part of the ophiolite-like units (e.g. Andrade *et al.*, 1976; Andrade, 1977), or as a broadly arc-related massif reflecting the northward subduction of oceanic crust (Quesada *et al.*, 1994). Although the gabbroic complex is locally deformed, it rather appears as a stitching pluton, intruded into the previously accreted ophiolite-like unit and the continental rocks of the Ossa-Morena Zone, possibly during the left-lateral transpressional deformation (Dallmeyer *et al.*, 1993; Quesada *et al.*, 1994). Available radiometric data in this area are limited to $^{39}Ar/^{40}Ar$ measurements on amphibole, which indicate that cooling below the *ca.* 500°C isotherm occurred about 340 Ma ago in that area (Dallmeyer *et al*., 1993). However, Ruffet (1990) interpreted a 336.4±0.8 Ma plateau age of an amphibole from the Beja gabbro in terms of an unrealistically high closure temperature around 800°C, while Dallmeyer *et al.* (1993) considered as likely that their 339±1 Ma ages on hornblende were not significantly younger than crystallization of the pluton.

In order to put tighter constraints on the igneous emplacement age of the Beja gabbroic complex, two samples were collected in the eastern (Serpa) and western (Torrao) parts of the massif, and studied by the U-Pb dating method on zircon concentrates. Nearly concordant data points were obtained in both cases, corresponding to ages of 350±4 Ma (2*(sigma)*) at Serpa and 352±4 Ma at Torrao that we interpret in terms of igneous emplacement, based on the >900°C blocking temperature of the U-Pb system in zircons (Lee *et al.*, 1997).

These results clearly demonstrate that the Ar/Ar dates obtained on the Beja gabbro (Ruffet, 1990; Dallmeyer *et al.*, 1993) do not represent igneous crystallization ages. Ar/Ar ages measured on amphiboles from the country-rocks of the gabbro, both in the ophiolite-like units and in the Ossa-Morena Zone (Dallmeyer *et al.*, 1993) also cluster around 340 Ma. It is concluded that the Ar/Ar ages merely reflect the regional cooling below 500°C, which occurred at least 10 Ma after the magmatic emplacement of the Beja gabbro, and probably records the uplift of the suture zone relative to the subsiding South Portuguese Zone.

It is also clear that the 350 Ma igneous age invalidates the palaeomagnetic reconstructions proposed by Perroud *et al.* (1985), which were based on results obtained on the Beja gabbro, assumed to be Late Devonian. As a corollary, the large oceanic domain (about 1,700 km) inferred by these authors between southern and northern Iberia should be dismissed, with significant implications on the timing of final accretion of the Variscan Belt in that area.

Based on available geological timescales, the *ca.* 350 Ma age corresponds to the Late Tournaisian, suggesting that the intrusion of the Beja gabbro occurred at the same time as the volcanic activity recorded in the Toca da Moura complex in the Santa Susana region (Santos *et al.*, 1987), about 20 km to the NW. At a larger scale, the Beja gabbro is also broadly coeval with the bimodal volcanism of the Pyrite Belt in the South Portuguese Zone (Schermerhorn, 1970; Munhá, 1979), and, more tentatively, with mafic-ultramafic occurrences scattered along a NW-SE lineament south of the Los Pedroches batholith (Crousilles *et al.*, 1976). Taking into account this large scale context, it may be inferred that the magmatic emplacement of the Beja gabbro occurred in an extensional (probably, transtensional) tectonic setting, much more favourable than a compressional one to the ascent and emplacement into the crust of a large, mantle-derived magma body. Also, the Beja gabbro was not related to an active subduction of oceanic lithosphere, in view of the probable pre-Famennian age of the collision between the Ossa-Morena and South Portuguese Zones (Oliveira *et al.*, 1986; Munhá *et al.*, 1989). Its internal deformation probably occurred during the Late Visean to Middle Westphalian compressional episodes well documented in the Pyrite Belt by SW- propagating thin-skinned fold and nappe tectonics and synorogenic flysch sedimentation (Oliveira, 1990; Silva *et al.*, 1990; Quesada, 1997).

20 samples of the Beja gabbroic complex have been analysed for the Rb-Sr and 12 for the Sm-Nd isotope systematics, using isotope dilution thermal ionization mass spectrometry. The measured Sr and Nd isotopic results have been corrected for *in situ* radioactive decay of ^{87}Rb and ^{147}Sm using the 350 Ma U-Pb zircon age. No isochron relationship was obtained. However, four samples collected at Torrao enable an errorchron (MSWD=5.6) to be calculated, corresponding to an age of 351±31 Ma (2*(sigma)*) in good agreement with the U-Pb zircon age. The age-corrected $^{87}Sr/^{86}Sr_{350}$ and *(epsilon)*Nd_{350} display a large range of values (from 0.7041 to 0.7093 and from +4.0 to -6. 1, respectively) which documents a rather complex petrogenetic history. The more primitive Sr and Nd isotope signatures are measured in the mafic cumulates south of Odivelas, while radiogenic Sr and unradiogenic Nd isotope compositions occur in the more evolved facies exposed near Serpa. The trend of decreasing *(epsilon)*Nd_{350} with decreasing $^{147}SM/^{144}Nd$ and increasing SiO_2 concentration is reminiscent of crustal assimilation combined with fractional assimilation (AFC). A peculiar sample collected near Serpa has a continental crust-like signature ($^{87}Sr/^{86}Sr_{350}$=0.719 and *(epsilon)*Nd_{350}=-9.3) suggesting that very large degrees of contamination occurred close to the margin of the plutonic body.

Preliminary data obtained on samples from the ophiolite-like unit in the Guadiana valley show that the flaser-gabbros display *(epsilon)*Nd values close to zero or even slightly negative, irrespective of the age chosen for the correction for *in situ* radioactive decay of ^{147}Sm in the range 350-500 Ma, assumed to encompass the true geological age. This is because the $^{147}Sm/^{144}Nd$ ratio of these rocks does not differ greatly from the chondritic value, making the calculation of *(epsilon)*Nd relatively insensitive to the age correction. In contrast, most amphibolites (metabasalts) of the same area, sampled north and south of the Beja gabbro, have positive, albeit variable *(epsilon)*Nd. Only a few samples reach highly positive values (*(epsilon)*$Nd_{350\ or\ 500}$ *ca.* +8) similar to those typical for N-MORBs. These samples resemble the Acebuches amphibolites (Bard, 1977; Dupuy *et al.*, 1979; Quesada *et al.*, 1994). Four samples of these amphibolites, collected south of Aracena, give fairly homogeneous *(epsilon)*Nd values ca. +9, irrespective of the age (350 Ma or 500 Ma) assumed for the correction of *in situ* radioactive decay, as also shown by Castro *et al.* (1996). These isotopic results suggest that the Beja-Acebuches ophiolitic complex is not only disrupted and geochemically heterogenous (Quesada *et al.*, 1994), but also composite, since the gabbroic rocks do not appear to be cogenetic with the metabasalts. Based on Nd isotope evidence, it is suggested that only some of the metabasalts were extracted from a mantle source that was highly depleted in LREE on a time-integrated basis and did not suffer significant interaction with continental components. Only these metabasalts display unequivocal, N-MORB-like oceanic affinities, as do the igneous blocks from the Peramora Melange of the Pulo do Lobo Formation, as inferred from their REE characteristics (Eden, 1991).

Baikalian/Cadomian deformation and metamorphism along the northern margin of Baltica, NW Russia and NE Norway

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Neoproterozoic lithostratigraphic successions metamorphosed at low to very low-grade characterise the northern extremity of Baltica adjacent to the Barents and Pechora Seas. Extending over some 1,800 km from the Timan range and Kanin Peninsula in NW Russia, via the Rybachi and Sredni Peninsulas of Kola to the northeastern part of Varanger Peninsula in Norway, these predominantly terrigenous successions were deposited in two different sedimentation regimes or domains (pericratonic and basinal) separated by a major fault zone trending NW-SE. Marked contrasts in both thicknesses and sedimentary facies are found between the fluvial to locally shallow-marine, pericratonic successions to the southwest of the fault zone, and the largely marine, in part turbiditic rocks of the basinal regime; and island-arc volcanites of higher metamorphic grade, cut by granites, occur beneath the Pechora Basin between the Timan and the Urals. In the Timan, the oldest Neoproterozoic rocks are of Middle Riphean age; and in the

Kola-Varanger region, Upper Riphean. In southwestern parts of Varanger Peninsula, successions extend up into Vendian and Cambrian, and include important occurrences of Varangerian tillites at the base of the Vendian.

The Riphean crustal extension and rifting which gave rise to the NW-SE-trending, fault-controlled basin development was succeeded by a tectonic deformation of the sedimentary (and concealed volcanic) successions, involving basin inversion, folding and the generation of a pervasive cleavage, arising from SW-directed compressive stresses. Throughout the belt, in the oceanic domain, from Timan to Rybachi and also in NE Varanger, the characteristic structural feature is of SW-facing, open to tight, mesoscopic and larger-scale folds with a steep, NE-dipping, penetrative axial-plane cleavage. Metamorphic grade is generally in anchizone, though partly in greenschist facies and lowermost amphibolite facies in northern Timan, on Kanin, and in drillcores recovered from beneath the Pechora Basin. In successions of the pericratonic regime, only diagenesis grade has been reported from all parts of the belt. In Timan, the basinal facies thrust southwestwards upon the peripratonic successions. Gabbros and granite bodies postdate the metamorphic fabrics in N Timan and in Pechora drillcores, while dolerite dykes transect the folds and cleavage on Rybachi and NE Varanger.

Constraints on the timing of this folding and metamorphism are, as yet, less than perfect. In the Timan, isotopic data, mostly K-Ar ages, are suggesting that the main synmetamorphic folding of the Riphean successions occurred during the period 600-575 Ma - the Baikalian orogenic event. Recent single-zircon dating of post-metamorphic granites in drillcores from the Pechora Basin have yielded ages of 560-550 Ma, giving a minimum age for the Baikalian deformation in the deeper parts of the eugeoclinal, oceanic domain. In the Rybachi-Sredni area, mafic dykes cutting cleavage have given unclear, but probably pre-Ordovician ^{40}Ar-^{39}Ar mineral ages; while palaeomagnetic data from these same dykes favour a Late Vendian to Cambrian age. Rb-Sr illite dating from the principal pericratonic/oceanic fault zone on Rybachi-Sredni has yielded a maximum age of 570 Ma for the basinal inversion and synmetamorphic folding. In NE Varanger, one particular dyke cutting an early cleavage has given a U-Pb zircon date of ca. 567 Ma. Work is in progress to try to date the Baikalian metamorphism more precisely, both on Rybachi and in NE Varanger Peninsula.

Thermal effects of the Évora and Beja igneous massifs on the Viana do Alentejo-Alvito units (Ossa-Morena Zone, SW Iberian Variscan fold belt)

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In Viana do Alentejo-Alvito region, several tectostratigraphic units affected by a N-S trending, W verging antiformal macrostructure have been described by previous authors (e.g. Carvalhosa, 1971, 1983; Teixeira 1972, 1981; Oliveira, 1991; Fonseca, 1995; Rosas, 1996; Rosas *et al.*, 1998). This macrostructure is bounded to the West by the igneous Beja massif, and to the North by the igneous Évora massif. The western vertical limb of the Viana-Alvito antiform is intruded by dioritic lithologies of the igneous Beja Massif, whereas its eastern long limb comprises, from the bottom to the top, felsic gneisses (in core of antiform), marbles and metapelites.

The first characterized deformation event (D1) of the regional Variscan tectonics is represented by a pervasive E-W trending, S dipping, planar fabric (S1), on top of which a N-S stretching lineation is recorded (Fonseca, 1995; Rosas, 1996; Silva, 1996). Observed macroscopic and microscopic syn-D1 kinematic criteria indicate a top to the North sense of shear. The second Variscan deformation event is characterized by folding of S1 and generation of the N-S antiformal geometry described above. Syn-D2 structures show a top to the West sense of shear.

Up to now, the Viana-Alvito tectostratigraphic units were thought to be interrupted to the North of Viana do Alentejo, due to the intrusion of granitic lithologies of the Évora massif (Carvalhosa & Zbyzewski, 1972). These authors mapped a considerable area of migmatites surrounding the igneous Évora massif to the N of Viana do Alentejo, but they did not report the original lithologies because migmatization prevented their recognition.

However, recent field work shows that the Viana-Alvito sequence and structure continue to the North of this location, up to the contact with the granitic rocks of the Évora massif. In the field, it is possible to recognize the sequence of (migmatized) metapelites on the top of (high temperature methamorphosed) marbles, typical of the eastern long limb of the Alvito-Viana antiformal macrostruture. In the metapelitic lithologies, migmatization is very strong but the palaeossome preserves relicts of the schistosity of the metasediments and makes possible their recognition. In a similar way, in marbles adjacent to the East, preliminary macroscopic observations of evidence for high temperature metamorphic overprint include: (a) granoblastic texture with centimetric calcite grains, showing grain boundary area reduction, and (b) abundant recrystallization of wollastonite exhibiting randomly oriented megacrysts, not only along the planar fabric (metamorphic layering), but also at the hinges of folds, and randomly substituting previous minerals within rigid inclusions around which the metamorphic layering is deflected with a sigmoidal geometry.

Wollastonite recrystallization in the western limb of the Viana-Alvito antiform is still affected by later deformation, and most likely is a thermal effect of the gabbroic intrusions of the Beja massif. However, the wollastonite recrystallization due to the granitic intrusions of the Évora massif is clearly post-kinematic. Thus, these relationships show that gabbroic rocks are older than the granitic rocks, and that there is a tectonic event in between (D2?).

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Microtectonics of the Viana-Alvito key geotraverse (Ossa-Morena Zone, SW Iberian Variscan fold belt)

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Along the Viana do Alentejo-Alvito key geotraverse, it is possible to observe a North-South trending, West verging, antiformal macrostructure comprising several tectostratigraphic units (e. g. Carvalhosa 1971, 1983; Teixeira 1972, 1981; Oliveira, 1991; Fonseca, 1995; Rosas, 1996): felsic gneisses (of unknown age), Cambrian? marbles, Precambrian? metapelites of the unit called "Série Negra de Água de Peixes" and Silurian? metapelites of the "Xistos de Moura" unit, besides imbricated (eclogitized) metabasites.

From the tectonic point of view, at a macroscopic scale, two main Variscan deformation events are recognised: (a) an early event (D1) characterised by pervasive planar fabric (S1), exhibiting a roughly East-West direction dipping southwards, with an associated North-South stretching lineation; and (b) a second deformation event (D2), that overprints D1 structures by folding S1 according to the mentioned antiformal geometry. In the field, observed D1 structures exhibit a top to North sense of shear, whereas D2 structures indicate a top to the West sense of movement.

In thin section, D1 microstructures are better preserved. Their geometry and kinematics corroborate the field observations, but vary with the considered lithologies.

In the marbles, the S1 planar fabric is almost completely erased by occurrence of static, or post-kinematic, recrystallisation. Evidence of this are also recognised in the felsic gneisses and include coarser grain size, grain boundary area reduction and triple junctions in quartz aggregates with a granoblastic texture. Nevertheless, relicts of a dynamic recrystallising fabric (mylonitic recrystallisation) are still observed in a few thin sections.

However, well preserved D1 structures are observed in the metapelites. In garnet micaschists of the "Série Negra", thin sections parallel to the stretching lineation exhibit abundant garnet porphyroblasts, some of which show sigmoid inclusion patterns corroborating the syn-D1 top to the North sense of shear. The same microstructures are observed in imbricated metabasites (retrogressed in the greenschist facies) in feldspar porphyroblasts.

In micaceous quartz-feldspar schists of the "Série Negra" unit, preliminary observations show the existence of an inclusion pattern, inside twined feldspar grains, exhibiting the folded geometry of a previous planar structure. These inclusion patterns are statically overgrown by feldspar that suffered late boudinage, with fine quartz-feldspar aggregates in the neck of the micro-boudins. Elongated mica grains show deflection around the feldspars.

In thin sections parallel to the stretching lineation in the mica-quartz schists of the "Xistos de Moura" unit, better preserved microstructures include: C'-type micro-shear bands, micafish and polycrystalline foliation fish, all confirming the top to the North syn-D1 shear sense. In thin sections perpendicular to the stretching lineation of these lithologies, it is also possible to observe a D2 crenulation affecting the syn-D1 planar fabric.

The implications off this study for the regional interpretation of this microtectonic evidence allows a more detailed characterisation of the early Variscan progressive deformation episode, or even points to possible interference with previous (pre-Variscan) deformation pulses. Correlation with metamorphic overprinting relations is expected to be crucial.

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Geochronological, geochemical and petrological studies in two areas of the Ossa-Morena Zone: the Monesterio complex and the Calera de León granite

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The Monesterio granodiorite (emplaced in a migmatitic complex) and the Calera de León granite are neighbouring bodies situated in the southern limb of the Olivenza-Monesterio antiform, separated by the Monesterio thrust. Dating these granitoids, as well as the study of their geochemical and petrological characteristics, is important for the understanding of the relationships among magmatism, metamorphism and deformation in the Ossa-Morena Zone from late Precambrian to Variscan orogeny times.

The granitic bodies have been dated with the single-zircon stepwise-evaporation ^{207}Pb/^{206}Pb method. Only samples from the migmatitic leucosomes, dated with the Rb-Sr method, plot on an isochron. Application of this method to the Calera granite is extremely complicated as some samples are affected by hydrothermal alteration.

We have studied the geochemistry and the petrology of the different rock types of the Monesterio complex. In addition, we have carried out the same studies to distinguish the different facies of the Calera granite. Although the calc-alkaline and peraluminous chemistry of these two bodies, there is an age difference between them:

(a) The Monesterio granodiorite (^{87}Sr/^{86}Sr int=0.7049±21) crystallization age is 510±4 Ma. Leucosomes give a similar Rb-Sr age of 511±40 Ma (^{87}Sr/^{86}Sr int=0.7091±48), i.e. Early Cambrian.

(b) In the Calera granite, preliminary geochronological data show older ages than those of the Monesterio complex and similar to those given by other authors: 549±16 Ma (Ordóñez Casado, 1998). Therefore, these data link the Calera granite with the common late Precambrian-Early Cambrian magmatism in the Ossa-Morena Zone (Alhillones igneous complex, 585±5 Ma, Schäfer, 1990; 552±10 Ma, Ordóñez Casado, 1998; Táliga granite, 541±42, 530±32 Ma, Galindo, 1990; Mosquil tonalite, 544+6/-5 Ma, Ochsner, 1993).

The Calera granite is also interesting from a petrological and structural point of view due to its northern contact with the Monesterio thrust (Variscan orogenic cycle), thus presenting important petrographic and chemical deformational characteristics.

The joint study of these neighbouring areas gives an idea of the events from late Precambrian to Variscan orogeny times.

THERMOCHRONOLOGICAL EVOLUTION OF THE BRAGANÇA CONTINENTAL ALLOCHTHONOUS TERRANE (GALICIA-TRÁS-OS-MONTES ZONE)

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The Bragança massif can be described as a superposition of several exotic nappes emplaced during the Variscan orogeny. The uppermost thrust complex corresponds to a Continental Allochthonous Terrane (CAT), composed of several lithologies that have been rooted in the lower crust and the upper mantle before the Variscan exhumation (which commonly caused amphibolite-facies retrogression). Structural information reveals a complex tectonic evolution: five main deformation phases have been recognized; the first Variscan orogenic phase corresponds to the fourth phase identified in the CAT.

HP-granulites and eclogites are the lithotypes that preserve evidence of the earliest deformation phases. They display clockwise P-T-t paths and internal microstructures in garnet grains reveal that prograde metamorphism in those rocks was contemporaneous with non-coaxial deformation. Geochemically, the HP-granulites reflect, at least locally, remobilization and removal of highly incompatible trace elements, under high-grade conditions, probably through a melt phase. The eclogites have diverse geochemical signatures indicating protolith compositions similar to N-MORB or to basalts from supra-subduction settings; some alkaline compositions have also been identified. The geochemical diversity of the eclogite protoliths could have been generated by the operation of a back-arc marginal basin.

Sm-Nd geochronological information (four-point wr-mineral isochron) on a HP-granulite indicates an age of 1.0 to 1.1 Ga for the peak metamorphic assemblage. This suggests that some of the rocks present in the CAT represent remnants of a Grenvillian basement. Isotope data obtained on an eclogite sample reveal disturbance of the Sm-Nd system, preventing the dating of the HP assemblage of that rock; however, the values corresponding to the lines wr-grt-cpx and wr-grt (440 and 508 Ma, respectively) can be viewed as minimum ages for the eclogite-facies metamorphism and, therefore, are in accordance with the proposed occurrence of the eclogite-facies metamorphism during a pre-Variscan event. An age of 389 Ma (wr-mineral Sm-Nd isochron) was obtained in a metasomatic vein cutting across an eclogite body. The metasomatic event corresponds to strong hydration of the metabasites by fluids liberated from the enclosing gneisses during decompression reactions, thus reflecting the tectonic exhumation of originally deep-seated rocks during the Variscan orogeny.

Ultramafic rocks and intrusions of dominant gabbroic composition are also present in the CAT of the Bragança massif, but they do not record the first two deformation phases identified in the HP-granulites and in the eclogites. The gabbroic rocks show evidences of partial granulitization under static conditions; their metamorphic path is characterized by cooling between 900 and 600°C at essentially isobaric conditions (~8 kb); Sm-Nd isotope data indicate that the cooling of those plutonic bodies occurred during the Cambrian/Ordovician times; trace element and isotope geochemistry reveal that the gabbroic rocks crystallized from magmas similar to continental tholeiites.

Ultramafic rocks correspond mainly to peridotites with interlayered pyroxenites; sometimes, *boudins* of garnet-bearing pyroxenites are observed. According to major element compositions, peridotites seem to represent refractory lithologies; the pyroxenite layers would correspond to refertilization due to the penetration of basaltic magmas in the upper mantle. Patterns of REE normalized concentrations in the peridotites reveal the occurrence of LREE enrichment; this was probably due to a process of cryptic metasomatism. Some pyroxenite bodies (including the garnet pyroxenites) have trace element contents that can be explained by crystal segregation from alkaline magmas; these type of melts were also probably responsible for the cryptic metasomatism in the peridotites. A wr-mineral internal isochron of 485 Ma was obtained in a garnet clinopyroxenite, showing that the ascent of the alkaline magmas is, at least, of lower Ordovician age.

Considering structural, petrological and geochronological information on the Bragança CAT, the HP-granulites and the eclogites seem to correspond to polycyclical rocks that have passed through pre-Variscan orogenic events. Some of those rocks can represent pieces of a Grenvillian basement. Gabbroic rocks and pyroxenites represent magmatic events in the lower crust and in the upper mantle during the extensional period corresponding to the onset of the Variscan tectonic cycle. The thermal effects of the lower Palaeozoic magmatism and the Variscan orogenic remobilization probably caused disturbance and resetting of the isotopic systems; this would explain the scarcity of Precambrian ages obtained in geochronological studies.

THE WEST IBERIAN MASSIF: A KINEMATIC AND DYNAMIC OVERVIEW

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Concerning the pre-Mesozoic evolution of the Iberian Massif, it is possible to recognize a continuous transpressional regime from the Cadomian cycle to the end of the Variscan times.

An early episode of deformation acted along an almost linear transcurrent orogen until the Lower Devonian in the Ossa-Morena Zone, associated with tangential transpression and tectonic denudation.

From the Lower-Middle Devonian onwards, this linear orogen evolved into the arcuate structure of the Iberian-Armorican Arc, coeval with foreland Carboniferous basins in the South Portuguese Zone and Cantabrian Zone.

Progressive deformation worked during the orogenic evolution with no turning points between the Precambrian times and the Upper Carboniferous, confirmed by a continuity of kinematics and dynamics.

GEOCHEMISTRY AND Sm-Nd ISOTOPE SYSTEMATICS ON THE UPPER PRECAMBRIAN - LOWER CAMBRIAN SEDIMENTARY SUCCESSIONS IN THE CENTRAL IBERIAN ZONE, SPAIN

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Twelve detailed Units (Units I to IV, upper Precambrian; Units V to XII, Lower Cambrian; Valladares *et al*., 1998) have been recently defined in the sedimentary successions of the Schist-Greywacke Complex in the Salamanca-Cáceres region (Central Iberian Zone, CIZ). On the basis of this excellent knowledge of the vertical stratigraphical record, twelve samples of pelites have been selected for a chemical and isotopic (Sm-Nd) study of those Units. The results indicate younger TDM-model ages for the upper Precambrian (1.1 to 1.2 Ga) than for the Lower Cambrian (1.7 to 2.5 Ga), and they also indicate a gradual decrease of epsilon Nd (T550) values from -0.4 (upper Precambrian) to -7.5 (Lower Cambrian) suggesting that juvenile contributions decreased towards the top of the column. Trace element binary diagrams also reveal chemical changes indicating that more granitic crustal compositions gradually replaced juvenile contributions.

The upper Precambrian-Lower Cambrian boundary is not known exactly and there are not angular unconformities separating UP-LC sediments but rather a discontinuity between Unit IV and V probably related to a sea level fall (Valladares *et al*., 1998). The chemical maturity shown by beds in the Units VI-VIII in the more proximal areas of the basin (northeastwards) together with high Y abundances (up to four times background values) and relatively important cerium negative anomalies (Ce/Ce*=3D 0.65 to 0.83) in these beds suggest a strong chemical alteration (involving REE mobility), probably related to weathering conditions during the sea level fall. By contrast, stratigraphic sections in more distal areas (southwestwards) of the basin do not show any influence of this kind of alteration. The high Y abundances and Ce/Ce* negative anomalies could probably be used to detect not only the sedimentary Units above the discontinuity but also as palaeogeographical tools. The geochemical and isotopic results are consistent with stratigraphic and sedimentological findings. Consequently, the general stratigraphic section previously proposed (Valladares *et al*., 1998) is a good reference section that can be applicable to all the CIZ given the lack of coeval volcanics and the remarkable chemical homogeneity of the upper Precambrian and the Lower Cambrian sedimentary materials (Ugidos *et al*., 1997a, b; Valladares *et al*., 1998, 1999). According to these authors, relatively high values of parameters as Ti and Zr abundances, Ti/Nb ratios and epsilon Nd data recorded by the UP series clearly contrast with lower ones shown by LC compositions. Other published chemical and isotopic results on upper Precambrian-Lower Cambrian samples from different areas of the CIZ also define the same two groups of compositions [see data in García *et al*. (1991), Nägler *et al*. (1995), Beetsma (1995), and Tassinari *et al*. (1996)], but unfortunately these data lack detailed stratigraphic and sedimentological information. In spite of this, the great similarity shown by geochemical data from different areas and those from the known stratigraphic column are enough to strongly support the following generalizations for the CIZ: (a) The upper Precambrian sedimentary successions are chemically and isotopically (Sm-Nd) very homogeneous and record the inheritance of recycled juvenile contributions; (b) the Lower Cambrian successions are relatively more heterogeneous and those juvenile contributions greatly decreased or are absent; (c) the upper Precambrian and Lower Cambrian sedimentary successions in the CIZ seem unrelated to coeval magmatically active settings.

UPPER PROTEROZOIC-LOWER CAMBRIAN SHALES IN THE CENTRAL IBERIAN ZONE: CHEMICAL FEATURES AND IMPLICATIONS FOR OTHER PERI-GONDWANAN AREAS

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Chemical data on upper Proterozoic and Lower Cambrian shales (UP and LC respectively) from an extensive region in the Central Iberian Zone (CIZ) record distinctive differences, indicate relatively more mafic contributions to the UP than to the LC and are consistent with the higher epsilon Nd (T) values shown by the UP (Nägler *et al*., 1995; Ugidos *et al*., 1997). Moreover, these results indicate a gradual transition from the UP to the LC sediments and support the stratigraphic findings by Valladares *et al*. (1998). The chemical and Sm-Nd isotopic results on late Proterozoic-Cambrian metapelites from N Portugal (Beetsma, 1995) are similar to those reported for the UP. Thus, the geochemical homogeneity of the UP-LC extends along more than 400 km within the CIZ. It is proposed that the UP sediments in the CIZ would have mainly derived from recycled mixtures of juvenile and old components in interior orogens through associated continental deposits until its final deposition in upper Proterozoic basins. By contrast, the LC succession probably records more abundant components from older continental blocks underlying those continental deposits. This interpretation plausibly accounts for the chemical and isotopic features shown by the UP and the LC, and also for the observed differences between the Armorican Massif and the CIZ. The main implication is that juvenile contributions to upper Proterozoic and Lower Cambrian sediments have different meanings: provenance from an active zone (Central and Western Europe; also Ossa-Morena Zone?) or inherited from recycled sources (CIZ). Thus, the geological settings supplying juvenile igneous contributions to each of these zones were not only unrelated but also magmatically active at different times. The Meguma Zone (MZ), a peri-Gondwanan terrane in Nova Scotia, share important features with the CIZ. Examples are: (a) Stratigraphic inversion has been suggested on the basis of Sm-Nd data (Eberz *et al*., 1991) and zircon age data (Krogh & Keppie, 1990) in the MZ and is indicated by Sm-Nd isotope results in the CIZ (Ugidos *et al*., 1997); (b) the source of Meguma rocks was also a deeply eroded craton and the Meguma metapelites show low epsilon Nd values (see Clarke & Halliday, 1985); (c) peraluminous granites show younger Sm-Nd model ages than the corresponding sedimentary country rocks in the MZ and the CIZ (Clarke *et al*., 1988; Beetsma, 1995); (d) both zones show thick sedimentary series, mainly consisting of shales and fine-grained, well sorted and chemically, texturally and petrologically mature sandstones (Schenk, 1997; Valladares *et al*., 1998); (e) turbiditic

deposits are predominant as fan lobes and channels on the mid-fan area of submarine fan systems in the MZ (Schenk, 1997) and as channels on the upper fan and slope areas in the CIZ (Valladares *et al*., 1998). All these similarities are relevant and compatible with a common provenance area for both zones. The difference, however, is that the Middle and Upper Cambrian series are present in the MZ (Schenk, 1997), whereas the main part of Middle Cambrian and the whole of the Upper Cambrian are absent in the CIZ as is also the case in the West Africa craton. To account for this difference, it is proposed that the CIZ would have been more proximal to the West Africa craton and that both areas would have contributed to the more distal Middle and Upper Cambrian sediments in the MZ.

PARALLELS OF PERI-GONDWANAN EVOLUTION IN THE VARISCAN MOUNTAIN CHAIN

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Leaving appart the multiple Variscan transformations characteristic for so many pre-Mesozoic basement areas in Central Europe -the Alps included-, parallels of a peri-Gondwanan evolution can be shown. Zwart & Dornsiepen (1978) derived pre-Variscan units from the former pre-Cambrian "S-Europe-African Block", Ziegler (1984) included "Gondwana-derived" microcontinents in his palaeotectonic maps, and similar ideas were taken up by Weber (1984), Erdtmann (1991), Franke (1992), Stampfli (1996), Linnemann *et al*. (1998), and von Raumer (1998).

The peri-Gondwanan assemblage of Variscan basement areas (e.g. Iberia, Armorica, Moesia, French Central Massif, Saxothuringian and Moldanubian domains, External Massifs, Penninic domain, parts of the southern Alps and the Austroalpine basement) composes the "Hun superterrane" (Stampfli, 1996), or "Noric Composite Terrane" of the Eastern Alps (Frisch & Neubauer, 1989). Using a tentative Silurian reconstruction (von Raumer & Stampfli, 1999), different stages of plate tectonic evolution (involving blocks of Cadomian basement) are recognized. These stages include the formation of Precambrian to Cambro-Ordovician sedimentary basins, oceanic crust and volcanic arcs, followed by an Ordovician orogenic collage before the late Ordovician break-up leading to the opening of the Palaeotethys.

In current reconstructions, Precambrian basement relics are derived from the Neoproterozoic Avalonian-Cadomian belt at the Gondwana margin, and are supposed to represent "exotic" blocks related to the opening of the Rheic ocean. The existence of regular patterns of Precambrian rift structures, related to sedimentary troughs, and leading to formation of Cambrian oceanic crust, may have produced one or more parallel "Rheic" rifts separated by narrow "Cadomian" basement areas. They may have originated at either side of the Rheic ocean, at the Gondwana or the Laurentia-Baltica margin, but represent common features of break-up of a former late Precambrian supercontinent (Murphy & Nance, 1989).

Depending on the relative location in the peri-Gondwanan configuration, the Variscan basement areas mentioned above may include one ore more stages of their evolution, Cadomian basement, pre-Cambrian to Cambrian sedimentary troughs, Cambro-Ordovician oceanic crust, and active margins, sedimentary basins in relation to the Ordovician break-off, and Ordovician-Silurian active margins related to the drift towards Laurussia.

CADOMIAN TECTONOMETAMORPHIC EVENTS IN THE BOHEMIAN MASSIF (CZECH REPUBLIC)

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The Cadomian orogeny was active during the late Proterozoic and Early Cambrian at the northern, Andean-type margin of the supercontinent Gondwana (e.g. Nance *et al*., 1991; Nance & Murphy 1994). Continental Europe south of the Iapetus suture and west of the trans-European suture zone was part of this margin. Thus, Cadomian imprints can be recognized here at many places.

The Cadomian basement of central Europe was more or less overprinted and/or reactivated during the Variscan and Alpine orogenic cycles. This is the reason why our knowledge about Cadomian events in central Europe is relatively scarce. There are only a few exceptional domains where Cadomian basement could largely escape younger tectonometamorphic imprints. One of these domains is the Teplá Barrandean unit within the core of the Bohemian Massif, the latter forming the largest surface exposure of pre-Alpine basement in central Europe. Late Cadomian crustal tilting, indicated by metamorphic isograds (biotite, garnet, staurolite, kyanite isograd; e.g. Vejnar, 1982), allows to study the impact of Cadomian orogeny in the Teplá Barrandean unit at different structural levels reaching from the lower crust to the surface.

The oldest rocks of the Teplá Barrandean unit are referred to as "Kralupy Zbraslav group" (Chlupáč, 1993, and references therein). They consist of Riphean to Vendian metagreywackes, metasiltstones, metacherts and felsic to basic metavolcanics. The younger strata, referred to as "Stechovice group", consist of upper Proterozoic flyschoid metasediments including metagreywackes, shales and a few metaconglomerates.

Cadomian metamorphism in the tilted parts of the Proterozoic basement implies a classic clockwise P-T path including a medium pressure stage, at 6-7 kbar and 450-550°C in the garnet zone, and a subsequent low pressure imprint at 2-4 kbar and 500-550°C in the garnet zone (Zulauf, 1997). The age for the Cadomian metamorphism has been determined at 540-550 Ma by microprobe dating of metamorphic monazite sampled from metagreywackes of the staurolite zone of the Domazlice crystalline complex (Zulauf *et al*., 1999).

A first deformation event (D_1) predates the Barrovian-type mineral assemblages (garnet, staurolite, kyanite). Pervasive top-to-the-North mylonitic D_2 shearing, related to the low pressure metamorphism and growth of sillimanite, was succeeded by low pressure static annealing, eastward crustal tilting and emplacement of calc-alkaline Cambrian plutons and dykes (520–510 Ma; U-Pb zircon data; Zulauf *et al*., 1997; Dörr *et al*., 1998) that partly intruded into ENE-WSW trending dextral transtensional shear zones (Zulauf & Helferich, 1997).

The increase in the degree of syn-D2 low pressure metamorphism and subsequent static annealing from North to South (Zulauf, 1997), along with the southward increase in the number of granitoid pebbles within the upper Proterozoic flysch (Maška & Zoubek, 1960), suggest a Cadomian magmatic arc towards the South of the recent Teplá Barrandean unit.

U-Pb zircon dating of magmatic pebbles, sampled from upper Proterozoic and Lower Cambrian conglomerates, show melt intrusion and extrusion along this arc at ca. 594 and ca. 570 Ma, respectively (Dörr *et al*., 1992).

A Cadomian magmatic arc south of the recent Teplá Barrandean unit and the top-to-the-North D_2 movements are attributed to south-directed subduction at the northern margin of Gondwana that ceased close to the Precambrian/Cambrian boundary, probably because of a collision with a microplate or an oceanic magmatic arc. Subduction was replaced by Lower Cambrian dextral transtension associated with calc-alkaline magmatic activity and deposition of molasse-like overstep sequences that were succeeded by younger Middle Cambrian marine sediments (Chlupáč, 1993). The generally calc-alkaline characteristics of the Cambrian granitoids do not necessarily indicate prolonged Cadomian subduction during the Cambrian. It can be equally well explained in terms of remelting of arc-type crust in a post-collisional high-heat flow regime.

It has to be emphasized that a similar geometric arrangement and timing of Cadomian subduction and subsequent late Cadomian events have been described from the Cadomian belt of northern Brittany (Nance *et al*., 1991).