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The Armorica 'microplate': fact or fiction? Critical review of the concept and contradictory palaeobiogeographical data

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Abstract

The problem of an 'Armorica microplate', detached from Gondwana and having had during part of the Palaeozoic an independent latitudinal evolution, is reconsidered in terms of a critical review of the palaeomagnetic data that were the very roots of this concept and through an alternative approach based on palaeoclimatic and palaeobiogeographical data. Palaeomagnetic data for the Silurian and the Devonian of the south European regions supposedly constituting the Armorica microplate remain rare and ambiguous. Those from Gondwana are more numerous but contradictory enough to give rise to diverging models regarding the latitudinal evolution of this continent. Consequently, the reality of an Armorica microplate cannot be considered as established. On the contrary, lithological indicators of palaeoclimate and palaeobiogeographical data are in total harmony and indicate that, in actual fact, the southern European regions remained permanently closely connected with Gondwana, of which they composed the northern margin. Although repeatedly maintained for more than 20 years, the concept of an Armorica microplate can thus be considered a fiction. This conclusion should lead to the dismissal of geodynamical models proposed for the Variscan Belt to which this concept was integrated and are contradicted by inescapable palaeobiogeographical constraints.

Keywords: Palaeozoic; palaeogeography; Armorica microplate; palaeomagnetism; palaeobiogeography; Variscan belt

1. Introduction

For more than 30 years it has been established that during the Early Palaeozoic and especially the Ordovician Period, the palaeogeography of the present-day peri-Atlantic regions (Fig. 1) comprised three major continents, Laurentia, Baltica and Gondwana, situated in different latitudes and separated by the Iapetus and Rheic oceans. Subsequently, a more complex palaeogeographical configuration has been proposed, with intervening microplates whose evolution was supposedly independent of that of the major continents.

The Armorica microplate concept is especially important because, quite apart from pure palaeogeographical problems, reconstruction and geodynamical evolution proposed for the Variscan (= Hercynian) Belt of SW Europe vary greatly, depending on whether it is accepted or not.

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The aim of the present paper is: (1) to propose a critical review of the palaeomagnetic data from which the concept of an Armorica microplate originated and persisted, (2) to restate the sedimentary and palaeontological data, frequently ignored or underestimated, that contrast sharply with this concept, and (3) to study the implications of this concept for the understanding of the Variscan Belt in SW Europe.

2. The concept of the Armorica microplate

The existence, in Ordovician palaeogeography, of three major continents, Laurentia, Baltica and Gondwana (Fig. 1), was originally based on distinct faunal provinces, characterised by proper benthic faunas (especially trilobites and brachiopods) inhabiting the epicontinental marine shelves (Spjeldnaes, 1961; Whittington and Hughes, 1972; Williams, 1973, a.o.). The proper characteristics of these benthic faunas, the differences in lithologies and biodiversity, allowed a rough estimation of their respective latitudes (Spjeldnaes, 1961; Webby, 1984; Scotese and Barrett, 1990; Witzke, 1990), which were subsequently corroborated by palaeomagnetic data (see references in Van der Voo, 1993).

Fig. 1. Ordovician palaeogeography of the present-day peri-Atlantic regions (after Cocks and McKerrow, 1993, simplified).

Some years before the formal definition of the Armorica microplate (Van der Voo, 1979, 1982), several authors had already suggested the possible existence of microplates in the pre-Variscan palaeogeography of SW Europe. These various models shared the view that all or part of southern Europe constituted an autonomous palaeogeographical unit, sandwiched between Gondwana and northern Europe (Baltica and later Laurussia), from which it was separated respectively by a 'Proto-Mediterranean' or 'Tethys' Ocean to the south, and a 'Saxo-Thuringian' or 'mid-European' Ocean to the north (Laurent, 1972; Johnson, 1973; Riding, 1974; Badham and Halls, 1975; Lorenz, 1976; Badham, 1982). However, this hypothesis did not become very popular until it was revived by palaeomagnetic arguments which apparently made it much more credible for a large number of geoscientists.

The concept of a microplate or microcontinent Armorica, including southwestern England and Wales, the different regions of Variscan Europe and probably also the Avalon peninsula and New England, was based originally on palaeomagnetic data (Van der Voo, 1979, 1982; Jones et al., 1979). For the Late Proterozoic and the Cambrian, the palaeomagnetic data from the regions included in the microplate Armorica were similar to those from Gondwana, which showed that both were closely associated. Similar results were later obtained for the Ordovician (see references in Perroud et al., 1984a). Conversely, the palaeomagnetic data for the Late Devonian indicated that Armorica and Gondwana were in different latitudes and that Armorica was at that time juxtaposed with or very close to the southern border of Laurussia (= Euramerica) that included northern Europe. It thus appeared that, between the Ordovician and the Late Devonian, Armorica had moved independently in latitude, which justified the status of microplate.

The palaeogeographical organisation of both the earliest and the latest Palaeozoic did not pose important problems. On the other hand, the palaeogeographical evolution during the Late Ordovician, the Silurian and the Devonian remained much more enigmatic. The scarcity of palaeomagnetic data for these periods and the ambiguity of some of them allowed various interpretations and scenarios.

Some authors considered that Armorica had detached from Gondwana and had drifted northwards on its own; in this interpretation Gondwana had later followed a similar evolution, to join Armorica during the Carboniferous, after closure of the ocean that had separated them. The time schedule of these events remained uncertain, the collision of Armorica and Laurentia being placed either in the Late Ordovician (Van der Voo, 1979) or in the Devonian (Van der Voo et al., 1984).

For some others, Gondwana and Armorica had first drifted northwards as a whole and joined the southern border of Laurussia (Laurentia+Baltica). They had then separated, Armorica holding its position whereas Gondwana retreated southwards, this second phase being accompanied by the opening of a 'proto-Tethys' ocean between Armorica and Gondwana. Finally, Gondwana had moved northwards again to join the palaeogeographical units already assembled to form the Late Palaeozoic Pangea. In the type of illustration favoured by the palaeomagnetists, this complex evolution corresponds to the 'loops' that appear in the apparent polar wander path (APWP) of Gondwana.

However, all the proposed scenarios supposed that Armorica and Gondwana had been separated by a wide ocean at some period of the Palaeozoic.

The geographical extent of the Armorica microplate was subsequently reduced, owing to the distinction of Avalonia (Fig. 1), a microplate defined first on palaeontological arguments (Cocks and Fortey, 1982, 1990) and later on palaeomagnetic data (see references in Van der Voo, 1993; Bachtadse et al., 1995). The regions constituting Avalonia, i.e. northern Germany, Belgium, England, Wales and southern Ireland (= Eastern Avalonia), together with eastern Newfoundland, Nova Scotia, New Brunswick and eastern New England (= Western Avalonia) were originally included in the Armorica microplate (Van der Voo, 1979), although some had considered they were a southwestern extension of Baltica (Hughes et al., 1975).

According to Cocks and Fortey (1982, 1990), Avalonia was part of Gondwana until the early Ordovician; it detached from this major continent during the Ordovician, with opening of the Rheic Ocean, and moved northwards to join Baltica, with closure of the Tornquist Sea (= Tornquist's Ocean), either at the end of this period or in the Early Silurian (Cocks et al., 1997). This implied that the Armorica microplate sensu stricto should be restricted to the Variscan regions of southern and central Europe (Van der Voo, 1988).

3. Critical review of basic palaeomagnetic data

A well-argued discussion of the concept of the Armorica microplate necessitates a review of the middle Palaeozoic palaeomagnetic data, both from Gondwana and from southern European Variscan regions, from which the autonomy of Armorica was inferred.

First, it must be noted that the palaeogeographical conclusions derived from palaeomagnetic data are generally adopted without any reservation by those who make use of them to support geodynamical models. This is all the more surprising because most of the publications at the root of such palaeogeographical interpretations indicate clearly that ambiguities and problems exist and that the proposed conclusions are the result of a choice or a 'preference' between different hypotheses (see a.o. Scotese and McKerrow, 1990; Van der Voo, 1993).

3.1. Gondwana: Silurian and Devonian palaeomagnetic data

3.1.1. Silurian

The basic and crucial data for the Silurian come from igneous rocks of the Aïr region that are part of a long series of igneous complexes extending through Niger and Nigeria. Some of these rocks, dated at ca 435 Ma, contain a complex magnetisation with a component, considered 'primary' and of Early Silurian age, that gives a South Pole position in southern Chile and places North Africa in tropical latitudes (Hargraves et al., 1987; Van Houten and Hargraves, 1987; AIR in Fig. 2). This implies that, in the 'middle'

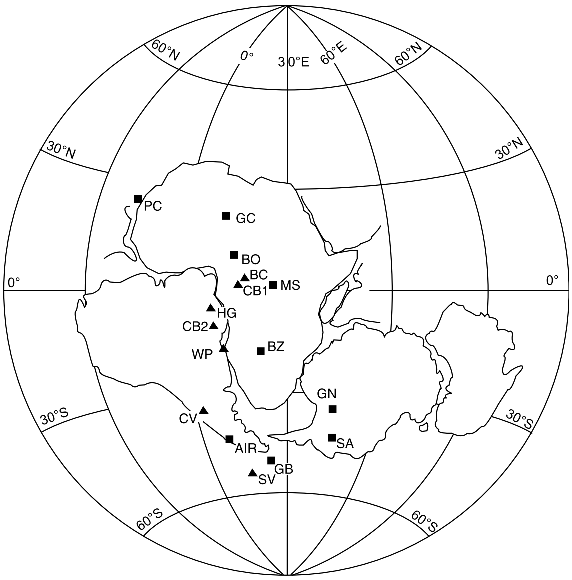

Fig. 2. Late Ordovician through Late Devonian palaeopole positions deduced from African (dots) and Australian (triangles) palaeomagnetic data (see references in the text). Gondwana reassembly after Bachtadse and Briden (1990). Symbols: AIR, Aïr; BC, Brewer Conglomerate; BO, Bokkeveld Group; BZ, Ben Zireg; CB1 and CB2, Canning Basin; CV, Comerong Volcanics; GB and GC, Gilif Hills; GN, Gneiguira; HG, Hervey Group; MS, Msissi norite; PC, Pakhuis–Cedarberg formations; SA, Sabakola; SV, Snowy River Volcanics; WP, Worange Point Formation.

Palaeozoic, North Africa was in latitudes similar to those of the southern border of Baltica. This model has been widely reproduced in subsequent palaeogeographical syntheses, although it supposes an extraordinarily high plate velocity (25–40 cm/yr, according to various authors) totally unknown in the recent periods, and despite the similar position of Africa in the Carboniferous–Permian (Bachtadse and Briden, 1991).

It can also be noted that Bachtadse et al. (1987) have studied sedimentary rocks slightly older, i.e. of latest Ordovician age, in the western Cape Fold Belt of South Africa. The study of the Pakhuis and Cedarberg Shale formations suggests a pole position in westernmost North Africa (PC in Fig. 2), at a large distance from that deduced from the Aïr (Bachtadse et al., 1987, figure 13). This would imply either an enormous and very fast latitudinal change of Gondwana between the latest Ordovician and the Early Silurian or an erroneous interpretation of the age of the magnetisation observed in the Aïr.

Moreover, Moreau et al. (1994) have recently published new geochronological data on the Aïr igneous complexes that give a radiometric age of ca 410 Ma, corresponding to the Silurian–Devonian boundary. With this revised age, the Aïr palaeopole position in southern Chile is rather close to the palaeopole obtained by Schmidt et al. (1987; see below) from the Lower Devonian Snowy River Volcanics of SE Australia (pole SV in Fig. 2).

3.1.2. Devonian

For more than 20 years, the Late Devonian latitudinal position of Gondwana has been based on the palaeomagnetic data obtained from the Msissi norite in Morocco (Hailwood, 1974). This fundamental reference (pole MS in Fig. 2) was ruled out when it was established that the age of the rock was in fact close to 140 Ma and that no component of its magnetisation could thus correspond to the Devonian (Salmon et al., 1986). However, a localisation of the Devonian South Pole in Central Africa was maintained on the basis of palaeomagnetic data obtained mainly from Australia, and also from Africa.

With regard to the Australian data, several problems exist, related (1) to possibly conflicting results obtained in different parts of the Lachlan Fold Belt of SE Australia, and (2) to their representativeness for Gondwana as a whole after reassembly of the southern continents.

3.1.2.1. SE Australia. The Early Devonian Snowy River Volcanics contain a multicomponent magnetisation with a pre-folding component regarded as acquired during the initial cooling of these rocks. The corresponding Early Devonian palaeopole (SV in Fig. 2) lies SSW of the southern extremity of South America (Schmidt et al., 1987).

The Comerong Volcanics of late Middle to early Late Devonian age (ca 370 Ma) were studied by Schmidt et al. (1986). In spite of the difficult study of the complex magnetisation and of the somewhat different behaviour of samples during demagnetisation processes, Schmidt et al. (1986)

considered that the palaeopole corresponding to the pre-folding component was situated west of southern Argentina (CV in Fig. 2) and was a key pole position for Gondwana as a whole in the Middle–Late Devonian.

Famennian red sandstones of the Hervey Group have yielded a magnetisation component that indicates a pole position either at the western limit of Central Africa (Li et al., 1988, figure 8) or in westernmost Brazil (Bachtadse and Briden, 1990, figure 1), depending on the model used for reassembly of the southern continents. This pole position (HG in Fig. 2) is clearly distinct from that proposed by Schmidt et al. (1986) for a slightly older period (see above). As no fold test was possible in the Hervey Group, the age of the magnetisation, according to Li et al. (1988), could possibly be Early Carboniferous.

The magnetisation of the red sandstones of the Late Devonian Worange Point Formation is dominated by a component that post-dates the mid-Carboniferous folding. However, about one-third of the samples studied by Thrupp et al. (1991) also contain a component that seems to be pre-folding although a fold test is not clearly conclusive. The corresponding pole position (WP in Fig. 2) is rather close to that obtained by Li et al. (1988) from the Famennian rocks of the Hervey Group (HG in Fig. 2).

3.1.2.2. Cratonic Australia. Some results have been also obtained from Devonian rocks of the stable craton of NW Australia, specifically from the Frasnian and Famennian reefal limestones of the Canning Basin (Hurley and Van der Voo, 1987). These results indicate a palaeopole position in central Africa (CB1 in Fig. 2). However, in the absence of a fold test, the age of the characteristic magnetisation could be chemical and Early Carboniferous rather than depositional and Late Devonian (see Schmidt et al., 1987, pp. 146–147; 1990, p. 94). Chen et al. (1995) have reinvestigated various lithofacies of these limestones. Their conclusions are that the characteristic component of magnetisation is of primary origin and that the resulting pole position (CB2 in Fig. 2) is rather close to the Late Devonian palaeopole positions obtained from SE Australia and overlaps that obtained originally by Hurley and Van der Voo (1987).

Later on, the upper part (Undandita Member) of the Brewer Conglomerate from central Australia was studied by Chen et al. (1993). These rocks are dated as late Famennian, very close to the Devonian–Carboniferous boundary (ca 355 Ma), by spore assemblages. The samples collected from cores previously drilled in the northeast of the Amadeus Basin contain a multicomponent magnetisation. One component is interpreted as drilling-induced; the second one, found only in four samples from a single core, could be a mid to Late Carboniferous overprint; the third one, considered primary and of latest Devonian–earliest Carboniferous age, gives a pole position (BC in Fig. 2) in Africa, close to the pole CB1 obtained by Hurley and Van der Voo (1987) from the Canning Basin.

3.1.2.3. Africa. African data come from South Africa, Sudan, Algeria and Mauritania.

In the Western Cape Fold Belt of South Africa, Bachtadse et al. (1987) studied brown and red sandstones from the Bokkeveld Group, considered to be Early to Middle Devonian, probably Middle Devonian as the overlying beds of the Witterberg Group have yielded Givetian fossils. Only a small percentage of the samples studied (13 out of 119) from a single site (out of 17), gave a magnetisation component different from the present-day field direction. Although the corresponding pole, situated in Central Africa (BO in Fig. 2), is not far from that deduced from the Canning Basin, the Bokkeveld data are of rather poor quality (Bachtadse and Briden, 1991, p. 637) and the deduced pole should not reasonably be considered as truly conclusive.

In the Gilif Hills of the Bayuda Desert (northern Sudan), Bachtadse and Briden (1991) have studied acidic intrusive and effusive rocks of mid-Devonian age (377 Ma, Rb/Sr). One of the three components of magnetisation observed is considered to be a Carboniferous overprint that gives a pole position to the south of South America (GB in Fig. 2). Another component was supposedly acquired during or shortly after the closure of the Rb/Sr system and would be representative for the Middle Devonian. This component, recognised in 11/18 sites and 39/114 samples, indicates a pole position in southwestern Libya (GC in Fig. 2). However, it must be noted that these results are not constrained by fold tests and come from a region where at least five pronounced episodes of volcanic activity occurred between 574 and 157 Ma, as mentioned by Bachtadse and Briden (1991, p. 638). More recently, Chen et al. (1993) have suggested a reverse interpretation for these results and considered that (1) magnetisation GC originally interpreted as primary would rather be an Early Carboniferous overprint, and conversely that (2) the magnetisation interpreted as a Carboniferous overprint could be primary, the corresponding pole GB being situated between the Early Devonian Snowy River Volcanics pole (SV) and the early Late Devonian Comerong Volcanics pole (CV).

Famennian 'griotte' limestones from Ben Zireg in the northern part of the Béchar Basin (Algeria) have been studied by Aïfa et al. (1990). In addition to a syn- or post-folding component of magnetisation, these authors have observed a prefolding component corresponding to a pole position in southern Africa that places North Africa at a latitude of ca 35°S. This pole (BZ in Fig. 2) differs strongly from the pole position in Central Africa proposed by the above-mentioned studies. Curiously, this pole BZ is mentioned very rarely in more recent publications, although it is rated as high-quality ('quality factor' $Q = 6$ in Van der Voo, 1993, table A4).

Kent et al. (1984) have investigated Early–Middle Devonian reddish sandstones of the Gneiguira Supergroup from the westernmost part of the Taoudeni Basin (Mauritania). The magnetisation component considered 'characteristic' corresponds to a pole position to the east of South Africa (GN in Fig. 2) and places the northern part of this continent in low latitudes (ca 20°S). However, Kent et al. (1984) considered that this component could be a Carboniferous remagnetisation. This was also noted by Kent and Keppie (1988, p. 474), although they favoured the other interpretation. Van der Voo (1988, p. 318) considered that this pole should not be used for the Devonian, an opinion apparently shared by Kent and Van der Voo (1990), who did not maintain this reference in their list of selected poles for Gondwana.

Soffel et al. (1990) published a complete revision of the palaeomagnetic data obtained from the Sabakola ring complex of northern Sudan. Several isotopic studies (K/Ar and Rb/Sr) of different rocks of the complex have given various ages (see references in Soffel et al., 1990, p. 413), but it was considered that they point to an Early to Middle Devonian age. The component of magnetisation considered 'primary' indicates a pole position (SA in Fig. 2) to the southeast of South Africa, i.e. not far from the Gneiguira pole of Kent et al. (1984), but also conspicuously close to the Permo–Carboniferous South Pole. Moreover, Soffel et al. (1990) did not exclude the possibility that this component of magnetisation could be Early to Middle Carboniferous, and this pole was excluded for the Devonian by Van der Voo (1993, table A4).

3.1.3. Checkup of the palaeomagnetic data for Gondwana

When an attempt is made at compiling a synthesis of the Devonian palaeomagnetic data set for Gondwana, it seems virtually impossible for a non-specialist to make a selection of the most reliable data, even after careful reading of the original publications. Almost every study includes some uncertainties, most frequently concerning the complex structure of the magnetisation and the precise age of the 'characteristic', 'primary', component that is at the basis of the pole position proposed. It can also be noted that this complexity and these uncertainties, although generally mentioned, are not very precisely documented in synthetic and review papers. However, it has been repeatedly noted by most palaeomagnetists (e.g. Van der Voo, 1993; Bachtadse et al., 1995; Tait et al., 2000) that the APWP for Gondwana during mid-Palaeozoic times, i.e. the drift history of this huge continent, is insufficiently resolved and still remains a controversial matter of debate.

All models agree that the South Pole was within, or close to, NW Africa in the Ordovician, and in Antarctica by the Late Carboniferous–Early Permian. The problems concern the intervening mid-Palaeozoic times, and, essentially, two contrasting models are proposed. The first one considers a regular and steady northward drift of Gondwana from the Late Ordovician up to the Carboniferous, which translates into a simple APWP for Gondwana ('Path X'; see Fig. 3). The alternative model is much more complex and implies a northward movement (Ordovician to Late Silurian–Early Devonian), followed by a southward 'retreat' (Early Devonian to Late Devonian–Early Carboniferous), and, finally, a northward drift (during the Carboniferous). This model translates into a complex APWP for Gondwana ('Path Y'; see Fig. 3) characterised by two hair-pin loops.

In the 1990s, the more complex model was favoured by most palaeomagnetists (e.g. Bachtadse and Briden, 1990; Kent and Van der Voo, 1990; Van der Voo, 1993), although it required very high drift rates and two drastic changes in the movement of the Gondwana plate. More recently, the hypothesis of a steady northward drift of Gondwana and a simpler model (similar to 'Path X') have regained more advocates (Bachtadse and Briden, 1991; Bachtadse et al., 1995; and especially Tait et al., 2000), who take account of the probable Early Devonian age of the Aïr palaeopole and consider that the data set from SE Australia should not be used to define the APWP for Gondwana as a whole. However, a pole position in Central Africa is maintained for the whole Devonian period (Tait et al., 2000, figure 3) on the basis of the palaeomagnetic results obtained from cratonic Australia and from Sudan.

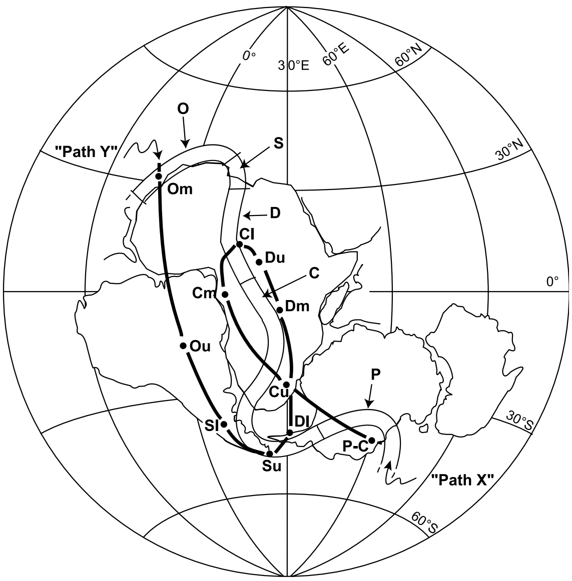

Fig. 3. Late Ordovician through Late Devonian palaeomagnetically derived APWPs for Gondwana. Black curve: 'path Y' after Bachtadse and Briden (1990). Double-lined curve: 'path X' after Bachtadse and Briden (1991), Tait et al. (2000) (see references in the text). Abbreviations: O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; l, lower; m, middle; u, upper.

3.2. Armorica: Silurian and Devonian palaeomagnetic data

3.2.1. Silurian

For the Silurian period, the only palaeomagnetic data for SW Europe come from Spain in the Iberian Peninsula.

Basaltic lavas interstratified within the Llandovery graptolitic black shales of the Almadén syncline of the southern Central Iberian Zone have yielded a pre-folding magnetisation considered to be of Early Silurian age. It indicates that the Iberian Peninsula and thus Armorica were in tropical latitudes at that time (Perroud et al., 1991), which fits well with the Aïr pole. However, as already noted by Perroud et al. (1991), the problem of plate velocity arises, as the Armorica microplate should have moved from relatively high latitudes in the latest Ordovician (Hirnantian glaciomarine deposits) into the tropical latitudes suggested for the Llandovery. It has been shown later that this magnetisation was in fact a pre-folding remagnetisation of Late Devonian or Early Carboniferous age (Parès and Van der Voo, 1992).

In the Cantabrian Zone, red beds of the San Pedro Formation (close to the Silurian–Devonian boundary) have also yielded a pre-folding component of magnetisation that corresponds to a palaeolatitude of ca 20°S (Perroud and Bonhommet, 1984). However, despite a positive fold test, the age of this component is loosely controlled and could correspond to any time between the Silurian–Devonian boundary and the middle Carboniferous (see discussion in Van der Voo, 1993; Van der Voo et al., 1997).

Tait et al. (1994) have studied Late Silurian (late Wenlock to late Pridoli) rocks from the Barrandian Basin of central Bohemia (Czech Republic). In addition to a present-day overprint (component A), they isolated two distinct components of magnetisation. The first one (component B) is post-folding and corresponds to the Late Carboniferous pole position for stable Europe. The other one (component C) passes a fold test and is interpreted as representative of the Late Silurian latitudinal position (23°S) of Bohemia. Their conclusion is that this part of the Armorica microplate should thus be adjacent to the southern border of Laurussia during the late Wenlock–late Pridoli time interval. However, Tait et al. (1994) noted that these results would imply large-scale (140°) anticlockwise rotation of the Bohemian Massif before acquisition of the post-folding B component. In addition, it can be noted also that (1) only just half of the studied sites (eight out of 21) and samples (48 out of 106 for B, 56 out of 111 for C) could be used to obtain the mean palaeopoles, and (2) apparently there was no significant difference in the site means with respect to the age of the rocks studied when the late Wenlock–late Pridoli time interval was long enough to allow recording of latitudinal evolution.

3.2.2. Devonian

Tait (1999) reported palaeomagnetic results, from well dated Lower Devonian limestones (L'Armorique Formation, Lochkovian–lower Praguian) of the westernmost Armorican Massif, which she considered indicative of a very low latitude (19°S) for this part of the Armorica microplate. However, in the absence of any fold test, the only control of the age of the magnetisation being a contact test with a dyke whose precise age is unknown, Tait's interpretation can hardly be accepted at face value, and it is most probable that these data correspond to a Carboniferous remagnetisation (see more complete discussion in Robardet et al., 2001).

Tait and Bachtadse (2000) have recently studied the palaeomagnetism of well dated latest Silurian to Early Devonian limestones from two localities of the Eastern Pyrenees (EP) and the Catalonian Coastal Ranges (CCR) in NE Spain (Rueda Formation, La Creu and Olorda formations, respectively). These limestones contain a multicomponent magnetisation. The first component (A) is a present-day overprint. The second component (B), identified only in the CCR, is post-folding but its age remains uncertain and could be either Late Carboniferous or Early Triassic. The third component (C) is present both in the EP and CCR. A fold test is not totally significant but suggests a pre-folding age, which is also supported by a positive 'regional' fold test when the data from the two regions are combined. This component C corresponds to a pole position that places the CCR and EP at a latitude of about 30°S in the latest Silurian–Early Devonian. This is considered by Tait and Bachtadse (2000) as similar to the results obtained from the Lower Devonian of the Armorican Massif (Tait, 1999) and the Upper Silurian of Bohemia (Tait et al., 1994). However, it must be noted, as already mentioned by Tait and Bachtadse (2000, p. 23 600), that this component C could alternatively be a Cretaceous or more recent overprint. It is not surprising that such difficulties of interpretation are encountered in those regions of the Variscan Belt where a more recent Meso–Cenozoic tectonic development occurred, and it seems rather curious to have selected these regions for testing the palaeogeographical position of the Iberian Peninsula in Late Silurian–Early Devonian times.

The palaeomagnetic results obtained in the Montmartin syncline (Normandy, Armorican Massif) from the red beds of the Hyenville Formation (Jones et al., 1979) were at the very root of the Armorica microplate concept. These red beds, at that time considered Upper Devonian, had yielded a nearly univectorial magnetisation corresponding to very low latitudes (about 8°S). This magnetisation was similar to the post-folding component obtained from Cambrian and lower Ordovician rocks in the same region (Jones et al., 1979; Perroud et al., 1982). However, due to misappreciation of the geological evolution of the region, especially of the Carboniferous age of the folding, and despite the absence of a fold test, this magnetisation was considered representative for the Armorican Massif in the Late Devonian. The corresponding low latitude was similar to that of northern Europe and very different from that of Gondwana, which gave rise to the concept of the Armorica microplate.

It was later demonstrated, by a negative fold test, that this magnetisation was younger than the Carboniferous folding of the Montmartin syncline, and, additionally, that there were no data proving a Late Devonian age for the Hyenville Formation, which should be considered most probably Early Ordovician in age (Perroud et al., 1984b).

The magnetisation observed in metamorphosed volcanic rocks (dated Late Devonian: 379–355 Ma) of southern Limousin in the French Massif Central (Edel, 1987) corresponds to a rather high latitude, but these data from a region where metamorphism was important cannot be interpreted easily (see discussion in Bachtadse et al., 1995).

Non-metamorphic and very low-grade metamorphic sedimentary and volcanic rocks of Middle to Late Devonian and Early Carboniferous ages have been studied in the Harz Mountains, the Franconian Forest and the southern Vosges (Bachtadse et al., 1983, 1995). These rocks are situated within three distinct 'zones' of the Variscan Belt, that are the Rheno-Hercynian, Saxo-Thuringian and Moldanubian zones, respectively. The pre-folding palaeomagnetic data indicate similar low latitudes of about 13°S for the three regions in the Middle–Late Devonian. Bachtadse et al. (1983, 1995) concluded that, at that time, the drift history of Avalonia and Armorica had come to an end and that they were already assembled with Laurussia.

3.2.3. *Checkup of palaeomagnetic data for Armorica*

This critical review shows that uncontroversial palaeomagnetic data for the Silurian and the Devonian of the Variscan regions of southern and central Europe, that constituted the so-called Armorica microplate, are very rare, not to say missing. Armorica is now considered generally as a complex collage of terranes (the 'Armorican Terrane Assemblage'; see references in Franke et al., 2000), this assumption being supposedly supported by the palaeomagnetic results obtained in Late Silurian and Early Devonian rocks from Bohemia, NE Spain and the Armorican Massif. In fact, neither the composite character of Armorica, nor its breakoff from Gondwana and its independent latitudinal evolution, can be considered convincingly demonstrated by the existing palaeomagnetic results. This is because (1) the age of the magnetisations observed in NE Spain and in the Armorican Massif remains ambiguous, which makes any comparison with those from Bohemia fruitless, and (2) the drift history of Gondwana during the Silurian and the Devonian still remains obscure.

4. Palaeoclimatically based geography and palaeobiogeography

An alternative approach to palaeogeographical evolution can be based on sedimentary and faunal characteristics which allow identification and delimitation of distinct palaeogeographical units and estimation of their palaeolatitudes.

Some lithofacies are indicators of palaeoclimate and thus of palaeolatitude (e.g. Webby, 1984; Scotese and Barrett, 1990; Witzke, 1990) and can be used to estimate the latitudinal evolution of a region or a larger unit.

Benthic faunas allow evaluation of the respective relations and proximity of palaeogeographical units, which is not possible with palaeomagnetical data that do not provide any constraint on longitude. The benthic faunas that lived on the epicontinental marine shelves had limited dispersive abilities (only through their pelagic larvae) and generally could not cross wide and deep oceanic areas. They are therefore especially important in characterising the different marine shallow-water shelves, in evaluating their proximity or distance, and in evidencing the 'faunal barriers' that controlled the geographical distribution of the palaeobenthos (e.g. Cocks and Fortey, 1982, 1990; Paris and Robardet, 1990).

Due to their important dispersive abilities, pelagic and planktonic organisms are mainly used for precise biostratigraphical control, but they can also be helpful for palaeogeography because their geographical distribution was controlled by sea-water temperature and latitude (e.g. Cocks and Fortey, 1982; Paris, 1993).

On the basis of sedimentary and faunal data, it is therefore possible to reconstitute the respective pre-Carboniferous latitudinal evolution of Gondwana and Armorica, and to clarify the problem of their relationship.

4.1. *Lithofacies indicators of palaeolatitudes*

4.1.1. *Ordovician*

On the North African part of Gondwana, the almost total absence of carbonates during the Ordovician (except bryozoan biostromes of Ashgill age in Libya and Morocco), the overall terrigenous composition of the sediments, and the glaciomarine deposits of the latest Ordovician (Hirnantian) related to the continental glaciation developed in Africa, indicate that the North Gondwanan regions were situated in high latitudes during the whole Ordovician period.

The same conclusions can be drawn for southern European Variscan regions, where the Ordovician successions are of the same type and include in their uppermost part glaciomarine deposits strictly equivalent to those of North Africa (Robardet and Doré, 1988). In these Variscan regions, the only episode of carbonate sedimentation occurred in the early–middle Ashgill, with bryozoan and pelmatozoan limestones considered to be temperate- or cold-water carbonates (Prasada Rao and Jayawardane, 1994; Vennin et al., 1998).

4.1.2. *Silurian*

During the Silurian, the anoxic sediments that characterise both North Africa and southern Europe are not by themselves latitude indicators. However, considering the rather short duration of this period and the high latitudes in the Late Ordovician, it seems highly improbable that any part of these regions might have reached low latitudes during the Silurian. This is corroborated by the absence or scarcity of carbonate deposits in North Africa and southern Europe when, at the same time, these lithofacies developed (Bassett, 1989; Bassett et al., 1989) in Avalonia and Baltica (Wales, Gotland, Estonia, Podolia). In southern Europe, the first carbonates appeared locally in the Wenlock and their importance increased in the Ludlow and the Pridoli in the areas (Pyrenees, Catalonia, Montagne Noire) situated in the northern distal part of the shelf (see Robardet et al., 1994; Gutiérrez-Marco et al., 1998). At that time they were still missing in the Ibero–Armorican regions situated in the inner shelf and in North Africa (Hollard and Willefert, 1985; Legrand, 1985). It can also be added that brachiopod taxa representative of the cold-water '*Clarkeia* fauna' occur in the Pridoli of the Armorican Massif (Babin et al., 1979).

All these data contrast sharply with the models that place, in the Silurian, North Africa and/or Armorica in low latitudes similar to those of the southern border of northern Europe.

4.1.3. *Devonian*

In the southern European regions, the Lower Devonian successions comprise well developed carbonates, with an increasing importance in the middle and upper parts of the System. This is the case in the Armorican Massif, the Iberian Peninsula, Pyrenees and Montagne Noire (see references in Robardet et al., 1994), and also in the Barrandian area of Bohemia and the Carnic Alps, where the carbonates are more important and reefs more frequent (Chlupac, 1988; Schönlaub, 1993).

These data do not match the models where Armorica is placed in very low latitudes in the earliest Devonian (Tait, 1999). Such models would suppose that Armorica had crossed tropical latitudes during the Silurian, an hypothesis which finds no support in the sedimentary successions of this age. Armorica did not reach relatively low latitudes, favourable to a well developed carbonate sedimentation, before the Devonian.

In North Africa (Moroccan Anti-Atlas, Algerian Sahara, Libya) carbonates remain of minor importance in the Lower Devonian and are not actually well developed before the Middle and Late Devonian (Wendt, 1988; Bitam et al., 1996; Gourvennec et al., 1997; Boumendjel et al., 1997a).

The possible occurrence of glacial or peri-glacial rocks in the Upper Devonian or the Lower Carboniferous of Central Africa has sometimes been considered as supporting a polar position of this region at these times. This assumption was based on Caputo and Crowell's (1985) publication on the migration of glacial centres across Gondwana during the Palaeozoic. Glacial deposits were mentioned in the mid-Famennian of northern South America (Brazil) and it was suggested that similar rocks possibly occurred in Africa, especially in the Agades region of Niger (Caputo and Crowell, 1985, with previous references therein). A recent study rather favours an Early Carboniferous (early Viséan) age for the rocks of the Agades region and suggests that they could correspond to small local icecaps at a latitude of ca 50°S (Lang et al., 1991).

The expansion of carbonate and evaporite sedimentation in the Late Devonian and Early Carboniferous of North Africa is consistent with the steady northward drift of Gondwana and is in conflict with the hypothesis that places the central part of Africa near the South Pole at this time (Witzke and Heckel, 1988).

4.1.4. *Palaeoclimatically derived APWP for Gondwana*

Scotese and Barrett (1990) have established a statistical technique, based on the geographical distribution of lithological indicators of climate (carbonates, evaporites, coals and tillites), to estimate the past position of the geographic pole. This technique was used to obtain a palaeoclimatically derived APWP of the South Pole across Gondwana during the Palaeozoic, established on eight pole positions corresponding to eight time intervals between the Early Cambrian and the Early Permian (Scotese and Barrett, 1990, figure 13). This APWP (Fig. 4) agrees much better with the palaeomagnetic data that place the Devonian South Pole in Argentina than with the results that place it in Central Africa.

In addition, the parallel sedimentary evolution observed in North Africa and in the Variscan regions of southern and central Europe gives no support to the proposal that these regions have been separated at any time between the Late Ordovician and the Late Devonian.

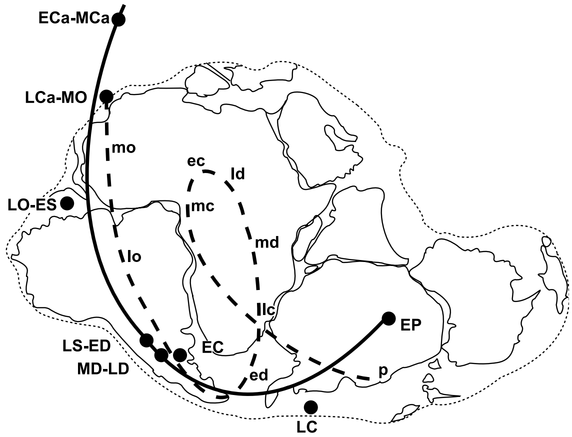

Fig. 4. Ordovician through Permian palaeoclimatically derived APWP for Gondwana (after Scotese and Barrett, 1990, simplified), compared with palaeomagnetically derived path Y (dashed line). Ca, Cambrian; O and o, Ordovician; S, Silurian; D and d, Devonian; C and c, Carboniferous; P and p, Permian; E and e, early; M and m, middle; L and l, late.

4.2. *Faunas and floras*

4.2.1. *Silurian*

In the Silurian successions of both southern–central Europe and North Africa, pelagic organisms dominate the fossil record and do not provide precise palaeobiogeographical data. This is so for the acritarchs, whose patterns of distribution are controlled by latitude, but also by environmental conditions and other factors (Le Hérissé and Gourvennec, 1995; Le Hérissé et al., 1995). However, several Early Silurian (Telychian) graptolite species, such as *Metaclimacograptus asejradi*, *Metaclimacograptus flamandi*, and *Parapetalograptus meridionalis*, are good biogeographical markers for the shallowest areas of the Silurian marine shelf. These species occur in the Central Iberian Zone, in the Iberian Cordillera, as well as in North Africa (Algeria, Libya) and suggest close links between these regions within the inshore areas of the North Gondwanan shelf (Gutiérrez-Marco et al., 1998).

4.2.2. *Devonian*

During the Devonian, sediments deposited in oxygenated environments and their corresponding benthic marine faunas were abundant and diversified, which allows comparisons between various regions of North Africa and Europe and evaluation of their affinities.

4.2.2.1. Armorica–Gondwana relations. The very high values of the coefficients of similarity ($C_S = 0.90$) for Early Devonian (Lochkovian) chitinozoan assemblages preclude any important difference in latitude and also the existence of a wide ocean between the Armorican Massif and the Algerian Sahara. Conversely, these coefficients are much weaker ($C_S = 0.37$–0.48) between these regions and northern Europe (Podolia and Poland) situated at the southern margin of Laurussia (Paris, 1993). This suggests that there was a noticeable difference of latitude for North Gondwana and northern Europe.

It had already been noted that invertebrate benthic faunas (and also vertebrates) from Variscan Europe and North Africa show so many affinities that it is not possible to imagine that they were separated by a wide ocean or any other faunal barrier during the Devonian (Young, 1987, 1990; Morzadec et al., 1988; Paris and Robardet, 1990; Robardet et al., 1990, 1991, 1993; Racheboeuf, 1990). However, these data have generally been ignored or underestimated, and, despite some slight doubts (Van der Voo, 1993, p. 248; Torsvik et al., 1990, p. 38), the concept of an Armorica microplate separated from Gondwana has been maintained by most palaeomagnetists.

More recently, palaeontological investigations have been carried out in the southern flank of the Tindouf Basin (Bitam et al., 1996; Gourvennec et al., 1997) and in the Ougarta Ranges (Boumendjel et al., 1997b; Plusquellec et al., 1997) of the Algerian Sahara, which were unambiguously part of 'stable' Gondwana. They have entirely corroborated and more fully illustrated the strong faunal affinities that existed between Gondwana and southern Europe during the Devonian (Figs. 5 and 6).

The Early Devonian vertebrate record (jawless and jawed 'fishes'; Blieck, 1982; Young, 1987, 1990) shows that: (1) faunas from Laurussia were dominated by actinolepids, pteraspids and cephalaspids; and (2) these groups were absent or very poorly represented in the southern European faunas (Spain, Portugal, Armorican Massif) which are closely similar, in taxonomic composition, to those from Morocco, Algeria and Libya, where the ichthyofauna was dominated by other placoderms, sharks and various acanthodians. These data suggest that southern Europe was part of Gondwana and still separated from Laurussia by a faunal barrier during the Early Devonian. In the Middle and Late Devonian, weaker differences indicate closer proximity between southern Europe–Gondwana and Laurussia and therefore contradict the hypothesis of a wide ocean between Laurussia and Gondwana.

In the Lochkovian, the Pragian and the Emsian, a number of invertebrate benthic fossils occur both in the Saharan regions and in Variscan Europe, especially in the Iberian Peninsula and the Armorican Massif and also, to a lesser degree, in Bohemia (Figs. 5 and 6). This is established for corals, various families of brachiopods, crinoids, trilobites and ostracods (Lethiers and Raymond, 1993; Boumendjel et al., 1997b; Plusquellec et al., 1997; Le Menn, 1997; Plusquellec, 1998; Plusquellec and Hladil, 2001). It must be emphasised that, in many cases, these affinities are established on the occurrence of the same species, which shows the absence of any 'reproductive isolation' within the benthic populations and allows definition of an 'Ibarmaghian Domain' (Plusquellec, 1987) comprising the Saharan regions, the Iberian Peninsula and the Armorican Massif.

4.2.2.2. Armorica–Laurussia and Gondwana–Laurussia relations. It has already been noted that during the Early Devonian the faunal affinities between southern Europe and the southern border of Laurussia increased progressively (Paris and Robardet, 1990; Robardet et al., 1990). During the Pridoli and the Lochkovian, southern European benthic faunas were clearly distinct from those found in northern France (Boulonnais, Artois, Ardenne), in the autochthonous units of the Rhenohercynian Zone (Belgium and Germany) and in all the regions that were at the southern border of the Old Red Sandstone Continent (= Laurussia). At these times there were virtually no species in common and the rare affinities observed concern only a few genera, which

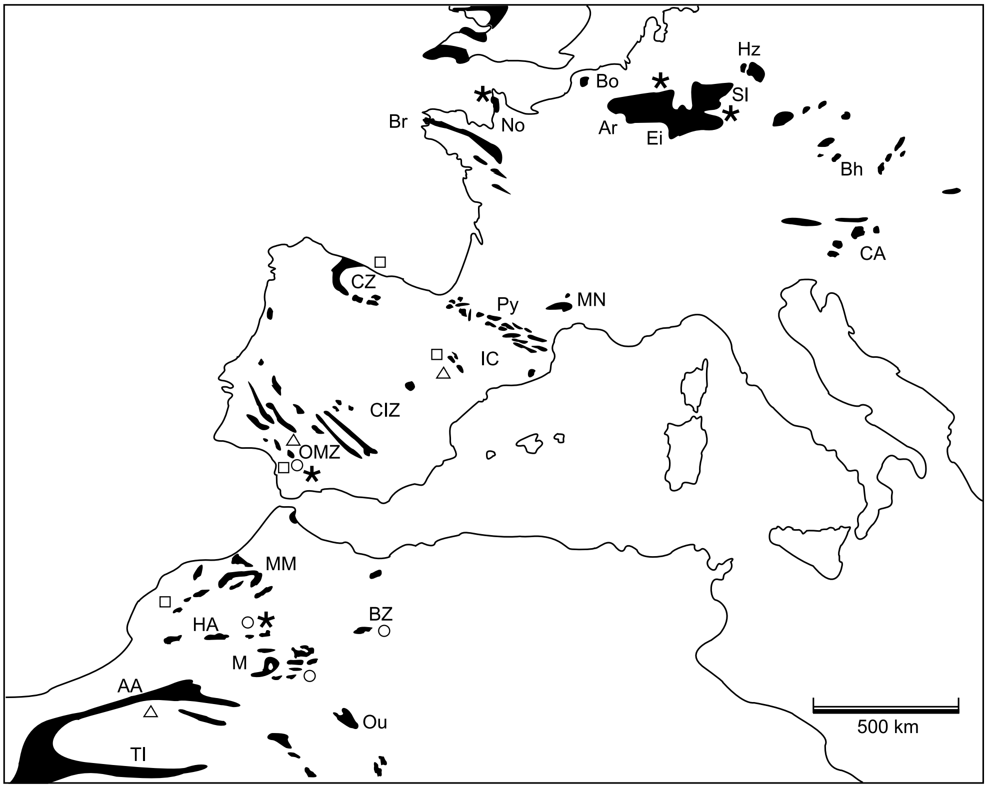

Fig. 5. Geographical distribution of some Early Devonian ostracod and trilobite species (see references in the text). Symbols: asterisks, *Gibba schmidti*; circles, *Phacops* (*Prokops*) *benziregensis benziregensis*; squares, *Metacanthina lips*; triangles, *Treveropyge wallacei*. Geographical key-symbols: AA, Moroccan Anti-Atlas; Ar, Ardenne; Bh, Bohemia; Bo, Boulonnais; Br, Britanny; BZ, Ben Zireg; CA, Carnic Alps; CIZ, Central Iberian Zone; CZ, Cantabrian Zone; Ei, Eifel; HA, Moroccan High Atlas; Hz, Harz; M, Maider; MM, Moroccan Meseta; MN, Montagne Noire; No, Normandy; OMZ, Ossa Morena Zone; Ou, Ougarta; Py, Pyrenees; Ti, Tindouf Basin.

shows that the two areas were still separated by the faunal barrier of the Rheic Ocean. From the Pragian onwards, there was an increasing number of brachiopod, coral, trilobite and crinoid species common to both domains, which strongly suggests that the width of the Rheic Ocean was decreasing (Figs. 5–7).

Through the Middle and Late Devonian, the rugose corals of the 'Eastern Americas Realm' show a decreasing endemism that corresponds to faunal migrations between Laurussia and Africa–southern Europe (Oliver, 1977; Plusquellec et al., 1997).

Studies of Devonian chonetacean brachiopods (Racheboeuf, 1990) have shown that: (1) the identity, at the species level, of Early Devonian faunas from southern Europe and northern Sahara precludes the existence of any faunal barrier between these regions; and (2) during the Middle Devonian, faunal migrations from the 'Eastern Americas Realm' into the Saharan regions do not support at all the hypothesis of a wide ocean between Laurussia and Gondwana. Similar conclusions arise from the geographical distribution of Givetian ostracods (Lethiers and Racheboeuf, 1993).

The benthic faunas from the Meguma terrane of Nova Scotia can also be mentioned. The Upper Silurian faunas of this area had northern European affinities corresponding to a localisation in the southern part of Laurussia. The presence of typical southern European and northern Gondwanan species of trilobites, crinoids and brachiopods in the Lochkovian to early Emsian faunas of Meguma also implies faunal migrations and rela-

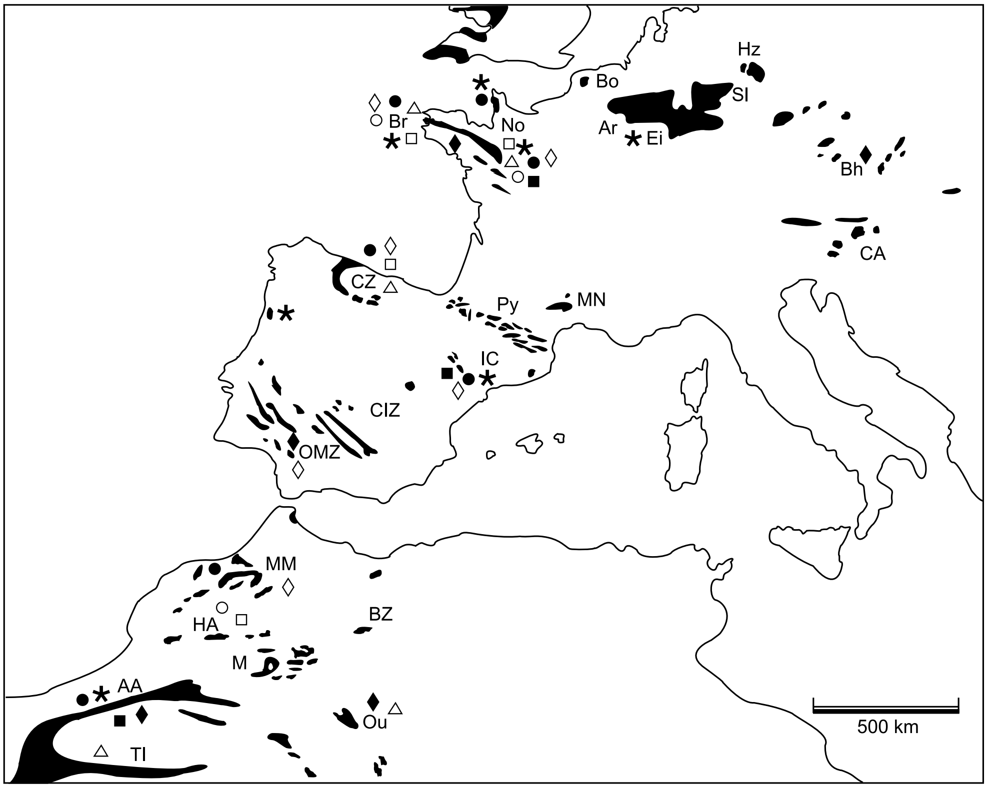

Fig. 6. Geographical distribution of some Early Devonian brachiopod and coral species (see references in the text). Symbols: black diamonds, *Eucharitina oehlerti*; open triangles, *Ctenochonetes jouannensis*; asterisks, *Ctenochonetes aremoricensis*; black dots, *Renaudia mainensis*; black squares, *Davoustia davousti*; open diamonds, *Plicanoplia carlsi*; open dots, *Plicanoplia alani*; open squares, *Procterodictyum polentinoi*. Geographical key-symbols as in Fig. 5.

tionships between these regions from the Early Devonian onwards (Bouyx et al., 1997).

Young (1987, p. 292) noted similarities of the Late Devonian shallow marine fishes from SE Morocco with those from eastern North America (especially large arthrodires) and Baltica (osteolepiform sarcopterygians).

Close proximity of Gondwana and Laurussia during the late Middle and Late Devonian is attested also by plant micro- and macrofossil evidence. The geographical distribution of land plant miospores in the Givetian and Frasnian shows that NW Gondwana (Libya, Brazil) and southern Laurussia (Boulonnais, Ardenne, Rhenish regions) had similar vegetation patterns and similar climatic conditions (Streel et al., 1990 with references therein). Moreover, Meyer-Berthaud et al. (1997) reported, in the lower Famennian of SE Morocco, the occurrence of a large trunk of *Callixylon erianum*, a species already known in North America, which provides a supplementary and clear evidence of affinities between Gondwanan and Laurussian floras in the Late Devonian. It must be noted that these palaeobotanical data both concern the Late Devonian, i.e. precisely the time interval when, according to palaeomagnetic models, the ocean supposedly separating Gondwana and Laurussia would have reached its maximum width.

4.3. *Checkup of palaeobiogeographical data*

All the sedimentological and palaeontological data summarised above (Figs. 4–7) lead to the same conclusions:

(1) There is no argument in favour of a sepa-

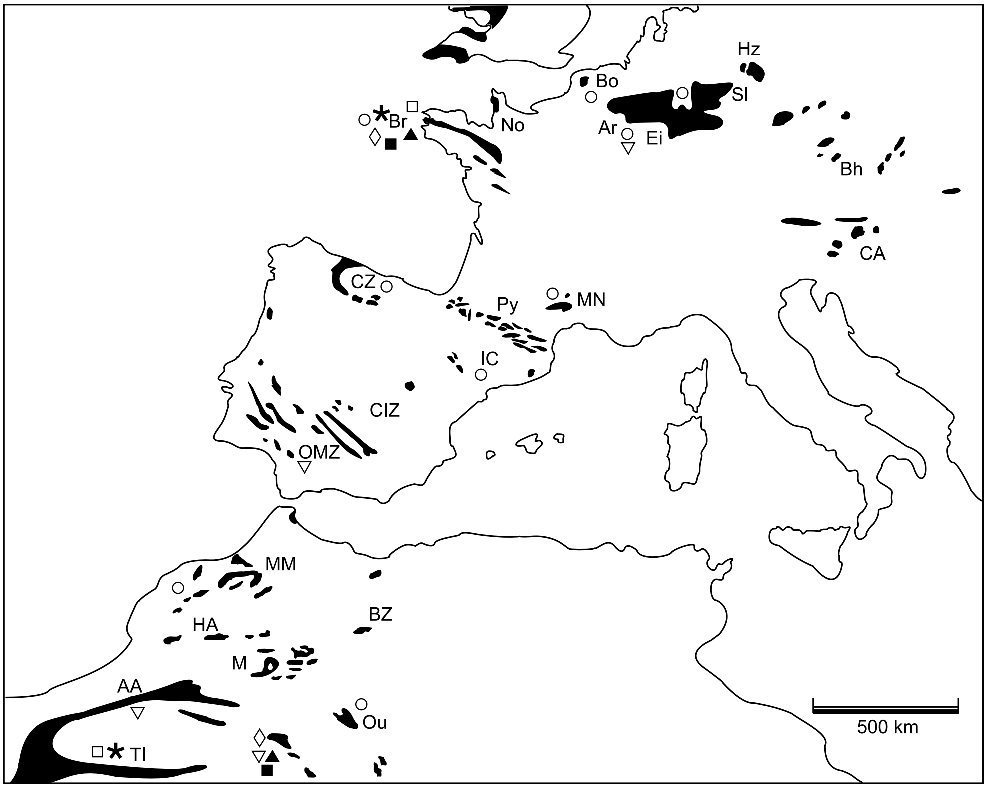

Fig. 7. Geographical distribution of some Middle and Late Devonian species (see references in the text). Symbols: open dots, *Polyzygia neodevonica*; open squares, *Salairocrinus kerevensis*; asterisks, *Mediocrinus squiffiecensis*; open diamonds, *Laudonomphalus regularis*; black squares, *Eutaxocrinites kergarvanensis*; black triangles, *Gilbertsocrinus tenuis*; open triangles, *Centrorhynchus letiensis*. Geographical key-symbols as in Fig. 5.

ration between the Variscan regions of southwestern and central Europe (= the so-called Armorica microplate) and Gondwana at any moment of the Palaeozoic. On the contrary, the geographical distribution and the evolution of lithofacies and, furthermore, the persistent affinities of planktonic organisms, various groups of marine invertebrates, vertebrates and floras show that all these regions remained closely linked during the whole Palaeozoic.

(2) Neither is there any argument that could suggest association or proximity of Armorica and Baltica–Avalonia (or later Laurussia) during the ‘middle’ Palaeozoic (i.e. between the Late Ordovician and the Early Devonian); these two palaeogeographical units remained separated by the Rheic Ocean during the Ordovician, the Silurian and the earliest Devonian and closure of this oceanic faunal barrier did not begin before the Pragian.

These conclusions are totally at variance with palaeogeographical models, mostly based on palaeomagnetic data, which purport to show that the southern European regions formed a microplate Armorica derived from Gondwana and consider that it had a separate evolution and history, distinct from that of Gondwana, during a large part of the Palaeozoic.

5. Implications for the Variscan Belt of SW Europe

Agreeing (or not) with the concept of a microplate Armorica, separated from Gondwana during a large part of the Palaeozoic, has important implications for reconstructing the Late Palaeozoic configuration of the Variscan Belt of SW Europe (Fig. 8) and understanding its formation.

Accepting the existence of a microplate implies indeed that there were two distinct major oceans in the pre-orogenic palaeogeography, the first one separating Armorica from Baltica–Avalonia (and later from Laurussia), and the second one between Armorica and Gondwana. This means that two distinct oceanic sutures should be identified within the Variscan Belt.

Conversely, when it is considered that Armorica was permanently part of Gondwana, the formation of the belt should have resulted from the closure of a single ocean separating Gondwana from Baltica–Avalonia (and later from Laurussia).

This problem has become even more complicated and confused because a number of authors have turned aside from the original signification of the term 'Armorica' and adapted this denomination in their own way. In its original definition, emended after distinction of Avalonia, the Armorica microplate was supposedly composed of the Variscan regions of southern Europe, i.e. the Iberian Peninsula, most of France, part of Germany, Bohemia and southern Poland (Van der Voo, 1988, 1993 p. 249). Considering the recent literature, it appears that 'Armorica' may include all these Variscan regions of southern and central Europe, but it is frequently considered to have been an 'archipelago' of semi-autonomous terranes separated by minor oceanic basins rather than a coherent microplate (= Armorican Terrane Assemblage; Tait et al., 1994; Tait, 1999; Tait and Bachtadse, 2000; Crowley et al., 2000). The hypothesis of several blocks situated between Gondwana and Laurussia reaches its maximum extent in the models proposed by Ziegler (1990, with previous references therein), who considers that the Palaeozoic crustal consolidation of western and central Europe resulted from the stepwise accretion to Laurussia of various Gondwana-derived microcratons.

Following the proposed occurrence of two distinct oceanic sutures (see below) within the Variscan Belt (Matte, 1986a,b, 1991), several authors have reserved the denomination 'Armorica' for the regions sandwiched between these two sutures (Fig. 8). In this case, despite some variations, it is considered generally that: (1) Armorica comprised the middle and northern regions of the Armorican Massif, part of the Iberian Peninsula, Saxo-Thuringia and Bohemia; and (2) the other southern European regions (the southern part of the Armorican Massif, southern France, part of the Iberian Peninsula, Corsica–Sardinia) either composed a separate microplate or were included in Gondwana (e.g. Rey et al., 1997; Faure et al., 1997; Matte, 2001).

In less frequently quoted models, Armorica is not distinguished clearly from Avalonia and the middle and northern regions of the Armorican Massif are associated with the Ardenne (Neugebauer, 1989; Lefort, 1990; Piqué, 1991; Piqué et al., 1994). In these models, southern France and Iberia are also considered either to be part of the Gondwana margin or a separate additional microplate 'Iberia'.

These examples illustrate the very real confusion that prevails as regards the signification of the term 'Armorica'.

It is largely beyond the scope of the present paper to discuss in detail the various and conflicting models that have been proposed for the Variscan Belt of SW Europe (for such a discussion see Robardet, 2002). However, it can be noted here that, until now, most of the models proposed have been based on syn- to late-orogenic structural, metamorphic and magmatic data, and have generally paid very little attention to the pre-Variscan palaeogeographical constraints. A large number of these models have uncritically incorporated the concept of the Armorica microplate, and, influenced also by present-day geography, have proposed the existence of two distinct oceanic sutures corresponding to two distinct oceans in the pre-Variscan palaeogeography (Fig. 8):

– the Rheic Ocean, extending between the Variscan regions of southern Europe and those of northern Europe, whose suture would be found, in France, to the north of the Mid–North Armorican Domain, and,

– the South-Armorican Ocean (= Ligerian Ocean or Massif Central Ocean), whose suture, partly obliterated by the South Armorican Shear

Zone, would be situated between the Mid–North Armorican and the South Armorican regions, and would be prolongated into the Massif Central.

In these models, it is also generally assumed that the prolongation of both oceanic sutures can be followed within the Iberian Peninsula: the former between the Ossa Morena and South Portuguese zones (Pulo de Lobo or Beja suture) and the latter running offshore west of Galicia and prolongating between the Central Iberian and Ossa Morena zones as a 'cryptic' suture (Fig. 8) obliterated by the Badajoz–Córdoba Shear Zone (e.g. Burg et al., 1981).

The above-mentioned results of palaeobiogeographical analysis allow such models to be dismissed because they are inconsistent with: (1) the global distribution of faunas and floras during pre-Carboniferous times; and (2) the smaller-scale palaeogeographic relations between the Iberian Peninsula and the Armorican Massif (Paris and Robardet, 1977; Robardet et al., 1990; Paris, 1998). A model with a single major Variscan ocean, proposed by several authors (e.g. Quesada, 1991; Quesada et al., 1994; Martínez Catálan et al., 1997) for the Iberian part of the Variscan Belt, also proves suitable for the French part of the belt

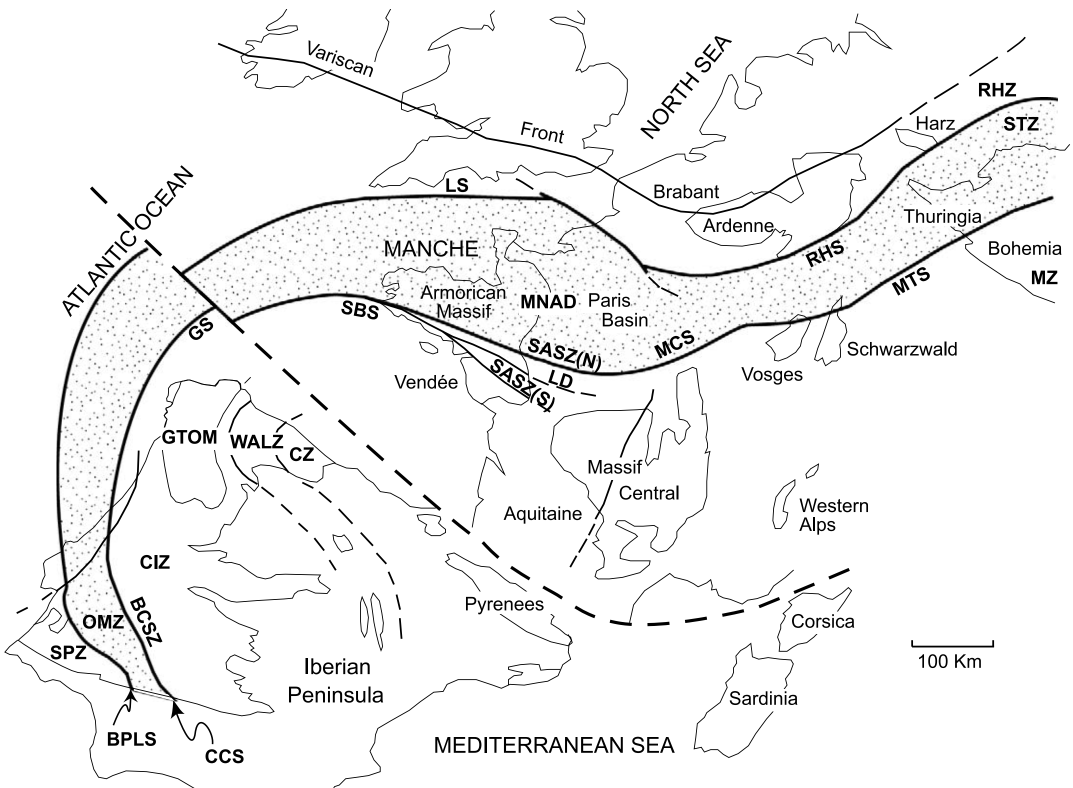

Fig. 8. Schematic map of the Variscan Belt in southwestern and central Europe, with tectonostratigraphic units, major shear zones and oceanic sutures proposed by various authors (see references in the text). Abbreviations: Tectonostratigraphic units: CIZ, Central Iberian Zone; CZ, Cantabrian Zone; GTOM, Galicia–Trás os Montes Zone; LD, Ligerian Domain; MNAD, Mid–North Armorican Domain; MZ, Moldanubian Zone; OMZ, Ossa Morena Zone; RHZ, Rheno-Hercynian Zone; SPZ, South Portuguese Zone; STZ, Saxo-Thuringian Zone; WALZ, West Asturian–Leonese Zone. Shear Zones: BCSZ, Badajoz–Córdoba Shear Zone; SASZ, South Armorican Shear Zone, northern branch (N), southern branch (S). Oceanic sutures: BPLS, Beja–Pulo de Lobo suture; CCS, Coimbra–Córdoba suture; GS, Galicia suture; LS, Lizard suture; MCS, Massif Central suture; MTS, Münchberg-Teplá suture; RHS, Rheno-Hercynian suture; SBS, Southern Brittany suture. The stippled area corresponds to the restricted extent of the Armorica microplate in the models with two oceanic sutures (e.g. Matte, 2001; see text).

and would much more effectively match the palaeobiogeographical constraints (Robardet, 2002).

6. General discussion and conclusion

For a non-specialist, it seems very difficult to apply a reliability filter on published palaeomagnetic results and thereby make a selection of the most conclusive data. This is all the more evident since, at present, there is no clear consensus within the palaeomagnetist community itself, which shows that the extant data do not provide unambiguous and decisive evidence on the respective latitudinal evolution of Gondwana and Armorica during the Silurian and the Devonian.

As noted above, palaeomagnetists have proposed various and sometimes contrasting models, based on different data or on differing interpretations of the same data. This de facto situation has been illustrated above by: (1) the reverse interpretation (primary vs overprint) of two components of magnetisation identified in Mid-Devonian rocks from Sudan (Bachtadse and Briden, 1991; Chen et al., 1993); (2) the Early Silurian vs Early Devonian age of the Aïr palaeopole (Hargraves et al., 1987; Moreau et al., 1994); and (3) the opposite views concerning the use of SE Australia data as representative for Gondwana as a whole (Schmidt et al., 1990; Tait et al., 2000).

Moreover, it appears that the quantitative character of palaeomagnetic data can be somewhat illusory for the palaeolatitude where the rocks were formed because, as a general rule for the Palaeozoic, secondary components have frequently been added to the primary magnetisation. Consequently, the main problem that affects the reliability of the palaeomagnetic data concerns the precise age of the supposed primary magnetisation. The field tests used to constrain this age provide important constraints but no absolute certainty. For instance, a positive fold test only shows that the magnetisation was acquired before folding, but not necessarily when the rock was formed, because this test cannot identify a possible pre-folding remagnetisation (see e.g. the case of the Silurian volcanic rocks at Almadén).

The advantage of the palaeoclimatic and palaeobiogeographical data is that their age is unequivocal. These data can be reduced to nothing by penetrative deformation and/or strong metamorphism, but, when preserved, their age has never thereby been modified. Moreover, these data, although rarely quantified by means of similarity coefficients of faunal assemblages, allow more precise evaluation of the respective relations and proximity of the regions studied than palaeomagnetism, which allows only comparison of their palaeolatitudes. This is most probably one of the reasons why Scotese and McKerrow (1990, p. 14) have considered palaeoclimatic indicators more weighty arguments for positioning the Devonian South Pole.

The objective of the present paper was to reconsider the question of the Armorica microplate by: (1) a return to and a re-evaluation of the palaeomagnetic data that were at the very root of this concept; and (2) an alternative approach based on palaeoclimatic and palaeobiogeographical data.

A critical review shows that palaeomagnetic data for the Silurian and the Devonian are: (1) far too rare and still ambiguous for the southern European regions supposedly constituting the Armorica microplate; and (2) more numerous for Gondwana but contradictory enough to give rise to various and diverging models for the latitudinal evolution of this continent.

Consequently, the reality of an Armorica microplate, detached from Gondwana, and having had an independent latitudinal evolution, separate from that of Gondwana during part of the Palaeozoic (Fig. 9), cannot be considered as established. On the contrary, lithological indicators of palaeoclimate and palaeobiogeographical data, concerning both marine vertebrates and invertebrates, and also land plants, are in total harmony and indicate that the southern European regions have, in actual fact, remained permanently in close connection with Gondwana of which they composed the northern margin (Fig. 9).

Although repeatedly maintained for more than 20 years, the concept of the Armorica microplate can thus be considered a fiction.

These conclusions should lead to a re-evaluation of a number of the models proposed for

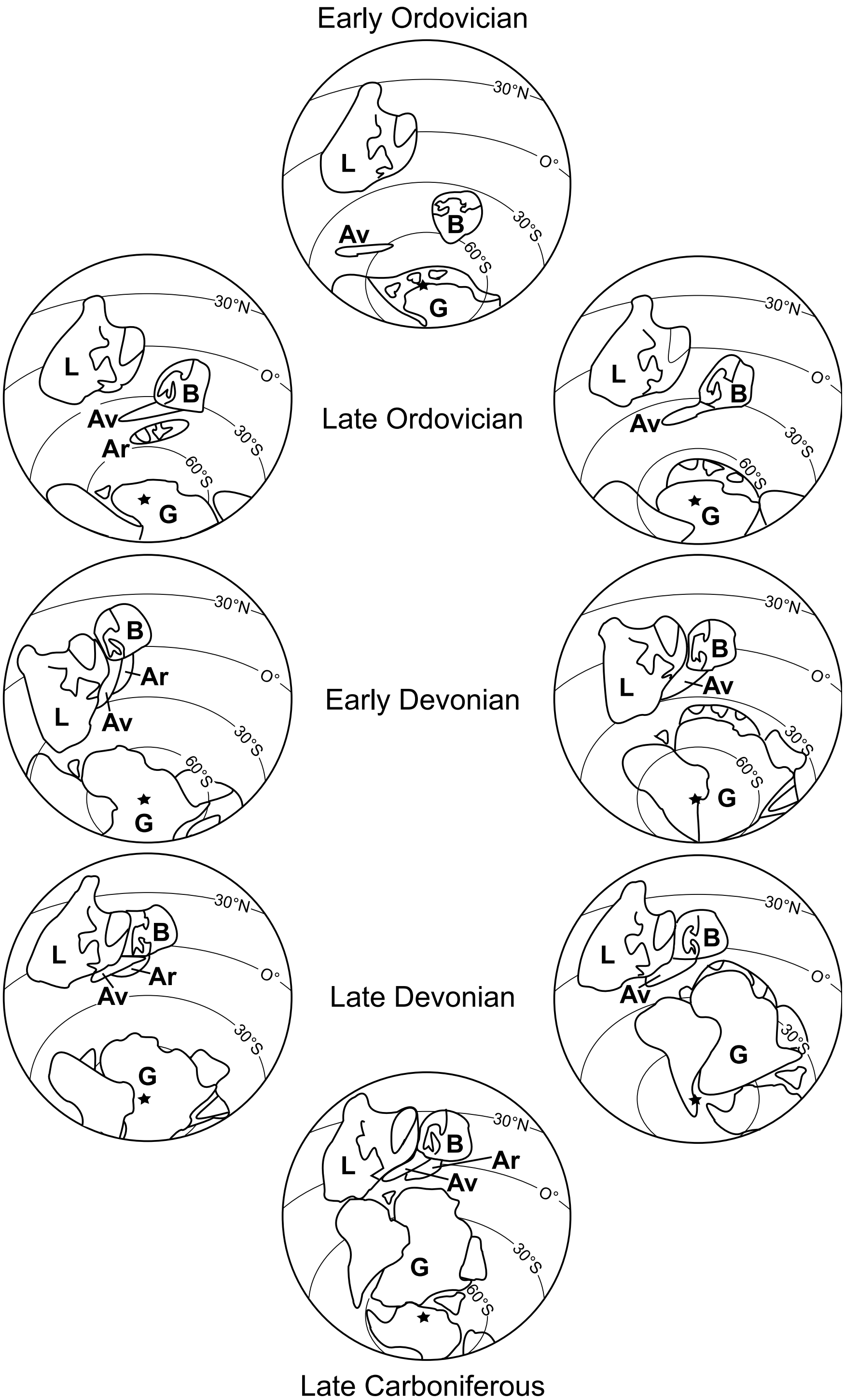

Fig. 9. Two different models of the Early Ordovician through Late Carboniferous palaeogeographical evolution of the present-day peri-Atlantic regions. Abbreviations: L, Laurentia; B, Baltica; G, Gondwana; Ar, Armorica; Av, Avalonia. Left side: based on palaeomagnetic data (after Tait, 1999 and Tait et al., 2000). Right side: based on palaeoclimatic and palaeobiogeographical data (after Paris and Robardet, 1990; Robardet et al., 1990; Paris, 1998).

the Variscan Belt that had incorporated this fictitious concept and are in contradiction with inescapable palaeobiogeographical constraints.

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