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1. PRE-MESOZOIC BASEMENT OF THE WESTERN IBERIAN CONTINENTAL MARGIN AND ITS PLACE IN THE VARISCAN BELT[1]

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ABSTRACT

The study of plutonic and metamorphic rock samples from 15 dredge hauls and 41 cores from the western Iberian margin has led to the recognition of westward extension of the zones of the Iberian Massif Variscides. The offshore area studied appears to consist of several zones, from north to south:

Central Iberian Zone on the continental shelf of Galicia and northern Portugal
Ossa-Morena Zone from Galicia Bank to south of Nazaré Canyon
South Portuguese Zone to the south of Lisbon

These zones were located where the continents fit together prior to the opening of the Atlantic. This position limits tracing of the Ossa-Morena Zone north from the western margin of the Iberian Massif, because the zone abuts units of the Rheno-Hercynian Zone. Toward the west, the Ossa-Morena Zone is adjacent to Avalon Zone formations that were unaffected by the Hercynian Orogeny. It appears that the Ossa-Morena Zone corresponds to the eastern margin of the Avalon Zone, which was involved in the Hercynian Orogeny.

The proposed new structural arrangement of the Iberian-Armorican Arc contrasts with previous cylindrical geodynamic models and rejects the classic correlations between the South Portuguese and Rheno-Hercynian Zones and between the Ossa-Morena and Saxo-Thuringian Zones.

INTRODUCTION

Syntheses concerning the Hercynian fold belt present a wide range of possible correlations between the Iberian segment of this chain and the neighboring domains of Europe, North America, and Africa (Dewey and Burke, 1973; Riding, 1974; Ries and Shackleton, 1976; Lefort, 1983; Lorenz and Nicholls, 1984; Ziegler, 1986; Vaï and Cocozza, 1986). Part of the difficulty in establishing these correlations is due to the lack of detailed knowledge of the Hercynian basement of the western Iberian margin. Uncertainty about this region, which comprises one fifth of the Iberian Peninsula, has caused previous authors to note it as an area of uncertain tectonic affinity, and its attribution to fold belt zones has been of a highly speculative nature.

Nevertheless, some information is available on the nature of the Hercynian basement at the western Iberian margin. Study of the 15 dredge and 41 core samples collected across this area over the past 15 years gives evidence of the presence of continental basement. Sampling at the northern part of the margin (Fig. 1) includes cores from the inner shelf (Boillot et al., 1975) and dredges from the slopes of Galicia Bank and Vigo and Vasco da Gama seamounts (Dupeuble et al., 1976; Mauffret et al., 1978; Groupe Galice, 1979; Boillot et al., 1979; Mougenot et al., 1985). Dredge samples collected from the Nazaré Canyon and around the small islands of Berlengas and Farilhões (Boillot et al., 1975) in the central part of the margin complement previous information from these islands (Andrade, 1937). Additionally, numerous cores (and two dredge hauls on the continental slope) from areas farther south—between the Cape of Sines and Cape São Vicente (Fig. 2)—have also recovered Hercynian basement (Baldy et al., 1977).

The total sample set consists of about 100 samples of continental basement rock, representative of a relatively homogenous distribution across the western Iberian margin (Figs. 1 and 2). The samples appear to be consistent with a pattern of tectonic zonation, thus enabling a broad description of basement characteristics, which in turn leads to an extrapolation onto the margin of the zones observed in the Iberian Hercynides.

TECTONIC ZONATION IN THE IBERIAN HERCYNIDES

The Iberian Hercynides have been subdivided into several zones parallel to the Hercynian tectonic trend (Lotze, 1945) and analogous to those zones described previously in Central Europe (Fig. 3) by Kossmat (1927). Paleogeographic, volcanic, structural, metamorphic and plutonic aspects characterizing the zones are summarized in Table 1. The zones are bounded either by deep-seated faults that were reactivated several times during the Paleozoic or by sutures, such as the Porto-Badajoz-Cordoba suture separating the Central Iberian Zone from the Ossa-Morena Zone (Burg et al., 1981) and the Theic Ocean suture separating the Ossa-Morena Zone from the South Portuguese Zone (Lefort, 1983). The diversity of the Central Iberian Zone has prompted its proposed division into two subzones, although there is no structural discontinuity across the subdivision.

The classic zoned representation of the Hercynian fold belt has been supplanted by a more explicit geodynamic picture (e.g., fig. 1 in Matte, 1986). Nevertheless, the zonation established by Lotze (1945) is still useful for describing the fold belt and providing criteria for correlation. Such correlation was the primary objective of this study, in attempting to link offshore

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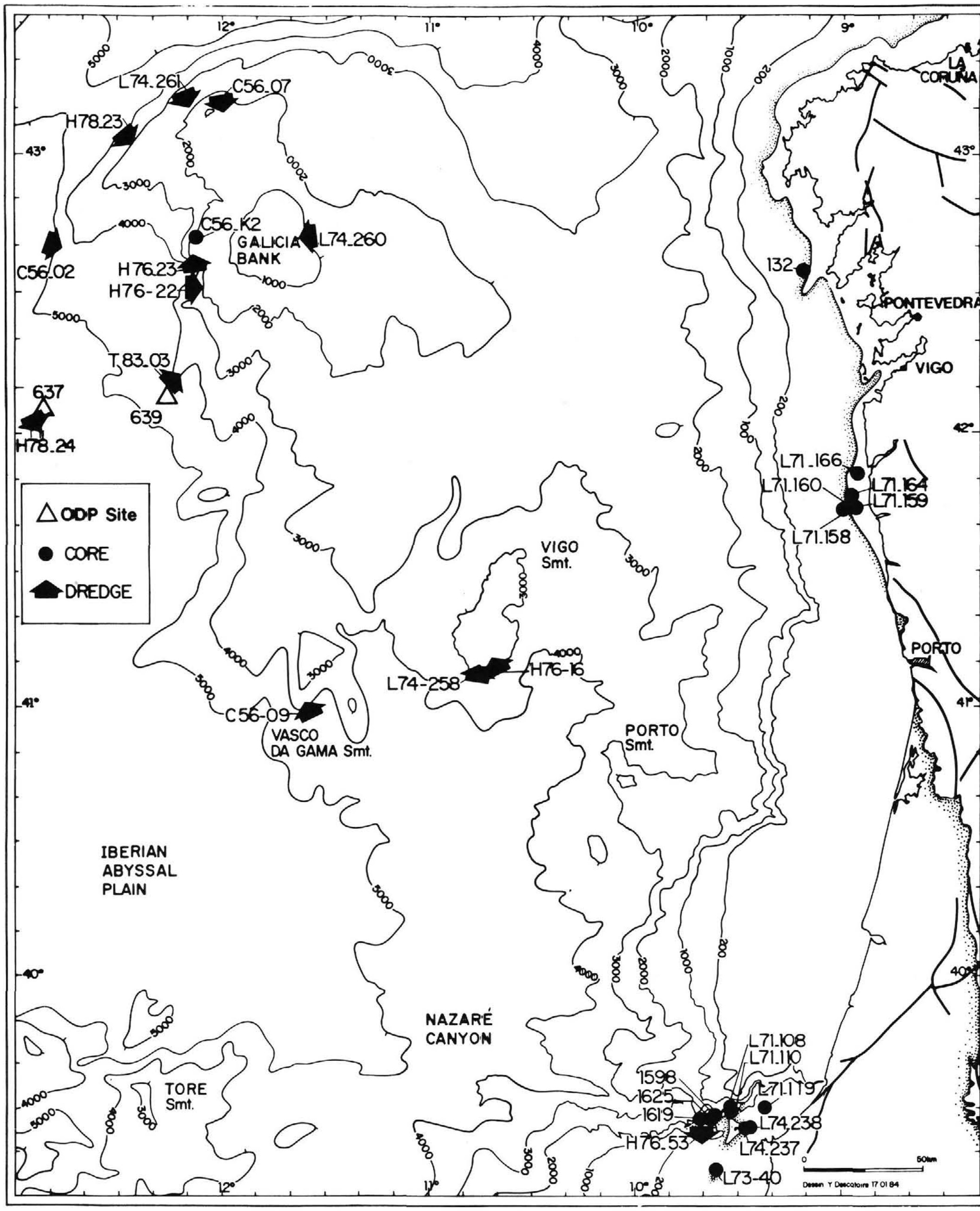

Figure 1. Simplified bathymetric map of the continental margin northwest of the Iberian Peninsula (after Laughton et al., 1975), showing positions of pre-Mesozoic basement samples. Stippled line indicates outcrop limit of post-Hercynian cover, including offshore areas. Bathymetric contours in meters.

basement areas on the western Iberian margin to basement outcrops in Spain and Portugal.

NATURE OF THE WESTERN IBERIAN MARGIN BASEMENT

Basement off the Galicia Coast and Northern Portugal

Several cores taken off the coast of northern Portugal recovered rock samples identical to nearby mainland outcrops (Fig. 1). Core 132 (from north of Pontevedra) sampled the Caldas de Reis granite. Cores L71-158 and L71-166 consist of greenschist facies feldspathic quartzites, micaschists, and metarhyolites corresponding to the Ordovician-Silurian formations of the synclinorium east of Porto, in the Central Iberian Zone.

Basement of the Northwest Iberian Continental Slope

Most of the data concerning the western Iberian margin comes from samples of the Galicia Bank, the westernmost segment of continental crust belonging to the Iberian Massif. Nine dredge hauls (Table 2), nearly all from areas west of the bank, were found to contain predominantly metamorphic rocks of sedimentary origin belonging to the low-pressure amphibolite facies and a variety of granitic rock types. The latter include abundant biotite or biotite-hornblende tonalites and peraluminous granites. In addition, there are minor amounts of low-grade metasediments and low- to intermediate-pressure granulites.

The distribution of rock types appears to follow a pattern. The two dredges from the northwestern slope of Galicia Bank

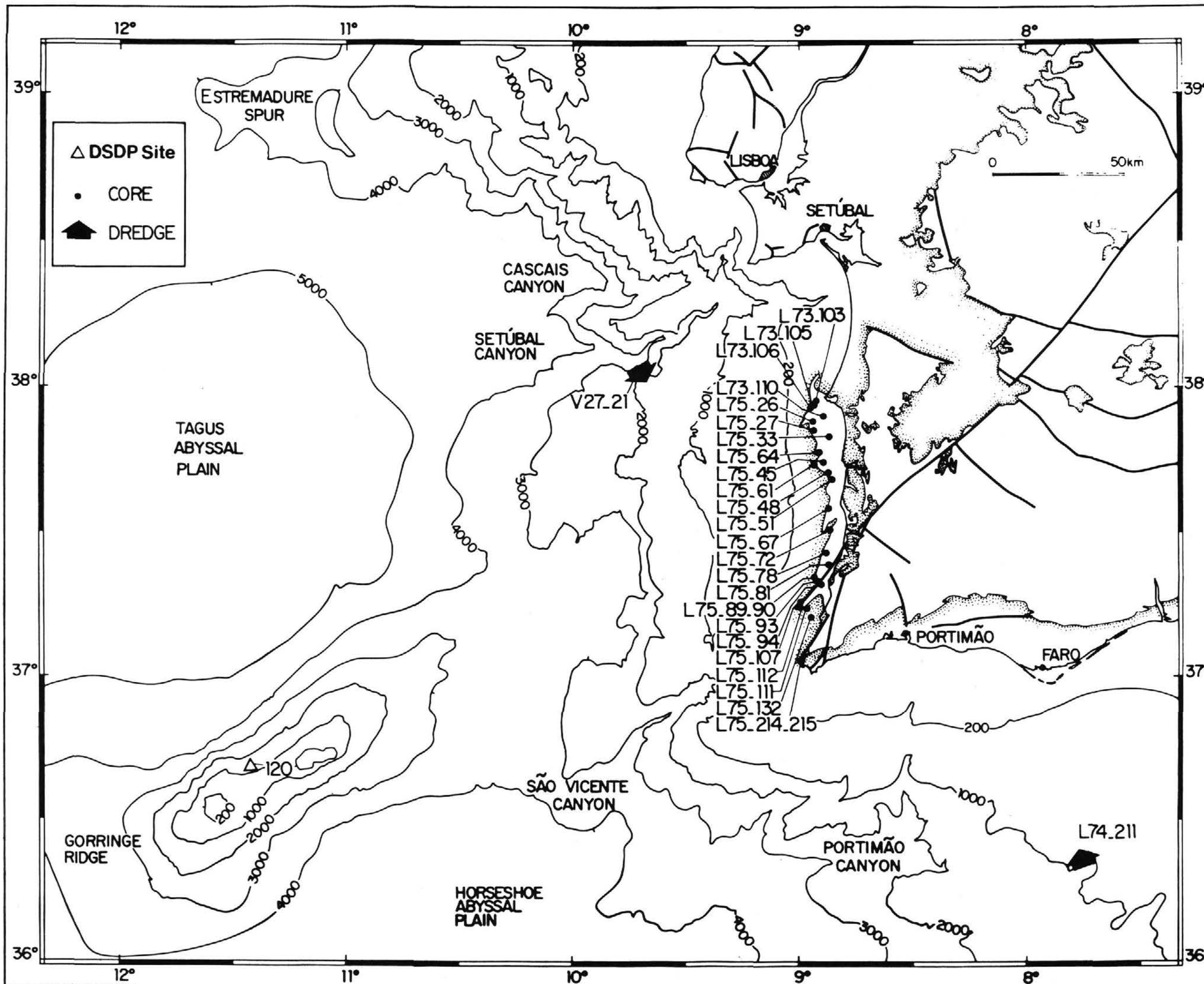

Figure 2. Simplified bathymetric map of the continental margin southwest of the Iberian Peninsula (after Laughton et al., 1975), showing positions of pre-Mesozoic basement samples. Stippled line indicates outcrop limit of post-Hercynian cover, including offshore areas. Bathymetric contours in meters.

(C56-07 and L74-261) both contain the same types of peraluminous granite and micaschist. Greenschist facies metasediments and cataclastic biotite-bearing granodiorites were recovered in three deep-water dredges (C56-09, T83-03, and H78-23) from between Vasco da Gama Seamount and Galicia Bank. Granulites were found in two dredge hauls (L74-258 and L74-260) from shallower water nearer the coast. This distribution suggests that the local zonation in the crust reflects the presence of progressively shallower tectono-metamorphic units toward the west.

The geological history of the basement can be reconstructed as follows. Initial deposits of mudstones, arkosic sandstones, and some calcareous sediments were metamorphosed and deformed with slaty cleavage or schistose foliation. Crenulation is visible in the least metamorphosed facies. According to relationships between deformation and mineral growth, greenschist or low-pressure amphibolite metamorphism continued after the main phase of deformation. A late-stage crenulation is synchronous with retrogression. Plutonic activity that accompanied and followed these tectono-metamorphic events included the early intrusion of calc-alkaline granitic rocks and peraluminous leucogranites (now deformed), followed by peraluminous granites or calc-alkaline granites, granodiorites, and tonalites (undeformed). The granulites (1500 m.y. old; Postaire, 1983) form part of a pre-Hercynian basement complex.

To summarize, the nature and development of the continental slope basement northwest of the Iberian Peninsula are similar to those known from the internal zones of the mainland Hercynian fold belt, as observed in western Galicia and the Ossa-Morena Zone (Julivert et al., 1977, 1980). However, the dredge granulites have no onshore equivalents; the granulites from the northwestern Iberian nappes are of the high-pressure type and are probably Paleozoic in age (J. J. Peucat, pers. comm., 1986).

Basement to the West of Nazaré Canyon

Hercynian basement crops out to the south of Nazaré Canyon around the islets of Berlengas and Farilhões (Table 2). This group of small islands consists of biotite-bearing monzonitic granites (Berlengas) and deformed muscovite-bearing or two-mica leucogranites and pelitic gneisses (Farilhões) (Andrade, 1937; Andrade and Brack-Lamy, 1949). Sampling around the is-

Table 1. Summary of Iberian basement characteristics.

ZONES	SEDIMENTATION	PALEOZOIC VOLCANISM
CANTABRIAN ZONE	1 - Upper Proterozoîc : thick turbidite-bearing succession, slightly deformed before deposition of the Cambrian. 2 - Cambrian-Visean : thin succession of platform deposits with sedimentary breaks; correspond to shallow-water sedimentation. 3 - Namurian-Westphalian : thick sequences made up mostly of turbidites. 4 - Westphalian D - Stephanian : post tectonic molasse.	Minor phases of activity during the Mid-Cambrian and Caradoc : basic and intermediate volcanism of alkaline affinity.
WEST ASTURIAN LEONESIAN ZONE	1 - Upper Proterozoic : thick turbidite- bearing succession, slightly deformed before deposition of the Cambrian. 2 - Cambrian-Lower Devonian : very thick succession of shallow-water deposits, followed by Caradoc turbidites, thinnly developed Silurian black shales (transgressive) and Lower Devonian reef facies. 3 - Lower Carboniferous : scarce outcrops of turbidite-bearing facies. 4 - Westphalian-Stephanian : post-tectonic molasse.	Minor basaltic and rhyolitic activity during the Caradoc.
CENTRAL IBERIAN ZONE — GALICIAN AND CASTILLAN SUB-ZONE	1 - Upper Proterozoic : Peraluminous, acid volcanics at the northern boundary of the sub-zone. Elsewhere, a thick turbidite-bearing succession. Slight deformation before the deposition of Palaeozoic strata. 2 - Pre-Hercynian Palaeozoic formations : No significant outcrop of dated Cambrian. Discordant Ordovician succession of moderate thickness formed of quartzites at the base passing up into mudstones. Thick sequence of Silurian turbidites in the North of the sub-zone. Rare outcrops of turbidite-bearing Lower Carboniferous.	Major acid volcanism of alkaline affinity, with occasional basic volcanism, during the Silurian.
CENTRAL IBERIAN ZONE — W. LUSTIANIAN AND ALCUDIAN SUB-ZONE	1 - Upper Proterozoic : Thick turbidite-bearing succession, slightly deformed before depositions of ? Vendian strata. 2 - Vendian-Cambrian : A thin, incomplete succession of shallow-water deposits slightly deformed before deposition of the Ordovician. 3 - Ordovician-Upper Devonian : A mainly sandy and shaly succession of moderate thickness corresponding to shallow water facies. 4 - Lower Carboniferous : Culm facies. 5 - Westphalian : limnic facies. Stephanian : molasse deposits.	Minor acid and basic volcanism during the Ordovician. Silurian spilites. Basic volcanism during the Late Devonian.
OSSA-MORENA ZONE	1 - Proterozoic : Polyphase metamorphic complex and thick turbidite-bearing succession, both strongly affected by Cadomian orogenesis. 2 - A thick Cambrian succession represented by platform facies at the base, followed by a turbidite-bearing sequence containing basic volcanics. Sandy-shaly facies in the ordovician coresponding to deep-water deposits. The Silurian contains volcanics and black shales. Lower-Mid Devonian shows platform facies. 3 - Upper Devonian : turbidite-bearing facies. 4 - Stephanian : limnic facies.	Major spilitic volcanism during the Mid-Cambrian. Oceanic tholeiites of ordovician age. Major acid and basic volcanism during the Silurian.
SOUTH PORTUGUESE ZONE	Upper Devonian : sandstones and shales. Lower Carboniferous : volcano-sedimentary complex. Upper Visean-Namurian : turbidites.	Major volcanic phase with spilites and quartz-keratophyres during the Tournaisian-Visean.

lets (Boillot et al., 1975) and on the southern flank of Nazaré Canyon (Andrade, 1937) has yielded undeformed porphyritic granites containing biotite and hornblende (H76-53), deformed muscovite-bearing or two-mica leucogranites (L71-108), and various pelitic or semipelitic schists with sericite, chlorite, biotite, and albitized plagioclase (dredge L73-40; cores 1598, 1619, 1625, L74-237, and L74-238). A variety of schists with large porphyroblasts of chlorite and rutile that occurs as reworked material within a conglomerate (L71-119) is identical to rock types from the Vasco da Gama Seamount. Therefore, it is apparent

PRINCIPAL PHASES OF HERCYNIAN DEFORMATION (D)	HERCYNIAN REGIONAL METAMORPHISM	HERCYNIAN PLUTONISM
D1 - Westphalian : overthrusts and nappes of décollement with assymetric folds facing towards the interior of the cantabrian arc. D2 - Upper Westphalian - Stephanian : flexure folds.	Incipient metamorphism localized in the S.E. part of the zone.	Small scarce granitic (sensu lato) stocks of the calc-alkaline, post-tectonic type.
D1 - Lower Carboniferous : fold nappes in the West of the zone passing into overturned folds which face the interior of the regional fold-arc in the East, associated with a foliation or a flow schistosity. D2 - ? Namurian : folding and thrusting, with formation of strain slip cleavage. D3 - Westphalian : upright folds crenulation cleavage.	Most of the zone is metamorphosed in the greenschist facies, apart from the N.W. which is in the amphibolite facies. Metamorphism is intermediate between the medium pressure and the low pressure types: the peack is attained between deformation phases D1 and D2 or during D2.	Small scarce granitic (sensu lato) massifs of the calk-alkaline or peraluminous, post-tectonic type, mostly of Upper Carboniferous age, throughout the zone, except in the NW where medium-sized massifs are observed as follows : - Lower Carboniferous : syntectonic peraluminous leucogranites. - Upper Carboniferous : post-tectonic cal-alkaline granites and granodiorites.
D1 - Upper Devonian-Lower Carboniferous : major overlapping nappes, including ophiolitic units and units affected by various high pressure metamorphic facies. The emplacement of nappes is accompanied by formation of recumbent folds in the autochton. D2 - Phase of microfolding, with subvertical axial planes, associated with thrust movements. D3 - ? Westphalian : upright folds and domes synchronous with granite emplacement.	Plurifacial metamorphism in the autochtone, generally with in the amphibolite facies, begining with a metamorphism intermediate between the medium pressure and the low pressure types and terminating with low pressure type during the D3 phase.	Large batholiths and medium-sized massifs as follows : - Lower-Mid Carboniferous : synorogenic calc-alkaline granodiorites and peraluminous leucogranites. -Upper Carboniferous : late stage orogenic granodiorites, calc-alkaline granites and peraluminous leucogranites.
D1 - Lower Carboniferous : upright folds.	Most of this sub-zone is in the greenschist facies.	Large batholiths and medium-sized massifs as follows : - Lower Carboniferous : scarce synorogenic peraluminous leucogranites. - Upper Carboniferous : numerous late-stage massifs of biotite granite, two-mica granite and biotite-cordierite granite.
D1 - Upper Devonian : overlapping nappes and recumbent folds facing SW, associated with formation of cleavage. D2 - Pre-Stephanian : upright folds or overfolded to the SW, accompanied by crenulation cleavage.	Most of the zone is in the greenschist facies. Low pressure amphibolite facies is locally developped and becomes more and more important towards the N.E.	Small to medium-sized massifs : - Lower-Mid Carboniferous : syn-orogenic gabbros, diorites, tonalites, granodiorites, calc-alkaline granites and some rare peraluminous leucogranites (in the NE of the zone). - Stephanian : late-stage and post-orogenic gabbros, diorites, tonalites, granodiorites and calc-alkaline granites.
D1 - Westphalian : overlapping nappes and overfolds facing SW, accompanied by formation of cleavage. D2 - Post-Westphalian : upright folds with local development of crenulation cleavage.	Metamorphism decreases gradually from NE to SW, showing a zonation from the chlorite zone, through the prehnite-pumpellyite facies to very low grade.	Rare post-tectonic massifs of gabbro, diorite and granite localized in the NE of the zone.

that the basement of the Portuguese continental shelf to the south of Nazaré Canyon is similar to that observed on the continental slope northwest of the Iberian Peninsula.

Continental Margin Basement to the Southwest of the Iberian Peninsula

Pre-Mesozoic basement also crops out on the inner shelf of the South Portuguese margin between the Cape of Sines and the Cape São Vicente (Fig. 2). Coring here yielded rocks belonging to the South Portuguese Zone (Baldy et al., 1977). For the most part, samples are made up of clastic sedimentary rocks assigned as follows:

1. A flysch (Culm facies) formation of late Visean-Westphalian age (graywackes, coarse- or fine-grained mudstones, small-scale and sand-shale sequences; L75-26, L75-33, L75-45,

L75-48, L75-51, L75-64, L75-67, L75-72, L75-81, L75-90, L75-93, L75-94, L75-132, L75-214, L75-215, L73-103, L73-106, and L73-110).

2. A "Sub-Culm" volcano-sedimentary formation of Tournaisian–early Visean age (tuffs and mudstones; L75-61, L75-78, L75-89, L75-111, and L75-112).

3. Quartzitic phyllites and orthoquartzites of late Devonian age (L73-105 and L75-27). A silicified dolomitic limestone of probable early Carboniferous age (L75-107) was sampled also. These facies are typical of the South Portuguese Zone; their offshore occurrences are a result of Tertiary faulting (Mougenot et al., 1979). Similarly emplaced Culm flysch facies have been recovered in dredges from the continental slope to the south of the Setubal Canyon (V27-21; Fig. 2) and on the Guadalquivir Bank south of the Algarve (L74-211; Table 2).

CORRELATION OF THE WESTERN IBERIAN MARGIN BASEMENT AND THE IBERIAN MESETA

Samples from the Galicia and northern Portuguese continental shelf belong to the Central Iberian Zone, whereas samples from the southwestern Iberian margin between the Cape of Sines and Cape São Vicente are part of the South Portuguese Zone. The basement of the northwestern Iberian continental slope (Galicia Bank and Vasco da Gama and Vigo seamounts) has a consistent assemblage of rock types that correlate with mainland Hercynian zonations on the basis of metamorphic and plutonic criteria. The tonalites and biotite-hornblende granodiorites commonly found in the Ossa-Morena Zone are well represented on the northwestern Iberian continental slope. In contrast, the abundant peraluminous leucogranites of Galicia (Central Iberian Zone) are rarely found on the slope. The typical features of overlapping nappes in the Central Iberian Zone of Galicia and northwestern Portugal are absent from the margin; these features include amphibolites of meta-igneous origin, eclogites, high-pressure granulites, garnet peridotites, and peralkaline orthogneisses.

Based on this evidence, we propose that the basement of the northwestern Iberian margin correlates with the Ossa-Morena Zone. The Berlengas-Farilhões archipelago and the continental shelf basement south of the Nazaré Canyon, which has strong affinities with offshore areas to the north and with mainland outcrops to the south, provide evidence for continuity between the northwestern Iberian margin and the Ossa-Morena Zone. The petrographic observations from offshore samples (Table 2) are in good agreement with interpretations given by Lefort et al. (1981) and Lefort (1983), who propose that the Porto-Badajoz-Cordoba suture extends toward the north, parallel with the shelf break off Galicia, which suggests that a contact between the Ossa-Morena and South Portuguese Zones should be found near Lisbon.

DISCUSSION

Extension of the Ossa-Morena Zone

According to cylindrical geotectonic models, the Ossa-Morena Zone continues north through France into Central Europe, where it is equivalent to the Central German Crystalline Rise (Ellenberger and Tamain, 1980) or the Saxo-Thuringian Zone (Julivert and Martinez, 1983). Another model traces the Ossa-Morena Zone westward into Africa and North America (Vaï and Cocozza, 1986). It is possible to test these models by comparing the nature prior to the opening of the Atlantic of the basement massifs adjacent to the northwestern Iberian margin (Fig. 3).

Table 2. Dredge samples from the West Iberian margin.

Lithological composition of the Berlenga-Farilhões archipelago, according to C.Freire de Andrade (1937).	
- Berlenga, Estelas Serro da Velha, Medas :	-Coarse grained pink granites, more rarely granodiorites, with chloritized biotite and slightly cataclased.
- Farilhões, Forcadas:	- Muscovite-bearing leucogranitic orthogneiss with accessory amounts of biotite and garnet. - Pegmatites. - Pelitic gneisses and feldspathic quartzites containing two micas.
- Dredge samples : ***1598***	- Biotite-bearing pelitic gneiss.
1619	- Chloritic schist ("greenschist"), micaschist, two-mica leucogranitic orthogneiss.
1625	- Muscovite-chlorite schists.
Core-samples from the Nazaré region (apart from H76-53)	
*** L71 - 108 ***	- Coarse-grained two-mica leucogranites, slightly deformed. - Two mica-bearing leucogranite, orthogneiss.
*** L71 - 110 ***	- Two-mica leucogranite, slightly deformed, similar to one of the L71 -108 samples.
*** L71 - 119 ***	- Conglomerate containing pelitic clasts with large porphyroblasts of chlorite and rutile. The pebbles are similar to material sampled in dredge C56 -09 from the Vasco da Gama Seamounts.
*** L 73 - 40 ***	- Sericitic greenshist with chlorite and porphyroblasts of rutile.
*** L 74 - 237 ***	- Feldspathic quartzites containing muscovite, chlorite and accessory amounts of biotite.
*** L 74 - 238 ***	- Feldspathic quartzite containing muscovite, green biotite and chlorite.
Core-samples : coastal shelf of Galicia and North Portugal.	
*** 132 ***	- Biotite-bearing porphyritic granite type, identical to that observed on the coast at Caldas de Reis.
*** L 71 - 158 ***	- Meta-rhyolite with small augen structures, containing muscovite and rare biotite.
*** L 71 - 160 ***	- Fine-grained sericitic schist. - Fine-grained micaschist with abondant muscovite, chlorite and biotite.
*** L 71 - 164 ***	- Fine-grained feldspathic quartzite with rare muscovite and chlorite.
*** L 71 - 166 ***	- Fine-grained sericitic schist.

Models showing the fit of the continents before the opening of the North Atlantic generally place Galicia Bank just south of Flemish Cap in such a way that the northwestern scarp of Galicia Bank is in continuity with the southeastern scarp of Flemish Cap (Olivet et al., 1984; Lefort, 1985). The Flemish Cap base-

Table 2 (continued).

SAMPLES LOCATION	LITHOLOGY
*** H 78 - 23 *** - Univ. Paris VI - NW Slope of Galicia Bank 43°04' N - 12°27'W 3900 - 3200 m water depth	- Strongly cataclased biotite-bearing granodiorite, with development of chlorite and epidote at the expense of primary biotite and plagioclase.
*** L 74 - 261 *** - Univ. Paris VI - NW Slope of the Galicia Bank 43°12'N - 12°10'W 3000 - 2600 m water depth	- Porphyritic, monzonitic granites with biotite and muscovite, slightly cataclased and chloritized. One sample contains garnet and sillimanite. - Undeformed, chloritized microtonalite rich in biotite. - Fine-grained micaschists with abundant biotite and rare muscovite in the matrix. Small porphyroblasts of biotite and muscovite cut across the foliation. Green tourmaline.
*** C 56 - 07 *** - C N E X O - NW Slope of the Galicia Bank 43°10'N - 12°00'W 1900 - 1800 m water depth	- Two-mica, porphyritic granites identical to those in L 74 - 261. - Fine grained micaschists with abundant biotite. Large porphyroblasts of biotite and muscovite identical to those in L 74- 261. Green tourmaline. - Banded gneiss. Psammitic layers contain plagioclase, green amphibole and sometimes biotite. Calc-silicate layers rich in garnet, diopside and zoisite. Rare sphene, carbonate and scapolite are crystallized in cracks oblique to the foliation.
*** C 56 - 02 *** - C N E X O - External ridge of Galicia Bank 42°39'N - 12°50'W 4800 - 4500 m water depth	- Serpentinite with characteristic "mesh" structure; chrysotile and antigorite. Altered olivine.
*** H 78 -24 *** - Univ. Paris VI - External ridge of Galicia Bank 42°02'N - 12°51'W 5200 - 5000 m water depth	- Highly altered lherzolite. Primary orthopyroxene, clinopyroxene and spinel oriented parallel to early foliation. Secondary serpentine mineral (lizardite) replacing olivine, enstatite and diopside. - Breccia with clay-rich cement and angular clasts of extremely altered peridotite identical to serpentinites at this locality.
*** H 76 - 23 *** - Univ. Paris VI - W Slope of Galicia Bank 42°36'N - 12°07'W 3000 - 2500 m water depth	- Medium grained, undeformed tonalites with biotite and hornblende. - Coarse grained tonalite with biotite, highly chloritized, similar to micro-tonalite of L 74 -261. - Fine-grained quartzo-feldspathic gneiss of sedimentary origin containing oligoclase, biotite and variable amounts of microcline. - Banded gneisses very similar to those of dredge C56-07. Calc-silicate layers contain diopside, colourless clinoamphiboles and zoisite. Microcline is present in certain bands. Cracks cutting across foliation are sealed with scapolite.
*** H 76 - 22 *** - Univ. Paris VI - W Slope of Galicia Bank 42°31'N - 12°07'W 3900 - 2800 m water depth	- Cataclased potassic granophyre with rare biotite and muscovite. - Micaschits with large porphyroblasts of biotite, muscovite, cordierite and pink andalusite. Apart from the two last minerals, these samples are similar to micaschists of L74 - 261 and C56 - 07.
*** T83 - 03 *** - Univ. Paris VI - W Slope of Galicia Bank 42°11'N - 12°14'W 4700 - 4000 m water depth	- Slightly deformed muscovite-biotite leucogranite. - Cataclased biotite-bearing granodiorite, similar to that of H78 - 23. - Fine-grained sericite schist with chlorite and green biotite,-similar to Ordovician mainland outcrops. -Sericitic phyllite with chlorite and organic matter, similar to Silurian mainland outcrops. - Red sandstones with carbonate cement, illite-rich, feldspar-poor with mica and kaolinite. Similar to Stephanian-Autunian formations on land of the Buçaco type. - Undeformed greywackes and lithic sandstones with abundant clay-rich matrix. Similar to Permo-Carboniferous outcrops on land.
*** L74 - 260 *** - Univ. Paris VI - E Border of the Galicia Bank 42°42'N - 11°35'W 1400 - 1000 m water depth	- Undeformed, coarse-grained monzonitic granite with biotite. - Light coloured, undeformed tonalite with biotite chloritized. Comparable with tonalites from L74 - 261 and H76 - 23. - Pebbles of granulites : hornblende-bearing pyriclasites with variable amounts of amphibole; enderbitic gneiss.
*** C56 - 09 *** - C N E X O - Vasco da Gama Seamounts 40°58'N - 11°33'W 4100 - 3800 m water depth	- Phyllites very similar to those of T83 - 03. Large porpnyroblasts of chlorite and biotite (later chloritized) in a matrix of quartz and sericite. Large porphyroblastic rutile prisms. - Meta-arkoses interbedded within the phyllites : coarse grained layers with detrital quartz and plagioclase surrounded by a fine sericitic cement. Porphyroblasts of chlorite, chloritized biotite and rutile. Green tourmaline.
*** L74 - 258 *** - Univ. Paris VI - Vigo Seamount 41°08'N - 10°45'W 3400 - 2800m water depth	- Tonalitic orthogneiss with biotite and hornblende. - Granodioritic orthogneiss with biotite. - Granulites : khondalitic/kinzigitic gneisses; acid charnockite; hornblende-garnet pyriclasite; ultrabasic orthopy-roxene- bearing granulite with amphibole, olivine and phlogopite.
*** H76 - 16 *** - Univ. Paris VI - Vigo Seamount 41°09'N - 10°41'W 3100 - 2600 m water depth	- Deformed biotite-bearing granite. - Hornblende pyriclasites with accessory amounts of biotite.
*** H76 - 53 *** - Univ. Paris VI - Nazaré Canyon 39°24'N - 9°38'W 1000 - 600 m water depth	- Light-coloured, undeformed biotite-bearing granodiorites with accessory amounts of hornblende. Relatively rich in sphene, apatite and zircon.
*** V27 - 21 *** - Lamont D.G.O. - Setúbal Canyon 38°02'N - 9°42'W 2700 - 2200 m water depth	- Greywacke-mudstones (Culm facies) with graded, laminated units parallel to So bedding stratification. Quartz, chlorite and some muscovite and tourmaline. Slight S_1 schistosity parallel to So . Phyllites are microfolded about axes oblique to So which define S_2 schistosity.
*** L74 - 211 *** - Univ. Paris VI - Guadalquivir Bank 36°21'N - 7°45'W 1100 - 800 m water depth	- Culm facies greywacke. Angular, detrital quartz with some mica and tourmaline. Quartzo-sericitic cement with chlorite, limonite and micritic calcite.

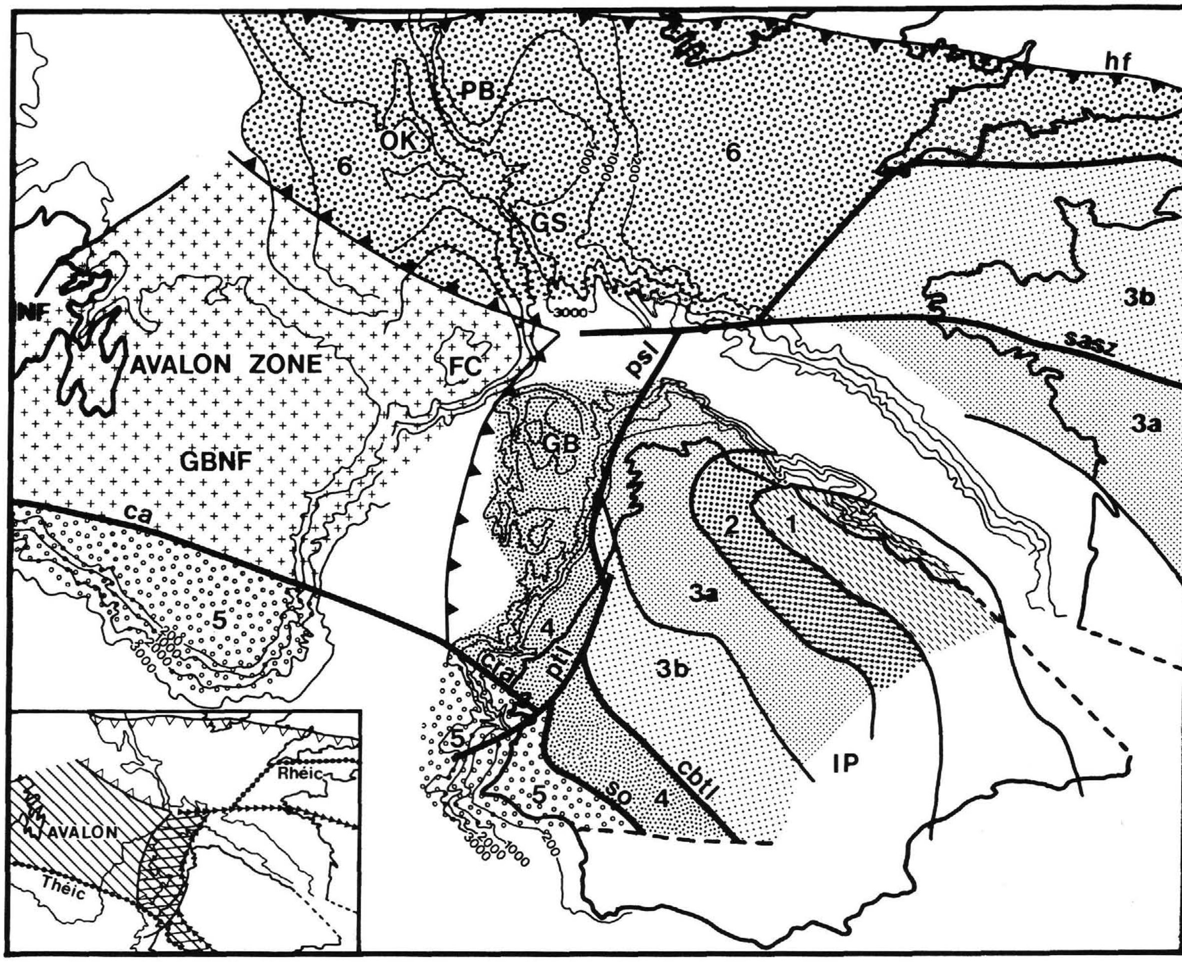

Figure 3. Tectono-metamorphic zonation of the Hercynian fold belt in Iberia and adjoining regions. Positions of the continents prior to the opening of the Atlantic modified from Lefort (1983). 1 = Cantabrian Zone; 2 = West Asturian and Leonesian Zone; 3a = Galician and Castillan Subzone (Iberia) and South Armorican Zone (France); 3b = West Lusitanian and Alcudian Subzone (Iberia) and North and Central Armorican Zone (France); 3a + 3b = Central Iberian Zone (Iberia); 4 = Ossa-Morena Zone; 5 = South Portuguese Zone; 6 = Rheno-Hercynian Zone; hf = Hercynian Front; sasz = South Armorican Shear Zone; psl = Petite Sole lineament; cbtl = Cordoba-Badajoz-Tomar lineament; ptl = Porto-Tomar lineament; psl + cbtl + ptl = Porto-Badajoz-Cordoba suture; cra = Cap de la Roca anomaly; ca = "Collector" anomaly, equivalent to Theic Ocean suture; so = Ficalho overthrust; IP = Iberian Peninsula; GB = Galicia Bank; GBNF = Grand Banks of Newfoundland; NF = Newfoundland; FC = Flemish Cap; OK = Orphan Knoll; PB = Porcupine Bank; GS = Goban Spur. In France, zones 3a and 3b are separated by a suture (e.g., see Matte, 1986), whereas on the Iberian Peninsula the boundary between the equivalent domains is gradual. These data are consistent with the opening of a South Armorican Ocean during the Early Paleozoic, as suggested by Lefort and Ribeiro (1980), and constrain the width of this small ocean. Insert shows the distribution of the Hercynian fronts (triangles), Rheic and Theic oceans sutures (dots), South Armorican and Porto-Badajoz-Cordoba sutures (arrows), Avalon Zone (lines), and Ossa-Morena Zone segment of the Avalon Zone that was reactivated during the Hercynian Orogeny (crossed lines).

ment is composed of granodiorites emplaced between 833 and 751 Ma ago, as well as Hadrynian acidic volcanics of low-metamorphic grade that have been unaffected by orogenesis since the end of pan-African events (King et al., 1985). The basement of the central part of the Grand Banks includes unmetamorphosed or poorly metamorphosed Paleozoic strata in addition to Precambrian formations (Lilly, 1965; Jansa and Wade, 1975); in particular, the Devonian contains organic-walled microplankton that have not experienced any metamorphism (Jenkins, 1974). The basement of the Canadian margin appears to have been little affected by the Acadian Orogeny and was not involved in the Hercynian; therefore, this type of basement cannot be linked directly to the western Iberian margin, where there are abundant Hercynian granitic and metamorphic rocks.

By the same line of reasoning, Devonian and Carboniferous sediments from the Goban Spur (Auffret et al., 1979; Lefort et al., 1985) are too poorly deformed and metamorphosed to belong to the internal zones of the Hercynian fold belt.

Thus, it is not possible to extend the northwestern Iberian margin basement either to the north or to the west, as proposed in previous models. As a consequence, the Ossa-Morena Zone is delimited by the northern and western flanks of the Galicia Bank. The boundary of the Ossa-Morena Zone to the north of Galicia Bank corresponds to the South Armorican Shear Zone (Fig. 3), and to the west, the Ossa-Morena Zone is apparently bounded by another suture or a Hercynian front.

Extension of the South Portuguese Zone

Cylindrical models of fold belts connect the Rheno-Hercynian Zone with the South Portuguese Zone (Oliveira et al., 1979; Franke and Engel, 1986). Some of these models suggest extension of the South Portuguese Zone into North Africa (Dewey and Burke, 1973; Lorenz and Nicholls, 1984). Other models separate the South Portuguese Zone and Rheno-Hercynian Zone by a metamorphic belt (Vaï and Cocozza, 1986) or by a domain that was undeformed during the Hercynian, including eastern Newfoundland, the Grand Banks, and Flemish Cap (Lefort, 1983).

Given that no samples that could have belonged to the South Portuguese Zone are observed on the northwestern Iberian margin and that there appears to be no room for extension of the South Portuguese Zone between the northwestern Iberian margin and the central part of the Grand Banks, it would seem that the hypothesis of joining the Rheno-Hercynian Zone and South Portuguese Zone should be abandoned. Rather, it is more likely that the South Portuguese Zone belongs to the northern African margin and is bounded to the north by the Theic Ocean suture (Fig. 3), which is marked by a strong magnetic anomaly to the south of the Grand Banks (the "Collector" anomaly; Lefort, 1983).

Significance of the Ossa-Morena Zone and Western Boundary of the Iberian-Armorican Arc

The Precambrian and pre-Carboniferous Paleozoic formations of the Ossa-Morena Zone display African affinities and are fundamentally different from other formations of the same age in the Iberian Peninsula (Herranz Araujo, 1984; Robardet, 1982). Paleomagnetic measurements from the Ossa-Morena Zone also evidence the separation of this zone from Iberia prior to the Late Paleozoic (Perroud et al., 1985). These two lines of argument indicate that the Ossa-Morena Zone and the rest of Iberia belonged to different tectonic plates before the Devonian, with the suture zone represented by the Porto-Badajoz-Cordoba lineament (Burg et al., 1981).

Preceding the opening of the Atlantic, the fit of the continents positioned the Avalon Zone (eastern Newfoundland, central and northern Grand Banks, and Flemish Cap), which was not affected by the Hercynian Orogeny (Haworth and Lefort, 1979), opposite the offshore extension of the Ossa-Morena Zone on the western Iberian margin. Either a suture, which could be an extension of the Rheic Ocean suture (Matte, 1986), or an Hercynian front must exist between these two domains. No trace of a suture has been found between Flemish Cap and the Galicia margin; the peridotites recovered on Ocean Drilling Program Leg 103 were emplaced during the Mesozoic and cannot be interpreted as Paleozoic ophiolitic slices (Boillot et al., 1980, 1985, 1986; Girardeau et al., this volume).

The Proterozoic history of the Ossa-Morena Zone is similar to that of the Avalon Zone (Herranz Araujo, 1984), the latter of which is considered as part of a pan-African belt added to North America during the Paleozoic (O'Brien et al., 1983). Therefore, the Ossa-Morena Zone probably corresponds to that part of the Avalon Zone that was deformed and metamorphosed with the Iberian Peninsula during the Hercynian plate collision. The contact between the east Canadian and west Iberian continental margins should broadly correspond to one of the fronts of the Hercynian fold belt and would also be the western structural boundary of the Iberian-Armorican Arc.

CONCLUSIONS

The pre-Mesozoic basement of the western Iberian continental margin consists of formations belonging to the Central Iberian, Ossa-Morena, and South Portuguese Zones of the mainland Iberian Hercynian fold belt.

The Ossa-Morena Zone forms the major part of the western Iberian margin and appears to be bounded by several sutures and major faults: the Porto-Badajoz-Cordoba lineament to the east, a probable Theic Ocean suture to the south, a Hercynian front to the west, and a possible extension of the South Armorican Shear Zone to the north.

The eastern border of the Avalon Zone could have been involved in the Hercynian Orogeny, with the Ossa-Morena Zone interpreted as belonging to this type of basement. Under these conditions, the external zones of the Hercynides (i.e., the Rheno-Hercynian and South Portuguese Zones) are not directly linked to but continue as parallel belts to the north and south of the Avalon Zone (Fig. 3). Thus, study of the western Iberian margin basement leads to the proposition of a new structural pattern for the Iberian-Armorican Arc that is more complex and less dependant on large-scale cylindrical arrangements than previous models.

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