Read at the Annual Conference of the Ussher Society, January 1990

Implications of a supercontinent model for the Avalon composite terrane to the Late Proterozoic evolution of the North Armorican Massif

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Nance. R.D., Murphy, J. B., Strachan, R.A. and D'Lemos R.S. 1990. Implications of a supercontinent model for the Avalon composite terrane to the Late Proterozoic evolution of the North Armorican Massif. *Proceedings of the Ussher Society*. 7, 228-231.

A three-stage evolution from late Precambrian magmatic arc through latest Precambrian strike-slip regime to early Palaeozoic stable platform typifies both the Avalon composite terrane of the Northern Appalachians and the North Armorican composite terrane of NW France. In both terranes, late Precambrian calc-alkaline granitoid bodies and coeval volcanics show arc-related affinities and are associated with volcanogenic turbidite successions attributed to deposition within a variety of volcanic arc basins. Latest Precambrian to Early Cambrian redbeds and bimodal continental rift volcanics record the development of an extensional strike-slip regime within the former arc, and are overlain by Early Palaeozoic platformal overstep sequences that contain the Acado-Baltic fauna of the lapetus cycle.

Like the Avalonian cycle, termination of Cadomian orogenic activity in the North Armorican composite terrane lacks evidence for mayor continental collision and may reflect the break-up of a late Precambrian supercontinent and the replacement of broadly southward-directed subduction along one of its margins by transform activity of predominantly sinistral sense. If so, the resulting closure of arc-related basins and the development of an Early Palaeozoic platform may have accompanied the formation of Iapetus and the associated rise in sea level, but would have taken place on the active margin of a pre-existing ocean rather than the rifted "European" margin of Iapetus.

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Introduction

On a pre-drift reconstruction of the North Atlantic, the North Armorican composite terrane of NW France and the Avalon composite terrane of the Northern Appalachians form a distinctive tectonostratigraphic belt extending from Brittany and Normandy (Dupret *et al.* 1990; Rabu *et al.* 1990) through southern Britain (Thorpe *et al.* 1984) to Atlantic Canada and New England (O'Brien *et al.* 1983; Rast and Skehan 1983; Nance, 1986). While the details of stratigraphic succession and the timing of tectonic events vary between individual regions, the late Precambrian geology of the entire belt is typified by the association of four sequential tectonostratigraphic elements: magmatic arc, arc basin, strike-slip regime, and shallow-marine platform. Any model that accounts for this succession of tectonic regimes, such as that proposed for the Avalon composite terrane by Murphy and Nance (1989), is therefore likely to be applicable to the development of the belt as a whole.

In the Avalon composite terrane, late Precambrian (c.630-580Ma) calc-alkaline granitoid bodies and co-genetic, terrestrial volcanics and volcaniclastics typically show arc-related geochemical affinities and are generally attributed to Late Precambrian subduction (Keppie *et al.* 1990 and references therein). Gneisses associated with these rocks give similar ages and may represent the metamorphic infrastructure of the late Precambrian magmatic arc. Associated volcanogenic turbidite successions contain volcanics of both continental tholeiitic and calc-alkaline affinity and have been attributed to deposition within a variety of volcanic arc basins (Knight and O'Brien 1988; Pe-Piper and Piper 1989; Murphy *et al.* 1990). Where kinematic data is available, basin development appears to be associated with ductile shear zones of sinistral shear sense (Nance and Murphy 1990). Unconformably overlying sequences of latest Precambrian to Cambrian (c.550Ma) bimodal volcanics and redbeds are also characteristic (Bevier and Barr 1990) and are thought to be the product of rift and/or wrench basins developed in a strike-slip regime (Smith and Hiscott 1984). The successions are then unconformably to disconformably capped by Cambro-Ordovician platform sequences containing trilobites of the Acado-Baltic (Atlantic realm) fauna which have been widely used to define the southern or "European" margin of the lapetus Ocean (Cocks and Fortey 1982).

This tectonostratigraphic history essentially records the evolution of an active continental margin. Yet it broadly coincides with the c.625-555Ma rifting and early drifting phase of the Iapetus cycle as recorded in the development of the miogeoclinal succession on cratonic eastern North America (Bond *et al.* 1984). Hence, the evolution of the Avalon composite terrane on the southeastern margin of the Appalachian orogen contrasts with that of the orogen's northwestern margin in a manner that is inconsistent with the orogen's development through the symmetrical opening and closing of the Iapetus ocean.

To account for these features, Murphy and Nance (1989) have suggested that the tectonostratigraphic history of the Avalon composite terrane records the termination of subduction through transform activity in response to the break-up of a late Precambrian supercontinent. In this paper, we apply a modification of this model to the Cadomian evolution of the North Armorican composite terrane, following a brief review of the region's late Precambrian to Early Palaeozoic evolution. We then examine some of the implications of this model to continental reconstructions for the Precambrian-Cambrian boundary interval and their bearing on the inception of the Iapetus cycle.

North Armorican Composite Terrane

Although the Cadomian tectonostratigraphic record of the North Armorican composite terrane (Fig. 1) is more complex than that of Avalon, late Precambrian magmatic arc activity is again essentially terminated by sinistral strike-slip movements of latest Precambrian to Early Cambrian age (Strachan *et al.* 1989). A Cadomian magmatic arc root may also be present in the North Armorican composite terrane in the form of the calc-alkaline gneissic-plutonic Penthièvre complex (Shufflebotham 1990), boulders of which have been dated at c.655-670Ma (Guerrot and Peucat 1990) in the Cesson conglomerate at the base of the adjacent Brioverian succession.

The basic submarine pillow lavas of the lower part of the Brioverian succession exposed in the Tregor region and the Baie de St. Brieuc (Cabanis *et al.* 1987; Lees *et al.* 1987) are generally thought to represent the initial phases of opening of a marginal basin system bordered to the NW by a major volcanic arc (Dupret *et al.* 1990; Rabu

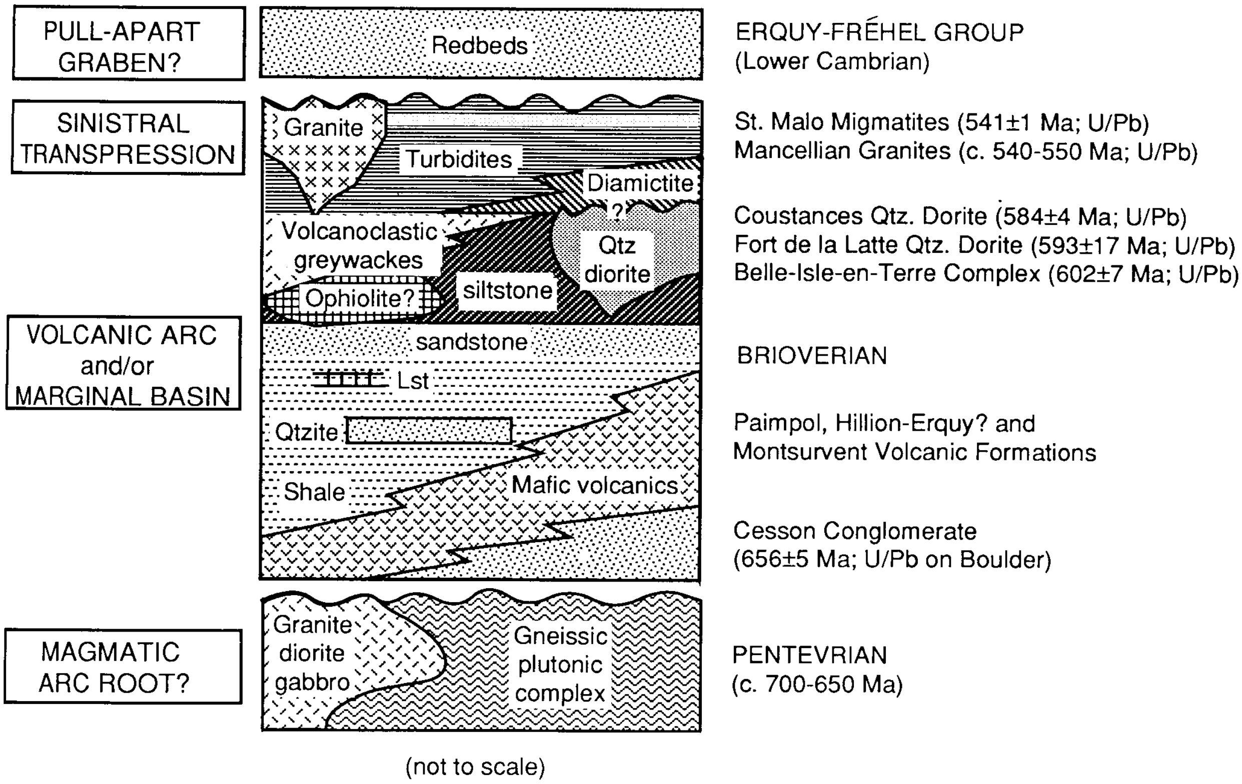

Figure 1. Simplified interpretive tectonostratigraphic column for late Precambrian to Early Palaeozoic rocks of the North Armorican composite terrane in Brittany, Normandy and Maine, NW France (see text for sources).

et al. 1990). This basin may have been floored by oceanic-type crust, possibly represented by the 602Ma Belle-Isle-en-Terre complex which Peucat *et al.* (1981) interpret as an obducted ophiolite. The overlying Brioverian sediments which form the bulk of the sequence are mainly turbidites and are also likely to represent a marginal basin succession.

U-Pb ages for calc-alkaline, volcanic arc plutonism intrusive into the Brioverian, which is locally associated with andesite-rhyolite volcanism, span the interval c.615-525Ma (Brown *et al.* 1990 and references therein). Deformation and metamorphism are polyphase: (a) prior to 600-610Ma on Guernsey and Sark; (b) prior to 560-570Ma in the Baie de St. Brieuc; and (c) c.540Ma in the St Cast/St Malo region (Peucat 1986; Brun and Balé 1990; Strachan *et al.* 1990; D'Lemos *et al.* 1990). However, the peak of orogenesis is thought to involve intra- or back-arc basin inversion with mid-crustal anatexis in the St Malo and Mancellian regions and sinistrally transpressive terrane accretion at c.540Ma (Strachan *et al.* 1989: Brown *et al.* 1990).

Unconformably overlying Lower Cambrian redbeds, that include the Erquy-Fréhel Group and the Rozel Conglomerate and Alderney Sandstone formations, are interpreted to record alluvial sedimentation in small rift and/or pull-apart graben (Went and Andrews 1990). In Lower Normandy, the Brioverian is unconformably overlain by Early Palaeozoic platformal sediments containing bimodal volcanics and shallow-marine Acado-Baltic fauna (Doré 1972).

Discussion

Despite its obvious oversimplification, several important generalities emerge from this brief review. First, the evolution of the North Armorican composite terrane, like that of the Avalon composite terrane, can be interpreted to record the transition from a late Precambrian magmatic arc setting to an Early Palaeozoic shallow-marine platform. Second, late Precambrian subduction would appear to have spanned the interval 670Ma to 540Ma prior to its decay in the North Armorican composite terrane and 630Ma to perhaps 580Ma in the Avalon composite terrane. Third, subduction in both terranes was apparently accompanied by the development of volcanic arc basins (ranging from small volcanic arc rifts to larger marginal basins possibly floored by oceanic crust) and resulted in the deposition of volcanogenic turbidites. Fourth, the arc-platform transitions were initiated at about 540Ma in the North Armorican composite terrane and about 570Ma in the Avalon composite terrane, and were accompanied by strike-slip movement of predominantly sinistral sense that resulted in the closure of some late Precambrian volcanic arc basins and the opening of pull-apart graben and rifts during the latest Precambrian and Early Cambrian. Finally, in the absence of crustal thickening, large-scale horizontal shortening, widespread regional metamorphism, and significant post-orogenic molasse, the arc-platform transition in both terranes lacks evidence of major continental collision. Hence, the ocean bordering the late Precambrian magmatic arcs presumably survived the termination of subduction to border the Early Palaeozoic platform.

In an attempt to account for these features in the Avalon composite terrane, Murphy and Nance (1989) proposed a preliminary tectonic model that involves the termination of subduction through transform activity. In this model (Fig. 2), which we here apply to the North Armorican composite terrane, the development of an extensional magmatic arc and perhaps a variety of volcanic arc basins locally floored by oceanic crust is attributed to oblique subduction with a left-lateral component of movement. The termination of subduction, the partial closure of the volcanic arc basins and the resulting development of local unconformities, and the opening of rift and/or pull-apart graben, are attributed to transform activity of sinistral sense during the latest Precambrian. This wrench regime locally persisted into the Cambrian but yielded to shallow-marine platformal conditions with rising Cambrian sea levels.

A degree of support for such a scenario can be found in continental reconstructions for the late Precambrian and Early Palaeozoic. Most palaeomagnetic studies place the North Armorican Massif (and the Avalon composite terrane) along the northern flank of Africa during the earliest Palaeozoic

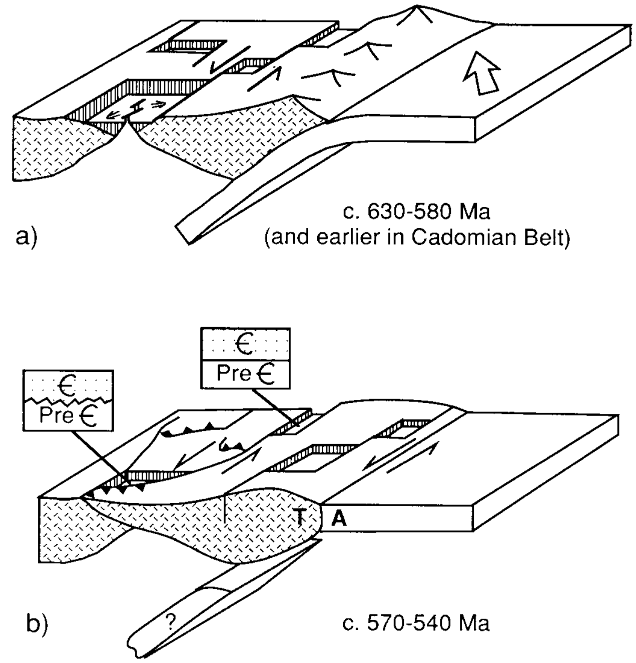

Figure 2. Schematic plate tectonic model for the late Precambrian to Early Palaeozoic evolution of the North Armorican and Avalon composite terranes. (a) Oblique, late Precambrian subduction and the generation of an extensional magmatic arc containing a variety of volcanic arc basins locally floored by oceanic crust. (b) Termination of subduction with the development of a sinistral transform system, closure of some but not all the volcanic arc basins, and formation of pull-apart graben during the latest Precambrian and Cambrian. Deformation of Precambrian rocks may be mild or locally intense resulting in both disconformities and angular unconfonnities at the Precambrian-Cambrian boundary.

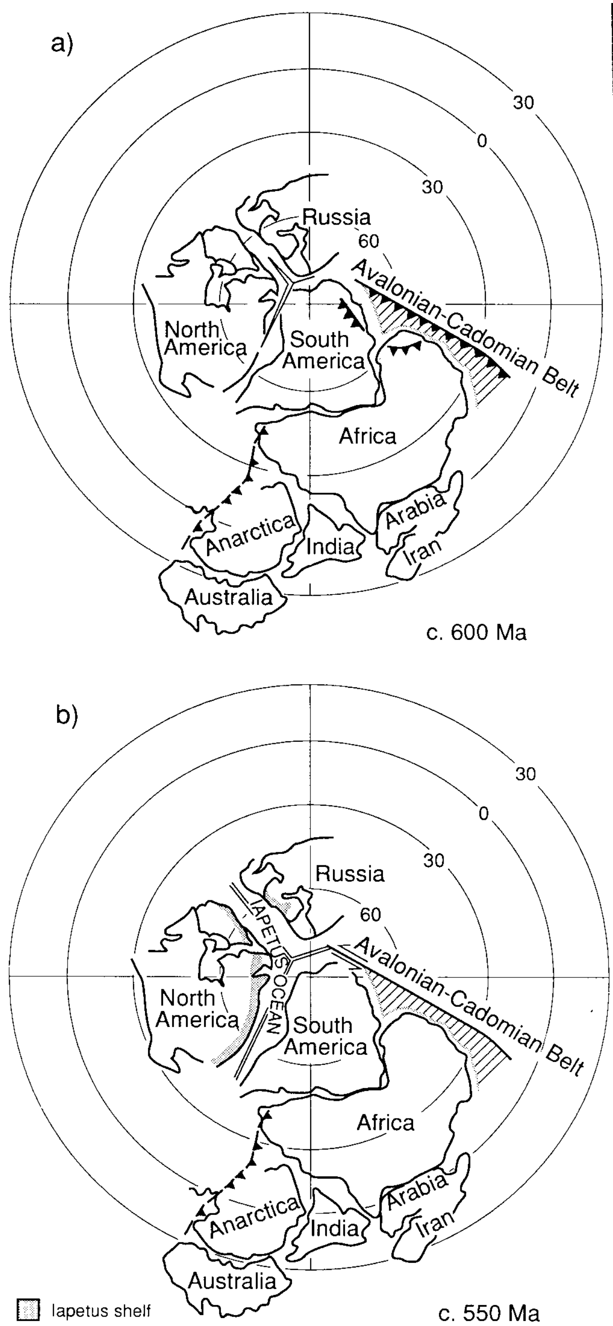

Figure 3. Late Precambrian continental reconstruction showing (a) major plate boundaries and the proposed location (after Van der Voo, 1988) of the Avalonian-Cadomian belt with respect to the late Precambrian supercontinent of Bond *et al.* (1984) prior to the inception of the Iapetus cycle at c.600Ma, and (b) conceptual configuration following break-up of the supercontinent of Bond *et al.* (1984) and the development of a sinistral transform with initial opening of the Iapetus Ocean at c. 550Ma. South polar equal-area reconstruction modified after Bond *et al.* (1984).

(see Van der Voo 1988 for a review), while Bond *et al.* (1984) have proposed that the break-up of a late Precambrian supercontinent occurred between 625Ma and 555Ma based on the distribution and subsidence history of late Precambrian to Early Palaeozoic miogeoclinal sequences. Super-continent breakup at c.600Ma has also been proposed on the strength of palaeomagnetic studies (Piper 1987) and on the basis of Early Palaeozoic first-order sea-level curves (Worlsey *et al.* 1984).

Although the validity of Bond *et al.'s* (1984) continental reconstruction (Fig. 3) is uncertain, it successfully reunites areas of Grenville and Pan-African orogenesis into two linear belts (Keppie *et al.* 1990) and provides a potential explanation for the late Precambrian evolution of both the Avalonian and Cadomian orogenic cycles. Thus, the inception or resurgence of subduction in both regions may reflect the transfer of subduction from the closing interior oceans to the supercontinent's periphery following amalgamation of this supercontinent during the late Precambrian (Fig. 3a). Similarly, the termination of subduction could have occurred with rifting and the onset of drifting (Fig. 3b) since the separation of Baltica from South America would have required the near-orthogonal propagation of a mid-ocean ridge into the Avalonian-Cadomian system. If this occurred, the geometry is such that their intersection could, in turn, have led to the development of a sinistral transform system through ridge-trench interaction. Furthermore, the position of the Avalonian-Cadomian belt with respect to the developing Iapetus system suggests only an indirect tectonic linkage existed between them, and implies that the Acado-Baltic fauna of the North Armorican and Avalon composite terranes developed on the active margin of an older ocean rather than the rifted "European" margin of Iapetus.

Other late Precambrian continental reconstructions (Van der Voo *et al.* 1984; Piper 1987; Taylor and Strachan 1990) differ from that of Bond *et al.* (1984) and from each other, and would require significant modifications to the model we propose here. Yet each retains two of the model's essential features. Firstly, in being marginal to north Africa, the North Armorican and Avalon composite terranes would continue to occupy peripheral positions with respect to a Gondwanan supercontinent where subduction might be expected, and secondly, both terranes remain well removed from the contemporary site of Iapetus rifting and, hence, can be only indirectly linked to the evolution of the Iapetus Ocean.

Acknowledgements. This paper was completed while Nance and Murphy were on sabbatical leave at Oxford Polytechnic and has benefitted from many discussions with members of the Department of Geology at that institution and from the facilities afforded them there. R.D. Beckinsale, H. Colley, G.K. Taylor, and C.G. Topley are acknowledged in particular. A NSF International Cooperative Research grant (INT-8921515) to Nance and a NSERC International Collaborative Research grant (ICR-0092597) to Murphy are also acknowledged.

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