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

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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; Vai 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; Mougénot 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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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
PRE-MESOZOIC BASEMENT OF THE WESTERN IBERIAN CONTINENTAL MARGIN

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 Berlangas and Farilhões (Table 2). This group of small islands consists of biotite-bearing monzonitic granites (Berlangas) 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.

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

Llets (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)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
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<tbody>
<tr>
<td>D1</td>
<td>Westphalian: overthrusts and nappes of décollement with asymmetric folds facing towards the interior of the Cantabrian arc. D2: Upper Westphalian - Stephanian: flexure folds.</td>
</tr>
<tr>
<td>D3</td>
<td>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 autochthon. D2: Phase of microfolding, with subvertical axial planes, associated with thrust movements. D3: Upper Westphalian: upright folds and domes synchronous with granite emplacement.</td>
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<tr>
<td>D2</td>
<td>Lower Carboniferous: upright folds.</td>
</tr>
<tr>
<td>D3</td>
<td>Lower Devonian-Lower Carboniferous: overlapping nappes and recumbent folds facing SW, accompanied by formation of cleavage. D2: Pre-Stephanian: upright folds or overfolded to the SW, accompanied by crenulation cleavage.</td>
</tr>
</tbody>
</table>

## Hercynian Regional Metamorphism

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 peak is attained between deformation phases D1 and D2 or during D3.

## Hercynian Plutonism

Small scarce granitic (sensu lato) stocks of the calc-alkaline, post-tectonic type.

Most of this sub-zone is in the greenschist facies. Low pressure amphibolite facies is locally developed and becomes more and more important towards the N.E.

Large batholiths and medium-sized massifs as follows:
- Lower Carboniferous: scarce synerogenic peraluminous leucogranites.
- Upper Carboniferous: numerous late-stage massifs of biotite granite, two-mica granite and biotite-cordierite granite.

Most of the zone is in the greenschist facies. Low pressure amphibolite facies is locally developed 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.

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.

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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 Tournaissian–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 placed 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 MESTEA

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 (Ellenberg and Tamain, 1980) or the Saxo-Thuringian Zone (Jullivet 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>
<thead>
<tr>
<th>SAMPLES LOCATION</th>
<th>LITHOLOGY</th>
<th>SAMPLES LOCATION</th>
<th>LITHOLOGY</th>
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<tr>
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<tr>
<td><strong>H 78 - 23</strong></td>
<td>Strongly cataclasised biotite-bearing granodiorite, with development of chlorite and epidote at the expense of primary biotite and plagioclase.</td>
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<td>Slightly deformed muscovite-biotite leucogranite.</td>
</tr>
<tr>
<td>- Univ. Paris VI - NW Slope of Galicia Bank</td>
<td>43°04'N - 12°27'W</td>
<td>3900 - 3200 m water depth</td>
<td>- Catedasised biotite-bearing granodiorite, similar to that of H78 - 23.</td>
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<tr>
<td><strong>L 74 - 251</strong></td>
<td>Porphyritic, monzonitic granites with biotite and muscovite, slightly cataclasised and chloritized. One sample contains garnet and sillimanite.</td>
<td></td>
<td>Fine-grained sericite schist with chlorite and green biotite, similar to Ordovician mainland outcrops.</td>
</tr>
<tr>
<td>- Univ. Paris VI - NW Slope of the Galicia Bank</td>
<td>43°12'N - 12°10'W</td>
<td>3000 - 2600 m water depth</td>
<td>- Sericite phyllite with chlorite and oligoclase, similar to Shariar mainland outcrops.</td>
</tr>
<tr>
<td><strong>C 56 - 07</strong></td>
<td>Two-mica, porphyritic granites identical to those in L 74 - 251. Fine-grained micaschists with abundant biotite. Large porphyroblasts of biotite and muscovite are identical to those in L 74 - 261. Green tourmaline.</td>
<td></td>
<td>Red sandstones with carbonate cement, feldspar-poor with mica and kaolinite. Similar to Stephanian-Austinian formations on land of the Bucaco type.</td>
</tr>
<tr>
<td>- CNEXO - NW Slope of the Galicia Bank</td>
<td>43°10'N - 12°00'W</td>
<td>1500 - 1800 m water depth</td>
<td>- Undeformed greywackes and lithic sandstones with abundant clay-rich matrix. Similar to Permo-Carboniferous outcrops on land.</td>
</tr>
<tr>
<td><strong>C 56 - 02</strong></td>
<td>Serpentinite with characteristic &quot;mesh&quot; of olivine.</td>
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</tbody>
</table>
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 Castillian 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; saasz = South Armorican Shear Zone; pal = Petite Sole lineament; chl = Cordoba-Badajoz-Tomar lineament; ptl = Porto-Tomar lineament; pal + chl + ptl = Porto-Badajoz-Cordoba suture; crl = 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).

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 Rhen-Hercynian Zone by a metamorphic belt (Vai and Coccozza, 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 Rhen-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 Théic 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 (Perrout 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 Rhec Ocean suture (Matte, 1986), or a 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 employed 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 Théic 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 invoked by 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 Rhen-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 dependent on large-scale cylindrical arrangements than previous models.

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