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A Lower Devonian age for the Corvock Granite and its significance for the structural history of South Mayo and the Laurentian margin of western Ireland

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Abstract

The Silurian Croagh Patrick succession, which crops out just south of a fundamental Caledonian structural zone near Clew Bay, western Ireland, is a series of psammites and pelites with a strong penetrative cleavage. These rocks are intruded by the Corvock granite. A suite of minor intrusions associated with the granite contains the regional cleavage whereas the Corvock granite is undeformed. New U-Pb dates are 413 ± 7 / -4 Ma for a strongly cleaved sill and 410 ± 4 Ma for the main granite and closely constrain the age of crystallization of the granite and coeval cleavage formation as Lower Devonian (Lochkovian or Pragian), implying syn- to late-kinematic granite emplacement. These data are consistent with evidence for strong sinistral shear shown by the Ox Mountains granodiorite just to the north-east dated at 412.3 ± 0.8 Ma. This Devonian cleavage is superimposed on Ordovician rocks of the South Mayo Trough. The localisation of the strong deformation is interpreted as being due to its position at a restraining bend during regional sinistral motion on a segment of the Fair Head-Clew Bay Line to the north. Contemporaneous deformation in the syn-

kinematic Donegal batholith suggests a transfer of sinistral motion to this intra-Grampian structure rather than simple along-strike linkage to the Highland Boundary Fault in Scotland. Our new data indicate diachronous deformation during the late Silurian and early Devonian history of the Irish and Scottish Caledonides and also support previous interpretations of diachronous deformation between these areas and the Appalachian orogens.

Keywords: Caledonides, geochronology, granites, cleavage formation, Ireland, Devonian

Introduction and regional geology

The geology of South Mayo in western Ireland is an important area in understanding the history of the Laurentian margin. It is the only location where Lower Palaeozoic rocks are reasonably well exposed immediately south of a major tectonic structure that can be traced from NE Scotland to the Atlantic and is variously referred to as the Highland Boundary Fault (HBF) in Scotland and the Fair Head Clew Bay Line (FHCBL), or the Clew Bay Zone in Ireland (Fig. 1a). In South Mayo, Ordovician sedimentary rocks are preserved in an open synclinal structure, the South Mayo Syncline, which shows important provenance differences in the earlier parts of its history between the northern and southern limb successions. The northern limb has evidence of erosion an earlier ophiolite (Wrafter and Graham 1989; Dewey and Mange 1999), remnants of which are preserved in the Clew Bay Complex to the north. The southern limb has evidence of erosion of an arc emplaced into continental basement, the Connemara massif that currently lies to the south (McConnell et al., 2009).

The contacts of the Ordovician rocks and their likely source areas are everywhere unconformably overlain by successions of Silurian age that are, from south to north, the Killary Harbour-Joyce Country succession, the Croagh Patrick succession and the Louisburgh-Clare Island succession (Fig.1b). The Killary Harbour-Joyce Country succession is well dated biostratigraphically as mid to late Telychian (late Llandovery) to Sheinwoodian (early Wenlock) (Harper et al. 1995; Rickards, 1973; Rickards and Smyth 1968). The Croagh Patrick succession is everywhere strongly deformed with a penetrative cleavage in many places and has been metamorphosed to low greenschist facies. The age of this succession is less well constrained (Williams and Harper 1991) as 'probable Llandovery' because the faunas that have been recovered are very strongly deformed and do not contain anything that is precisely age diagnostic. The Louisburgh-Clare Island succession is of late Silurian age (Ludfordian to Pridoli) based on the dating of a tuff horizon within the succession at 423 ± 4 Ma (Graham et al. 2020).

Two major granitic bodies occur within and to the south of the Clew Bay Zone, namely the Ox Mountains Granodiorite and the Corvock Granite (Fig. 1b). The Ox Mountains Granodiorite shows evidence for emplacement under strong sinistral shear (McCaffrey 1992) and has been reliably dated at 412.3 ± 0.8 Ma (Chew and Schaltegger 2005; U-Pb ID-TIMS). An earlier whole rock age of 487 ± 6 Ma (Pankhurst et al. 1976; Rb-Sr) is clearly not recording the crystallisation age of the Ox Mountains granodiorite but is most likely an artefact of mixing between magmas derived from juvenile and crustal sources (Chew and Stillman 2009). To date the Corvock Granite has only been dated via the Rb-Sr system at 381 ± 19 Ma (Leake 1978) and 387 ± 12 Ma (O'Connor 1989). The main aim of this investigation was to determine the age of the Corvock Granite using U-Pb zircon geochronology and to assess the implications of this age for the structural history of the strongly deformed rocks of the Croagh Patrick succession.

69 These data are important in assessing along-strike comparisons with Scotland to the east and
70 Newfoundland to the west.

71

72 **Local geology**

73 The Corvock Granite intrudes both the Ordovician rocks of the north limb succession of the
74 South Mayo Trough and also the rocks of the Silurian Croagh Patrick succession. Although it
75 is difficult to follow all of the earlier detailed subdivisions of the stratigraphy made further
76 to the east (Dewey 1963), a threefold subdivision of the Silurian stratigraphy into a lower,
77 strongly quartzose psammitic unit (Cregganbaun Formation), a middle, locally very muddy
78 pelitic unit (Bouris Formation) and an upper, less-purely quartzose, locally calcareous
79 psammitic unit (Lough Nacorra Formation) is mappable on a regional scale. The area to the
80 west of the Corvock Granite is very poorly exposed with significant bog-covered areas
81 between the exposed granite and the coast. The revised map of this western area is shown
82 in Figure 2.

83 The Corvock granite has a well-developed thermal aureole in which the sedimentary rocks
84 are hornfelsed. A suite of minor intrusions is mainly granitic in composition but some
85 appinite dykes have a close spatial association with the main granite body. The main
86 Corvock Granite has been described by Stanton (1960) and O'Connor (1989). The granite is
87 well exposed in the hills of Corvockbrack and Knockaskeheen ('C' and 'K' on Fig. 2a) but
88 much of the western part of the granite is very poorly exposed. Both the above authors
89 noted that the granite is coarsely crystalline and undeformed. It consists mainly of quartz,
90 microcline, oligoclase, biotite and muscovite with accessory apatite, pyrite, zircon,
91 haematite and epidote. O'Connor (1989) noted a range of composition from granodiorite to

leucocratic granite and common secondary chloritisation of biotite and sericitisation of feldspar. The associated feldspar-porphyry dykes plot on the main trend and represent the least fractionated material. Silica contents vary from 69.34 % (porphyries) to 75.68% (leucogranite). Stanton (1960) noted that part of original cap of hornfelses is preserved on Knockaskeheen where contacts dip at low angles. Contacts with country rock are sharp and adjacent rocks are intruded with granite veins and dykes. The marginal part of the granite contains numerous hornfels xenoliths that are stated to be richer than normal in biotite (Stanton 1960). Inamdar and Kelly (1979) attempted to delimit the three dimensional shape of the main granite using a mixture of gravity and magnetics. Their cross-section shows a sheet-like geometry, thicker in the southeast, and they interpreted the granite to be a laccolithic intrusion. These authors and O'Connor (1989) also reported two sets of feldspar porphyry dykes, the younger of which are undeformed and radiate outwards from the granite although they considered both sets to predate granite emplacement. Neither work noted textural changes at the margins of the granite. Kelly and Max (1979) considered that the granitic sills were everywhere cut by the granite.

Stanton (1960) noted that many, though not all, of granitic dykes and sills associated with the granite show a cleavage parallel to regional cleavage of slates. This fieldwork has confirmed the original observations that the minor intrusions carry the regional cleavage (Fig. 2c). Most of the granitic intrusions in the Cregganbaun area have steep dips that are parallel to the bedding in the sedimentary rocks and are likely to have been intruded as sills that were then folded.

Anderson (1960) stated that the porphyry intrusions of Cregganbaun predate the regional metamorphism. He also suggested that local thermal metamorphism preceded the regional

metamorphism and as a result fossils are less distorted in strata closer to the granite than from localities further west. Our field observations that the fragments of fauna found so far in the Cregganbaun area are less distorted than those fragments we have found further west agreeing with Anderson's observations. These observations are made not only close to the granite but also in an area where the concentration of granitic sills is greatest. Possible explanations of these observations are: (i) A sufficiently large concentration of sills to produce a thermal aureole before development of cleavage (ii) The minor intrusions produced a rigid framework that shielded these areas during the regional cleavage forming event (iii) The intrusion of the Corvock granite was a protracted syn-kinematic event and that a significant magma body and associated aureole was already present at the time of cleavage formation with the last phases of intrusion that produced the now-exposed undeformed granite post-dating the cleavage formation. We do not currently have the ability to state which of these hypotheses is most likely.

Field evidence clearly demonstrates that the main Corvock Granite cross-cuts the main cleavage-forming folds (Dewey 1967; Kelly and Max 1979; Graham et al. 1989). However, Dewey and McManus (1964) interpreted the curvature of the main (F1) structures as due to the Corvock granite behaving as a rigid body during the main F1 producing deformation causing the folds to deflect around it. Anderson (1960) ascribed these structures to his second deformation phase which he interpreted as pre-dating the intrusion of the Corvock granite. Stereoplots of bedding and cleavage for areas west and north of the Corvock granite (Figs. 2, 2c) demonstrate these open warps that did not develop any new fabrics.

137 Perhaps the most parsimonious interpretation of the data is that the main folds largely pre-
138 date the Corvock granite but were then deflected by the rigid body of the granite during a
139 protracted deformation event. These characteristics are seen in several other granitic
140 plutons of this general age in northern Britain (Woodcock et al. 2019). Thus the granite as a
141 whole is truly syn-kinematic and that the development of the aureole, the main cleavage
142 fabric and the arcuate folds of this cleavage all occurred within a relatively restricted time
143 span. The deflection of cleavage strikes seen closer to the Maam Fault zone is likely to have
144 a different cause and is interpreted as being due to fault drag.

145 The cause and timing of the strong deformation that characterises the Croagh Patrick
146 succession has long been a missing element in understanding the development of this part
147 of the Laurentian margin. It has been noted by several workers that the deformation
148 appears to be strongest in the north and to show a decrease in intensity southwards
149 (Anderson 1960; Dewey 1963; Dewey and McManus 1964; Bickle et al. 1972; Kelly and Max
150 1979). The deformation extends into the Ordovician rocks to the south such that, for
151 example, intersection lineations in the Sheeffry Formation at Doolough plunge at 70° in
152 rocks which are part of an open sub-horizontal syncline (Graham in press fig. NW12.1). Thus
153 inferring large-scale structural relationships within the Ordovician rocks of the Mweelrea
154 Syncline based on the use of minor structures is not possible. It is likely that the generation
155 of the South Mayo Syncline was not accompanied by cleavage formation and that all of the
156 cleavage fabrics seen in the Ordovician rocks of the South Mayo Trough are later.

157 **Geochronology: methods and results**

158 In this study we attempt to determine the age of the main Corvock granite and place
159 constraints on the age of the main cleavage forming event affecting the Croagh Patrick

succession. Two sample localities were chosen, one from within the undeformed Corvock Granite (M203, Fig. 2) and one from a thick sill that shows evidence for the main cleavage forming fabric (M204, Figs. 2,3). Sample M203 is from a granodiorite at Irish Grid reference 86294.78382 (53.742912, -9.724428) which is very close to one of the data points used by O'Connor (his sample 751194 from 863.783). This sample was collected away from the main, granitic part of the intrusion owing to its slightly more mafic (granodioritic) composition at that locale. In our experience, zircon crystals in more-mafic phases of a pluton have simpler U/Pb systematics and a tighter range of ages than those from more-silicic phases (cf. Barth et al., 2016).

The second sample, M204, was collected at 80053.73862 (53.700726, -9.8167797) from the central part of a sill south-west of Cregganbaun that is at least 20 m across (Fig. 3). The margins show a very strong cleavage that parallels that seen in the country rock (Fig. 4a) and this cleavage becomes less intense towards the central part of the intrusion (Fig. 4b). Several other sills in this area show a similar relationship to the regional structure, the thickest being in excess of 50 m across strike (Fig. 4c, d).

Samples were crushed and zircon grains separated by standard procedures (e.g., Gehrels, 2000). We recovered 20 grains from M203 and 17 from M204. Analysis was done at the University of California, Santa Barbara's Laser Ablation Split-Stream laboratory. A Photon Machines 193nm excimer laser with a HeLex sample cell with a 25-micrometer beam, coupled to a Nu Instruments Plasma high-resolution multicollector inductively coupled mass spectrometer (LA-ICPMS), was used for U and Pb isotope analysis. Primary standard 91500 (1062 Ma; Wiedenbeck et al., 1995) was analysed after every 7-10 unknowns; secondary standards GJ-1 (602 Ma; Jackson et al., 2004; Kylander-Clark et al., 2013), Plesovice (337 Ma;

183 Sláma et al., 2008), Temora (417 Ma; Black et al., 2003), AusZ (38.9 Ma; Kennedy et al.,
184 2014) and 9435 (56.4 Ma; Chang et al., 2006) were alternated between 91500 analyses. Our
185 results for the standards are within 2% of published values.

186 Isotopic-ratio and -age data are provided in Table 1. $^{206}\text{Pb}/^{238}\text{U}$ ages are considered most
187 accurate for grains <1000 Ma and $^{207}\text{Pb}/^{206}\text{Pb}$ ages for grains >1000 Ma. Ages were analysed
188 for discordance using a ratio of $^{206}\text{Pb}/^{238}\text{U} / ^{207}\text{Pb}/^{235}\text{U}$ for Phanerozoic grains and $^{206}\text{Pb}/^{238}\text{U}$
189 $/ ^{207}\text{Pb}/^{206}\text{Pb}$ for Precambrian grains. Analyses that are >10% normally discordant or 5%
190 reversely discordant or are spuriously young are listed in Table 1 as “rejected grains” and
191 are not used in the overall age determinations (cf. Lodes et al. 2020; Dobbs et al. 2021). We
192 used the TuffZirc algorithm in Isoplot (Ludwig, 2003) to assess likely crystallisation ages for
193 the two units (Figs. 5, 6); sample M204 yielded a TuffZirc age of $413 \pm 7 / -4$ Ma (Fig. 5a); the
194 age of M203 is 410 ± 4 Ma (Fig. 6a).

195 **Interpretation of results**

196 The Corvock granite is shown to be of early Devonian age, either Lockhovian (419 – 412.4
197 Ma) or Pragian (412.4 – 407.3 Ma) (Becker et al. 2020). Although the two ages obtained
198 here overlap within uncertainty, the slightly older age indicated by M204 is entirely
199 consistent with field observations. We infer that the deformation affecting the Croagh
200 Patrick succession post-dates $413 \pm 7 / -4$ Ma and pre-dates the cross-cutting main granite at
201 410 ± 4 Ma with a most likely age that is close to the current best estimate of the Lower
202 Devonian Lochkovian-Pragian boundary at 412.4 Ma (Becker et al. 2020). As this is almost
203 exactly the very precise age obtained by Chew and Schaltegger (2005) for the Ox Mountains
204 granodiorite (412.3 ± 0.8 Ma) that was emplaced under strong sinistral shear, it seems most
205 reasonable to interpret these as the same event. Throughout the outcrop of the Croagh

Patrick succession cleavage is consistently clockwise of bedding suggesting formation under sinistral transpression. The Louisburgh-Clare Island succession shows a more variable development of cleavage due to its position at a higher structural level and cleavage development is very strongly spatially controlled by proximity to major faults. On the southern part of Clare Island a strong cleavage is also consistently clockwise of bedding and demonstrably related to sinistral shear with marked along-strike and vertical extension.

Old Red Sandstone successions deposited in intermontane basins of Emsian to Eifelian age (c. 395-390 Ma) are present east of Clew Bay (see Graham 2009 for summary) that indicate formation under sinistral transtension before a kinematic flip at some later stage in the Devonian to dextral transpression (McCaffrey 1997). It is difficult to determine what was occurring at depth during this time period as only this upper structural level is preserved but there is clear evidence of continued sinistral motion on the main FHCBL structure into the mid-Devonian.

The new data presented here demonstrate major early Devonian sinistral deformation of early Devonian (Lochkovian) age was localised along the major structure of the Clew Bay zone that forms part of the FHCBL in western Ireland. This produced a strong cleavage south of the fault zone in the Croagh Patrick succession that was also superimposed on the Ordovician rocks to the south. This strong deformation is observed over a cross-strike dimension of at least 15 km.

This brings into question the relationship of the structure seen in the Clew Bay zone to that seen in the Killary Harbour–Joyce Country succession to the south. In this latter area the finer-grained rocks show only a weak development of cleavage in the eastern part that becomes more closely spaced and intense in the upper part of the succession west of the

229 Maam Fault zone and immediately to the south of the Salrock Thrust (Fig. 1). The age of this
230 cleavage formation is poorly constrained but it cannot be assumed that it is
231 contemporaneous with that seen further north and detailed in this paper. Cleavage
232 formation in this southern area may also be localised with development partly controlled by
233 proximity to major faults.

234 **Discussion and wider implications**

235 We address the possible causes of Devonian deformation and how it might relate to other
236 parts of Ireland and Britain and to the Appalachian orogen of North America. There are
237 obvious questions as to why this deformation is localised just to the south of the Clew Bay
238 fault zone. Throughout most of its length in Ireland and Scotland the margin of Laurentia
239 trends NE-SW but in the Clew Bay area the fault zone swings significantly to a more E-W
240 orientation. In western Ireland this complex fault zone is up to 20 km across, encompassing
241 the Ox Mountains inlier and the whole of Clew Bay between the Achill Beg Fault in the north
242 and the southern margin of the Clew Bay Complex (Fig. 1b). The most likely explanation is
243 that on a local scale South Mayo underwent deformation at a restraining bend of this major
244 fault zone that is taken to mark the eastern edge of Laurentia (Figs. 1, 8). The genesis of the
245 Devonian intermontane basins may be related to activity on a series of NNE-SSW faults with
246 normal displacements that are part of a releasing bend within this wide structural zone
247 (McCaffrey 1997).

248 The major structures in South Mayo match remarkably well those that would be predicted
249 from models of sinistral shear (Fig. 7b). The dextral movements on the Maam Valley fault
250 system (Fig. 7a) have previously only been constrained as 'probably post-Wenlock'. Our new
251 data strongly suggest an early Devonian age for the dextral strike slip. Similarly the sinistral

252 Bohaun shear zone that lies adjacent to the post-Carboniferous Erriff Valley Fault (Fig. 7a)
253 has previously only been constrained by the Ordovician rocks that are affected by it. Its style
254 and orientation suggest that this may also be an early Devonian structure.

255 The picture becomes less clear to the north-east of the Ox Mountains inlier (Fig. 1). In the
256 northern part of Ireland what lies along the FHCBL is largely covered by later rocks. This
257 lineament is partly defined by geophysics although it clearly marks the south-eastern limit of
258 Dalradian rocks. However, there is evidence for sinistral motion associated with the well-
259 studied Donegal batholith which includes a major shear zone associated with the eastern
260 margin of the main Donegal granite and is paralleled by the Leannan Fault (Fig. 1a). Detailed
261 work dating discrete magmatic pulses of the batholith (Archibald et al. 2021) has
262 demonstrated a history that probably spans about 30 Ma. Here the evidence for marked
263 syn-magmatic sinistral movements are given by ages from the main Donegal granite of $414 \pm$
264 3 Ma (U-Pb zircon) (Archibald et al. 2021). These support an earlier U-Pb zircon date of 411
265 ± 2 Ma (Halliday et al. 1980) for the Trawenagh Bay granite that is interpreted to also be
266 associated with sinistral shear and is also interpreted to be the youngest element of the
267 batholith. This suggests that sinistral displacement to accommodate the oblique collision
268 was being accommodated in this intra-Grampian fault zone further north in the early
269 Devonian.

270 The Donegal shear zone and Leannan Fault are generally agreed to be a splay of and to link
271 with the Great Glen Fault system in Scotland. The Great Glen fault zone (GGF) offers many
272 close comparisons to western Ireland, such as the small Old Red Sandstone-type basins of
273 Lower and Middle Devonian age involved in the fault zone (Trewin and Thirlwall 2002). The
274 timing of movement on the GGF is less well constrained and is best given by dates on the

275 Strontian (Rogers and Dunning 1991; 425 ± 3 [U-Pb zircon] and 423 ± 3 [U-Pb titanite] and
276 Clunes (Stewart et al. 2001; 427.8 ± 1.9 Ma) intrusions which are both inferred to be
277 associated with sinistral motion.

278 A relatively undeformed sedimentary succession of mid-Silurian age (Marshall 1991;
279 McKellar et al. 2020) is exposed farther south and just to the southeast of the Highland
280 Boundary Fault (Fig. 1a, Fig. 8), which is generally thought to be a continuation of the FHCBL.
281 This could be attributed to deformation in this Scottish sector, where the main trend of the
282 fault zone is NE-SW, being largely strike slip with movement being strongly concentrated
283 within the main fault zone (McKay et al. 2020). The Lintathen porphyry, dated at $415.5 \pm$
284 5.8 Ma (Rb-Sr) (Thirlwall 1988) is claimed to show a 34 km sinistral displacement across the
285 HBF (Mendum and Noble 2010). However, strong arguments based on lithological and
286 provenance linkages have been advanced for very limited strike-slip displacement that could
287 be attributed to the early Devonian (Tanner, 2008; Hartley and Leleu 2015). Moreover,
288 Tanner (2008) noted that there is no clear evidence that the Highland Boundary Fault can be
289 traced along strike into Ireland arguing that the available field data do not support it being
290 traceable SW of Bute in the Firth of Clyde.

291 We interpret these various sets of data as showing that sinistral accommodation occurred
292 on a number of major fault zones at varying times within the general late Silurian – early
293 Devonian time span. In Ireland it appears that the Devonian motion dated in this paper
294 probably transferred to the main Donegal shear zone, with the northeastern part of the Ox
295 Mountains and the south-western part of the Leannan Fault where it reaches Donegal Bay
296 being effectively fault tips. It is possible that some accommodation occurred along the
297 continuation of the FHCBL into the HBF structure.

298 Correlation across the Atlantic to the Appalachian orogeny of North America is more
299 difficult at this time period compared to the earlier history of Iapetus. There is general
300 agreement that some major lineaments can be matched. Thus the zone that approximates
301 the eastern margin of Laurentia that is marked by the HBF – FHCBL in Europe can be
302 correlated with the Baie Verte Brompton Line (Pollock et al. 2012). In Newfoundland the
303 junction between peri-Laurentian and peri-Gondwanan zones is marked by the Red Indian
304 Line (Fig. 8), which separates the Notre Dame subzone from the Exploits subzone of the
305 Dunnage zone and marks the main Iapetus suture. In Ireland and Britain this suture can be
306 traced from the Solway Firth in the east to the Shannon estuary (Fig. 8) on the west coast of
307 Ireland. Thus the area considered in this study lies along strike from the Laurentian side of
308 Notre Dame subzone of Newfoundland.

309
310 The post-Taconic history of the Appalachian-Caledonian belt is characterised by the
311 progressive accretion of several peri-Gondwanan terranes (Pollock et al. 2012). The
312 accretion of Ganderia to Laurentia in North America is interpreted as causing the Salinic
313 orogeny (Van Staal et al. 2009). This orogenic event is not obviously represented in Ireland
314 and Britain. The accretion of Avalonia to Ganderia, and by implication to Laurentia, is
315 interpreted to be the cause of the Acadian orogeny. It is possible that early Acadian
316 orogenesis may overlap the Salinic (van Staal et al. 2009).

317 In Ireland and Britain the late Silurian continued to be a period of 'soft' collision (Chew and
318 Strachan 2014) as the area was situated between the cratonic blocks of Laurentia, Baltica
319 and Gondwana. There is overall agreement that two main episodes of deformation affected
320 the Laurentian margin in Ireland and Britain. An early event produced by collision of volcanic

arcs with the Laurentian craton is termed the Grampian on the east side of the Atlantic and matches well with the Taconic orogeny of the Appalachians. The later event, perhaps best just labelled as 'late Caledonian', relates to the final closure of the Iapetus Ocean that was strongly oblique in the Irish and British sector. It is inappropriate to use the term Scandian which relates to a well-documented near-orthogonal collision between Baltica and Laurentia that has clear spatial limits and is not manifested south of the Great Glen Fault (Strachan et al. 2020). This 'late Caledonian' event has often been referred to as Acadian, a term for the Avalonia – Ganderia collision in the Appalachians. It is by no means certain that this collisional event seen in the Appalachians is always contemporaneous with many of the events seen in Ireland and Britain (see Woodcock et al. 2019 for a comprehensive review) and thus we retain 'late Caledonian' to avoid any implied correlations. The data presented here show that locally strong deformation of early Devonian age occurred in western Ireland but this may be restricted in areal extent.

On an orogen scale it is clear that the accretion of various peri-Gondwana terranes to Laurentia is markedly diachronous (Pollock et al. 2012). Many attempts have been made to compile data on the timing of this later oblique deformation that affected the Laurentian margin in the Irish and British sectors, often with a search for synchronicity (e.g. Dewey and Strachan 2003). Miles et al. (2016) suggested that regionally clockwise transecting cleavage appears after the onset of 'Acadian' transpression at c. 404 Ma and that it is only weakly developed and very locally recognised north of the Iapetus suture. Our new data indicate that this cannot be substantiated as the deformation adjacent to the Laurentian margin considered here is constrained to between 413 ± 7 – 4 and 410 ± 4 Ma and moreover is strongly developed. Regional compilations of data can only be as good as their data base and thus the new data presented here provide an important constraint. Fault zones with a

major strike slip component typically show changes in the main locus of deformation with time. Thus we would not expect any great synchronicity in detail but would expect more evidence for local diachronism as is seen in much of the data discussed above and in that compiled by Woodcock et al. (2019).

Conclusions

New data confirm an early Devonian (probably Lochkovian) age for the Corvock Granite of western Ireland; this age is the same as that previously obtained for the Ox Mountains granodiorite that lies within the complex structural zone that characterises the south-eastern margin of Laurentia in this area. A suite of minor intrusions associated with the undeformed Corvock granite contain a strong regional cleavage that characterises their host rocks of the Silurian Croagh Patrick succession. The age of this cleavage can now be constrained as early Devonian, between $413 \pm 7/-4$ and 410 ± 4 Ma. This locally very intense deformation is likely to be spatially limited in extent and is interpreted to have been produced by constriction at a restraining bend of the major structurally controlled margin of Laurentia during overall sinistral collision. This 'late Caledonian' deformation can be temporally linked to sinistral motion associated with the eastern part of the Donegal batholith and the Leannan Fault further north. It is likely and to be expected that the oblique 'late Caledonian' collision in Ireland and Britain was accommodated by many different structures and that the timing of their main activity varied. Differences from the history along strike in Newfoundland are attributed to the diachronous accretion of peri-Gondwanan terranes to Laurentia that commenced earlier in North America.

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374

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515

516 **Tables**

517 Table 1 Isotopic data for samples M203 and M204

518

519 **Figure Captions**

- 520 1. (a) Location of South Mayo within the northwest parts of Ireland and Britain
- 521 (b) Simplified geology of South Mayo showing some of the major structures
- 522 discussed in this paper. Geological setting of the Corvock Granite within the regional
- 523 geology of western Ireland with sample locations shown.

- 524 2. (a) Revised geological map of the area west of the Corvock Granite. C –
525 Corvockbrack, K - Knockaskeheen
- 526 (b) Areas where field readings were taken for stereoplots in (c)
- 527 (c) Stereoplots of poles to cleavage for the three areas shown in (b). Red dots for area
528 3 are for readings from granitic sills
- 529 3. Detailed geological map of the area around Cregganbaun showing the locality for
530 sample M204 (53.700726, -9.8167797).
- 531 4. Field appearance of deformed granitic intrusions:
- 532 (a) Margin of the sill sampled for zircon; yellow line indicates the orientation of the
533 main cleavage, seen here in oblique view
- 534 (b) Central part of the sill where sample M204 was taken; the cleavage is less
535 intense here and is roughly parallel with the long axis of the hammer.
- 536 (c) (d) Cleaved granitic sills; cleavage is approximately parallel to the long axis of the
537 hammer.
- 538 5. Plots of age data for M204 (deformed) A. TuffZirc plot B. Concordia plot for all grains
539 C. Concordia plot for Devonian grains
- 540 6. Plots of age data for M203 (undeformed) A. TuffZirc plot B. Concordia plot for all
541 grains C. Concordia plot for Devonian grains
- 542 7. Schematic structural summary
- 543 a. Simplified outline of South Mayo with an interpretation of the genesis of the
544 early Devonian deformation localised at the major bend in the Laurentian
545 margin that occurs at the eastern end of Clew Bay. ABF – Achill Beg Fault,

546 OMG – Ox Mountains Granite, CG – Corvock Granite, EVF – Erriff Valley Fault,
547 BSZ – Bohaun shear zone, MVF – Maam Valley Fault zone

548 b. Structures predicted to develop under sinistral shear

549 8. Position of the study area relative to major lineaments in the Appalachian-
550 Caledonian orogen with location of the Corvock granite indicated. BVBL – Baie Verte
551 Brompton line; C – Connemara; DHF – Dover-Hermitage fault; FHCBL – Fair Head
552 Clew Bay line; GGF – Great Glen fault; HBF – Highland Boundary fault; IS – Iapetus
553 suture; LF – Leannan fault; NASA – North Atlantic Spreading Axis; RIL – Red Indian
554 line; SE – Shannon Estuary; SF – Solway Firth.

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SAMPLE NUMBER	U ppm	Th ppm	$^{207}\text{Pb}/^{235}\text{U}$	2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ
M203						
M203-3	377	202	0.491	0.012	0.06	0.00
M203-12	603	312	0.488	0.013	0.06	0.00
M203-23	400	283	0.491	0.016	0.06	0.00
M203-21	210	169	0.494	0.012	0.06	0.00
M203-7	414	29	0.497	0.013	0.07	0.00
M203-11	821	253	0.494	0.013	0.07	0.00
M203-5	259	122	0.493	0.021	0.07	0.00
M203-22	253	219	0.501	0.017	0.07	0.00
M203-26	507	244	0.494	0.014	0.07	0.00
M203-16	479	305	0.499	0.019	0.07	0.00
M203-10	410	689	0.503	0.015	0.07	0.00
M203-2	587	422	0.498	0.013	0.07	0.00
M203-20	186	145	0.502	0.016	0.07	0.00
M203-17	236	117	0.491	0.021	0.07	0.00
M203-6	608	368	0.514	0.013	0.07	0.00
M203-15	526	349	0.509	0.013	0.07	0.00
M203-25	205	93	0.513	0.019	0.07	0.00
M203-19	163	128	0.504	0.015	0.07	0.00
M203-18	490	255	0.507	0.015	0.07	0.00
M203-1	176	107	0.528	0.020	0.07	0.00
M203-27	293	110	2.722	0.107	0.23	0.01
<i>rejected grains</i>						
M203-24	288	121	2.010	0.881	0.06	0.01
M203-14	1760	1267	0.659	0.019	0.07	0.00
M203-8	243	36	0.618	0.015	0.07	0.00
M203-13	68	45	0.840	0.057	0.07	0.00
M203-4	948	539	0.911	0.046	0.07	0.00
M203-9	316	106	7.190	0.793	0.30	0.03
M204						
M204-1	81	56	0.498	0.013	0.07	0.00
M204-16	123	48	0.502	0.014	0.07	0.00
M204-6	310	108	0.495	0.013	0.07	0.00
M204-25	517	178	0.508	0.013	0.07	0.00
M204-15	500	74	0.499	0.017	0.07	0.00
M204-9	453	863	0.565	0.030	0.07	0.00
M204-10	1646	178	0.505	0.012	0.07	0.00
M204-23	398	409	0.503	0.012	0.07	0.00
M204-8	540	170	0.542	0.019	0.07	0.00
M204-7	542	230	0.538	0.028	0.07	0.00
M204-17	166	82	0.516	0.013	0.07	0.00
M204-2	226	65	0.515	0.017	0.07	0.00

M204-26	405	127	0.517	0.015	0.07	0.00
M204-27	70	80	0.564	0.023	0.07	0.00
M204-20	980	1010	0.550	0.039	0.07	0.00
M204-22	282	66	2.149	0.047	0.20	0.00
M204-11	63	49	13.570	0.326	0.52	0.01
<i>rejected grains</i>						
M204-24	370	153	0.146	0.010	0.02	0.00
M204-14	3410	826	0.661	0.048	0.05	0.00
M204-3	1570	410	0.458	0.036	0.06	0.00
M204-19	1050	409	0.576	0.019	0.06	0.00
M204-13	3040	1099	0.616	0.023	0.07	0.00
M204-21	630	201	0.605	0.032	0.07	0.00
M204-5	620	273	0.650	0.046	0.07	0.00
M204-4	399	235	0.636	0.049	0.07	0.00
M204-12	1110	740	0.786	0.095	0.07	0.00
M204-18	141	166	0.881	0.097	0.07	0.00

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Isotopic ratios

rho	$^{238}\text{U}/^{206}\text{Pb}$	2 σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ	rho	$^{207}\text{Pb}/^{235}\text{U}$
0.93	15.75	0.40	0.056	0.001	0.49	405
0.94	15.48	0.44	0.055	0.001	0.43	403
0.93	15.46	0.42	0.055	0.001	0.50	406
0.76	15.42	0.38	0.055	0.001	0.46	407
0.90	15.38	0.38	0.055	0.001	0.40	409
0.97	15.34	0.40	0.055	0.001	0.46	407
0.98	15.31	0.66	0.055	0.001	0.49	407
0.95	15.27	0.48	0.055	0.001	0.47	412
0.94	15.27	0.45	0.055	0.001	0.42	408
0.96	15.22	0.57	0.055	0.001	0.48	411
0.94	15.22	0.40	0.055	0.001	0.27	413
0.95	15.22	0.38	0.055	0.001	0.40	411
0.89	15.20	0.44	0.056	0.001	0.37	413
0.96	15.15	0.55	0.054	0.001	0.46	405
0.90	15.10	0.36	0.056	0.001	0.58	421
0.95	15.11	0.39	0.056	0.001	0.41	417
0.64	14.95	0.43	0.055	0.001	0.30	420
0.85	14.88	0.43	0.054	0.001	0.43	414
0.97	14.86	0.44	0.055	0.001	0.44	416
0.92	14.88	0.53	0.057	0.001	0.52	430
1.00	4.43	0.16	0.088	0.002	0.31	1333
0.97	16.05	1.53	0.225	0.067	0.17	1030
0.76	15.06	0.41	0.073	0.002	0.39	514
0.87	14.97	0.37	0.068	0.002	0.50	488
0.47	14.81	0.44	0.090	0.005	0.26	617
0.48	14.03	0.42	0.094	0.004	0.58	661
0.99	3.33	0.32	0.173	0.005	0.29	2100
0.17	15.29	0.32	0.055	0.001	0.43	411
0.75	15.27	0.38	0.056	0.001	0.49	413
0.88	15.22	0.40	0.055	0.001	0.45	408
0.87	15.20	0.43	0.056	0.001	0.48	417
0.95	15.17	0.50	0.055	0.001	0.49	411
0.33	15.16	0.35	0.062	0.003	0.38	454
0.93	15.13	0.34	0.055	0.001	0.55	415
0.88	15.13	0.34	0.055	0.001	0.48	414
0.88	15.04	0.51	0.058	0.001	0.48	440
0.83	14.99	0.43	0.060	0.002	0.44	436
0.68	14.96	0.34	0.055	0.001	0.45	422
0.91	14.86	0.44	0.056	0.001	0.40	422

0.93	14.81	0.41	0.056	0.001	0.49	423
0.63	14.62	0.40	0.060	0.002	0.45	454
0.91	14.47	0.85	0.058	0.002	0.50	443
0.87	5.02	0.11	0.078	0.002	0.44	1166
0.94	1.93	0.05	0.190	0.004	0.47	2720
0.94	51.02	4.04	0.054	0.001	0.14	138
0.46	19.10	0.45	0.091	0.006	0.59	513
0.98	17.67	1.39	0.059	0.001	0.47	381
0.97	15.63	0.54	0.065	0.001	0.46	461
0.86	15.20	0.43	0.068	0.002	0.33	487
0.81	15.11	0.39	0.065	0.002	0.48	484
0.52	14.84	0.64	0.069	0.004	0.54	507
0.65	14.67	0.35	0.068	0.005	0.44	498
0.87	14.43	0.37	0.080	0.008	0.40	581
0.76	13.46	0.32	0.085	0.008	0.48	634

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isotopic ages					Concordance
2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2σ	
5	397	6	467	13	0.98
6	404	8	397	15	1.00
8	404	7	417	19	1.00
5	405	6	411	24	0.99
6	406	6	428	18	0.99
6	407	6	418	9	1.00
12	408	15	408	17	1.00
10	409	10	428	17	0.99
7	409	9	421	15	1.00
11	410	13	424	20	1.00
7	410	7	423	15	0.99
6	410	6	410	14	1.00
8	411	8	434	22	0.99
12	412	12	381	17	1.02
5	413	5	456	19	0.98
6	413	7	442	13	0.99
11	417	8	421	39	0.99
7	419	8	389	27	1.01
7	420	9	403	16	1.01
11	420	12	475	22	0.97
26	1311	35	1374	13	0.98
230	389	35	2730	420	0.35
8	415	7	1002	25	0.81
5	417	6	867	20	0.85
29	421	9	1440	110	0.68
21	444	10	1523	73	0.68
110	1680	140	2579	41	0.79
5	408	3	435	31	1.00
7	409	6	442	26	0.99
6	410	7	403	17	1.00
5	411	8	446	18	0.99
9	411	10	406	12	1.00
17	412	5	673	89	0.91
4	413	4	417	8	0.99
5	413	4	413	18	1.00
11	415	11	530	29	0.94
17	416	8	581	68	0.95
5	417	4	434	26	0.99
9	420	9	433	21	1.00

8	421	8	437	14	1.00
13	427	8	612	63	0.94
24	431	23	506	42	0.97
6	1172	9	1158	10	1.01
12	2689	30	2740	6	0.99
9	125	10	370	41	0.90
28	329	4	1430	120	0.64
24	355	27	560	23	0.93
10	400	11	770	17	0.87
12	411	8	861	33	0.84
20	413	7	781	63	0.86
27	420	16	890	110	0.83
27	425	5	830	110	0.85
52	432	7	1180	200	0.73
49	462	6	1260	170	0.72

Draft

Lorem ipsum