Lithostratigraphy and palaeoenvironments of the sequences studied

During the early Carboniferous Ireland was located just south of the equator and was largely covered by a tropical, epeiric sea which transgressed northwards across Ireland due to crustal extension (Fig. SM1).

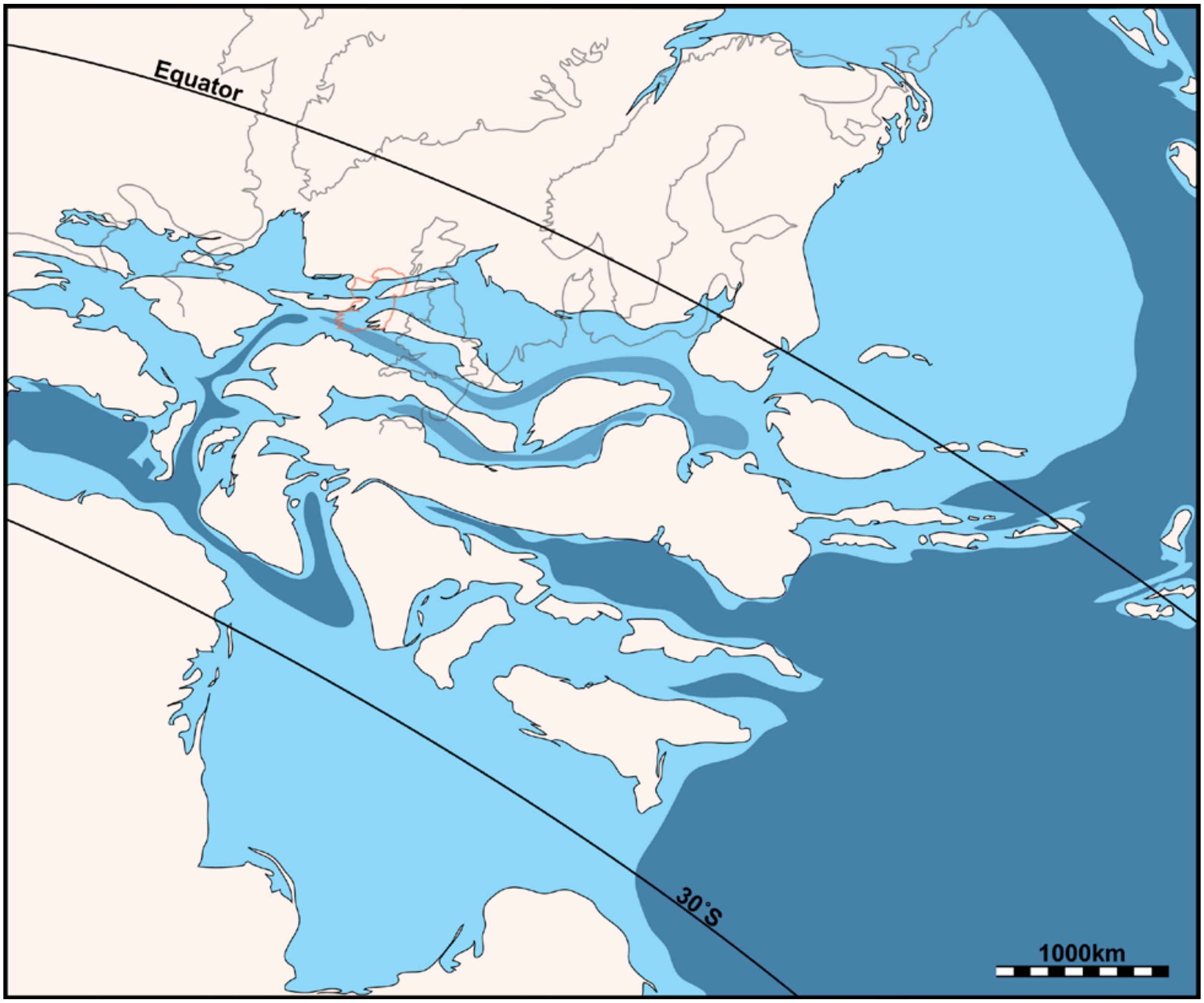

Fig. SM1. *Palaeogeographical map of NW Europe (Ireland is outlined in red) during the early Mississippian, ~350Ma. Tan colours represent emergent land, whilst blue areas represent marine bodies (darker blue colours indicate increasing depth). The large landmasses in the NW and SW of the map represent the continents of Laurentia and Gondwana respectively. Modified from the palaeogeographic projection of Blakey (2011).*

In the late Viséan, a complex combination of eustatic, localised tectonic and intrinsic sedimentological controls caused the development of a variety of lithologies across NW Ireland. Fig. SM2 provides an overview of the formations and palaeoenvironments of deposition, as well as the stratigraphic ranges of the five sections examined in the Sligo and Lough Allen Synclines.

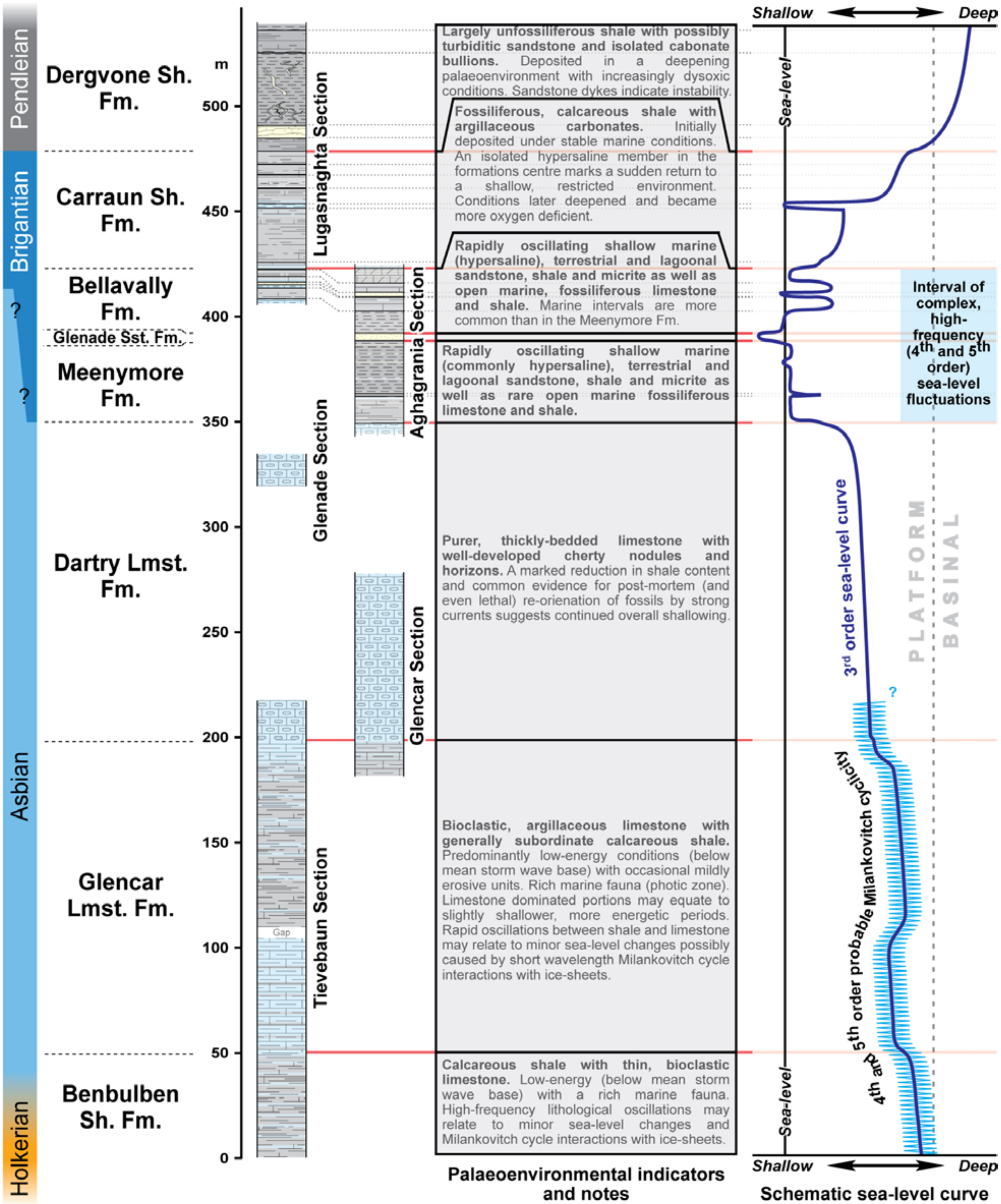

Fig. SM2. *Simplified lithostratigraphy and palaeoenvironmental evolution of the sequence examined. For more detailed information see Barham (2010).*

Each of the sections shown in Fig. SM2 are described briefly below (in ascending stratigraphic order) and shown geographically in Fig. SM3.

Tievebaun Section

A steep stream exposes the uppermost Benbulben Shale Formation as well as the complete Glencar Limestone Formation and its contact with the overlying Dartry Limestone Formation on the north face of Tievebaun Mountain Co. Sligo. Just over 216m (stratigraphical thickness) of nearly continuously exposed strata begins at 54.407ºN 8.358ºW.

Glencar Section

A stream cut in a hanging valley north of Lough Glencar near the Sligo-Leitrim border exposes ~94m of stratigraphy ranging from the upper Glencar Limestone Formation to the middle Dartry Limestone Formation. Uninterrupted exposure begins at 54.347ºN 8.386ºW and continues upstream.

Glenade Section

A nearly complete sequence of the Dartry Limestone Formation outcrops in a deeply cut stream in the townland of Leckanarainey, east of Glenade Lough, Co. Leitrim. The lower levels of the stream-cut are difficult to access and only a short interval of the upper levels of the Dartry Limestone Formation were studied, beginning at 54.361ºN 8.231ºW. The overlying contact with the Meenymore Formation is not exposed, although it can be constrained to within a ~12m stratigraphic gap.

Aghagrania Section

The Aghagrania River cut 2.5km ENE of Drumshanbo, Co. Leitrim, represents the type section for the Meenymore Formation as well as the most complete exposure of the Bellavally Formation. Additionally, at the sections base the uppermost part of the Dartry Limestone Formation, and at the sections top the lowermost Carraun Shale Formation, are exposed. Separating the Meenymore and Bellavally Formations is an anomalously thin equivalent of the Glenade Sandstone Formation. Approximately 86m of stratigraphy are exposed in total beginning at 54.057ºN 8.006ºW.

Lugasnaghta Section

Located between the townlands of Carraun and Lugasnaghta, a small tributary of the Sraduffy River runs NE off the slopes of Dough Mountain, Co. Leitrim and exposes the upper levels of the Bellavally Formation as well as the entire Carraun Shale Formation (type section) and the lower levels of the overlying Dergvone Shale Formation. The section begins at 54.336ºN 8.069ºW and can be traced upstream for ~1km horizontal distance (equivalent to just over 130m of stratigraphy).

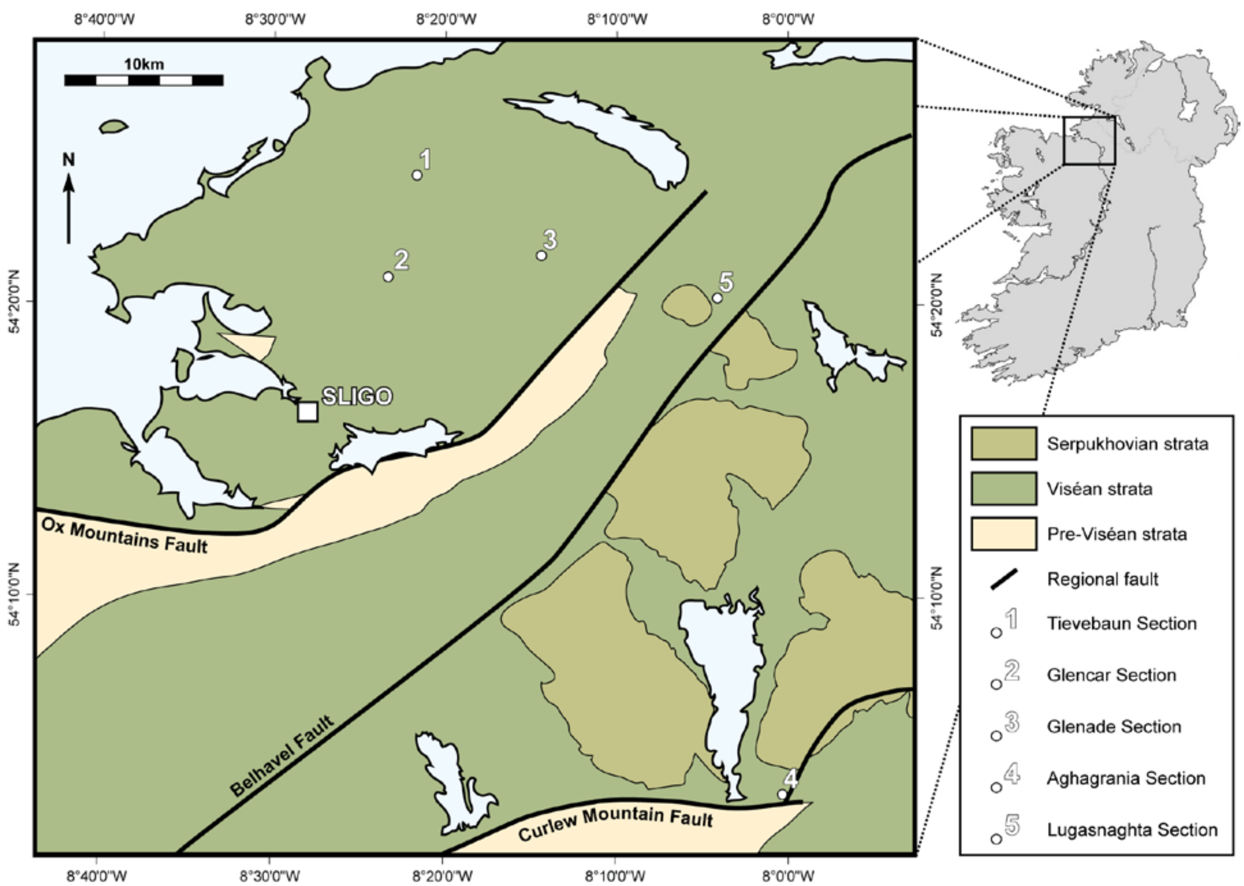

Fig. SM3. *Location map of NW Ireland showing the sections studied.*

Oxygen isotope analyses

Conodont and ichthyolith elements were recovered using standard rock processing techniques for limestone (~6% buffered Formic acid solution changed every 24-48hours) and shale (alternating desiccation and wetting with occasional addition of weak buffered acid, hydrogen peroxide and surfactant solutions to assist in disaggregating bound clay particles). No evidence for any treatment-induced alteration of $\delta^{18}O_{apatite}$ values was observed.

The best preserved elements (most lustrous, with no signs of recrystallisation) were selected under microscopic examination for oxygen isotope analysis (Table SM1). Biogenic apatite samples at the lowest possible taxonomic (generic or even specific) level, were chemically converted into Ag_3PO_4 using a modified version of the methodology described by O'Neil *et al.* (1994) and analysed using a high Temperature Conversion Elemental Analyser connected online to a ThermoFinnigan Delta Plus mass spectrometer as described by Joachimski *et al.* (2009). The accuracy and reproducibility of analyses were evaluated through replicate analyses of samples as well as internal and international standards. Reproducibility of triplicate sample and standard analyses was typically < ±0.2‰ (1σ). The average oxygen isotope composition of the international standard NBS 120c was determined as 22.58 ±0.13‰ (n=38), which is identical (22.58 ±0.09‰) to that reported by Vennemann *et al.* (2002).

All oxygen isotope analyses were undertaken in the Stable Isotope Laboratory in the Geo-centre of northern Bavaria, at the Friedrich-Alexander University of Erlangen-Nuremberg, Germany.

TABLE SM1. Samples for $\delta^{18}O$ analysis. Sample name prefixes refer to the relevant section of origin, i.e. GLTV = Tievebaun, DAGL = Glencar, DAGN = Glenade, AGHA = Aghagrania, CNLG = Lugasnaghta. Lithology abbreviations follow Dunham (1962) i.e. MS = mudstone, WS = wackestone, PS = packstone otherwise Sh. = shale, Lmst. = limestone, Dol. = dolomite and bul. = bullions. Locations are given in meters above the relevant sections base. Indet. = indeterminable, ~ = approximately.

Sample name	**Age**	**Formation**	**Member**	**Lithology & location**	**Taxon**		**Weight**	**$\delta^{18}O$** (‰ V-SMOW)	**1σ** (no. replicates)
CNLG19	Pendleian	Dergvone Sh.	Tonlegee Sh.	WS bul. 130m	Conodont	*G. bilineatus* (10), *G. girtyi* (3) P_1-elements & indet. S-elements (15)	0.996	20.17	0.20 (6)
CNLG15 AN-1	Brigantian	Carraun Sh.	Sranagross Dol.	MS 61m	Conodont	*G. bilineatus* (7), *G. girtyi* (9) P_1-elements & indet. platform blades (10)	1.168	20.20	0.17 (4)
CNLG14 OR1	Brigantian	Carraun Sh.	N/A	MS bul. 57m	Conodont	*G. bilineatus* (11) P_1-elements & indet. platform blades (4)	0.622	20.29	0.03 (3)
CNLG14	Brigantian	Carraun Sh.	N/A	MS bul. 57m	Ichthyolith	Actinopterygian scales (13)	1.103	19.09	0.22 (3)
CNLG9 OR1	Brigantian	Carraun Sh.	N/A	MS 39m	Conodont	*G. bilineatus* (5), *G. girtyi* (6) P_1-elements & indet. platform blades (3)	0.860	20.97	0.06 (3)
CNLG8 OR1	Brigantian	Carraun Sh.	N/A	MS 28m	Conodont	Mixed conodont assemblage, including *M. bipluti* P_1-elements	0.982	20.86	0.05 (3)
CNLG7 AN-2	Brigantian	Carraun Sh.	N/A	MS 23m	Conodont	*M. bipluti* (4) P_1-elements	1.027	20.94	0.10 (3)
CNLG6 OR1	Brigantian	Carraun Sh.	Derreens Lmst.	WS 18m	Conodont	*G. bilineatus* (2), *G. girtyi* (4) P_1-elements & indet. blade fragments (6)	0.683	20.50	0.12 (3)
CNLG A2	Asbian	Bellavally	Lugasnaghta Sh.	Sh. 3m	Ichthyolith	Acanthodian scales (15)	~1	17.99	0.15 (3)
CNLG A1	Asbian	Bellavally	Lugasnaghta Sh.	Sh. 3m	Conodont	*G. girtyi* (9) P_1-elements & indet. platform blades (7)	~1	21.10	0.07 (3)
CNLG1 AN2-1	Asbian	Bellavally	Sraduffy	WS 1m	Conodont	*G. bilineatus* (4), *G. girtyi* (14) P_1-elements & indet. platform blades (4)	1.036	21.06	0.05 (6)
AGHA13 AN-2	Brigantian	Carraun Sh.	Derreens Lmst.	WS 84m	Ichthyolith	Tip of a cladodont cusp	0.960	18.50	0.20 (3)
AGHA11	Brigantian	Bellavally	Corry	Sh. 83m	Ichthyolith	Cladodont cusp	~2	18.54	0.09 (3)
AGHA10 AN2-1	Brigantian	Bellavally	Sheena Sh.	WS 72m	Conodont	Incomplete *G. bilineatus* (2) & *G. girtyi* (12) P_1-elements	1.050	20.94	0.06 (2)
AGHA10 AN1-2	Brigantian	Bellavally	Sheena Sh.	WS 72m	Ichthyolith	Actinopterygian scales (6)	1.243	18.34	0.06 (2)
AGHA9 OR1	Asbian	Bellavally	Lugasnaghta Sh.	WS 64m	Ichthyolith	Palaeoniscid teeth (29)	1.205	18.87	0.03 (3)
AGHA9	Asbian	Bellavally	Lugasnaghta Sh.	WS 64m	Ichthyolith	"Ctenacanth"-type chondrichthyan scales (9)	1.083	18.10	0.11 (2)
AGHA6 OR1	Asbian	Meenymore	Corloughlin	MS 40m	Ichthyolith	Palaeoniscid teeth (23)	1.005	18.52	0.18 (3)
AGHA4 OR1	Asbian	Meenymore	Corloughlin	WS 25m	Ichthyolith	Palaeoniscid teeth (20)	1.090	18.69	0.14 (3)
AGHA4 AN-3	Asbian	Meenymore	Corloughlin	WS 25m	Ichthyolith	Actinopterygian scales (2)	1.339	18.52	0.16 (3)
AGHA D1	Asbian	Meenymore	Dorrusawillin	Sh. 21m	Ichthyolith	Enameloid from large orodont tooth	~1.6	18.83	0.08 (3)

AGHA3.2	Asbian	Meenymore	Drumcroman	MS 19m	Conodont	*G. bilineatus* (1), *G. girtyi* (15) P_1-elements & indet. blade (2) & platform (2) fragments	1.192	20.53	0.15 (3)
AGHA3.1	Asbian	Meenymore	Drumcroman	MS 18m	Conodont	*G. bilineatus* (4) & *G. girtyi* (16) P_1-elements	1.125	20.44	0.09 (4)
AGHA1 OR1	Asbian	Meenymore	Drumcroman	WS 10m	Ichthyolith	Palaeoniscid teeth (10)	1.296	18.94	0.06 (3)
AGHA1	Asbian	Meenymore	Drumcroman	WS 10m	Ichthyolith	Fragment of orodont tooth	1.051	18.56	0.26 (4)
DAGN1 AN-3	Asbian	Dartry Lmst.	N/A	WS 10m	Ichthyolith	Actinopterygian scale	1.070	17.97	0.25 (5)
DAGN1 OR1	Asbian	Dartry Lmst.	N/A	WS 10m	Ichthyolith	Palaeoniscid tooth. Very poor reaction	1.077	16.67	0.13 (3)
DAGL15	Asbian	Dartry Lmst.	N/A	MS 113m	Ichthyolith	Lissodus tooth fragment	1.177	18.95	0.23 (3)
DAGL1 OR1	Asbian	Dartry Lmst.	N/A	MS 0m	Ichthyolith	Actinopterygian scales (5)	0.841	18.24	0.20 (3)
GLTV39 OR1	Asbian	Glencar Lmst.	N/A	MS/WS 189m	Ichthyolith	Palaeoniscid teeth (10)	1.090	18.03	0.20 (3)
GLTV39 AN-2	Asbian	Glencar Lmst.	N/A	MS/WS 189m	Ichthyolith	Actinopterygian scale	1.346	17.61	0.02 (3)
GLTV36 OR1	Asbian	Glencar Lmst.	N/A	MS 169m	Ichthyolith	Palaeoniscid teeth (8)	1.348	17.82	0.06 (3)
GLTV30 AN-2	Asbian	Glencar Lmst.	N/A	MS 127m	Ichthyolith	Actinopterygian scale	1.668	15.86	0.10 (3)
GLTV28	Asbian	Glencar Lmst.	N/A	MS 111m	Ichthyolith	Cladodont fragment	1.218	17.07	0.10 (3)
GLTV27 OR1	Asbian	Glencar Lmst.	N/A	MS 103m	Ichthyolith	Palaeoniscid teeth (13)	1.349	17.46	0.09 (3)
GLTV22 OR1	Asbian	Glencar Lmst.	N/A	MS 70m	Ichthyolith	Actinopterygian scales (7)	1.230	16.79	0.14 (3)
GLTV21 AN-1	Asbian	Glencar Lmst.	N/A	WS 63m	Ichthyolith	Indet tooth fragments	1.445	17.35	0.06 (4)
GLTV20 OR1	Asbian	Glencar Lmst.	N/A	MS/WS 55m	Ichthyolith	Palaeoniscid teeth (8)	0.962	16.18	0.06 (3)
GLTV19 OR1	Asbian?	Benbulben Sh.	N/A	MS/WS 49m	Ichthyolith	Actinopterygian scales (3)	1.174	16.93	0.17 (3)
GLTV18 OR1	Asbian?	Benbulben Sh.	N/A	WS 41m	Ichthyolith	Palaeoniscid teeth (9)	0.774	16.00	0.10 (3)
GLTV17 AN-1	Asbian?	Benbulben Sh.	N/A	WS 35m	Ichthyolith	Fragment of large protacrodont tooth	1.035	16.77	0.07 (3)
GLTV16 OR2	Holkerian?	Benbulben Sh.	N/A	WS 29m	Ichthyolith	Palaeoniscid teeth (7)	1.196	15.79	0.07 (3)
GLTV16 OR1	Holkerian?	Benbulben Sh.	N/A	WS 29m	Ichthyolith	Indet. Tooth	0.854	16.69	0.08 (3)
GLTV15	Holkerian?	Benbulben Sh.	N/A	WS/PS 19m	Ichthyolith	Indet. material	1.090	17.68	0.15 (3)
GLTV14 OR2	Holkerian	Benbulben Sh.	N/A	WS 13m	Ichthyolith	Palaeoniscid teeth (10)	1.043	15.66	0.14 (3)
GLTV14 OR1	Holkerian	Benbulben Sh.	N/A	WS 13m	Ichthyolith	Actinopterygian scale	1.464	16.27	0.04 (3)
GLTV13 OR1	Holkerian	Benbulben Sh.	N/A	WS 6m	Ichthyolith	Palaeoniscid teeth (13)	1.004	15.13	0.14 (3)
GLTV12	Holkerian	Benbulben Sh.	N/A	WS 0m	Ichthyolith	Enameloid layer of indet. tooth	1.292	18.10	0.05 (3)

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