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Dear Editor,

We submit our reply to the Comment by van Staal and Winchester on our paper 'No Exploits back-arc basin in the Iapetus suture zone of Ireland', Journal of the Geological Society, 172, 740-747. While we welcome the discussion, we have not changed our interpretation and use the opportunity to explain our ideas further and correct the misunderstandings of van Staal and Winchester.

Authorship has changed slightly from the original, based on those who wished to contribute to the discussion. There are no figures or tables.

We look forward to hearing from you.

Yours faithfully,

Dr Brian McConnell

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Reply to Comment on 'No Exploits back-arc basin in the Iapetus suture zone of Ireland', *Journal of the Geological Society*, 172, 740-747

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We thank van Staal and Winchester (2017) for their discussion of our paper (McConnell et al. 2015) and their concise summary of the evolution of the Popelogan–Victoria Arc (PVA), Tetagouch–Exploits Basin (TEB) and Ganderian margin in the northern Appalachians. They make the case that we have failed to recognise the same tectonic elements and geological history in Ireland. They propose that we, in concluding there was no Exploits basin-equivalent in Ireland, have "an absence of evidence rather than evidence of absence". We have documented a stratigraphical sequence that provides evidence of a 10 My gap in volcanism at Bellewstown (c. 474–464 Ma) at a time when the TEB was actively opening further to the west along the orogen. We have placed that observation in the regional context of a middle–late Ordovician stratigraphical and faunal linkage to the Leinster Terrane (Parkes & Harper 1996), where volcanism demonstrates continued subduction under a N-facing volcanic arc on the Ganderian margin (McConnell 2000). We concede that the Bellewstown succession, if taken in isolation, could represent deposits on the passive margin of the TEB, but the Darriwilian–Sandbian volcanic rocks of north Leinster are too voluminous, too young and geochemically incompatible with representing remnants of the passive margin of a TEB-aged rifted arc basin.

Nowhere in our paper did we suggest, as claimed by van Staal and Winchester, that there is no equivalent to the rifted PVA in Ireland. The middle–late Ordovician, N-facing volcanic arc on the Ganderian margin is present through Wicklow–Waterford (McConnell 2000). At Avoca, c. 463 Ma (Fritschle 2016) peralkaline rhyolites indicate an extensional tectonic setting (McConnell et al. 1991). It is our contention that this extension is the along-strike and diachronous equivalent of rifting of the PVA to open the TEB. In Ireland, however, extension did not lead to spreading and back-arc basin formation. Van Staal and Winchester suggest that the PVA in Ireland could be entirely buried beneath a foreland basin after collision with the Laurentian margin. Previously, van Staal et al. (1998), in their seminal paper on Appalachian–Caledonian correlations, proposed that the small Grangegeeth terrane of arc volcanic rocks, to the north of Bellewstown, is a remnant of the accreted PVA, but McConnell et al. (2010) have since shown it to be of Laurentian origin.

We agree with van Staal and Winchester that there are “remarkable similarities in tectonic evolution between the Irish and North American Gander margins. Both were subjected to an Early Ordovician orogenic event – Penobscot in the Appalachians, Monian in the British Isles – and both accreted nearly coevally to composite Laurentia during Silurian closure of the Iapetus Ocean s.l., while situated on the lower plate”. We believe, however, that there were differences in the tectonic evolution of the two areas in the time period between those events. Indeed, van Staal and Winchester get close to our own preferred model when they suggest a “ major reduction in back-arc extension towards the northeast, such that the PVA continued into a north-facing Leinster–Lake District arc–back-arc system, could explain the lack of an exposed oceanic TEB equivalent in Ireland and Britain”. They note that “the lifespan (476-457 Ma) and uninterrupted nature of the PVA–TEB magmatism differs significantly from the more episodic Leinster–Lake District arc–back-arc system”. That, indeed, is what we have demonstrated at Bellewstown, with volcanic quiescence after c. 474 Ma, followed by renewed volcanism in a N-facing arc further south in the late Darriwilian, while Bellewstown remained on the Ganderian margin. We suggest that rifting was wider and earlier in the Appalachians (the TEB), while later and not fully developed in Ireland (the Avoca extensional volcanism), because of variations in slab rollback and oblique plate convergence, similar to the modern diachronous rifting of the continental Ryukyu arc to form the Okinawa Trough back-arc basin (Sibuet et al. 1987).

Van Staal and Winchester assert that volcanic shut-down was broadly synchronous in the late Ordovician along the N-facing arc, but subduction-related volcanism in the Dunquin Group in southwest Ireland is Wenlock in age (Sloan & Bennett 1990), indicating that vestiges of Iapetus lithosphere continued to be subducted in a southerly direction after the PVA had accreted to Laurentia. Thus, final closure of Iapetus in the Irish sector was achieved by both limited southward subduction under Ganderia and northward subduction of normal Iapetus lithosphere under the Laurentian accretionary margin. The details of the transition between the Newfoundland and Ireland Ganderian margins are hidden under younger rocks on the respective modern continental shelves, but aspects of this model can be tested with further detailed geochronological and geological data.

Van Staal and Winchester refer to a "Leinster–Lake District arc–back-arc system", but we consider that significant differences exist between the arc volcanism of these two areas. In the Lake District, volcanism evolves to subaerial caldera systems (Branney & Kokelaar 1994), with no evidence of the supra-subduction zone extensional tectonics seen in Leinster. We therefore agree with van Staal and Winchester on the difficulty of matching tectonic events from the patchy record preserved in ancient mountain belts and emphasise that differences emerge when details of tectonic reconstructions are pushed even relatively short distances along an orogen.

Van Staal and Winchester question the relevance of the detrital zircon record in Southern Uplands–Down–Longford accretionary prism sediments, even though they propose that a Ganderian volcanic arc accreted to that margin. McConnell et al. (2016) found that Ordovician and Cambrian zircons, typical of Ganderia, are present in Sandbian–Hirnantian Moffat Shale Group oceanic sediments from Monaghan (Ireland) that were deposited on the lower, oceanic plate before being emplaced as sequential thrust slices in the accretionary prism on the Laurentian margin. Moffat Shale, Sandbian to Telychian in age, is preserved in the Southern Uplands–Down–Longford accretionary prism, without evidence of deformation by collision of a PVA-type arc terrane (Stone 2014). Rather, the accretionary prism continued to grow outward from the Laurentian margin until the Ganderian margin was sufficiently close that it was overstepped by north-derived Wenlock greywackes (Kneller et al. 1993).

Although van Staal and Winchester ask in their discussion what caused Monian orogenesis in southeast Ireland (Tietzsch-Tyler 1996) and how north-facing Ordovician suprasubduction zone magmatism was subsequently established on Irish Ganderia, our Bellewstown paper has no direct relevance to that question. We accept the van Staal et al. (1998) model in which Monian orogenesis was caused by Penobscot obduction, as in the Appalachians. We are currently working on the Cummer serpentinite belt of Leinster (Gallagher 1989) to determine whether it is a fragment of obducted Penobscot lithosphere equivalent to the Gander River Ultrabasic Belt of Newfoundland. Alternatively, the Cummer belt, considering its close association with the c. 456 Ma Croghan Kinshellagh arc granite and the Avoca peralkaline rhyolites (Tietzsch-Tyler & Sleeman 1995; Fritschle 2016), may be a fragment of back-arc oceanic lithosphere from the abortive attempt to open a TEB-equivalent basin.

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