U-Pb zircon geochronology of the Galway Granite, Connemara, Ireland: implications for the timing of late Caledonian tectonic and magmatic events and for correlations with Acadian plutonism in New England

Martin Feely[1], Drew Coleman[2], Sadhbh Baxter[1], and Brent Miller[2]

1. Department of Earth and Ocean Sciences, National University of Ireland, Galway, Ireland.
2. Department of Geological Sciences, University of North Carolina, Chapel Hill, NC 27599-3315 USA.

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ABSTRACT

The Galway Granite occupies a key location in the Caledonides of western Ireland. The 80 km long, WNW-trending axis of the batholith lies astride and stitches the EW-trending Skerd Rocks Fault, a splay of the orogen-parallel Southern Uplands Fault. The Skerd Rocks Fault separates high-grade metamorphic rocks of the Connemara Massif from Lower Ordovician greenschist-facies metavolcanic and metasedimentary rocks. We present new isotopic U-Pb zircon age determinations, using thermal ionisation mass spectrometry (TIMS), for five granite samples from the central block of the Galway Granite. Early coeval diorite and granite magmas are concomitant with the development of pure flattening fabrics and are succeeded by emplacement of a suite of generally unfoliated granites intruded in a brittle fracture regime. The results of the U-Pb zircon geochronology (G1 = 394.4 ± 2.2 Ma; G2~402 Ma; G3 = 397.7 ± 1.1 Ma; G4 = 399.5 ± 0.8 Ma) indicate that the emplacement of the early suite occurred over at least 8 Ma and belongs to the Late Emsian stage. Samples of commingled diorite (G3) and granite (G4) yield ages that are indistinguishable within error. Sample G5 is from an alkali feldspar leucogranite that cuts the early suite. Zircon from this granite yielded a U-Pb age of 380 ± 6 Ma and a single concordant monazite yielded 383.6 Ma, indicating emplacement at the Givetian-Frasnian boundary and a gap of ~20 Ma between intrusion of the two granite suites. These data provide constraints on the timing of final movement on the orogen-parallel strike-slip Southern Uplands-Skerd Rocks Fault System, and have implications for correlations between Acadian plutonism in New England and in western Ireland.

RÉSUMÉ

Le granite de Galway occupe un emplacement clé dans les Calédonides de l'ouest de l'Irlande. Le batholite de 80 kilomètres de longueur suivant un axe ouest-nord-ouest chevauche et suture la faille orientée d'est en ouest des rochers Skerd, un évasement de la faille parallèle à l'orogène des Hautes terres du Sud. La faille des rochers Skerd sépare des roches métamorphiques à forte teneur du massif de Connemara de roches métasédimentaires et métavolcaniques d'un faciès de schistes verts de l'Ordovicien inférieur. Nous présentons de nouvelles datations isotopiques au U-Pb obtenues à partir de zircon, au moyen de la spectrométrie de masse à ionisation thermique (SMIT), de cinq échantillons de granite provenant du bloc central du granite de Galway. Les premiers magmas granitiques et dioritiques contemporains sont apparus en même temps que se sont établis les fabriques d'aplanissement pures et ils ont été suivis de l'intrusion d'un cortège de granites généralement non feuilletés pénétrant dans un régime de rupture fragile. Les résultats de l'exercice géochronologique au U-Pb à partir de zircon (G1 = 394,4 ± 2,2 Ma; G2 ~ 402 Ma; G3 = 397,7 ± 1,1 Ma; G4 = 399,5 ± 0,8 Ma) révèlent que l'intrusion du premier cortège s'est échelonnée au cours d'au moins 8 Ma et qu'elle remonte au stade de l'Emsien tardif. Des échantillons de diorite (G3) et de granite (G4) mélangés ont présenté des âges qu'il est impossible de distinguer sans erreur. L'échantillon G5 provient d'un leucogranite de feldspath alcalin qui entrecoupe le cortège initial. La datation au U-Pb à partir de zircon de ce granite a révélé qu'il était âgé de 380 ± 6 Ma et un échantillon de monazite concordant unique a été situé à 383,6 Ma, un âge témoignant d'une mise en place à la limite du Givétien et du Frasnien et d'un écart d'environ 20 Ma entre l'intrusion des deux cortèges granitiques. Ces données imposent des contraintes à la localisation chronologique du déplacement sur les groupements de décrochements parallèles à l'orogène des Hautes terres du Sud-rochers Skerd, et elles ont des répercussions sur les corrélations entre le plutonisme acadien en Nouvelle-Angleterre et dans l'ouest du l'Irlande.

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INTRODUCTION

In the North Atlantic region, the Caledonian Orogeny embraces Cambrian to Devonian tectonic and magmatic events associated with the development and subsequent closure of those parts of the Iapetus Ocean which were situated between Laurentia to the northwest and Baltica and Avalonia to the southeast and east (McKerrow *et al.* 2000). The orogeny includes several tectonic phases, many reflecting localized events like arc-arc, arc-continent, and continent-continent collisions, e.g., the Taconic Phase in the New England Appalachians and the Grampian Phase in Ireland and Britain.

The Caledonides of western Ireland occupy a key location along the Appalachian-Caledonian orogenic belt (Fig. 1a, b). They provide a significant N-S cross-section that includes the Laurentian margin in the north passing southwards through the South Mayo trough and the Connemara Massif to the Iapetus Suture and onto the Avalonian margin (Klemperer *et al.* 1991; Ryan and Dewey 1991; Friedrich *et al.* 1999). The South Mayo trough possesses island arc and ophiolite elements (Dewey and Ryan 1990). The boundary of the allochthonous Connemara metamorphic terrane with the South Mayo Trough is occluded by Silurian rocks. The Connemara metamorphic terrane defines the Grampian Phase in western Ireland and exposes rocks formed during a short-lived Lower Ordovician magmatic arc emplaced into Laurentian margin Dalradian rocks at ca. 475-463 Ma. (Friedrich *et al.* 1999). The Skerd Rocks Fault brings greenschist facies rocks of oceanic affinity, the Lower Ordovician South Connemara Group (Ryan *et al.* 1983; Williams *et al.* 1988), against the Connemara metamorphic terrane. Southward Klemperer *et al.* (1991) suggest that a mix of accreted, imbricated, oceanic, island arc, and continental sediments and volcanic rocks extend beneath the Carboniferous strata from Galway Bay to the Shannon Estuary which marks the southwestern end of the NE-trending Iapetus Suture in Ireland and Britain.

Three major strike-slip faults (i.e. The Great Glen, Highland Boundary and Southern Uplands Faults-see Fig. 1b) parallel the Iapetus Suture and mark significant kilometric-scale sinistral displacements of crustal blocks during the end stages of the orogen (Dewey and Strachan 2003). Furthermore, this set of regionally important orogen- parallel displacements is linked to the emplacement of late Caledonian granites in Britain and Ireland (Dewey and Strachan 2003 and references therein). High precision U-Pb geochronology (using TIMS) of the Newer Granites in Scotland has been used to constrain the timing of displacement along these faults. Early sinistral displacements along the Great Glen Fault, for example, are linked to the emplacement of the Clunes Tonalite at 427.8 ± 1.9 Ma. (Stewart *et al.* 2001). Indeed, Dewey and Strachan (2003) concluded that major orogen-parallel, strike-slip motion on the Great Glen Fault and related structures in Scotland occurred between ca.425 and 410 Ma.

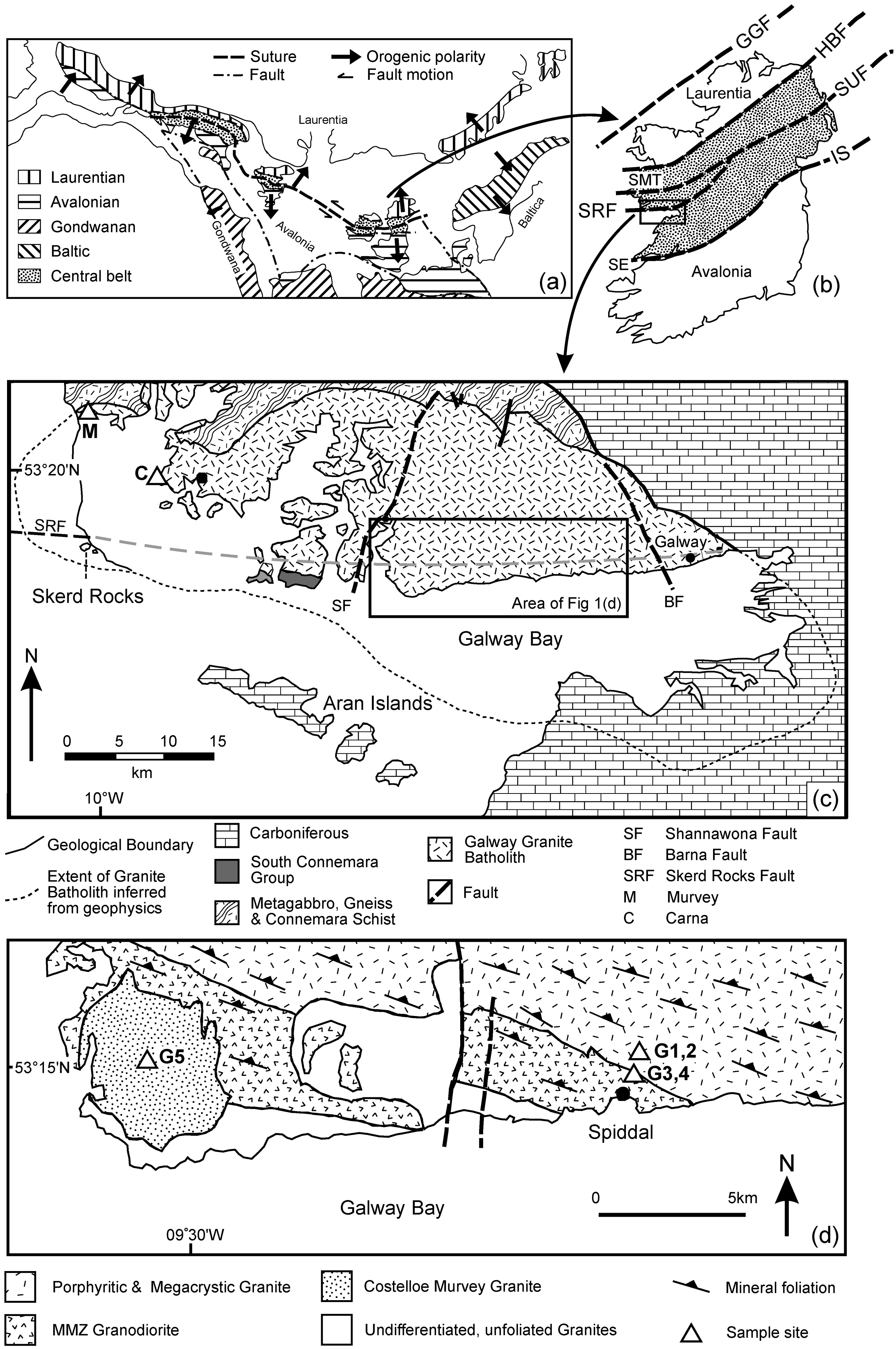
The ca.400 Ma Galway Granite marks an important element of the western Ireland Caledonides as it postdated and stitched a splay, the Skerd Rocks Fault, of one of these major strike-slip fault systems in Britain and Ireland, i.e. Southern Uplands Fault (Leake 1978). Here we report new high precision U-Pb zircon ages for the late-Caledonian Galway Granite and use them (a) to elucidate more fully the duration and timing of granite magmatism in Connemara, (b) to place time constraints on the finality of motion on the Skerd Rocks Fault and the regional implications for the major orogen-parallel faults, and (c) to explore implications for cross-Atlantic correlations with Acadian granite plutonism in the New England Appalachians.

GEOLOGY OF THE GALWAY GRANITE.

The Galway Granite is a late-Caledonian calc-alkaline batholith emplaced at ca. 400 Ma (Leggo *et al.* 1966; Pidgeon 1969) into the 474.5-462.5 Ma Metagabbro-Gneiss Suite to the north (Leake 1989; Leake and Tanner 1994; Friedrich *et al.* 1999), and into Lower Ordovician greenschist facies rocks (the South Connemara Group) to the south (McKie and Burke 1955; Williams *et al.* 1988). The batholith emplacement postdated the Skerd Rocks Fault which Leake (1978) considered to be a splay of the Southern Uplands Fault and to have strongly influenced its siting. The granite extends for several kilometers beneath the Carboniferous rocks of the Galway Bay area, as indicated on gravity and aeromagnetic maps (Murphy 1952; Max *et al.* 1983; Madden 1987). The long axis of the batholith is oriented WNW-ESE and is oblique to the E-W strike of the Skerd Rocks Fault. Two major faults, the NNE-trending Shannawona Fault (SF) and the NW-trending Barna Fault (BF), define the boundaries between the western, central, and eastern blocks (Fig. 1c) in the batholith.

The western and eastern blocks expose lithologies that range from granodiorite through granite to alkali granite (Leake 1978 and references therein). The petrology, geochemistry, and field relationships of the central block granites has been described in detail by the following: Feely and Madden (1986, 1987,1988); Whitworth and Feely (1989, 1994); Feely *et al.* (1989, 1991); El Desouky *et al.* (1996); Crowley and Feely (1997); Graham *et al.* (2000); Baxter and Feely (2002); Baxter *et al.* (in review). These studies presented unequivocal evidence for several phases of

Fig. 1 (Facing page) (a) Palaeogeographical map showing the position of Ireland within the Caledonian orogen (adapted from Ryan 2000). (b) Major lineaments in Ireland associated with the Caledonian orogen; Great Glen Fault (GGF), Highland Boundary Fault (HBF), Southern Uplands Fault (SUF), Skerd Rocks Fault (SRF) and Iapetus Suture (IS). South Mayo trough (SMT) and Shannon Estuary (SE). (c) Regional map of the Galway Granite batholith, with the location of samples analysed for Re-Os molybdenite geochronology. (d) The southern Central Block of the Galway Granite, with the locations of samples used in the U-Pb zircon geochronology discussed in this paper.


Suture
Fault
Orogenic polarity
Fault motion
Laurentian
Avalonian
Gondwanan
Baltic
Central belt
Laurentia
Avalonia
Gondwana
Baltica
(a)
GGF
HBF
SUF
IS
Laurentia
SMT
SRF
SE
Avalonia
(b)
M
53°20'N
C
SRF
Galway
Skerd Rocks
SF
Area of Fig 1(d)
BF
Galway Bay
N
Aran Islands
0 5 10 15
km
10°W
(c)
Geological Boundary
Extent of Granite Batholith inferred from geophysics
Carboniferous
South Connemara Group
Metagabbro, Gneiss & Connemara Schist
Galway Granite Batholith
Fault
SF Shannawona Fault
BF Barna Fault
SRF Skerd Rocks Fault
M Murvey
C Carna
53°15'N
G5
G1,2
G3,4
Spiddal
N
0 5km
Galway Bay
09°30'W
(d)
Porphyritic & Megacrystic Granite
MMZ Granodiorite
Costelloe Murvey Granite
Undifferentiated, unfoliated Granites
Mineral foliation
Sample site

granite emplacement. Interactions between coeval diorite and granite magmas (e.g. Mingling and Mixing Zone – MMZ) are concomitant with the development of pure flattening fabrics and are succeeded by emplacement of a suite of generally unfoliated granite units intruded in a brittle fracture regime. Thus, intergranite temporal relationships in this part of the batholith demonstrate that the Megacrystic Granite was emplaced first, along with the MMZ Granodiorite and its enclaves of coeval diorite magma. The Costelloe Murvey Granite (CMG) displays sharp, shallow, outward-dipping chilled marginal contacts with these earlier granites and represents the end stage of magma emplacement in the batholith (Fig. 1d).

Emplacement of the Galway batholith is considered by El Desouky *et al.* (1996) to have occurred in a crustal pull-apart between NW-trending dextral shear zones marked by the Maam and Clifden Faults. This model helps explain the WSW-ESE trend of the long axis of the batholith and the post-consolidation orthogonal faulting and dyking across the batholith and its envelope. Baxter *et al.* (in review) interpreted fabrics within the Megacrystic Granite and MMZ Granodiorite to reflect ballooning processes operating in successive magma batches (e.g., Megacrystic Granite and MMZ Granodiorite) at the emplacement level. These earlier granite batches were stoped by the later granite intrusions such as the CMG during a brittle fracture regime (Crowley and Feely 1997). The central block therefore exposes a juxtaposition of earlier deeper level granites with late-stage higher level granites.

U-PB GEOCHRONOLOGY OF THE GALWAY GRANITE

Sampling and analytical methods

TIMS U-Pb zircon geochronology was performed on five samples from the central block of the Galway Granite. Zircon selection, preparation, and thermal ionization mass spectrometry were carried out at the isotope geochemistry laboratory at the Department of Geological Sciences, University of North Carolina, Chapel Hill (Table 1; see footnote for analytical details). The sample set comprises two samples from the Megacrystic Granite, an enclave and its host MMZ Granodiorite, and one sample of the Costelloe Murvey Granite – see Fig. 1d for locations.

G1 and G2 are samples from the Megacrystic Granite which is a distinctive porphyritic granite comprising large (15–80 mm) pink megacrysts of K-feldspar (~15–20%) set in a coarse-grained (2–5 mm) groundmass of plagioclase (~44%), quartz (~22%), K-feldspar (~3–8%), biotite (~7–10%), and hornblende (~1–5%) with accessory titanite, allanite, apatite, zircon, and opaque minerals. Sample G2 is more equigranular and less mafic than G1.

G3 is an enclave hosted by the MMZ Granodiorite (see below). The enclaves are commonly medium to dark grey, and 0.2–0.8 m in length, with axial ratios ranging from 2:1 to 12:1. Mineralogically, they contain phenocrysts (1–4 mm) of plagioclase ± K-feldspar ± quartz, in a groundmass (<0.5 mm) of plagioclase (~52%), biotite (~31%), hornblende (~10%), and quartz (~2%), with accessory K-feldspar, titanite, apatite, zircon, allanite, and opaque minerals.

G4 is a sample of the granite host (i.e., MMZ Granodiorite) to sample G3. MMZ Granodiorite is typically medium- to coarse-grained (1 to 10 mm) and contains quartz (~27%), K-feldspar (~25%), plagioclase (~34%), biotite (~8%), hornblende (~3%), and accessory titanite, zircon, allanite, and apatite.

G5 is a sample of the CMG which is a light pink, medium- to coarse-grained alkali feldspar granite containing, on average, 38% quartz, 33% orthoclase, 27% albite (~An_5), and 2% biotite with accessory apatite, zircon, monazite, uraninite and thorite.

New U-Pb zircon ages: implications for the magmatic and structural history of the Galway Granite

The results of the U-Pb zircon geochronology (Fig. 2 and Table 2) indicate that the emplacement of the early suite occurred over at least 8 Ma and belongs to the late Emsian stage (Megacrystic Granite G1 = 394.4 ± 2.2 Ma; Megacrystic Granite G2~402 Ma; Diorite Enclave G3 = 397.7 ± 1.1 Ma; MMZ Granodiorite G4 = 399.5 ± 0.8 Ma).

The commingled diorite (G3) and granodiorite (G4) yield ages that are indistinguishable within error. The CMG sample, G5, yields a U-Pb age of 380.1 ± 5.5 Ma and a single concordant monazite yields a 383.6 Ma age indicating emplacement at the Givetian-Frasnian boundary and a gap of ~20 Ma between intrusion of the two granite suites. These ages support the field evidence cited above from the central block, and quantify the time gap between the emplacement of the early foliated suite and the intrusion of the CMG. Noteworthy here are the results of a gravity study by Madden (1987) which indicated that the central block is 3–4 km thinner than the western block, supporting the conclusion of Leake (1978) that the granite to the east of the SF was upthrown and eroded to expose a deeper level of the batholith. Furthermore, preliminary geobarometric studies indicate that crystallisation of zoned hornblende in the western block began at 2.6 ± 1.2 kb and ended at <1.5 ± 1.0 kb, whereas east of the SF unzoned hornblende crystallised at 4.3 ± 0.7 kb (Leake and Ahmed Said 1994).

The relatively young age of the CMG coupled with its relatively shallow emplacement level and crosscutting nature suggest that it was generated and emplaced syn- to post-uplift of the central block some 20 Ma after the crystallisation of the Megacrystic Granite and MMZ Granodiorite.

Two ages for the batholith have been reported for samples from west of the SF. One is a whole-rock Rb-Sr age of 398 ± 10 Ma (Leggo *et al.* 1966) and the second is a bulk zircon U-Pb age from the Carna Granite of 412 ± 15 Ma. (Pigeon 1969). More precise ages from the western end of the batholith have recently been determined for molybdenite hosted by the Carna and Murvey granites (Fig. 1c; locations C and M) by Selby *et al.* (in press) using the Re-Os geochronometer. The

Table 1. U-Pb analytical data for zircon from Galway granites in Connemara, Ireland.

Frac.		Concentrations		Atomic ratios							Ages (Ma)				Total
& no.*	Weight (mg)	U (ppm)	Pb† (ppm)	^{206}Pb§/^{204}Pb	^{206}Pb¶/^{238}U	(%err)	^{207}Pb¶/^{235}U	(%err)	^{207}Pb¶/^{206}Pb	(%err)	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Corr. coef.	common Pb (pg)
G1 megacrystic granite															
z1	0.0069	1649	106.9	21510	0.06098	(.12)	0.45862	(.16)	0.05455	(.10)	381.6	383.3	393.7	0.772	2.1
z2	0.0033	2250	158.9	15160	0.06094	(.15)	0.45878	(.18)	0.05460	(.10)	381.3	383.4	396.0	0.845	1.9
z3	0.0037	2137	140.5	7414	0.05790	(.12)	0.43546	(.16)	0.05455	(.10)	362.8	367.0	393.8	0.774	3.9
z4	0.0059	1276	85.15	12140	0.06183	(.11)	0.46495	(.15)	0.05454	(.10)	386.7	387.7	393.3	0.760	2.4
G2 megacrystic granite															
z2	0.0016	1212	81.99	5829	0.06430	(.17)	0.48505	(.20)	0.05471	(.10)	401.7	401.5	400.4	0.870	1.4
z3	0.0019	612.2	44.16	1700	0.06396	(.29)	0.48303	(.33)	0.05477	(.14)	399.7	400.2	402.9	0.903	2.8
G3 diorite enclave															
z1	0.0035	1318	88.04	4498	0.06359	(.13)	0.47897	(.17)	0.05463	(.11)	397.4	397.4	397.1	0.760	4.2
z2	0.0013	304.9	20.88	603.9	0.06460	(.66)	0.49271	(.73)	0.05531	(.30)	403.6	406.8	424.9	0.913	2.8
z3	0.0040	911.3	58.02	9988	0.06163	(.28)	0.46416	(.30)	0.05462	(.10)	385.5	387.1	396.9	0.944	1.4
z4	0.0019	635.1	45.35	3177	0.06413	(.20)	0.48521	(.24)	0.05487	(.13)	400.7	401.6	407.0	0.852	1.6
G4 magma mingling zone granodiorite															
z1	0.0058	272.1	18.69	3865	0.06393	(.18)	0.48191	(.22)	0.05467	(.12)	399.5	399.4	398.8	0.839	1.7
z2	0.0017	491.7	38.47	1011	0.06407	(.54)	0.48615	(.60)	0.05503	(.25)	400.4	402.3	413.4	0.910	3.4
z3	0.0014	490.1	38.66	1839	0.06420	(.30)	0.48831	(.35)	0.05516	(.17)	401.1	403.8	418.8	0.867	1.5
z4	0.0014	792.5	65.69	1627	0.06316	(.28)	0.47763	(.38)	0.05485	(.24)	394.8	396.4	406.1	0.773	2.8
G5 Costelloe Murvey Granite															
z1	0.0023	3167	237.4	557.4	0.05892	(.39)	0.44031	(.46)	0.05420	(.23)	369.1	370.5	379.2	0.864	22
z2	0.0035	3048	198.1	3385	0.05875	(.15)	0.43924	(.24)	0.05422	(.19)	368.0	369.7	380.4	0.637	3.4
z3	0.0058	5749	363.9	3859	0.05834	(.57)	0.43633	(.65)	0.05424	(.30)	365.5	367.7	381.1	0.887	5.6
z4	0.0022	1557	104.7	636.7	0.05782	(.62)	0.43508	(.68)	0.05458	(.26)	362.3	366.8	395.0	0.924	9.2
z5	0.0063	1856	120.3	2266	0.05818	(.18)	0.43474	(.34)	0.05419	(.27)	364.6	366.5	379.0	0.601	3.1
z6	0.0016	2018	125.8	934.8	0.05618	(1.31)	0.42001	(1.34)	0.05422	(.25)	352.3	356.1	380.3	0.982	7.9
z7	0.0010	4074	425.9	65.51	0.04450	(.33)	0.34580	(2.13)	0.05636	(2.02)	280.7	301.6	466.5	0.386	240
z8	0.0022	6303	426.3	146.4	0.04309	(.50)	0.31745	(3.64)	0.05343	(3.55)	271.9	279.9	347.3	0.247	130
z9	0.0058	5972	531.1	136.8	0.04152	(.41)	0.31698	(3.65)	0.05536	(3.52)	262.3	279.6	427.0	0.344	130
z10	0.0012	9690	679.4	57.68	0.02683	(.29)	0.20220	(3.11)	0.05466	(2.96)	170.7	187.0	398.2	0.531	410

*All fractions are single grain analyses. † Radiogenic Pb. § Measured ratio corrected for fractionation only. All Pb isotope ratios were corrected for mass fractionation using 0.18 %/amu. ¶ Corrected for fractionation, spike, blank, and initial common Pb. Common Pb corrections were made using Stacey and Kramers (1975) initial Pb.

Sample processing and U and Pb separation were performed at the University of North Carolina – Chapel Hill (UNC). Analysis was accomplished with a VG Sector 54 thermal ionization mass spectrometer at the UNC. Conventional separation techniques (ie., water table, heavy liquids, magnetic) were used. Grains were separated using a Frantz Isodynamic LB-1 magnetic separator. All fractions were handpicked by color, size, and morphology. Zircon fractions were air abraded (Krogh 1982). Dissolution and isolation of U and Pb followed the methods of Krogh (1973) and Parrish (1987). All fractions were spiked with a mixed ^{205}Pb-^{233}U-^{236}U spike. Purified Pb and U fractions were loaded on single Re filaments with silica gel and graphite, respectively. Decay constants used are $^{238}U = 0.15513 \times 10^{-9} yr^{-1}$, and $^{235}U = 0.98485 \times 10^{-9} yr^{-1}$ (Steiger and Jäger 1977). Weights are estimated using a video camera and scale, and are known to within 10%. Data reduction and error analysis was accomplished using the PbMacDat-2 by D.S. Coleman, using the algorithms of Ludwig (1989, 1990) and all errors are reported in percent at the 2σ confidence interval.

molybdenite samples hosted by the Carna Granite yielded a Re-Os age of 407.3 ± 1.5 Ma, while 410.5 ± 1.5 Ma and 410.8 ± 1.4 Ma were determined for two samples from the Murvey granite. Gallagher *et al.* (1992) showed that the disseminated and vein molybdenite hosted by both granites is magmatic in origin, and therefore the Re-Os ages cited here reflect granite crystallisation ages. Combining the molybdenite ages with the new U-Pb ages defines a period of granite emplacement in South Connemara from ca. 410 to 380 Ma. In addition, the leucocratic Murvey granite at the western end of the batholith was emplaced some 30 Ma before the intrusion, in the central block, of the lithologically similar CMG. The Megacrystic granite and the MMZ granodiorite and its coeval enclaves postdated the emplacement of the Carna and Murvey granites at the western end of the batholith by ~10 Ma.

This timeframe for the emplacement of the Galway granites correlates with the upper end of the general timescale for Silurian-Devonian 'Newer Granites' both to the north and south of the Iapetus Suture (see Fig. 3). A selection of recently published U-Pb TIMS ages has been also added to this timeframe, along with a monazite age (O'Connor *et al.* 1989) for the Leinster Granite (SE Ireland).

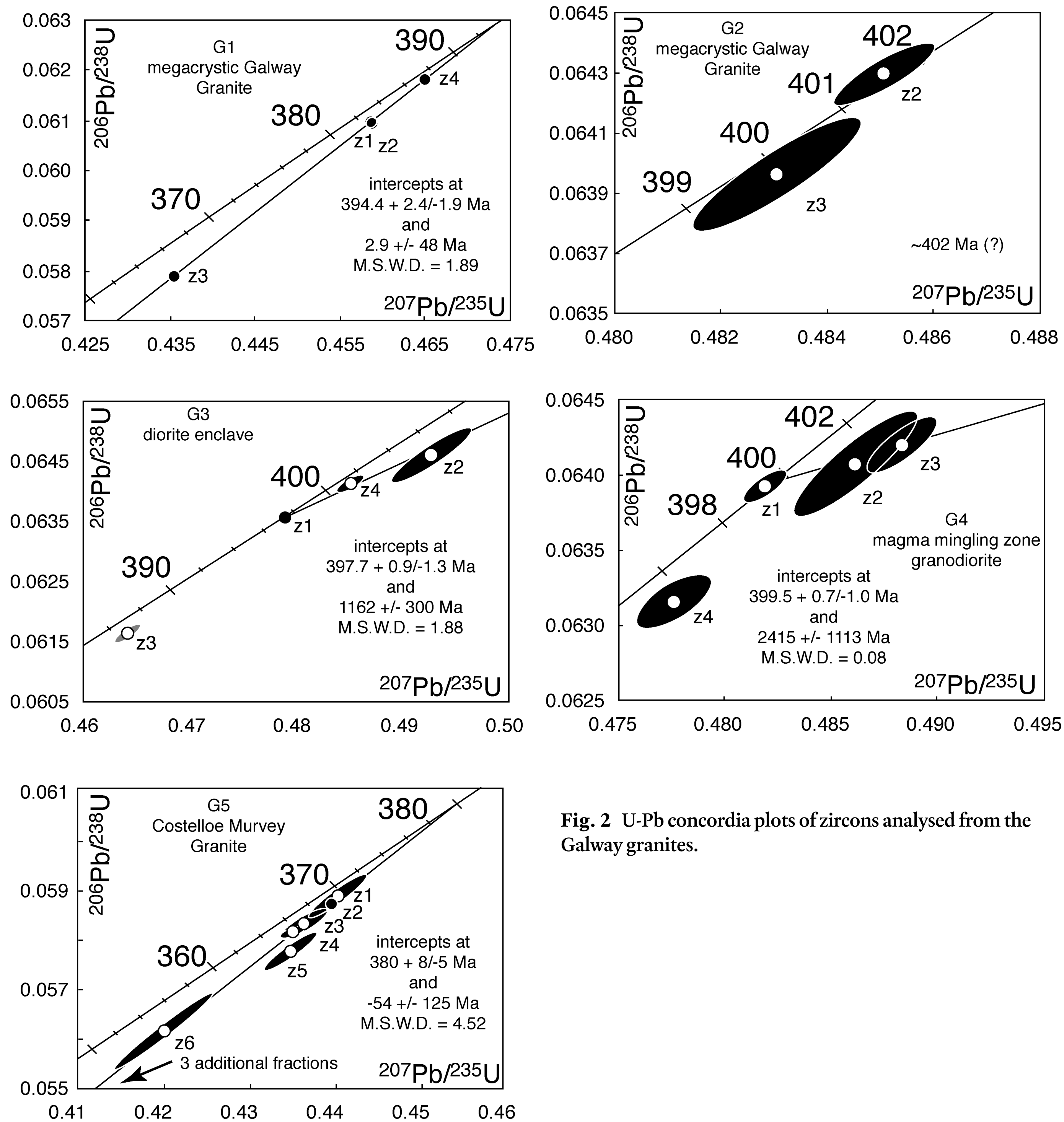


Fig. 2 U-Pb concordia plots of zircons analysed from the Galway granites.

DISCUSSION

Implications for the timing of the orogen parallel transcurrent faults in Britain and Ireland

It is apparent from Figure 3 that the emplacement of the Galway Granite postdated Iapetan convergence by ~10 Ma. Dewey and Strachan (2003) in a review of data relevant to the diachronous closure of Iapetus in the North Atlantic Caledonian sector argued that major left-lateral displacement along the orogen-parallel Great Glen Fault and related structures is necessary in the time period 425–410 Ma. Late Caledonian transcurrent faults like the Great Glen, Highland Boundary, and Southern Uplands faults have controlled the ascent and emplacement of granite magmas in Britain and Ireland (e.g., Hutton 1988; Hutton and Reavy 1992). The emplacement of the suite was in transtensional pull-aparts and dilational splays on sinistral strike-slip faults (Hutton

Table 2. Tabulation of age determinations presented in the text.

Granite	Geological setting	Method	Age
Megacrystic Granite (G1)	Central Block	U-Pb Single crystal (zircon)	394.4 ± 2.2 Ma.[1]
Megacrystic Granite (G2)	Central Block	U-Pb Single crystal (zircon)	~ 402 Ma.[1]
Enclave (G3)	Central Block	U-Pb Single crystal (zircon)	397.7 ± 1.1 Ma.[1]
MMZ Granodiorite (G4)	Central Block	U-Pb Single crystal (zircon)	399.5 ± 0.8 Ma.[1]
Costelloe Murvey Granite (G5)	Central Block	U-Pb Single crystal (zircon)	380.1 ± 5.5 Ma.[1]
Molybdenite bearing quartz veins	Hosted by Carna Granite; Western Block.	Re-Os Molydenite	407.3 ± 1.5 Ma.[2]
Disseminated molybdenite	Hosted by Murvey Granite; Western Block	Re-Os Molydenite	410.5 ± 1.5 Ma.[2]
Disseminated molybdenite	Hosted by Murvey Granite; Western Block	Re-Os Molydenite	410.8 ± 1.4 Ma.[2]
Carna Granite	Western Block	U-Pb Bulk zircon	412 ± 15 Ma.[3]
Errisbeg Townland and Murvey Granite	Western Block	Rb-Sr wholerock	398 ± 10 Ma.[4]

Sources: [1] this study, [2] Selby *et al.* (in press), [3] Pigeon (1969) and [4] Leggo *et al.* (1966).

1982, 1988; Hutton and McErlean 1991; Hutton and Reavy 1992; Jacques and Reavy 1994; Stewart *et al.* 2001). The 410 to 380 Ma period for the emplacement of the Galway granites postdated this period of major left-lateral displacements on these orogen-parallel faults. This timing is in keeping with the stitching nature of the Galway Batholith in relation to the Skerd Rocks Fault. The new ages, therefore, place an upper limit on the timing of major displacements on the Southern Uplands Fault system and support the assertion of Dewey and Strachan (2003) that the 425–410 Ma period was marked by major movement on the orogen-parallel transcurrent faults (Figs.1b, 3).

Implications for cross-Atlantic correlations with the Acadian granite plutonism in the New England Appalachians

Bradley *et al.* (2000) demonstrated that Acadian syn- and post-tectonic plutons ranging in composition from gabbro to granite are widespread in Maine and adjacent parts of New Brunswick, Quebec, New Hampshire, and Vermont. Dating (using U-Pb and Ar/Ar methods) of key plutons, many granitic in composition, across a broad swath from the Maine coast to the Maine-Quebec border allowed Bradley *et al.* (2000) to conclude that the Acadian deformation front and the locus of plutonism shifted over time, northwestward, across the northern Appalachian orogen. The timescale for this Acadian plutonism extends from ~420 to 360Ma, marked by the following groupings of pluton ages: (a) Ludlow to Lochkovian plutons that occur along the Maine coast; (b) Emsian plutons that form a NE -SW trending belt, ca.500 km long and some 120 km inland; (c) Late Emsian to Eifelian plutons in the age range 400 to 387.5 Ma that are scattered across the area; (d) Givetian to Early Tournasian plutons that are widespread throughout the region from the coast of Maine northward to the Quebec border.

The timespan of the Acadian orogen in Britain and Ireland is more restricted and extends from mid-Emsian to mid-Famennian (McKerrow *et al.* 2000; Dewey and Strachan, 2003; see Fig. 3). The onset of Galway granite plutonism predated the Acadian in Britain and Ireland but correlates with the Emsian, the Late Emsian to Eifelian, and the Givetian to Early Tournasian plutonic groups in Maine. Similarities in timing of plutonism exist in a general sense between the Galway Granite and for example the Seboeis and Moxie plutons (Emsian group – Bradley *et al.* 2000). These two granite plutons in Maine reflect relatively early pluton emplacement at ca.405 Ma followed by a significant time gap of ~35–40 Ma before the final emplacement event occurred, marked for example by the intrusion of the Beaver Cove pluton (ca.372 Ma) into the Moxie pluton and the East Branch Lake granodiorite (ca. 365 Ma) into the Sebois pluton. The emplacement of the 380 Ma CMG into the early suite of Galway granites (410 to 400 Ma) in Connemara also reflects a significant time gap of ca.20–30 Ma. Why there was a resurgence of volumetrically subordinate granite magmatism at the same crustal location some 20 to 30 Ma after the main phase of granite magmatism had occurred and apparently during the waning stage of orogeny warrants further investigation on both sides of the North Atlantic Ocean.

SUMMARY AND CONCLUSIONS

The TIMS U-Pb ages for the five samples from the Galway granite show that, in keeping with the field relationships, the Megacrystic and MMZ granites crystallised at ca. 400 Ma and were intruded by the CMG at ca.380 Ma. Furthermore, similar ages for both enclave and host (MMZ granodiorite) confirm

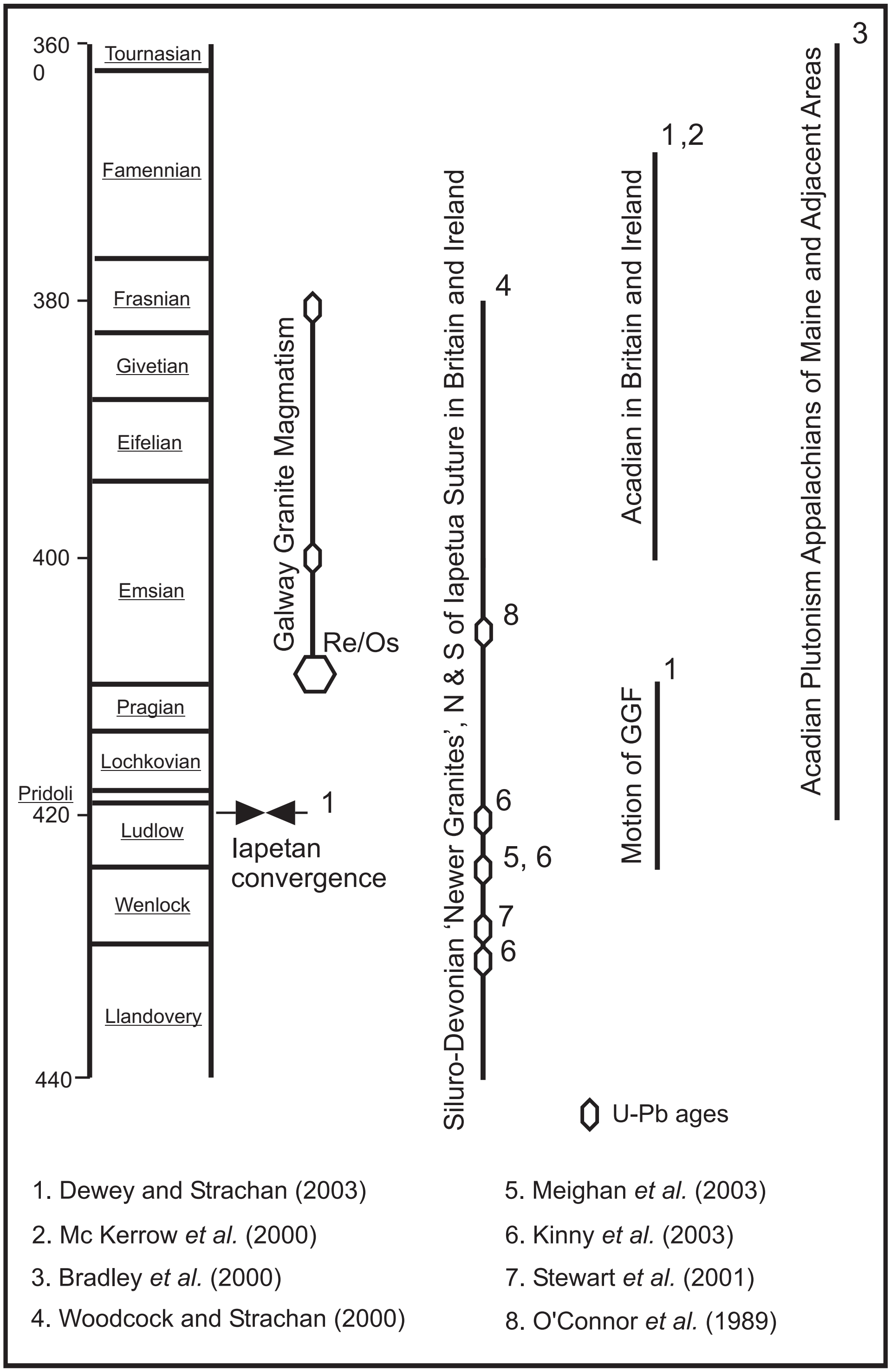


Fig. 3 A geochronology, tectonic and magmatic framework for the Galway granites highlighting its position in relation to Caledonian granite magmatism in Ireland, Britain and New England.

the coeveality of both magmas. When the TIMS ages are combined with new Re-Os dates (~ 410 Ma) from magmatic molybdenite at the western end of the batholith, it is apparent that Galway Granite plutonism extended discontinuously over a period of ca. 30 Ma. The juxtaposition of the high-level brittle fracture regime CMG with the deeper level Megacrystic and MMZ granites reflects upward movement on the bounding faults of the central block prior to emplacement of the CMG. The new ages also place constraints on the timing of motion on major orogen-parallel transcurrent faults, in particular the Southern Uplands and the Skerd Rocks faults. The emplacement of the Galway granites postdated movement on the Skerd

Rocks Fault, constraining final motion to ~410 Ma in keeping with the time constraints for final motion on the Great Glen Fault. The Galway Granite can be assigned to the Acadian, although the time span of the Acadian in New England is more extensive than in Britain and Ireland. Nevertheless useful correlations can be made between the timing and emplacement history of Acadian plutonism in Maine and in western Ireland. In particular, the Moxie and Seboeis plutons of Maine, like the Galway pluton, have intergranite intrusion histories punctuated by time gaps in the order of 30 to 40 Ma. These plutons reflect the resurgence of granite magma at the same crustal location after a very significant time gap and during the waning stages of the Acadian orogeny.

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