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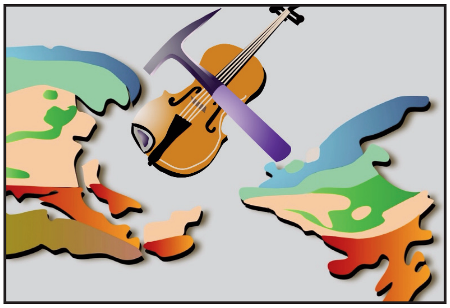

Does the Meguma Terrane Extend into SW England?

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SUMMARY
The peri-Gondwanan Meguma terrane of southern Nova Scotia, Canada, is the only major lithotectonic element of the northern Appalachian orogen that has no clear correlatives elsewhere in the Appalachians and lacks firm linkages to the Caledonide and Variscan orogens of western and southern Europe. This characteristic is in contrast with its immediate peri-Gondwanan neighbor, Avalonia, which has features in common with portions of Carolinia in the southern Appalachians and has been traced from the Rhenohercynian Zone of southern Britain eastward around the Bohemian Massif to the Carpathians and western Pontides. At issue is the tendency in Europe to assign all peri-Gondwanan terranes lying outboard of the Rheic suture to Avalonia, characterized by relatively juvenile basement and detrital zircon ages that include Mesoproterozoic populations, and those inboard of the suture to Cadomia, characterized by a more evolved basement and detrital zircon ages that match Paleoproterozoic and older sources in the West African craton.

Although the unexposed basements of Avalonia and Meguma are thought to be isotopically very similar, the Meguma sedimentary cover contains scarce Mesoproterozoic zircon and is dominated instead by Neoproterozoic and Paleoproterozoic populations like those of Cadomia. Hence, felsic magma produced by crustal melting in the Meguma terrane (e.g. the ca. 370 Ma South Mountain Batholith) is isotopically more juvenile (ε_{Nd} = –5 to –1, T_{DM} = 1.3 Ga) than the rocks it intruded (ε_{Nd} –12 to –7, T_{DM} = 1.7 Ga). By contrast, felsic magma produced by crustal melting in Avalonia (ε_{Nd} = –1 to +6, T_{DM} = 0.7–1.2 Ga) is isotopically similar to its host rocks (ε_{Nd} = –3 to +4, T_{DM} = 0.9–1.4).

The isotopic relationship shown by the Meguma terrane has also been recognized in the South Portuguese Zone of southern Spain, which is traditionally assigned to Avalonia. However, the Sierra Norte Batholith of the South Portuguese Zone (ca. 330 Ma; ε_{Nd} = +1 to –3, T_{DM} = 0.9–1.2 Ga) is on average more juvenile than the Late Devonian host rocks (ε_{Nd} = –5 to –11) it intruded, suggesting instead an extension of the Meguma terrane into Europe. Available data for the Cornubian Batholith of SW England (ca. 275–295 Ma; ε_{Nd} = –4 to –7, T_{DM} = 1.3–1.8 Ga) and the Devonian-Carboniferous metasedimentary rocks it intruded (ε_{Nd} = –8 to –11) suggests this may also be true of that part of the southern Britain (Rhenohercynian Zone) with which the South Portuguese Zone is traditionally correlated.

SOMMAIRE
Le terrane péri-gondwanien de Meguma en Nouvelle-Écosse au Canada, est le seul grand élément lithotectonique de l'orogène des Appalaches du Nord qui n'ait pas de correspondant avéré ailleurs dans les Appalaches et qui ne montre aucun lien sûr avec les orogènes calédonienne et varisque de l'ouest et du sud de l'Europe. Cette situation contraste avec celle de son voisin péri-gondwanien immédiat, l'Avalonie, qui partage certaines caractéristiques avec des portions de Carolinia des Appalaches du sud et qui a été suivi à partir de la zone rhénohercynienne dans le sud de la Grande-Bretagne vers l'est autour du massif bohémien jusqu'aux Carpates et l'ouest de la chaîne pontique. Ce qui est en question ici c'est la tendance en Europe à assigner l'Avalonie à tous les terranes péri-gondwaniens situés à l'extérieur de la suture rhéïque lesquels sont caractérisés par un socle relativement juvénile et des âges de zircons

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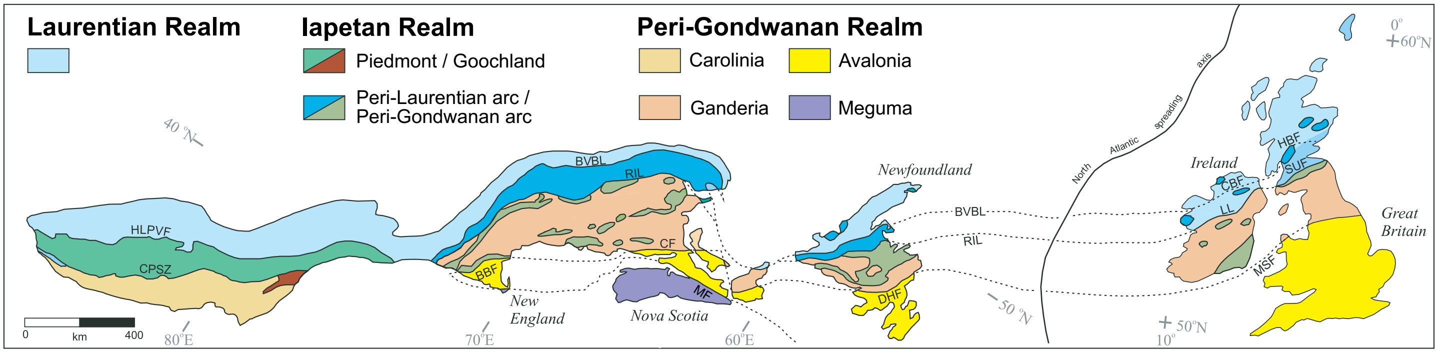

Figure 1. Appalachian lithotectonic realms and their continuation into Britain and Ireland (modified after Pollock et al. 2012). BBF = Bloody Bluff fault; BVBL = Baie Verte Brompton Line; CF = Caledonia fault; CPSZ = Central Piedmont shear zone; CBF = Clew Bay fault; DHF = Dover–Hermitage Bay fault; HBF = Highland Boundary fault; HLPVF = Hollins Line–Pleasant Valley fault; LL = Leadhills Line; MF = Minas fault; MSF = Menai Strait fault; RIL = Red Indian Line; SUF = Southern Uplands fault.

détritiques qui comportent des populations mésoprotérozoïques, et ceux situés à l'intérieur de la suture à Cadomia, lesquels sont caractérisés par un socle plus évolué et des âges de zircons détritiques qui correspondent à des sources du craton ouest africain paléoprotérozoïques et plus anciennes.

Bien que l'on estime que les socles non-exposés des terranes d'Avalonie et de Meguma soient très similaires isotopiquement, le couvert sédimentaire de Meguma ne renferme que de rares zircons mésoprotérozoïques, et ce sont plutôt les populations de zircons néoprotérozoïques et paléoprotérozoïques qui dominent, comme c'est le cas pour Cadomia. Il en ressort que le magma felsique produit par la fusion de croûte dans le terrane de Meguma (par ex. le batholite de South Mountain de 370 Ma env.) est isotopiquement plus jeune (ε_{Nd} = –5 à –1, T_{DM} = 1.3 Ga) que les roches qu'il recoupe (ε_{Nd} –12 à –7, T_{DM} = 1.7 Ga). Par opposition, le magma felsique produit par la fusion de la croûte dans le terrane d'Avalonie (ε_{Nd} = –1 à +6, T_{DM} = 0.7–1.2 Ga) est isotopiquement similaire aux roches de son encaissant (ε_{Nd} = –3 à +4, T_{DM} = 0.9–1.4).

Le profil isotopique du terrane de Meguma, traditionnellement assignée à l'Avalonie, a aussi été détecté dans la Zone sud-portugaise du sud de l'Espagne. Cependant, le batholite de Sierra Norte de la Zone sud-portugaise (ca. 330 Ma; ε_{Nd} = +1 à –3, T_{DM} = 0.9–1.2 Ga) est en moyenne plus jeune que l'encaissant du Dévonien moyen (ε_{Nd} = –5 à –11) qu'il recoupe, ce qui permet de penser à une extension du terrane de Meguma en Europe. Les données disponibles du batholite de Cornubian dans le S-O de l'Angleterre (ca. 275–295 Ma; ε_{Nd} = –4 à –7, T_{DM} = 1.3–1.8 Ga) et des roches métasédimentaires dévono-carbonifères qu'il recoupe (ε_{Nd} = –8 to –11) permet de penser qu'il pourrait en être de même de cette portion du sud de la Grande-Bretagne (Zone rhénohercynienne) avec laquelle la Zone sud-portugaise est traditionnellement corrélée.

INTRODUCTION

Correlation of the Appalachian Mountains of Atlantic Canada with the Caledonide and Variscan orogens of western and southern Europe dates to Wegener's earliest arguments for Continental Drift (Wegener 1912, translated by von Heune 2002) and, with the formalization of lithotectonic zones (Humber, Dunnage, Gander, Avalon and Meguma) within the northern Appalachian orogen (Williams 1976, 1978, 1979) attempts were made to establish their trans-Atlantic linkages (e.g. Schenk 1971; Tozer and Schenk 1978; Wones 1980; Gayer 1985, and references therein). The broad configuration of these correlations is now well established (Fig. 1), although the task has become more difficult with the reinterpretation of the lithotectonic zones as suspect terranes (Williams and Hatcher 1982, 1983; Williams 1984; Keppie 1985), since the pattern and nomenclature of terrane assembly has become increasingly complex with time (e.g. Lefort 1989; Dallmeyer 1989; Keppie and Dallmeyer 1989; Hibbard et al. 1995; van Staal et al. 1998; Martínez Catalán et al. 2002, and references therein).

A notable exception to this pattern of correlation is the Meguma terrane of southern Nova Scotia, the most outboard of the peri-Gondwanan terranes (Ganderia, Avalonia and Meguma) in the northern Appalachian orogen (Williams and Hatcher 1982) (Fig. 1). While differing in their tectonostratigraphic histories, each of these terranes is believed to have occupied a position off the northern (West African/Amazonian) margin of Gondwana in the Neoproterozoic/Cambrian (e.g. Nance et al. 2008). However, the Meguma terrane is the only major terrane in the northern Appalachian orogen that has no obvious correlatives elsewhere in the Appalachians (Williams 1978, 1979) and no confirmed linkages to either the Caledonide or Variscan orogens of Western Europe (see Waldron et al. 2009).

This is in contrast with its immediate peri-Gondwanan neighbours, Avalonia and Ganderia, both of which show age and isotopic similarities to parts of Carolinia in the southern Appalachians (e.g. Samson et al. 1995; Nance and Murphy 1996; Ingle et al. 2003; Hibbard et al. 2007a, b) and have been traced eastwards into Britain and Ireland (e.g. van Staal et al. 1998, 2009). Indeed, Avalonia has been traced eastwards from the Rhenohercynian Zone of southern Britain (e.g. Landing 2004; Shail and Leveridge 2009; Landing et al. 2013a, b) and Germany (e.g. Meissner et al. 1994; Cocks et al. 1997; Verniers et al. 2002) to the eastern Bohemian Massif in the Czech

Republic (Finger et al. 2000; Kalvoda et al. 2008), the South Carpathians of Romania (Balintoni et al. 2011), and the Pelagonian (Zlatkin et al. 2014), Serbo-Macedonian (Meinhold et al. 2010) and Istanbul zones (Okay et al. 2008) of Greece and Turkey.

By contrast, correlation of the Meguma terrane beyond the offshore Scotian shelf (King and MacLean 1976; Pe-Piper and Jansa 1999) and the southern Grand Banks (Haworth and Lefort 1979; Reid 1988) remains unresolved, although a possible linkage exists with the Suwanee terrane of the Florida subsurface (Hibbard et al. 2010; Waldron et al. 2011; Pollock et al. 2012).

This does not mean that correlations of the Meguma terrane in Europe have not been proposed. More than forty years ago, Schenk (1971) suggested that the Meguma Zone might continue into northwest Africa and southern Iberia, a correlation later advanced by Lefort (1989) on the basis of geophysical data (Fig. 2). In support of such a connection, detrital zircon ages from the Meguma Supergroup are consistent with a West African provenance (Krogh and Keppie 1990; Waldron et al. 2009), and Sm–Nd and U–Pb data from the South Portuguese Zone in southern Spain are consistent with a link between the Meguma terrane and southern Iberia (Braid et al. 2012).

Two other connections, based on lithostratigraphic similarities and matching detrital zircon populations, have recently been proposed between the Meguma terrane and the Harlech Dome region of North Wales (Waldron et al. 2011) (Fig. 2) and the Brabant Massif of the European Low Countries (Linnemann et al. 2012) (Fig. 3). These provocative correlations are of particular interest since they place the Meguma terrane (their Megumia) inboard of Avalonia in southern Britain and western Europe, which is precisely opposite to their relationship in the northern Appalachians.

In this paper, we examine the distinction between Avalonia and the Meguma terrane and the criteria that might be used to identify this distinction in Europe. We then use this approach to explore (i) whether the proposed continuation of the Meguma terrane into southern Iberia can be extended to that part of southern Britain (the Rhenohercynian Zone) with which the South Portuguese Zone is traditionally correlated (e.g. Frank 1989; Frank et al. 1995; Matte 2001; von Raumer et al. 2003), and (ii) what the implications of such a linkage might be to the potential presence of the Meguma terrane in the Harlech Dome region of North Wales and the Brabant Massif of the European Low Countries.

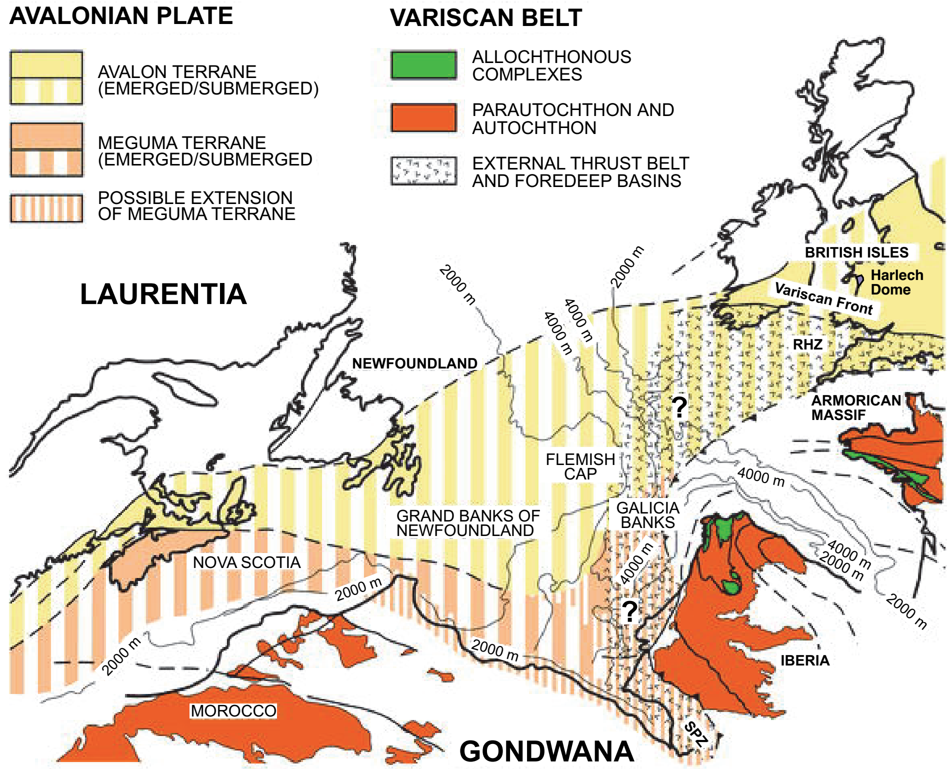

Figure 2. Trans-Atlantic correlation of Avalonia and the Meguma terrane (modified after Arenas et al. 2007, but based largely on Lefort 1989). RHZ = Rhenohercynian Zone; SPZ = South Portuguese Zone. Harlech Dome region of North Wales also shown.

MEGUMA AND AVALONIA

Avalonia and the Meguma terrane constitute the most outboard peri-Gondwanan terranes of the northern Appalachian orogen (Fig. 1) and, as with all peri-Gondwanan terranes, are believed to have been proximal to the northern (West African/Amazonian) margin of Gondwana in the late Neoproterozoic (e.g. Nance et al. 2008; Bassett 2009). Despite their shared paleogeography, Avalonia crops out discontinuously from southeastern New England to eastern Newfoundland, whereas outcrop of the Meguma terrane is restricted to the southern mainland of Nova Scotia (e.g. Waldron et al. 2009, 2011), where it is juxtaposed against Avalonia along the Minas Fault zone, an east-west dextral strike-slip zone of Late Paleozoic age (Keppie 1989; Murphy et al. 2011) (Fig. 1).

The two terranes are distinguished on the basis of their early Paleozoic stratigraphy – that of Avalonia is characterized by relatively thin, platformal successions of Cambrian–Early Ordovician siliciclastic rocks (e.g. Tanoli and Pickerill 1988; Landing and Murphy 1991; Landing 1995), which rest either conformably or unconformably on a variety of late Neoproterozoic arc-related volcanosedimentary assemblages, or nonconformably on associated magmatic arc granitoid rocks (e.g. O'Brien et al. 1990; Murphy et al. 1991). In contrast, the early Paleozoic stratigraphy of the Meguma terrane comprises a thick (>10 km) basinal succession of Cambrian (late Neoproterozoic?)–Early Ordovician siliciclastic turbidites (e.g. Schenk 1997) that make up the Meguma Supergroup (White 2008). These turbidites are sub-

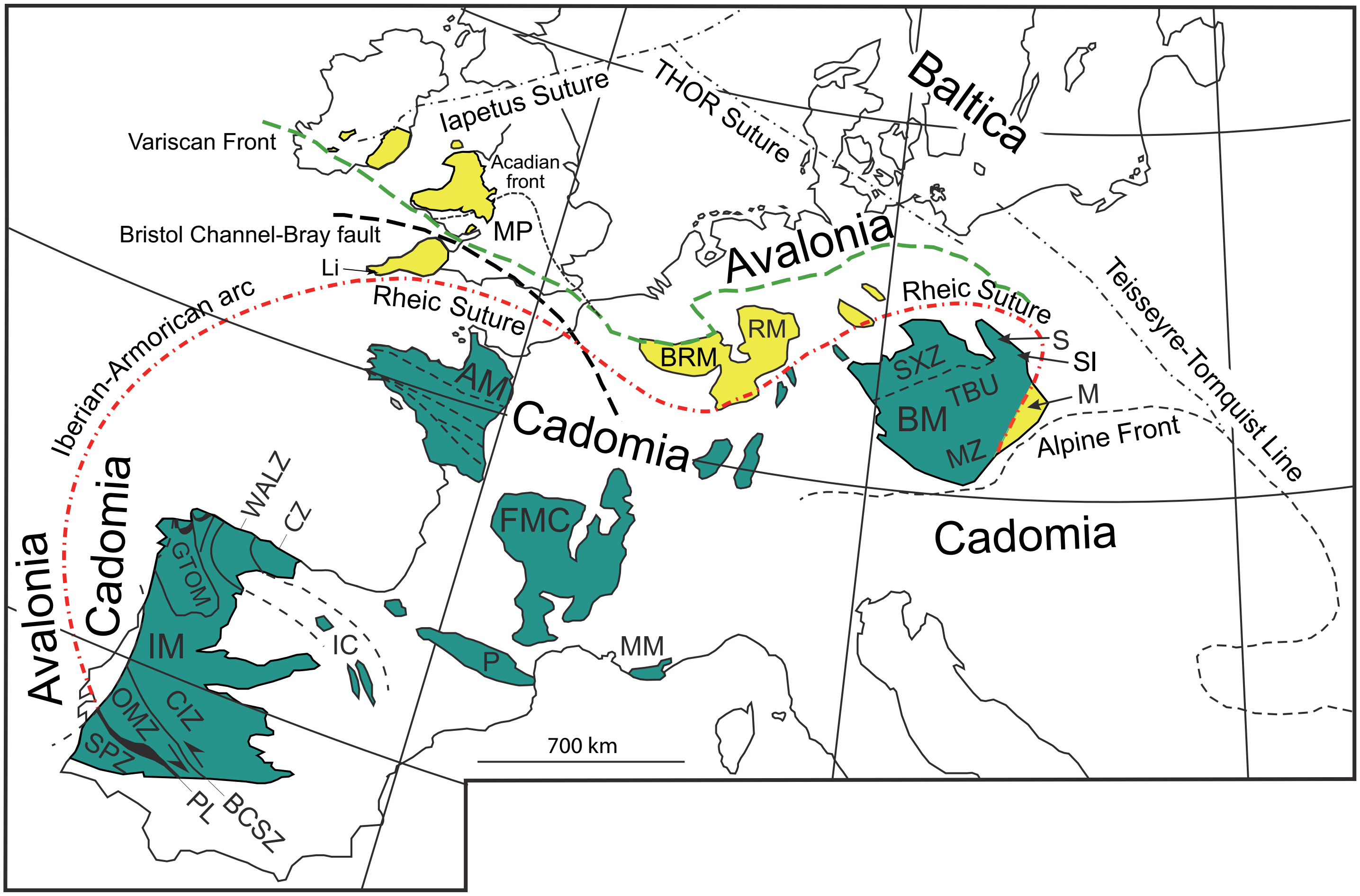

Figure 3. Location of the Rheic suture with respect to Avalonian, Cadomian and Variscan massifs in southeastern and central Europe (modified after Linnemann et al. 2007 and Nance et al. 2010). Abbreviations: (1) Iberia: BCSZ = Badajoz–Cordoba Shear zone; CIZ = Central Iberian zone; CZ = Cantabrian zone; IC = Iberian Chains; IM = Iberian Massif; GTOM = Galicia Trás-os-Montes zone; OMZ = Ossa-Morena zone; P = Pyrenees; PL = Pulo de Lobo oceanic units; SPZ = South Portuguese Zone; WALZ = West Asturian Leonese zone, (2) Western Europe: AM = Armorican Massif; FMC = French Massif Central; MM = Maures Massif; Li = Lizard ophiolite. (3) Central and Eastern Europe: BM = Bohemian Massif; BRM = Brabant Massif; M = Moravo-Silesian zone; MP = Midland Platform; MZ = Moldanubian zone; RM = Rhenish Massif; S = Sudetes; Sl = Ślęża ophiolite; SXZ = Saxo-Thuringian zone; TBU = Teplá-Barrandian Unit. Black = oceanic rocks of the Pulo de Lobo suture (Beja-Acebuches ophiolite) in southern Iberia and ophiolitic units of allochthonous complexes in NW Spain (Galicia).

divided into a lower, largely psammitic Goldenville Group and an upper, largely pelitic Halifax Group, and are interpreted as having been deposited in a rift between Gondwana and Avalonia that may have formed part of the system along which these two crustal blocks separated with the opening of the Rheic Ocean (Waldron et al. 2009). The Halifax Group is locally overlain unconformably by Silurian shallow marine sedimentary and bimodal volcanic rocks of the White Rock Formation, which are also thought to be the product of a rift environment (MacDonald et al. 2002). The fossiliferous siliciclastic rocks of the overlying Early Devonian Torbrook Formation record deposition in a shelf setting (Jensen 1975). Late Devonian–early Carboniferous continental clastic deposits of the Horton Group straddle the Minas Fault zone and, hence, overstep the terrane boundary with Avalonia (Keppie 1989; Murphy 2000).

In neither Avalonia nor the Meguma terrane is the basement, upon which these late Neoproterozoic and younger successions must rest, exposed. As a result, the composition of their basements is poorly known. However, available isotopic data suggest that the basement of both terranes is similar and likely of Mesoproterozoic age.

In Avalonia, Sm–Nd isotopic analyses of crustally derived (felsic), late Neoproterozoic (ca. 730 Ma and 630–570 Ma) to Devonian igneous rocks with Sm/Nd ratios typical of intracrustal melts, show similar initial ε_{Nd} values that range between –1.6 and +6.0 (e.g. Barr and Hegner 1992; Doig et al. 1993; Kerr et al. 1995; Murphy et al. 1996a, b, 2000, 2008; Samson et al. 2000; Thompson et al. 2012), suggesting the involvement of relatively juvenile basement (Nance and Murphy 1994, 1996; Murphy and Nance 2002). ε_{Nd} growth lines typically yield overlapping depleted mantle (T_{DM}) model ages in the interval 0.8–1.3 Ga in the northern Appalachians and 1.0–1.3 Ga in southern Britain (e.g. Davies et al. 1985; Thorogood 1990). Although older model ages that require a contribution from an ancient crustal source have also been recognized in the Welsh Borderlands and New England (Schofield et al. 2010; Thompson et al. 2012), the bulk of the Nd isotopic data strongly suggest that the T_{DM} model ages are characteristic of Avalonia. This includes data from complexes that predate the main phase of arc magmatism (630–570 Ma), suggesting that the model ages record a genuine tectonothermal event in the terrane's early history rather than the mixing of juvenile Neoproterozoic–Paleozoic and ancient crustal magmas (cf. Arndt and Goldstein 1987). In support of this event, ca. 1.0 Ga model ages are also recorded in the juvenile mafic rocks of the ca. 760 Ma Burin Group in Newfoundland, the oldest rocks in Avalonia (Murphy et al. 2008). Hence, successive generations of Avalonian felsic magmas appear to have been generated largely by recycling pre-existing crust of this age, rather than being the product of mixing of juvenile and ancient crustal components. If so, Avalonia must have a relatively juvenile, ca. 1.0–1.3 Ga basement (Murphy et al. 2000, 2004a; Keppie et al. 2012). In support of this, inherited zircon grains of Mesoproterozoic age occasionally occur in Avalonian felsic bodies (e.g. Tucker and Pharaoh 1991; Thompson et al. 2007; Schofield et al. 2010).

Avalonian sedimentary rocks show broadly similar Sm–Nd isotopic compositions to those of the igneous rocks with most ε_{Nd} values lying between –4 and +4, and T_{DM} model ages that cluster in the range 0.9–1.3 Ga (e.g. Davies et al. 1985; Thorogood 1990; Samson et al. 2000). These data suggest that sedimentation on Avalonia was, for the most part, derived locally by cannibalization of the Neoproterozoic Avalonian arc (e.g. Murphy and Macdonald 1993; Murphy et al. 2004b). In support of this, Avalonian detrital zircon populations (Fig. 4a) are typically dominated by late Neoproterozoic ages (e.g. Pollock et al. 2009; Barr et al. 2012) that closely match those of Avalonian arc magmatism (e.g. Nance et al. 2008). Only in the Silurian–Devonian Arisaig Group of Nova Scotia, which is thought to have been derived from Baltica with a progressively increasing input from Laurentia, do initial ε_{Nd} values become strongly negative (–4.8 to –9.3) and T_{DM} ages get older than 1.5

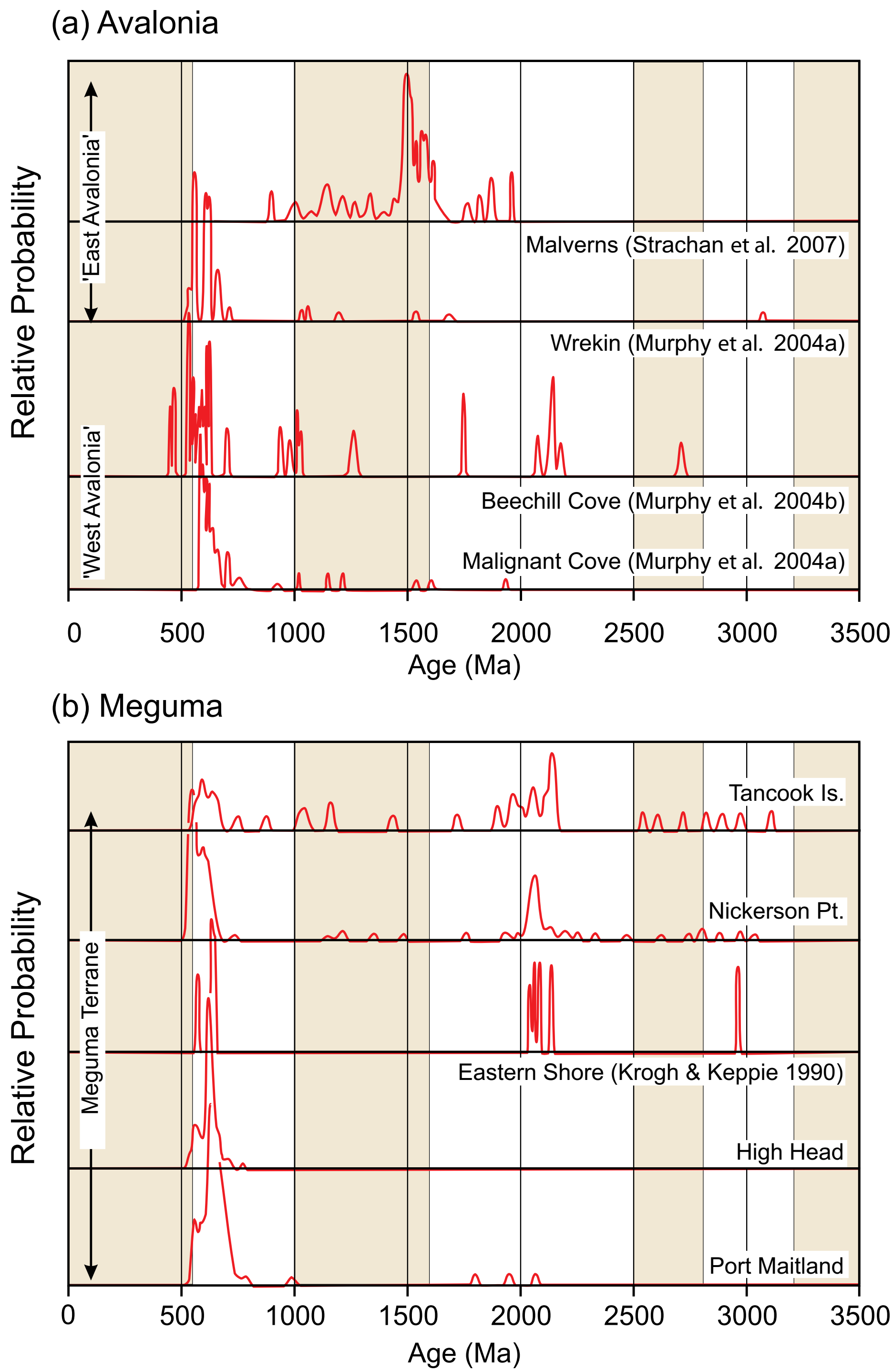

Figure 4. Comparative detrital zircon spectra for sedimentary rocks from (a) Avalonia (from sources identified), and (b) the Goldenville Group of the Meguma terrane (from Waldron et al. 2011).

Ga (Murphy et al. 1996b, 2004c). Also common among Avalonian detrital zircon populations are Mesoproterozoic ages (e.g. Keppie et al. 1998; Thompson and Bowring 2000; Murphy et al. 2004b, c; Barr et al. 2012; Thompson et al. 2012), which have been used to position the terrane during the Neoproterozoic/Cambrian in the proximity of Amazonia, the age provinces of which they broadly match (e.g. Nance et al. 2008).

By contrast, detrital zircon suites in the Meguma terrane generally lack Mesoproterozoic age populations. Instead, detrital zircon grains in the

Goldenville Group (Fig. 4b) usually include, in addition to important Neoproterozoic populations, those with ages that match Paleoproterozoic (ca. 2.1 Ga) and older sources in the West African craton (e.g. Krogh and Keppie 1990; Waldron et al. 2009). Rare Mesoproterozoic ages are present at the top of the Goldenville Group (Waldron et al. 2009) and occur in slightly more significant numbers in the overlying White Rock and Torbrook formations (Murphy et al. 2004d), but their abundance is low in comparison with Avalonia.

Despite the scarcity of Mesoproterozoic detrital zircon in the Meguma terrane, Sm–Nd isotopic data point to a Mesoproterozoic age for the unexposed basement beneath the Meguma Supergroup. With the exception of one sample (ε_{Nd} = +0.2, T_{DM} = 1.8 Ga), ε_{Nd} values for crustally derived felsic volcanic rocks in the ca. 440 Ma White Rock Formation are quite strongly positive (+1.1 to +6.8), and yield T_{DM} model ages of 0.6–1.3 Ga. This isotopic signature is indistinguishable from that of Avalonian felsic volcanic rocks, suggesting derivation from an isotopically very similar basement source (Keppie et al. 1997). Moreover, as these rocks predate all known deformation within the Meguma terrane, this crustal source is likely to have been the basement upon which the Meguma Supergroup was deposited.

Similarly, granulite-facies basement xenoliths in dykes that cut the Meguma Supergroup have yielded nearly concordant Avalonian (ca. 630–575 Ma) and Mesoproterozoic upper intercept U–Pb zircon ages (Owen et al. 1988; Greenough et al. 1999; see also Eberz et al. 1991). Likewise, the Sm–Nd isotopic systematics of granitoid rocks that intruded the Meguma terrane are consistent with an Avalonian-like lower crust (e.g. Clarke et al. 1997, 2000), while seismic reflection profiles, coupled with the Nd and Sr isotopic signatures of offshore plutons, suggest the existence of a relatively juvenile basement like that of Avalonia beneath the Meguma terrane of the Scotia Shelf (Pe-Piper and Jansa 1999). It therefore seems likely that the Meguma terrane is underlain by Avalonian basement.

CORRELATING MEGUMA: THE SOUTH PORTUGUESE ZONE

At issue with the trans-Atlantic correlation of the Meguma terrane is the tendency in Europe to assign all those peri-Gondwanan terranes lying outboard of the Rheic suture to Avalonia (Fig. 3), characterized by relatively juvenile basement like that of the Meguma terrane, but with detrital zircon ages that include Mesoproterozoic populations (e.g. Murphy et al. 2000, 2004a), and those peri-Gondwanan terranes lying inboard of the suture to Cadomia, characterized by a more evolved basement and detrital zircon with ages that, like those of the Meguma terrane, match Paleoproterozoic (ca. 2.1 Ga) and older sources in the West African craton (e.g. Linnemann et al. 2004; Samson et al. 2005). The suture separates Avalonia from Cadomia because Avalonia was detached from Gondwana with the opening of the Rheic Ocean in the Early Ordovician, whereas Cadomia remained behind (e.g. Linnemann et al. 2004; Murphy et al. 2006; Nance et al. 2010). Since the Meguma terrane also separated from Gondwana (e.g. van Staal et al. 1998, 2009; Murphy et al. 2004d; Waldron et al. 2009), any potential correlatives of this terrane in Europe would likewise occur outboard of the suture, that is unless some areas with Meguma basement–cover characteristics remained attached to the Gondwanan margin. Hence, the possibility exists that areas in Europe previously assigned to Avalonia could actually be correlatives of the Meguma terrane.

Given that the basements beneath Avalonia and the Meguma terrane are relatively juvenile and of Mesoproterozoic age, it is unlikely that potential correlatives of the Meguma terrane, if these exist in Europe or elsewhere in the Appalachians, can be readily distinguished from those of Avalonia on the basis of the isotopic composition of their felsic igneous rocks. Instead, the distinguishing characteristic of the Meguma terrane from an isotopic standpoint is the overwhelming predominance of Paleoproterozoic rather than Mesoproterozoic detrital zircon in its sedimentary cover, a fact that renders the isotopic composition of all but the base of the succession (which contains almost no pre-Neoproterozoic zircon; Waldron et al. 2009) significantly less juvenile than that of Avalonia, where Mesoproterozoic zircon is more common. This is because whole-rock Sm–Nd isotopic data from clastic sedimentary rocks reflect the weighted average of detrital contributions from the source areas (Thorogood 1990; Murphy and Nance 2002) and, since Sm and Nd in such rocks are concentrated in accessory minerals dominated by zircon, the whole-rock data tend to reflect the weighted average Sm–Nd isotopic composition of the detrital zircon. Although the calculated T_{DM} model age in clastic sedimentary rocks is a mixing age with no geological meaning (Murphy and Nance 2002), the envelope defined by the Sm–Nd data can be used as a distinguishing characteristic of the terrane in which the rocks occur. In the case of the Meguma Supergroup, the envelope defined by the Sm–Nd data (see below) is less juvenile than that of Avalonia, and this likely reflects their contrasting relative abundances of Paleoproterozoic (ca. 2 Ga) and Mesoproterozoic (ca. 1 Ga) detrital zircon.

Because of the basement to cover contrast in isotopic composition in the Meguma terrane, felsic magmas produced by crustal melting (which are isotopically similar to those of Avalonia) are significantly more juvenile than the rocks they intruded (Clarke et al. 1997). This characteristic is illustrated by the ca. 372 Ma granodiorite units of the South Mountain Batholith (Fig. 5), which record ε_{Nd} values of –5.2 to –1.4 and a T_{DM} model age of 1.26 ± 0.06 Ga, whereas the Meguma Supergroup, which the batholith intruded, shows ε_{Nd} values of –11.2 to –8.7 and a T_{DM} model age of 1.74 ± 0.1 Ga (Clarke et al. 1988). Even the Horton Group, which locally overlies the batholith unconformably, shows ε_{Nd} values (t = 360 Ma) of –10.9 to –6.0 and a T_{DM} model age of 1.45 ± 0.1 Ga (Murphy 2000). By contrast, Avalonian clastic sedimentary rocks, including those coeval with clastic rocks in the Meguma terrane, have isotopic compositions (ε_{Nd} = –4 to +4, and T_{DM} = 1.1 ± 0.2 Ga) that are similar to those of the felsic igneous rocks (ε_{Nd} = –1.6 to +6.0 and T_{DM} = 1.05 ± 0.25 Ga).

Although it is not unusual for

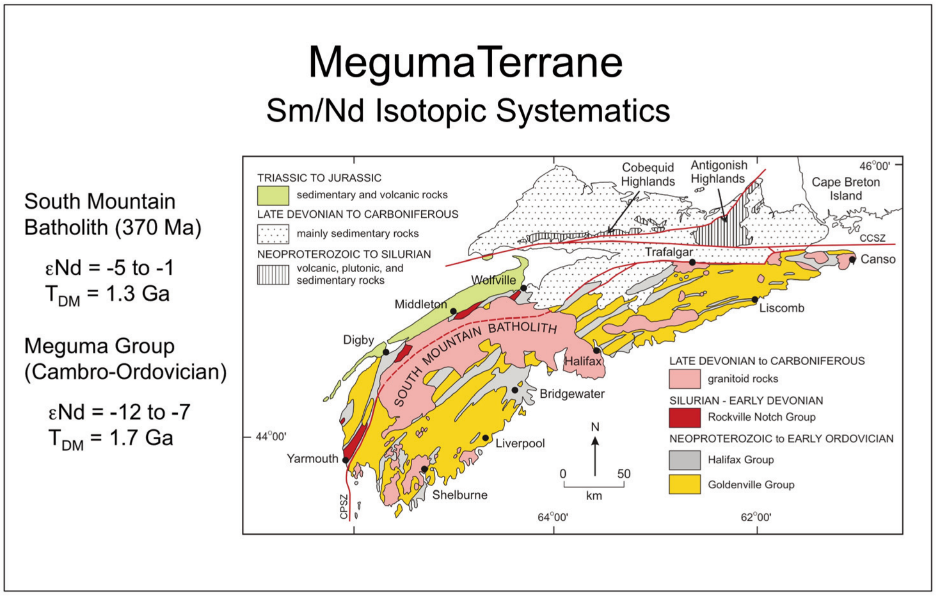

Figure 5. Geologic map and isotopic characteristics of the ca. 370 Ma South Mountain Batholith and the Meguma Supergroup it intruded in the Meguma terrane of southern Nova Scotia (isotopic data from Clarke et al. 1988, 1997; map from White and Goodwin 2011).

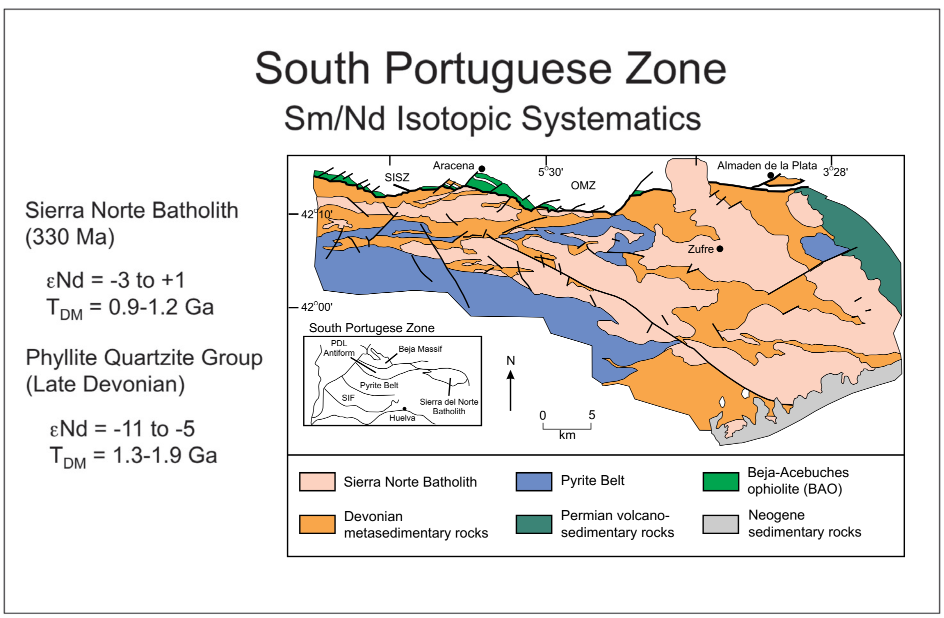

Figure 6. Geologic map and isotopic characteristics of the ca. 330 Ma Sierra Norte Batholith and the Late Devonian Phyllite Quartzite Group it intruded in the South Portuguese Zone of southern Spain (isotopic data from Braid et al. 2012; map modified from Braid et al. 2012 but based on de la Rosa et al. 1993). OMZ – Ossa Morena Zone; PDL – Pulo de Lobo Zone; SIF = Santa Iria Flysch; SISZ = South Iberian Shear Zone.

crustally derived plutons to have higher ε_{Nd} values than the host rocks they intruded, it is a relationship that can be used to distinguish the Meguma terrane from Avalonia. Hence, in Europe, where peri-Gondwanan terranes lying outboard of the Rheic suture are typically assigned to Avalonia (Fig. 3), this relationship, in addition to the isotopic signature, provides a potential means of distinguishing areas that may actually be correlatives of the Meguma terrane. In southern Spain, for example, the recognition of just such a relationship was used by Braid et al. (2012) to argue for the possible continuation of the Meguma terrane into the South Portuguese Zone, an allochthonous terrane of the Iberian Variscan Belt (Fig. 6).

The South Portuguese and Ossa Morena zones of the Variscan orogen in southern Iberia are tectonically separated by the Pulo do Lobo Zone (Fig. 3), which contains the Beja-Acebuches ophiolite and is widely interpreted as an accretionary complex associated with the closure of the Rheic Ocean between the South Portuguese and Ossa Morena zones in the Late Devonian–early Carboniferous (e.g. Eden 1991; Braid et al. 2011). The South Portuguese Zone lies outboard of the Rheic suture and is generally considered Avalonian (e.g. Leistel et al. 1997; Martínez Catalán et al. 1997), in contrast with the Ossa Morena Zone to the northeast, which is faunally linked to Gondwana throughout the Paleozoic (e.g. Quesada 1991; Robardet 2003).

The South Portuguese Zone comprises Upper Devonian to Lower Carboniferous sedimentary and bimodal volcanic rocks of the Iberian Pyrite Belt, the oldest component of which are Upper Devonian continental siliciclastic strata of the Phyllite Quartzite Group (Schermerhorn 1971). These rocks conformably underlie the volcanogenic massive sulphide-bearing rocks of the Pyrite Belt and, along the northeastern margin of the South Portuguese Zone, are crosscut by a variety of gabbroic to granitic plutons that make up the post-collisional, ca. 350–330 Ma (de la Rosa et al. 2002; Dunning et al. 2002) Sierra Norte Batholith (Fig. 6).

Sm–Nd isotope data from the composite Sierra Norte Batholith (Braid et al. 2012) show ε_{Nd} values of +1.4 to –9.6 and T_{DM} model ages of ca. 0.76–1.8 Ga, with the bulk of the data showing a more limited range (ε_{Nd} = +1.4 to –3.0; T_{DM} = ca. 0.9–1.2 Ga) (Fig. 6). U–Pb (zircon) data from the Sierra Norte Batholith reveal Neoproterozoic (561–647 Ma) and Mesoproterozoic (1075–1116 Ma) inheritance. In contrast, the Upper Devonian siliciclastic rocks of the Phyllite Quartzite Group show significantly more negative ε_{Nd} values (–7.5 to –10.4), and contain detrital zircon dominated (like that of the Meguma Supergroup) by Neoproterozoic (ca. 0.5–0.7 Ga), Paleoproterozoic (ca. 1.8–2.3 Ga) and minor Archean (ca. 2.5–2.9 Ga) ages (Braid et al. 2011) (Fig. 7). These results suggest that the Sierra Norte Batholith was derived from a lower crustal source of Neoproterozoic to Mesoproterozoic age, and that the basement beneath the South Portuguese Zone is compositionally more juvenile than the Devonian siliciclastic metasedimentary rocks that overlie it. This relationship, in which ancient upper crustal material overlies relatively juvenile basement, is similar to that documented in the Meguma terrane by the South Mountain Batholith and the Meguma Supergroup that the batholith intruded. This similarity led Braid et al. (2012) to follow Lefort (1989) in linking the South Portuguese Zone to the Meguma terrane, which, in Late Devonian times, would have occupied a position immediately outboard of southern Iberia.

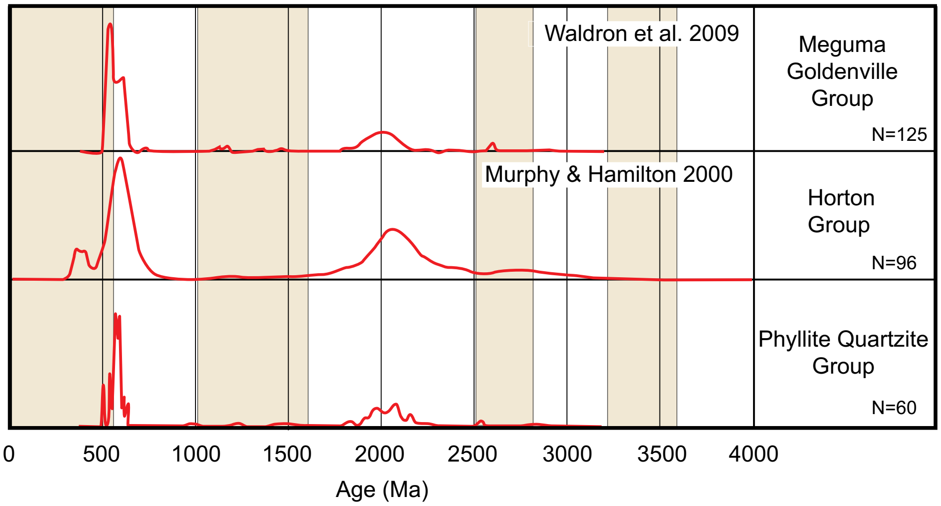

Figure 7. Comparative detrital zircon spectra for the Goldenville (Meguma terrane) and Horton groups (from sources identified), and the Phyllite Quartzite Group of the South Portuguese Zone (Braid et al. 2011).

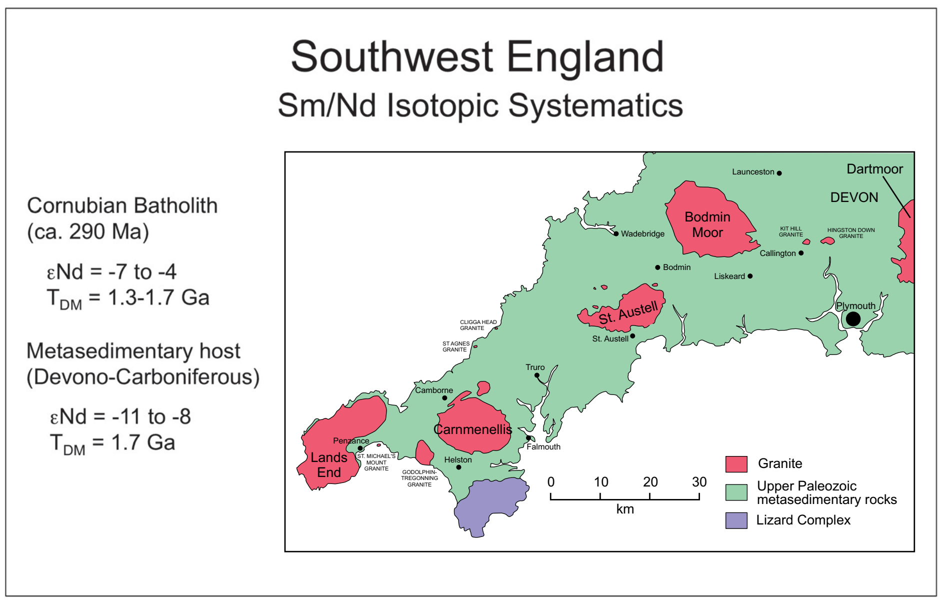

Figure 8. Geologic map and isotopic characteristics of the ca. 290 Ma Cornubian Batholith and the Devonian–Carboniferous metasedimentary rocks it intruded in the Rhenohercynian Zone of SW England (isotopic data from Davies et al. 1985 and Darbyshire and Shepherd 1994; map from Edmonds et al. 1975).

BASEMENT CONSTRAINTS IN SW ENGLAND

An obvious corollary to the linkage suggested by Braid et al. (2012) between the Meguma terrane of the northern Appalachians and the South Portuguese Zone of southern Iberia is whether the same linkage might exist for SW England, which lies along strike around the oroclinal Iberian-Armorican Arc (Fig. 3) and has long been correlated with the South Portuguese Zone (e.g. Andrews 1982; Matte 1986; Eden and Andrews 1990; Floyd et al. 1993). Indeed, if this were not the case, the nature of the orocline would come into question.

The Devonian–Carboniferous metasedimentary rocks of SW England (Fig. 8) constitute a passive margin succession that most probably developed in a marginal (and later foreland) basin north of the Rheic Ocean (e.g. Shail and Leveridge 2009). The succession is overthrust to the south by the Lizard ophiolite, which likely represents the oceanic floor of this marginal basin, and is intruded by early Permian (ca. 274–294 Ma; Chen et al. 1993; Chesley et al. 1993) post-collisional S-type granitoid plutons of the Cornubian Batholith. The region is considered to be part of the Rhenohercynian Zone of Western Europe (e.g. Holder and Leveridge 1986) (Fig. 2), which lies outboard of the Rheic suture and is widely assumed to be underlain by Avalonian basement (e.g. Franke 2000; Matte 2001). However, autochthonous pre-Devonian basement is not exposed and Shail and Leveridge (2009) noted that the basement in SW England might have originated as a separate (non-Avalonian) Gondwana-derived terrane.

Sm–Nd isotope data for the Cornubian Batholith reveal ε_{Nd} values between –4.3 and –7.7, and T_{DM} model ages of ca. 1.3–1.8 Ga (Darbyshire and Shepherd 1994). In contrast, ε_{Nd} values for the Devonian–Carboniferous county rocks range between –5.2 and –11.5, but are overwhelmingly –8 to –11 (Davies et al. 1985; Darbyshire and Shepherd 1994) (Fig. 8). Although the U–Pb age data (mainly monazite) from the Cornubian Batholith (Chen et al. 1993; Chesley et al. 1993) do not speak to potential granitoid inheritance, these results show the Cornubian Batholith to be significantly more juvenile than the rocks it intruded and, since there was only minor mixing of contemporary mantle-derived melts (e.g. Darbyshire and Shepherd 1994; Stimac et al. 1995), this primarily represents an inherited basement signature. The data further suggest that the batholith was derived from a composite lower crustal source which, while probably older than the <1.2 Ga age estimate of Hampton and Taylor (1983) based on lead isotopes, is nevertheless likely to be of Mesoproterozoic age (Darbyshire and Shepherd 1994). Hence, the relationship exhibited by both the Meguma terrane and the South Portuguese Zone, in which isotopically ancient upper crustal material overlies more juvenile basement, also appears to be present in SW England.

Although inheritance age data from the batholith is unavailable, detrital zircon ages from the Late Devonian Gramscatho Group (Fig. 9a) underlying the Lizard ophiolite (Strachan et al. 2014) are consistent with such an interpretation. These data show striking similarities to the West African signature of the Meguma Supergroup and closely match the detrital zircon populations of the Late Devonian Horton Group, which overlies the supergroup (Fig. 9b). The West African signature of the Horton Group reflects it derivation from the underlying Meguma Supergroup (Murphy and Hamilton 2000) and the same could be argued for the Gramscatho Group, in which case it would confirm the correlation of SW England with the Meguma terrane.

However, the provenance of the Gramscatho Group sedimentary rocks reflects a dominant upper plate source relative to the Rhenohercynian/Rheic suture. Gramscatho Group olistostromes contain unambiguous Armorican components indicated by Ordovician macrofossil assemblages (Sadler 1974), granitoid clasts indicative of Silurian and Upper Devonian arc magmatism (Dörr et al. 1999; Leveridge and Shail 2011), and detrital zircon populations that match those of the Armorican Massif in NW France (Strachan et al. 2014) which, as part of Cadomia, also has a West African signature (Samson et al. 2005). The mineralogical and geochemical composition of the group's deep marine sandstone is compatible with a dominant continental magmatic arc provenance that has been correlated with the westward continuation of the Mid-German Crystalline Rise magmatic arc from mainland Europe (Floyd et al. 1991). Nevertheless, it is possible that elements of SW England lower plate basement, isolated on the southern margin of the Rhenohercynian Zone as a component of the Hanseatic Terrane of Stampfli et al. (2013), were subsequently accreted to the upper plate during Late Devonian convergence and also formed a source component for the Gramscatho Group (Shail and Leveridge 2009).

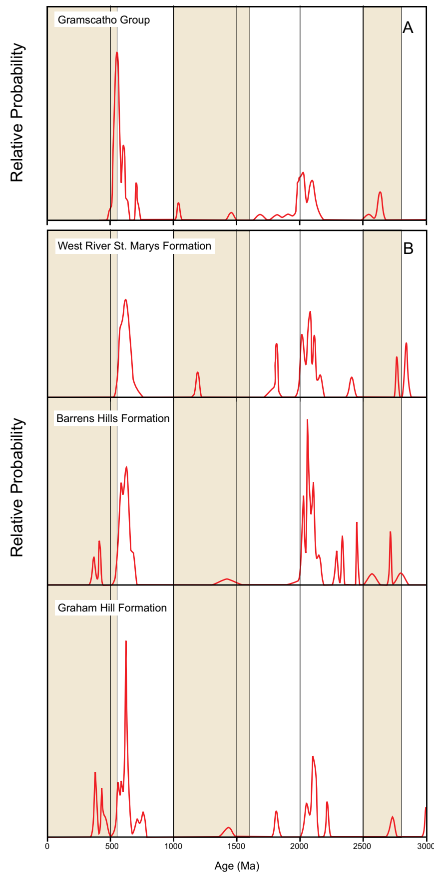

Figure 9. Comparative detrital zircon spectra for Late Devonian sedimentary rocks of (a) the Gramscatho Group in SW England (Strachan et al. 2014), and (b) the Horton Group in Nova Scotia (Murphy and Hamilton 2000).

DISCUSSION AND CONCLUSIONS

The ability to correlate terranes and identify areas of contrasting basement isotopic signature within complex orogenic belts is central to the palinspastic restoration of such belts and to the construction of paleocontinental configurations that document their evolution. In the northern Appalachians, the relationship in which isotopically ancient upper crustal sedimentary units overlie more juvenile lower crustal basement would appear to be a characteristic that distinguishes the Meguma terrane from neighbouring Avalonia. As a result, in the Meguma terrane, plutons derived from the basement, such as the South Mountain Batholith, are isotopically more juvenile than the country rocks they intruded. The same relationship holds for the Sierra Norte Batholith and its country rocks in the South Portuguese Zone (Braid et al. 2012), where it has been used to suggest that the South Portuguese Zone might be correlative with the Meguma terrane, rather than being part of Avalonia as is generally inferred for this part of southern Iberia.

Available data suggest that the same relationship may also hold for the Cornubian Batholith in SW England and the rocks of the Rhenohercynian passive margin that this batholith intruded. There are also striking similarities between zircon age population data from the Meguma Supergroup and overlying Late Devonian Horton Group and those from the Late Devonian Gramscatho Group (SW England) which has a dominant upper plate provenance relative to the Rheic suture (Waldron et al. 2011; Strachan et al. 2014).

Hence, the Meguma terrane (rather than Avalonia) may also be present in SW England in that part of the Rhenohercynian Zone with which the South Portuguese Zone is traditionally correlated. Such an eventuality would have significant implications for the interpretation of the Variscan Belt and the correlation of this belt throughout Europe.

The existence of the Meguma terrane in SW England would also be relevant to the proposed correlation of the Meguma Supergroup with Cambrian–Ordovician sediments of the Harlech Dome region of North Wales (Waldron et al. 2011) and, more recently, with the Cambrian–Ordovician sedimentary rocks of Megasequence 1 in the largely concealed Brabant Massif of the European Low Countries (Linnemann et al. 2012). These two correlations are not based on Sm–Nd isotopic data, but rather on matching detrital zircon records and lithostratigraphic similarities that include thick quartzose turbidites in the early Cambrian, highly Mn-enriched and bioturbated clastic sedimentary rocks in the middle Cambrian, anoxic pyrite-rich slate in the late Cambrian, and slate and sandstone with *Rhabdinopora flabelliformis* in the Tremadocian. But if both these correlations and that with SW England are correct, an interesting situation emerges with respect to the distribution of the Meguma terrane, which would come to lie both inboard and outboard of established Avalonia in the Welsh Borderlands and the British Midlands (e.g. Tucker and Pharaoh 1991; Compston et al. 2002).

Waldron et al. (2011) proposed several paleogeographic scenarios to account for the possible existence of the Meguma terrane (their Megumia) inboard of Avalonia (Fig. 10). The first (Fig. 10a) shows the peri-Gondwanan terranes juxtaposed with Gondwana in their late Paleozoic relative positions. The second (Fig. 10b) juxtaposes West (northern Appalachian) and East (British) Avalonia across a rift basin containing the basinal facies of the Meguma terrane. The third shows the basinal rift facies of the Meguma terrane separating Avalonia from Gondwana (Fig. 10c). The possible extension of the Meguma terrane into SW England would be incompatible with the third scenario (eliminating the need to invert the UK), but is consistent with the other two. But how could the Meguma terrane come to lie on both sides of Avalonia?

Figure 11 shows a possible explanation for this distribution. Given that the Meguma terrane and Avalonia have isotopically similar basements but contrasting cover successions and detrital zircon populations, it might have been possible for basinal facies like those of the Meguma Supergroup, that were sourced from Gondwana and so contain Gondwanan zircon populations, to have been deposited in a number of rift basins that opened as a result of Avalonia's separation from Gondwana in the early Paleozoic (e.g. Murphy et al. 2006). At the same time, the platformal sedimentary rocks of Avalonia could have been deposited on intervening horsts, where they would have been sourced locally from Avalonia and so contain Avalonian zircon populations. In this way, the Meguma terrane could come to lie both inboard and outboard of East Avalonia.

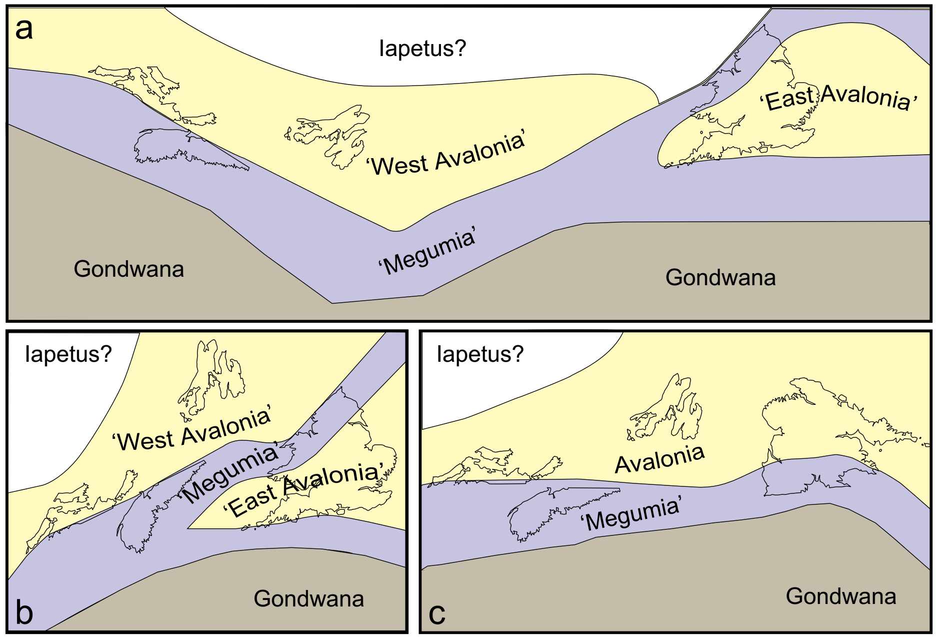

Figure 10. Early Cambrian plate reconstructions put forward to account for the possible presence of the Meguma terrane (Megumia) in North Wales inboard of Avalonia in the Welsh Borderlands and British Midlands (Waldron et al. 2011).

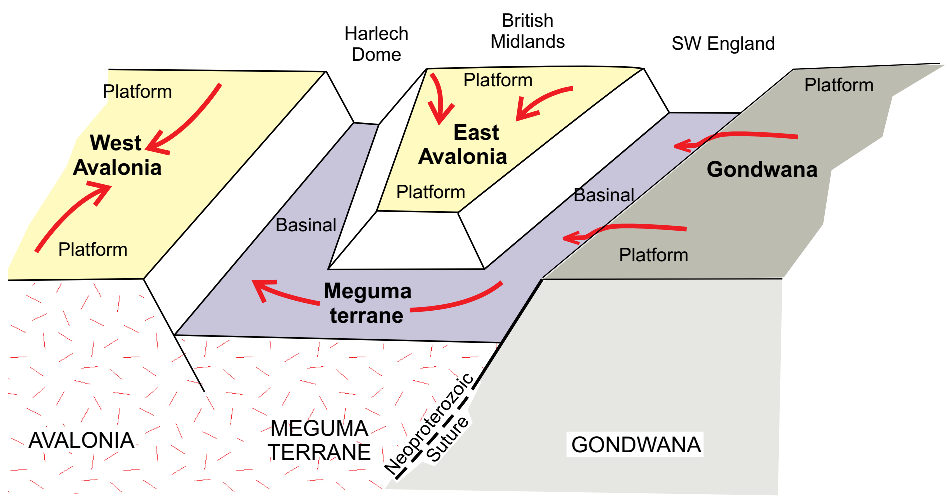

Figure 11. Cartoon explaining the possible occurrence of Gondwana-sourced basinal facies like those of the Meguma terrane on either side of the platformal facies of Avalonia in southern Britain.

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