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The production of a glass toggle: Iron Age craft specialisation along Scotland's western seaboard

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ABSTRACT

A glass toggle was found among the ashes of a domestic hearth during the excavation of an unenclosed Iron Age settlement at Kilninian, Isle of Mull, Argyll, Scotland. The hearth was radiocarbon dated to 168 cal BC*–cal* AD *3 (SUERC-46765). The toggle was covered with a black residue that was stuck to its surface and it looked hastily made, using low-quality aqua cullet. Chemical analyses, using LA-ICP-MS, indicate the glass used was a natron-based glass. The trace element composition suggested the glass was produced in the east Mediterranean area using coastal sands and had subsequently been recycled. The morphological examination using extended depth of field microscopy and micro-computed tomography revealed the toggle was shaped at low temperatures using contaminated glass. The black sooty residue found on the surface of the toggle was found to extend within the toggle and was fused with the object. This could only have happened during manufacture, when the glass was still hot enough to be malleable and stick to the contamination. The uncleaned residues on the surface and the presence of the unpolished pontil scar suggest the toggle may have fallen in the hearth during manufacture and was lost to its maker. Analyses of other glass toggles found in Scotland and Ireland confirmed that natron-based glass had also been used and the toggles were made in the same way as that from Kilninian.*

THE ARCHAEOLOGICAL CONTEXT

In advance of residential development at Kilninian, Isle of Mull (NGR NM 39956 45921), a programme of archaeological works was undertaken, which included a walkover survey, building recording and excavation. Archaeological excavation adjacent to and under a 19th-century barn revealed part of an unenclosed domestic settlement characterised by a number of pits, hearths and post holes (Illus 1). Full details of the excavation can be found in the archive.

Small post holes hint at the presence of one or two lightweight structures which would have provided shelter for a series of hearths; there was no evidence for a more substantial roundhouse structure. There were at least four domestic hearths upon which foodstuffs were prepared and cooked. The hearths were also used to dry barley, either on a daily basis before grinding into flour or for storage in one or more of the large pits. Sherds of handmade organic tempered ware, a granite hammerstone and a pallet stone were recovered from hearth contexts, and a bun-shaped

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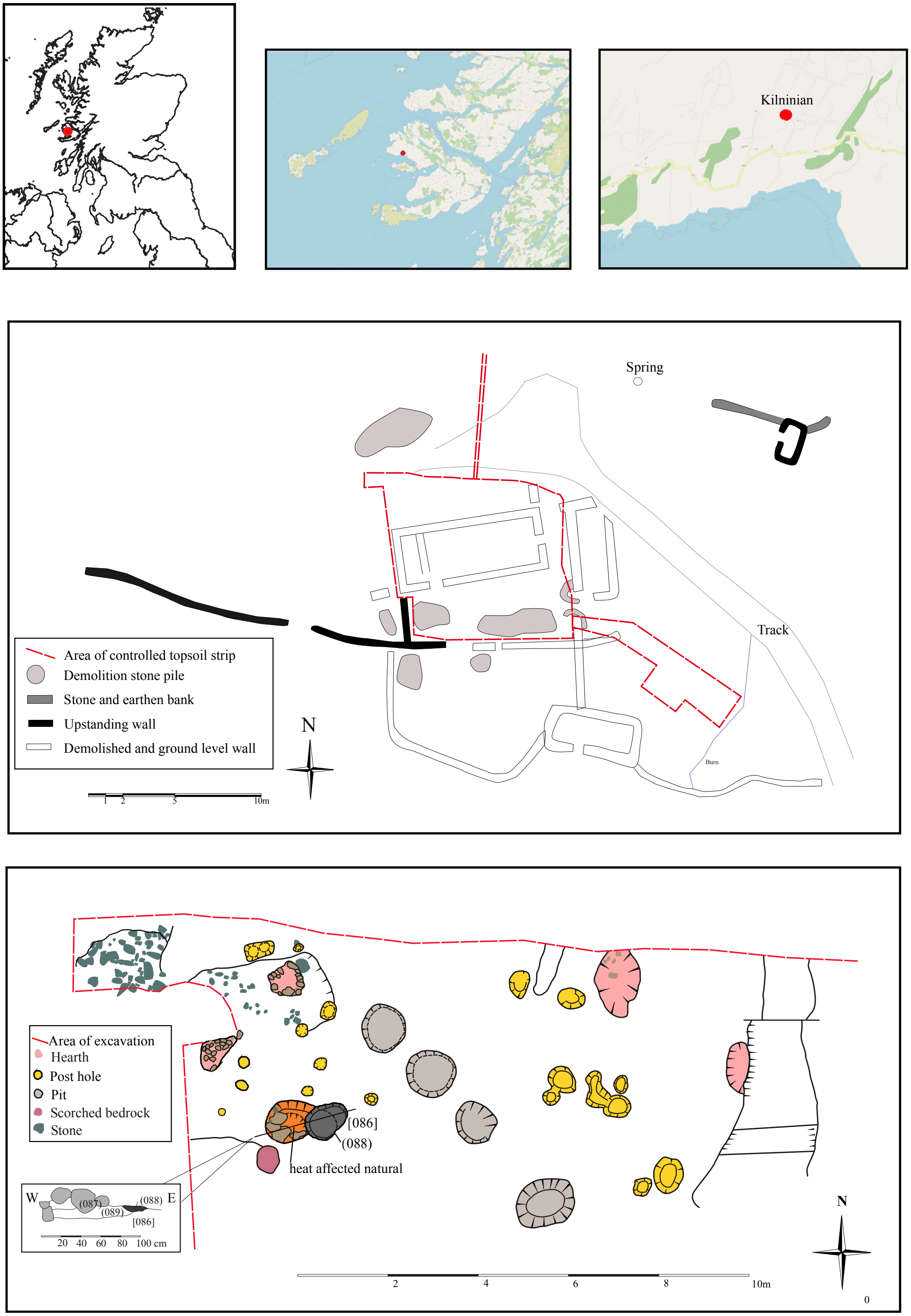


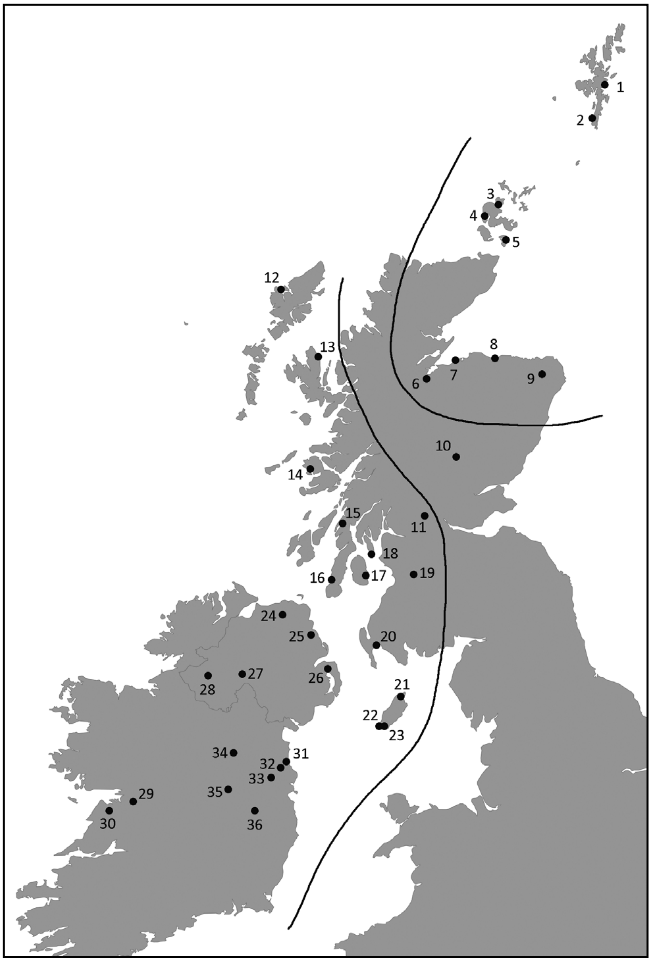
Illus 1 Location map and plan of archaeological features. (© Argyll Archaeology)

mica schist rotary quern from one of the pits. A glass toggle was recovered from among the in-situ ash of a figure-of-eight-shaped hearth [086] (Illus 1), which also contained carbonised cereal grain and minute fragments of burnt bone. One of the barley grains from this hearth has produced a radiocarbon date of 168 cal BC–cal AD 3 (SUERC-46765; Table 1). At one end of the hearth the fire had burned so hot that it had turned the silt bright reddish pink in colour. At the other end of the pit was a deposit of charcoal (088) from which the toggle was recovered. The toggle presented a number of interesting features, such as an unpolished pontil mark at one end and a black sooty residue firmly stuck to its surface. One hypothesis is that the toggle was accidentally lost, perhaps falling off clothing while the hot ashes were being raked out of the hearth. However, another explanation is that it may have been made on site, fashioned into shape from imported glass, and was accidentally dropped into the fire during its manufacture. Toggles of this type occur only at locations in Ireland, Scotland and the Isle of Man (Illus 2 & Table 2).

Scotland has produced a number of examples of late Iron Age glass body adornment, such as southern Scottish/northern English glass bangles (Kilbride-Jones 1938; Stevenson 1956, 1976) and north-eastern Scottish glass beads (Guido 1978; Henderson 1982; Bertini et al 2011; Bertini 2012). Another kind of typically Scottish Iron Age glass object are the rare glass marbles decorated with inlayed bicoloured eye spiral patterns, which have been found at a few locations in northern and eastern Scotland and at Traprain Law (Taylor 1982: 231). These small spherical objects have a small conical socket derived from their manufacture (Hunter, unpublished reports, 2011). The bangles are similar to some extent to Middle–Late La Tène continental ones, but were independently produced in northern Britain according to local styles; the Scottish beads, and especially Class 13 and 14 according to Guido's classification (Guido 1978), display unique designs evocative of an Iron Age ancestry, which may be a reflection of the local response to the threat represented by the Roman occupation. The spiral design used to decorate the marbles may have a similar meaning. In all cases, the peculiarity of their design and their geographical segregation in Scotland and northern England make them a likely candidate for local manufacture, implying the existence of a glass-working industry and a supply system for the glass used in their making (Paynter et al 2022). The chemical analyses performed on these objects so far demonstrate the Mediterranean origin of the glass (Stevenson 1956; Bertini et al 2011;

TABLE 1
Radiocarbon date from Kilninian. The calibrated age ranges are determined from the University of Oxford Radiocarbon Accelerator Unit Calibration program

Sample	*Material*	*Context*	*Species*	*Depositional context*	*Radiocarbon age (BP)*	*Calibrated date 68.2% probability*	*Calibrated date 95.4% probability*	*δ13C (‰)*
SUERC-46764	Carbonised cereal grain	78	*Hordeum vulgare*	Hearth fill	2121 ± 29	197–107 cal BC (68.2%)	345–322 cal BC (4.7%) 206–51 cal BC (90.7%)	−23.0
SUERC-46765	Carbonised cereal grain	88	*Hordeum vulgare*	Hearth fill	2059 ± 29	151–140 cal BC (6.1%) 112–39 cal BC (62.1%)	168 cal BC–cal AD 3 (95.4%)	−22.9



Illus 2 Map showing the location of discovery of toggles in Britain and Ireland. The geographic divisions reflect the slightly different methods of manufacture. (Reproduced from Hunter (forthcoming) with permission)

Bertini 2012). The presence of an alien and threatening cultural force may have encouraged the development of new ways of communicating a distinctive identity, displayed by the production of these small but impressive examples of local glassworks around the time of the Roman invasion (1st and 2nd century AD). This would have been enabled by a significant amount of raw materials coming from the recycling of vessel glass that, just like metals (in particular copper alloys), have been found to have been incorporated in local-style artefacts (Harding 2007; Hunter 2008).

However, in the context of the Scottish Iron Age, glass is very rare before its introduction during the Roman occupation of southern Scotland. Although the earliest glass in Britain dates back to 1550–1250 BC (Henderson 1988), for the greater part of the Bronze and Iron Ages most of it is in the form of beads and although there were a rising number of types and specimens in the later period, they seem to have been mostly continental imports (Henderson 1989). Recent excavation, though, is slowly changing this picture, with the working of glass for inclusion in metal objects, jewellery and beads evident from

Table 2
Database of known toggle beads found in Ireland, Scotland and the Isle of Man (adapted from Hunter (forthcoming), with permission). Data in red denotes those toggle beads that have been subject to morphological and compositional analysis as reported in this paper

No.	*Findspot*	*Detail*	*L (mm)*	*D (mm)*	*Notes*	*Site type*	*Date*	*Reference*
1	Clickhimin, Shetland	Polychrome reused	17	14	Bangle reused as toggle		Roman Iron Age	Hamilton (1968: 144, fig 64.2)
1	Clickhimin, Shetland	Bichrome: clear and yellow	26	13			Roman Iron Age	Hamilton (1968: 144, fig 64.1)
2	Scatness, Shetland	Polychrome reused			Bangle possibly reused as toggle/broken	Broch		Brown (2015: 429, pl 7.12.1)
3	Gurness, Orkney	Monochrome: translucent blue-green	29	18	Base of broch interior	Broch		Hedges (1987: 81, 247, fig 2.86, no. 829)
4	Howe, Orkney	Polychrome: translucent blue with opaque yellow and white	19.5	9		Broch	Unstratified	Henderson (1994)
5	Cairns, S Ronaldsay, Orkney	Monochrome: translucent blue-green	30	14	Estimated L; half survives	Broch	Roman Iron Age; near 2nd-century AD hearth	G Lloyd & M Carruthers pers comm
6	Culduthel, Inverness	Bichrome 'black'/yellow	17.5	9		Roundhouse settlement	Iron Age (50 BC–AD 130)	Hunter (forthcoming)
7	Culbin Sands, Moray	Bichrome: clear/yellow	24	13		Stray	Unknown	Hunterian B.1951.971
8	Port Gordon, Moray	Monochrome: translucent blue-green	23.5	15.3		Roundhouse	Iron Age	Bertini et al this paper
9	Buchan, Aberdeenshire	Polychrome: blue-green body, yellow strip, transverse cables				Stray		ABDUA: 15504; Bertini et al this paper
10	Black Spout, Pitlochry, Perth & Kinross	Monochrome: translucent blue-green	13	10	Reused Roman	Roundhouse	Roman Iron Age	Hoffmann (2013)

Table 2
Continued

No.	*Findspot*	*Detail*	*L (mm)*	*D (mm)*	*Notes*	*Site type*	*Date*	*Reference*
11	Leckie, Stirling	Polychrome: blue core, red/yellow cap	10	5		Broch	Roman Iron Age (phase 3); medieval	Hoffmann (2016: 149, 153), M Bertini pers comm
12	Loch na Beirgh, Lewis	Monochrome: translucent blue-green	15	10.5		Broch	Middle 1st millennium AD	Seen in Stornoway Museum, May 2018
13	Dun Raisaburgh, Skye	Monochrome: blue core, translucent outer coating				Stray near dun	Unknown	C Ellis pers comm (private collection on Skye)
14	Kilninian, Mull, Argyll	Monochrome: translucent blue-green	15	8	Unfinished	Settlement	Iron Age	Ellis (2012); C Ellis pers comm; Bertini et al this paper
15	Balure, Knapdale, Argyll	Monochrome: opaque mid-blue				Dun	Iron Age	Regan & Campbell (2022)
15	Balure, Knapdale, Argyll	Monochrome: translucent blue-green				Dun	Iron Age	Regan and Campbell (2022)
16	Dun Fhinn, Kintyre, Argyll	Monochrome: 'blue'				Settlement	Iron Age	RCAHMS (1971: 83–4, no. 203)
17	Monamore, Lamlash, Arran	Monochrome: blue	13	8.5		Neolithic chambered cairn		MacKie (1964: 27, fig 4, no. 9)
18	Dunagoil, Bute	Monochrome: deep blue	?	7		Hillfort	Iron Age	Mann (1915: pl II.9); Harding (2004: fig 2, no. 11)
19	Lochlee, South Ayrshire	Monochrome	12	6		Crannog	Possible Iron Age	Munro (1882: 137)
20	Luce Sands, Dumfries & Galloway	Monochrome: translucent blue-green	9.2	5.1			?	NMS X.BHB 14
20	Luce Sands, Dumfries & Galloway	Monochrome: translucent blue-green	15.6	7.9			?	NMS X.BHB 15

Table 2
Continued

No.	*Findspot*	*Detail*	*L (mm)*	*D (mm)*	*Notes*	*Site type*	*Date*	*Reference*
20	Luce Sands?, Dumfries & Galloway	Monochrome: opaque mid-blue	27.5	17.5			?	Stranraer Museum 1964.49=1988.319
21	Braust, Man	Monochrome: translucent blue-green	14.5	8.5			?	Manx Museum MM 1985-0012/1a (examined June 2011)
21	Braust, Man	Monochrome: translucent blue-green	15.5	9.5			?	Manx Museum MM 1985-0012/1b (examined June 2011)
21	Braust, Man	Monochrome: translucent blue-green	22	12			?	Manx Museum MM 1985-0012/1c (examined June 2011)
22	Ballacagen, Man	Monochrome: translucent cobalt blue	14.5	8		Roundhouse	Possible Roman Iron Age	Bersu (1977: 63, fig 21, no. B49)
23	Close-ny-Chollagh, Man	Monochrome: translucent blue-green	10	4.5		House site	Roman Iron Age	Gelling (1958: 94, fig 6)
23	Close-ny-Chollagh, Man	Bichrome: dark blue, vertical white trails	12	5.5		House site	Roman Iron Age	Gelling (1958: 94, fig 5)
24	Eden, Ballymoney, Co Antrim	Polychrome: opaque mid-blue and jade green with cable	22	10		Stray		Hunterian B.1914.523/2
25	Deer Park Farms, Co Tyrone	Bichrome: blue with lighter streaks	14	8.5		Settlement	Early medieval; AD 730–80	Lynn & McDowell (2011: 332, 339, pl 18.3, no. 2807)
25	Deer Park Farms, Co Tyrone	Monochrome: opaque blue	15	8		Settlement	Early medieval; AD 680–760	Lynn & McDowell (2011: 332, 339, pl 18.3, no. 2964)
25	Deer Park Farms, Co Tyrone	Bichrome: dull blue with lighter bands	17	8.5		Settlement	Early medieval; 9th–10th century	Lynn & McDowell (2011: 332, 339, pl 18.3, no. 1758)

TABLE 2
Continued

No.	*Findspot*	*Detail*	*L (mm)*	*D (mm)*	*Notes*	*Site type*	*Date*	*Reference*
26	Scrabo Hill, Newtownards, Co Down	Monochrome: dark blue	12	6		Stray		Hunterian B.1951.2651/1
26	Scrabo Hill, Newtownards, Co Down	Monochrome: translucent blue-green	15	11		Stray		Hunterian B.1951.2651/2
27	Clogher, Co Tyrone	Not stated				Hillfort	Early medieval	Warner & Meighan (1981: 54)
28	Kiltierney, Co Fermanagh	Bichrome: dark blue / yellow	14	5.5		Burial	1st century BC–1st century AD	Raftery (1981, fig 39, no. 3; 1983: 187, fig 153, no. 498)
29	Grannagh, Co Galway	Monochrome: 'faintly greenish'	11	6		Burial	Iron Age	Raftery (1981: 180, fig 32, no. 4; 1983, fig 154, no. 507)
30	Cahercommaun, Co Clare	Monochrome: green (unclear if translucent or opaque)	21.5	10		Settlement	Early medieval	Hencken (1938: 40, fig 24, no. 16)
31	Dowth, Co Meath	Unknown	16	8		Neolithic burial	Unknown	Coffey (1912: 47, fig 27)
32	Knowth, Co Meath	Monochrome: translucent yellow green	10.5	8.5		Burial 17; single find, pendant		Eogan (2012: 29); Raftery (2012: 234–5); Johnson (2012: 236, fig 7.2.2)
32	Knowth, Co Meath	Monochrome: translucent blue-green	13.5	7		Burial 20, child; fastener on large necklace	38 BC–AD 219	Eogan (2012: 31); Raftery (2012: 234–5); Johnson (2012: 238–9)
33	Lagore, Co Meath	Monochrome: 'greenish' – probably translucent blue-green	15	9		Crannog	Early medieval	Hencken et al (1951: 141, fig 67, no. 1471)
34	Lough Crew, Co Meath	Monochrome, 'greenish' – probably translucent blue-green	9	4		Neolithic burial	Unknown	Herity (1974: 237, fig 139, no. 34)

TABLE 2
Continued

No.	*Findspot*	*Detail*	*L (mm)*	*D (mm)*	*Notes*	*Site type*	*Date*	*Reference*
34	Lough Crew, Co Meath	Monochrome, 'greenish' – probably translucent blue-green	10	5		Neolithic burial	Unknown	Herity (1974: 237, fig 139, no. 33)
35	Ballinderry 2, Co Offaly	Monochrome: 'bluish' – probably translucent blue-green	25	12		Crannog	Early medieval	Hencken (1942: 51–2, fig 21, no. 251)
36	Dun Ailinne, Co Kildare	Monochrome: translucent blue-green	10	5		Ritual	Iron Age	Johnston & Wailes (2007: 120–1, fig 9-4, pl 9-6) (E.79.52)
36	Dun Ailinne, Co Kildare	Bichrome: blue/white streaks	13.5	6		Ritual	Iron Age	Johnston & Wailes (2007: 120–1, fig 9-4, pl 9-6) (E.79.2755)
36	Dun Ailinne, Co Kildare	Bichrome: blue/white streaks	14.5	9		Ritual	Iron Age	Johnston & Wailes (2007: 120–1, fig 9-4, pl 9-6) (E.79.840)
36	Dun Ailinne, Co Kildare	Monochrome: opaque red	14.5	9.5		Ritual	Iron Age	Johnston & Wailes (2007: 120–1, fig 9-4, pl 9-6) (E.79.50)
36	Dun Ailinne, Co Kildare	Monochrome: translucent blue-green	15	9		Ritual	Iron Age	Johnston & Wailes (2007: 120–1, fig 9-4, pl 9-6) (E.79.1616)
37	Co Antrim	Dark blue	24	10				Hunterian B.1914.523/1
38	Ireland, unprovenanced	Bichrome: opaque mid-blue with fine white trails	31.5	18.2				NMS X.FK 53 (Bell Collection)
38	Ireland, unprovenanced	Polychrome: translucent blue-green, yellow circles at ends, with yellow and red trails	30.5	19				NMS X.FK 57 (Bell Collection)

a single hearth, dating to 170 cal BC–cal AD 20, at Culduthel, Inverness-shire (Hunter 2021: 197).

In Argyll, settlement evidence for the Middle Iron Age (200 BC–AD 200) is dominated by substantial dry-stone walled roundhouses or duns (over 300 recorded). In contrast with the large 'centralised' forts of the Early Iron Age, there is a change in the dominant settlement type to a more devolved division of the land, with extended family-sized duns that may reflect a shift in the social organisation and landholding to one dominated by locally powerful farmers (Armit 2004). Although rare, artefacts that indicate wider social contacts and/or an awareness of traditions occurring elsewhere in Europe, and by association some elevation of status, have been recovered from a number of the duns in Argyll (Farley & Hunter 2015). These objects included a brooch, glass beads, toggles and ring-headed pins (Henderson 2007; Farley & Hunter 2015). The presence of exotica and other materials that originated in Europe and the Near East implies the existence of a complex network of local and long-distance trade and exchange (Campbell 2014, 2015; Hunter 2007, 2015). The recent excavation at Kilninian has demonstrated the existence of another settlement type in this period in Argyll characterised by timber-built structures with no apparent means of enclosure. It is postulated that the settlement at Kilninian may have housed the workers while the nearby dun may have housed the local landowner.

The aim of this study was to assess the evidence for the local manufacture of the toggle at Kilninian and to explore the likelihood of long-distance trade of scrap glass. The main objectives were to determine the compositional fingerprint of the glass used for the manufacture of the Kilninian toggle and examine the morphological details of the internal structure and the external features. Information on the chemical makeup of the glass has been used to investigate the type of glass used and its provenance, on the basis of trace element patterns. Morphological analysis has been used to investigate the method of manufacture of the toggle.

In addition, a number of other toggles housed in collections in Scotland and the Isle of Man were also subject to compositional fingerprinting and morphological analysis.

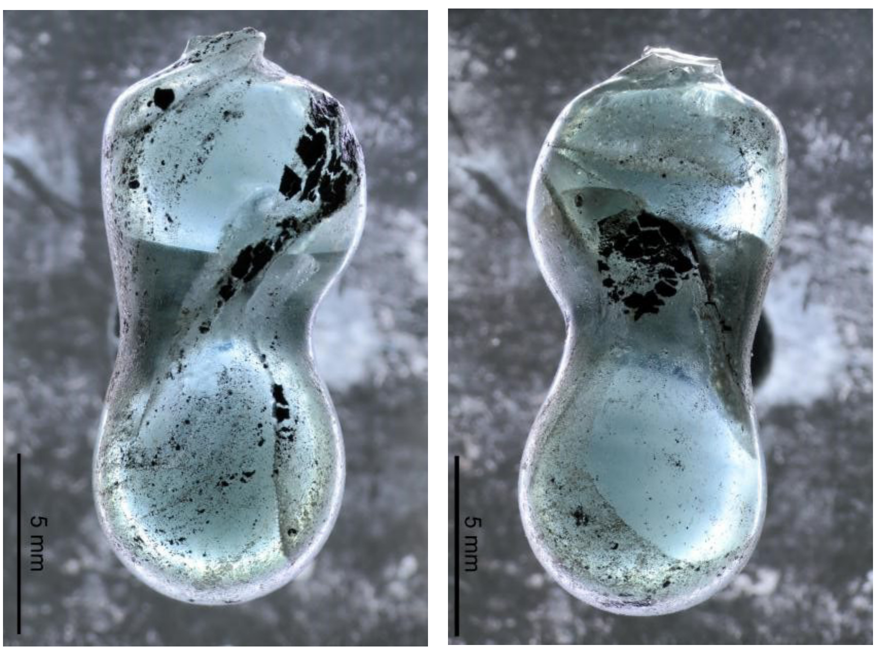
MATERIALS

The Kilninian toggle is a small dumbbell glass object of a rather unremarkable appearance (Illus 3).

The shape of the toggle is noticeably irregular and the end where the pontil scar (the mark left by the pontil rod when it was broken from the toggle) is situated shows a discernible overlapping fold of glass. The toggle weighs 1.134g, measures about 15mm along its long axes (excluding the pontil scar) and 8mm across at its widest point; the width at the central narrowing is about 5mm. The glass is naturally coloured (Foster & Jackson 2009), of the aqua tinge which is typical of many ancient glasses melted in reducing conditions. The surface of the toggle is marked by whitish streaks, which when examined more closely appear to stem from the presence of clouds of microscopic bubbles. Several areas of the surface are stained by a crusty and crackled black residue derived from the dissolved charcoal of the hearth, whose pattern seems to follow flowing lines evolving on the surface of the object before sinking into the body of the bead itself (Illus 4). The interior appears speckled, with relatively large bubbles easily visible to the naked eye or using low magnification.

The glass toggle was recovered from a thin layer of black carbon-rich ash of the hearth [086]. The charcoal within the ash was dominated by hazel, with smaller quantities of alder and birch. Carbonised cereal grains were also recovered from the ash; many were badly preserved but those that were identifiable were all barley. This barley may have been accidentally spilt during drying for storage, grinding into flour or immediate consumption. A small quantity of minute bone fragments was also recovered from the ashes; bones were often thrown back into the fire after a meal as they burn rather well. Carbonised seeds of sedge and one grass seed were also recovered. The eco-facts recovered from the hearth demonstrate its primary domestic function.

Illus 3 Toggle from Kilninian, seen under reflected light, with a magnification of 8× (taken at Sackler Biodiversity Laboratory, with a Canon EOS 550D camera attached to a Leica M125 Stereomicroscope). (© Argyll Archaeology)



Illus 4 Toggle from Kilninian, seen under transmitted light with a magnification 8×. (© Argyll Archaeology)

Glass toggles appear to be an indigenous phenomenon, as no glass forms of this type are known anywhere else in the Iron Age or Roman world other than those discovered in Scotland, Ireland and the four on the Isle of Man (Jordan 2009, 2010). Toggles are also known in copper alloy and bone (Hunter 2021: 200). In Scotland, artefacts of this type are generally found in the west, with a few notable exceptions, and along with the Irish and Isle of Man glass toggles, there is a clear western bias in their distribution (Table 2 & Illus 2). Hunter notes that the examples in the northern group are larger than those in the western group, and five of the northern group are bichrome whereas the western group examples are largely monochrome (Hunter forthcoming). Toggles vary in colour and decorations; Irish examples span from dark blue, to green and amber (all translucent, Jordan 2010), while the west-coast Scottish ones are predominantly aqua or dark blue. Most toggles are plain, but some, like the Culduthel toggle exhibit some form of decoration.

Of most interest to our site are the two glass toggles recovered in 2007 during excavation of the dun at Balure, Knapdale, on mainland Argyll (Regan & Campbell 2022). Balure dates to roughly the same period as Kilninian (50 cal BC–cal AD 120 SUERC-31665 and 200–1 cal BC SUERC-31664; Regan & Campbell 2022). Both of these toggles have a roughly polished pontil scar; one toggle appears to have been separated from the pontil by knocking it off and was then subsequently refined.

The dating of Atlantic Scottish toggle beads is in its infancy. Many of the blue toggle beads in Ireland are tentatively dated to 200 BC–AD 100, as are the ones from the Isle of Man (Jordan 2009, 2010). Some of the dated Scottish samples seem to belong to the Late Iron Age and Roman period and probably to the 1st and 2nd century AD, and a few to the early medieval period, as are some of the Irish examples (Table 2).

Toggles may have been used as decoration, possibly worn in the hair or attached to clothing, or the larger examples may even have been used as fasteners. The central constriction might have served to wind a thread around it and string the toggle (Ewan Campbell pers comm). However, it may also be suggested that these toggles could have been used as ear piercings, passed through the earlobe in the same fashion as the much earlier Eighteenth Dynasty Egyptian glass ear-plugs (Stern & Schlick-Nolte 1994). The wear noted on the middle section of some other examples (see below) would be compatible with both uses.

A second specimen, a dumbbell toggle found in Buchan (ABDUA: 15504), was used for comparing the chemical fingerprint of the glass. It is also made of aqua glass, clearly using cullet contaminated by the presence of differently coloured glasses that may have been present in the original recycled object. The toggle is decorated with a series of horizontal yellow cables and bordered at the extreme edges with one purple and opaque white twisted cable. No pontil mark was visible on the specimen and it is not clear whether it was manufactured using a pontil (and later completed by grinding and polishing the scar to render the bead round and seamless) or another method of manufacture. This is a somewhat unusual find, which seems to merge the simple style of western Scottish and Irish toggle beads and the complex decorations typical of the glass beads found in the North East of Scotland.

METHODS, INSTRUMENTS AND SETTINGS

Analyses were carried out by the Natural History Museum (NHM), London. A detailed morphological analysis and the visualisation of some of the external features with low magnification was aided by the use of extended depth of field (EDF) microscopy at the Sackler Biodiversity Imaging Lab. Compositional analyses were performed via Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the LODE (London Centre for Ore Deposits and Exploration) laboratory, in order to establish the compositional fingerprint and the provenance of the glass employed in the production of the bead. Finally, investigation of the morphological characteristics of the interior of the bead, with the view of establishing the method used for its manufacture, was carried out via analysis of the internal structure using X-ray micro-computed tomography (μCT) at the NHM's Imaging and Analysis Centre. Details of the methods can be found in Appendix 1 (available at https://doi.org/10.9750/PSAS.152.1352).

RESULTS AND DISCUSSION

COMPOSITIONAL ANALYSES

The base composition of the glass used for the manufacture of both toggles analysed for their chemical fingerprint consisted of silica (67%), high soda (17%), relatively high lime (9.5% in the Kilninian toggle and 8.5% in the Buchan toggle), and alumina (2.4%) (Table 3). Magnesia and potash were found to be below 1%, phosphorus (P) was about 450ppm. The glass contained high strontium (Sr) (540 ppm in the Kilninian toggle and 600 ppm in the Buchan toggle) and low zirconium (Zr) (41ppm and 32ppm respectively). No (de)colouring or opacifying agents were added to the matrix, which was rather depleted in trace elements. Typologically the glass can be characterised as a LMG (low magnesium glass). The base composition measured is typical of natron glasses (Shortland et al 2006; Davis & Freestone 2021: 209), and is compatible with the results previously obtained for Iron Age Class 13 and 14 beads (according to Guido 1978) from north-eastern Scotland (Bertini et al 2011; Bertini 2012). The high Sr and low Zr amounts present in the glass indicated the sand had a coastal origin (Freestone 2006). Boron (B) is remarkably high in the Kilninian toggle (360ppm), in an amount which is highest among the existing Scottish dataset; the Buchan toggle's B content is instead similar to the 'norm' (86ppm). At this stage it is not possible to identify its source. Comparison of the compositions measured in terms of major and minor components with the published literature showed the glasses analysed reflected the typical broader composition of 'Roman' glass, which was probably produced at some location in the eastern Mediterranean (Brill 1999; Silvestri et al 2008; Foster & Jackson 2009). This type of glass was predominant in the Late Iron Age and Roman periods, and was widespread in the Mediterranean area as well as in the north-western provinces, including Britain. The 'natural' aqua colour (Foster & Jackson 2009) of the glass is due to the small amounts of iron (Fe) (3,100ppm in the Kilninian toggle; 3,500ppm in the Buchan toggle) in the form of $Fe2^{+}$. Manganese (Mn) is relatively high (2,000ppm and 3,800ppm in each toggle respectively), but not in a concentration in which it may have been deliberately added as a decolouriser. Rather, its presence results from addition of Mn-decolourised glasses to the recycling batch (Freestone 2006). Copper (Cu) is the only other element normally associated with glass colouring that is present in relatively high amount (170ppm in the Kilninian toggle), whereas other impurities that could have been associated with the recycling of glass (eg cobalt (Co), antimony (Sb), lead monoxide (PbO)) seem to be present only in low concentrations. The similarity in the trace element pattern between the two toggles pointed to a similar source of sand used for the manufacture of the two raw glass batches.

MORPHOLOGICAL AND TECHNOLOGICAL INVESTIGATION

The morphological examination of the toggle bead from Kilninian, aided by extended depth of field photography, highlighted many features which are useful for the interpretation of its method of manufacture.

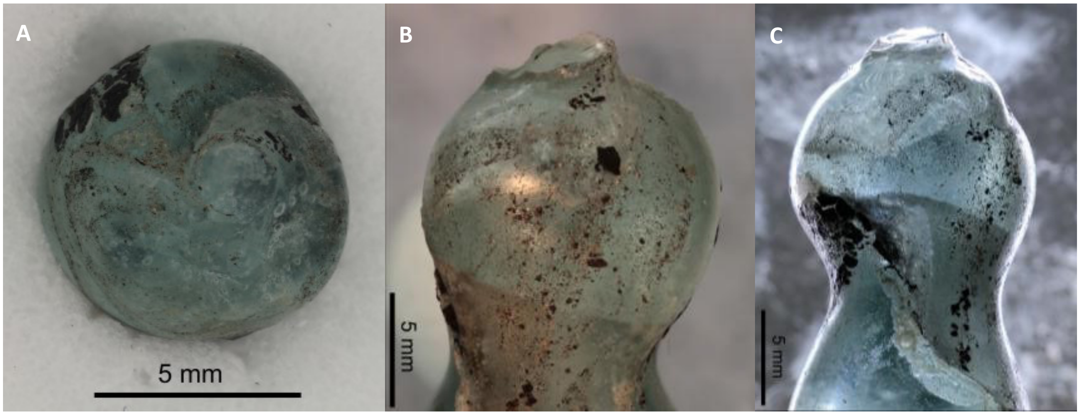
Features like the pontil scar (Illus 5a), the fold of overlapping glass at the pontil end (Illus 5b) and the black residue stuck on its surface (Illus 5c) are particularly diagnostic. It appears that a gather of glass was held at the end of a small pontil or mandrel (iron rod) while it was shaped. The blob of softened glass must have been first elongated to a cylindrical shape; then the narrowing at the middle section and at the pontil end would have been realised. The overlapping fold of glass at the pontil end was caused by poor control of the gather, which caused the malleable heated glass blob to drop and wind onto itself during manufacture; low temperature of the heat source at the site of production, or the insufficient skills of the

TABLE 3
Concentration of major and minor components and trace elements in the measurement of the Kilninian toggle and of Corning Museum of Glass standard B (CMG B) via the Internal Standard Independent method. The table reports precision of the measurements (RSD), the accuracy of the measurement of the analytical standard (Δ%), and the limits of detection (LoD) found. Main compositions are quoted in weight % (oxide) (w%o), trace elements in mg kg-1 (element), and LoD in mg kg-1 (oxide or element, as specified)

	Toggle bead			*CMG B*						
	AVERAGE	*SD*	*RSD (%)*	*Accepted values (w%o)*	*Accepted values (ppm)*	*AVERAGE*	*SD*	*RSD (%)*	*Bias (Δ%)*	*LoD (ppm)*
SiO_2	66.6	0.20	0.30	61.6		62.7	0.65	1.03	1.78	82.1
Na_2O	16.7	0.16	0.97	17.0		16.5	0.33	2.01	-2.96	3.38
CaO	9.41	0.11	1.14	8.56		8.22	0.19	2.31	-3.97	29.8
Al_2O_3	2.40	0.05	2.20	4.36		4.26	0.12	2.78	-2.26	0.221
MgO	0.57	0.01	1.07	1.03		1.01	0.02	2.03	-2.25	0.065
K_2O	0.80	0.07	8.68	1.00		0.98	0.02	2.11	-2.01	1.34
PbO	0.002	0.00	9.33	0.61		0.597	0.01	2.15	-2.08	0.04
Li	2.68	0.14	5.18		10.2	9.76	0.23	2.38	-4.65	0.026
Be	0.256	0.03	11.6			0.059	0.03	47.5		0.010
B	358	2.48	0.69		103	109	4.04	3.70	5.82	0.549
P	448	25.9	5.78		3578	3164	38.7	1.22	-11.6	4.53
Ti	342	4.53	1.32		540	585	11.2	1.92	8.36	0.071
V	11.8	0.13	1.07		188	173	2.74	1.59	-8.31	0.006
Cr	11.9	0.26	2.16		62.8	60.5	0.51	0.84	-3.72	0.274
Mn	2000	21.6	1.08		1936	1857	18.9	1.02	-4.08	0.061
Fe	3060	36.3	1.19		2643	2590	13.7	0.53	-2.00	1.96
Co	2.53	0.03	1.31		393	353	3.63	1.03	-10.2	0.009
Ni	7.92	0.20	2.55		786	774	6.99	0.90	-1.53	0.037
Cu	167	1.20	0.72		21249	21183	236	1.11	-0.31	0.059
Zn	29.0	31.6	109		1692	1671	46.4	2.78	-1.20	0.077

TABLE 3
Continued

	Toggle bead			*CMG B*						
	AVERAGE	*SD*	*RSD (%)*	*Accepted values (w%o)*	*Accepted values (ppm)*	*AVERAGE*	*SD*	*RSD (%)*	*Bias (Δ%)*	*LoD (ppm)*
As	2.76	0.12	4.51		22.1	20.1	0.49	2.43	-8.87	0.263
Rb	10.5	0.88	8.36		12.1	11.4	0.14	1.27	-5.72	0.011
Sr	540	6.54	1.21		169	163	3.16	1.94	-3.58	0.002
Y	8.76	0.28	3.15			0.39	0.01	3.12		0.000
Zr	40.7	1.07	2.64		185	166	3.32	2.00	-10.4	0.001
Ag	0.04	0.02	39.7		93.1	73.2	2.15	2.94	-21.4	0.014
Cd	< LoD					1.02	0.12	11.7		0.084
Sn	1.71	0.28	16.4		223	184	2.24	1.22	-17.7	0.172
Sb	89.8	0.34	0.38		3843	3648	73.2	2.01	-5.06	0.167
Ba	257	2.46	0.96		699	611	5.73	0.94	-12.5	0.007
La	9.08	0.07	0.74			0.187	0.01	4.48		0.001
Ce	14.1	0.14	1.00			0.161	0.00	2.27		0.000
Nd	5.86	0.15	2.51			0.067	0.01	15.7		0.001
W	0.0631	0.01	8.52			0.066	0.01	13.7		0.000
Au	< LoD					0.047	0.01	29.4		0.033
Bi	0.0049	0.00	62.2		39.6	41.4	1.14	2.75	4.54	0.008
Th	0.858	0.03	3.70			0.827	0.02	2.17		0.000
U	1.65	0.02	1.22			0.230	0.01	4.78		0.000
Total	**97.3**				**98.0**	**98.0**				



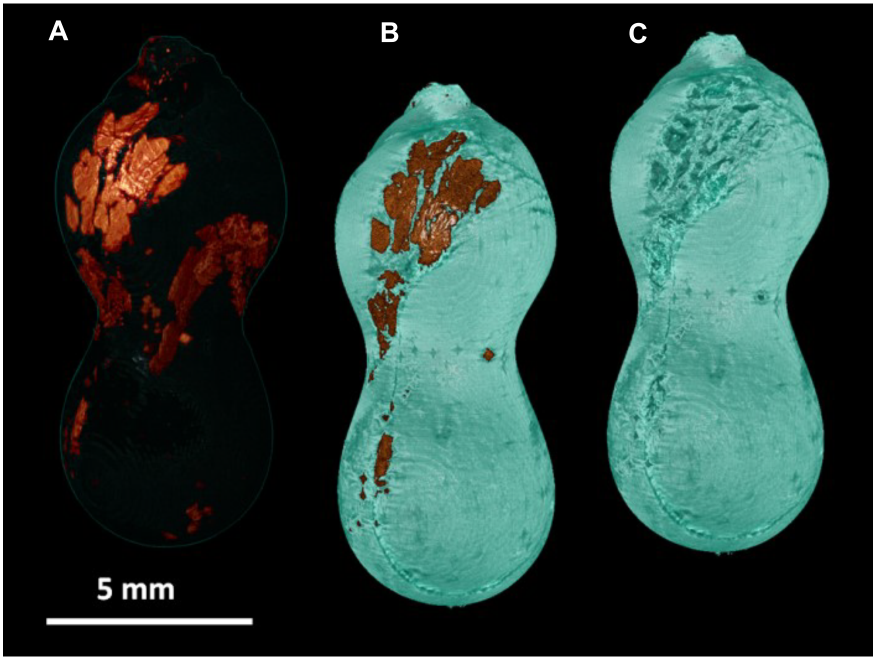
Illus 5 Particulars of toggle from Kilninian: (a) and (b) seen under reflected light; (c) transmitted light; (a) with a magnification 10×. The pontil scar and the additional fold of glass are clearly visible. (© Argyll Archaeology)

glass worker, may have been responsible for the inability to rectify this mistake. In modern glass working, in order to separate the object from the pontil a few drops of water would be dropped on the constriction at the base of the finished object to cause a thermal shock and separate it from the moil (the glass circling the tip of the pontil); the pontil scar would be removed during the finishing process. However, in this case the pontil scar was not ground or polished out. It is unlikely the glass worker deliberately left the object as such. Rather, given that the black residue found on the bead had not been cleaned off, it is much more likely that the toggle was manufactured *in loco* and that it snapped off during manufacture, dropping into the fire, where it could not be retrieved from the ashes. This black crackled residue was particularly interesting. In fact, it not only covers part of the surface, but also extends into the interior (Illus 6 & 7, Video 1).

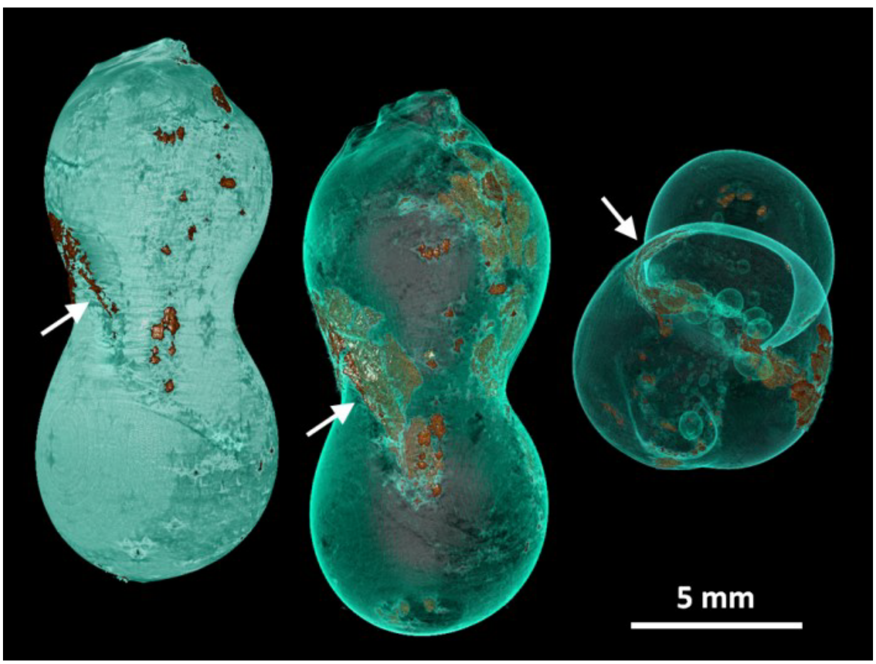
This means that the residue was already present on the glass before being shaped into a toggle bead. The reason for this could lie in the cullet being warmed up on a dirty, sooty surface, probably on the edge of the hearth, before being attached to the pontil, following the 'chunk gathering' method hypothesised by Stern (Stern 1999). Illus 8 proposes the system that seems to have been used for the manufacture of the toggle bead.

The analysis of the internal structure using μCT confirmed these observations and added valuable new information. We concentrated initially on the shape and size of the gas bubbles (Illus 9 & 10, Video 1).

There are a large number of bubbles in the toggle, which range in size from very small and microscopic ones (seeds) to considerably large ones (diameter greater than 200μm and up to over 1,000μm). Both provided very valuable insights. The largest bubbles showed a higher contrast than the small ones, which indicated the presence of a more absorbing gas within them. This could be a direct result of reducing gases from the fire being locked into air traps that would have been formed between layers of glass and as a consequence of surface imperfections or the deposition of dust grains onto the cooling surface of the first glass layer, which would act as entrapping centres and nuclei for bubble formation, respectively (Bertini et al 2014). These large bubbles are present in a low number, but they are always distorted and elongated. A few in particular are clearly drop shaped (Illus 9c). On one side, the irregular shape of these bubbles is again indicative of the low temperature used for the manufacture of the toggle: if the temperatures were higher and the glass could have been kept in a molten state for longer, the bubbles would have gone back to a spherical or sub-spherical shape. The position



Illus 6 Rendering of (a) ashes stuck on the surface of the toggle and partially encapsulated within it; (b) ashes as seen on the surface of the toggle; (c) the scar they leave on the toggle when artificially removed. (© Argyll Archaeology)

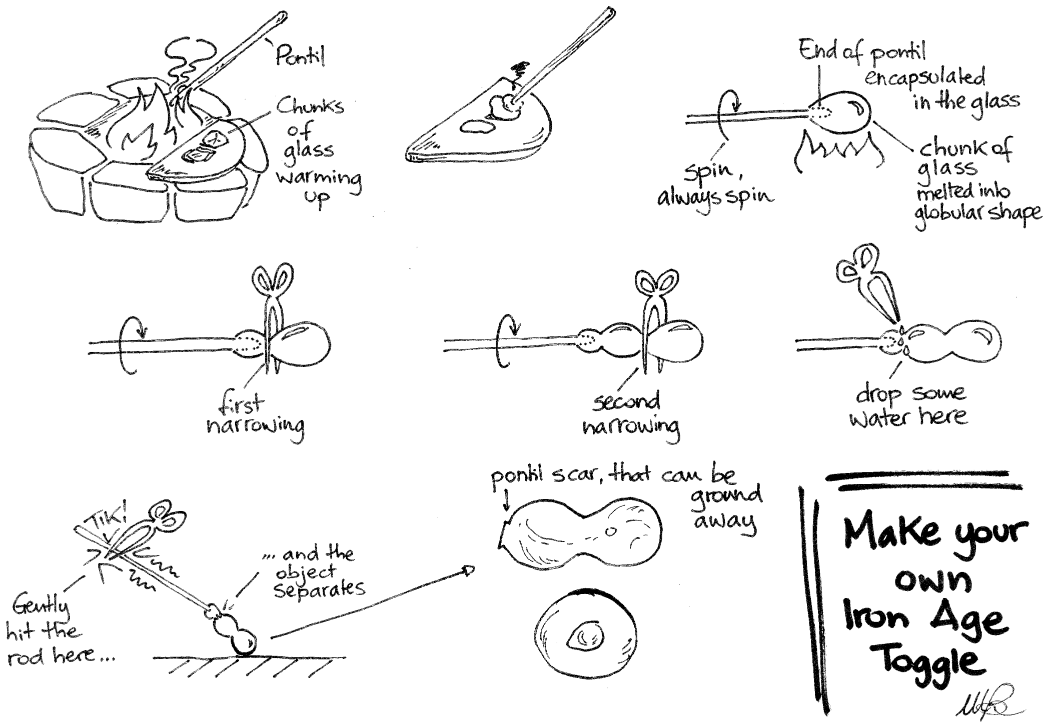


Illus 7 Detail of the ash contamination on the toggle. Note how the contamination revolves from the surface into the body of the toggle (white arrows). (© Argyll Archaeology)

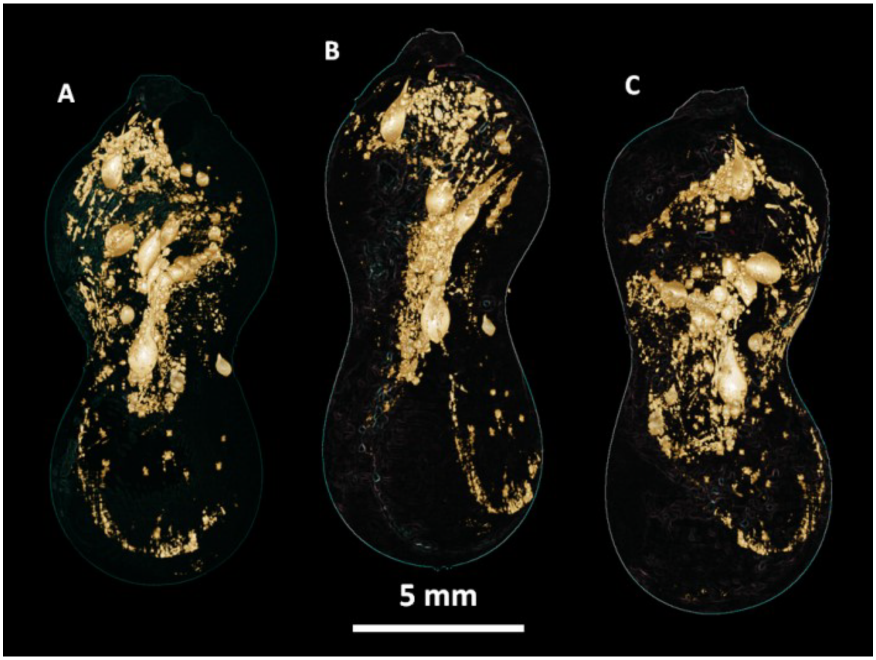
VIDEO 1 The video is available in the XML version of the article at https://doi.org/10.9750/PSAS.152.1352. (© Argyll Archaeology)

and profile of these also confirm that the toggle has been first pulled from a globular gather into an elongated shape. The application of pressure to produce the constrictions at the base of the toggle and at its centre and the manipulation of the gather to obtain the dumbbell shape would have determined the fusiform and drop shape of the bubbles. The examination of the small bubbles revealed that the toggle is not composed of a single fragment, but rather of four individual small glass shards which were then molten into a single gather (Illus 11).

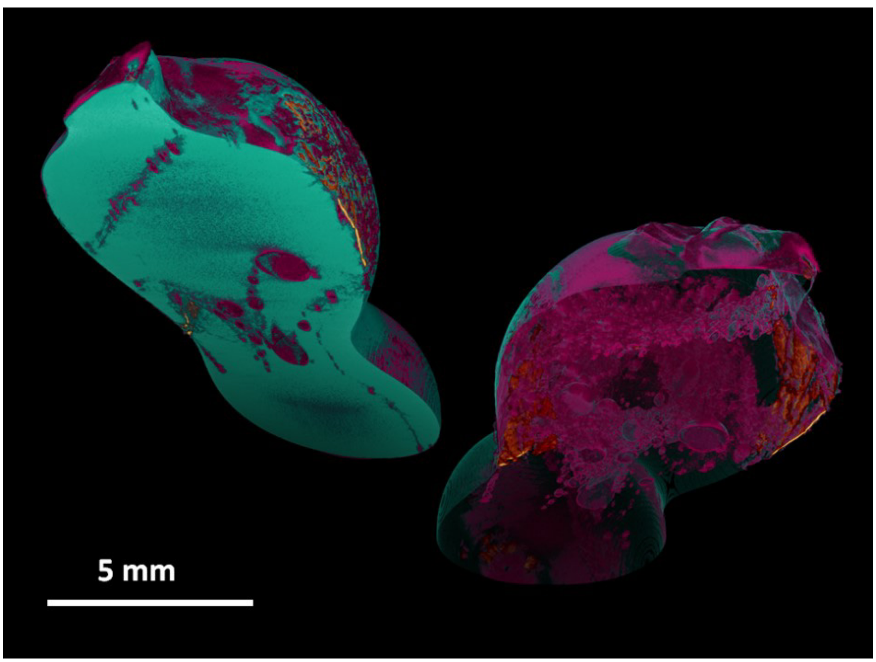
Interfaces of bubbles mark the interface between discrete fragments. Small bubbles and seeds could have been formed as a result of slight differences in the redox potential between overlapping layers of compositionally different glasses in their molten state, leading to seeding and elevated levels of bubble defects appearing in the glass with the highest oxidising potential (Bertini et al 2014). However, LA-ICP-MS



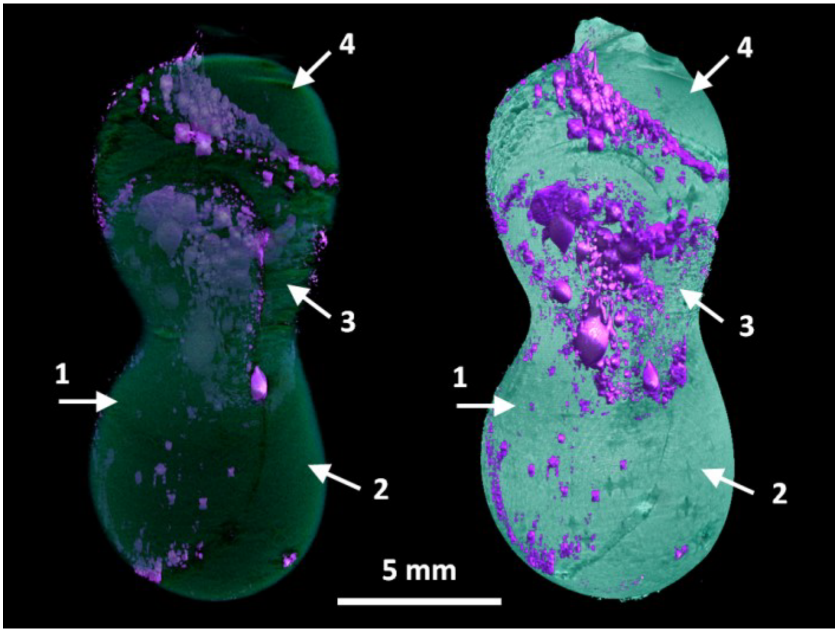
ILLUS 8 Proposed method of toggle bead manufacture. (© Argyll Archaeology)



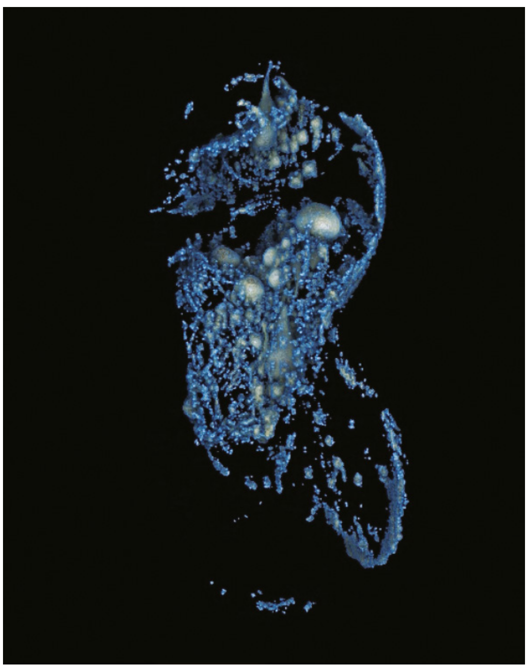
Illus 9 Rendering of the bubbles dispersed in the matrix of the toggle bead, marking the interfaces between the different chunks of waste glass used to produce the toggle (each picture is rotated 120°). (© Argyll Archaeology)



Illus 10 Rendering of the small bubbles that delimit the edge of the different glass chunks melted together to produce the toggle bead. (© Argyll Archaeology)



Illus 11 Individual chunks used for the manufacture of the toggle and separated by bubble interfaces. (© Argyll Archaeology)



Video 2 The video is available in the XML version of the article at https://doi.org/10.9750/PSAS.152.1352. (© Argyll Archaeology)

samplings in different areas of the toggle indicated that the fragments probably came either from the same glass object or from very similar glass batches, disproving this hypothesis. Instead, the preferential distribution of small bubbles around the outer edges of each fragment, and the presence of 'curtains' of relatively large bubbles (>100µm) between two of the fragments in particular, indicate they formed when the glass fragments made contact and merged into a single blob, entrapping bubbles in the roughness of the glass cullet surface and, possibly, around dust particles.

A further array of information was derived from the rendering of the black residue. The use of extended depth of field photography and µCT allowed us to verify that this material extended inside the body of the toggle and enabled the imaging of its entire pattern within the internal structure (Illus 6 & Video 2). This step conclusively confirmed that the contamination of the glass cullet occurred before the manufacture of the object, when individual softened fragments were progressively stuck onto each other to produce the base gather, and so it is not a deposition artefact. Most importantly, by imaging separately the glass and the black residue it was possible to observe that the glass surface under the black carbonised layer is rough and corrugated. Glass sticks only to materials that are at approximately the same temperature and those indentations could have been produced only if the glass had been put to soften on a rough surface already covered with this substance, where it had become imprinted. This could have been a charred piece of wood or charcoal or the side of the hearth, although more investigation would be necessary to clarify the nature of the residue.

TOGGLE PRODUCTION AT THE ISLE OF MULL: A ONE-OFF IRON AGE GLASS-WORKING SITE

The results outlined above demonstrated that the Kilninian toggle bead was manufactured within the very hearth within which it was discovered. The relatively high temperature of the hearth, evident in the discoloration of silt at the bottom of the fire pit, was sufficiently high to soften the glass and probably just enough to render it adequately malleable for working. The use of a number of glass fragments for the manufacture of such a small object, their poor aesthetic appearance and the fact that they were not discarded after their contamination imply that the glass resource was scarce and precious, so much so that every bit of glass would have been reused regardless of its appearance. However, no glass-working debris such as glass drops, glass fragments or unfinished glass objects were found within the hearth ashes, suggesting that this was a single manufacturing episode. Within a Scottish context this site is significant because the context in which the toggle was made has been radiocarbon dated. Furthermore, Kilninian appears not to be a high-status site such as a fort or dun but is, in Argyll at least, a rare example of an unenclosed Iron Age domestic settlement.

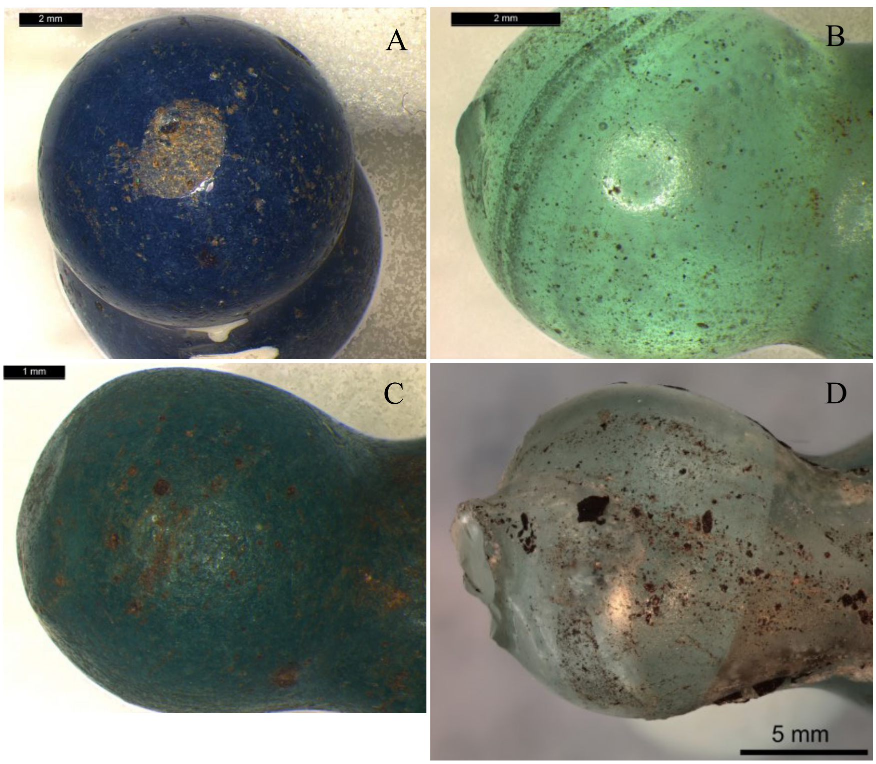
All the evidence from the examination of the Kilninian toggle suggests it was made on site using recycled glass. However, the toggle was made well before Agricola advanced into Scotland and before the first Roman invasion of southern Britain. Certainly, both before and after the Roman invasion of Britain, Roman glass from Mediterranean production centres arrived in southern Britain at trading posts such as Hengistbury Head, Dorset (Cunliffe 1978). The glass would have been in the form of ingots and could have reached Scotland via land routes to be then incorporated into the indigenous material culture. However, the means by which the glass cullet got to the Isle of Mull prior to the Roman invasion is likely to have included trading from Europe, perhaps via well-established Atlantic sea lanes (Henderson 2007). Pre-Roman, Iron Age sites where actual manufacturing of glass beads from reworked imported glass ingots has been demonstrated are extremely rare in Britain, and confined to Culbin Sands in Moray, Culduthel near Inverness, Dunagoil on Bute, Meare in Somerset and Hengistbury Head in Dorset (Hunter 2021: 201). The scarcity of pre-Roman glass bead manufacturing sites may be a true reflection of their rarity or, as Hunter suggests, the small area required for glass working (a single hearth) and the small size of the debris resulting from glass working (glass droplets, glass rods and discarded or lost beads) means that the discovery and identification of glass-working sites is largely a matter of luck coupled with a thorough sampling strategy (Hunter 2021: 201).

ADDITIONAL WORKS AND WIDER IMPLICATIONS

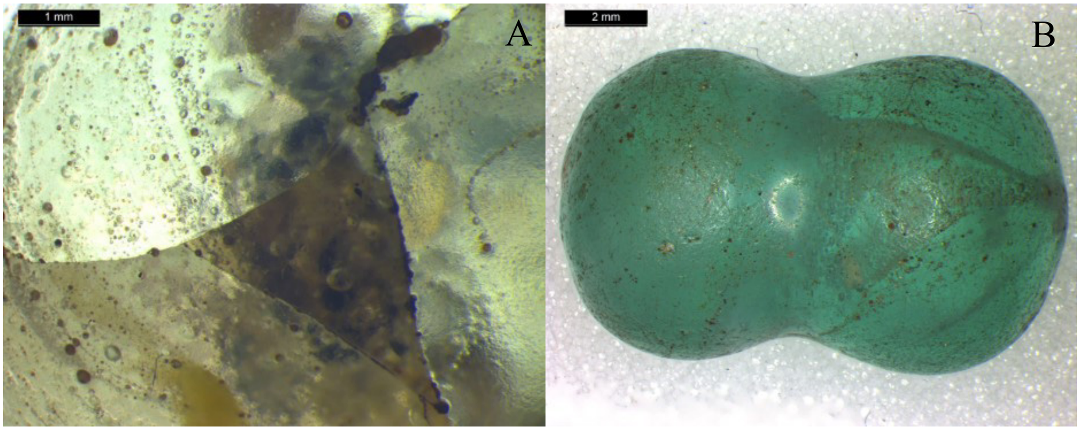
Fifteen other toggle beads (Table 2) were also subject to compositional and morphological analysis and the summary results and implications of this work are discussed below. All the toggles, apart from the Leckie Broch toggle, were made of the same basic soda-lime-silica glass, with similar major composition and trace elements. The obvious implication of this is that the chronological time-frame for the production of the glass is similar (Hunter 2021: 200 suggests this to be 200 BC–AD 200), and therefore many of the conclusions reached concerning the acquisition of glass and processes of manufacture of the Kilninian toggle are relevant to these other toggles. The technique of manufacture of the majority of the western toggles is the same, with pontil scars polished out to varying degrees (Illus 12), although Hunter (forthcoming) notes that the Port Gordon toggle was clearly formed using an iron rod placed centrally in the groove, and hollows or sprues confirm this for two other eastern-group toggles from Culduthel and Howe.

All the toggles were made from waste glass and most bear testimony to the use of every last scrap of glass. In most of the blue-green toggles, interface lines can be seen through the translucent glass, which shows that they were made of smaller fragments of glass fused together (Illus 13). Some of the fragments have the same composition and clearly come from the same broken object or original chunk of glass, while some fragments within the same toggle have different compositions, demonstrating that the toggle was made of glass from different batches and therefore from different broken objects and cullet.

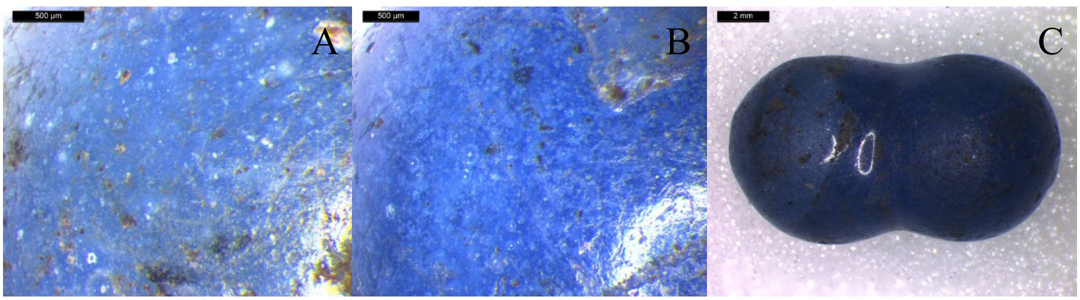
A similar picture is seen in the opaque blue toggles, but the difference between the fragments of glass was even more apparent because of the addition of cobalt-containing mineral ore and opacifiers, which introduced impurities and hence an overall greater variation in colour and composition. For example, the two fragments of glass in the toggle from Scrabo Hill, Newtownards, Co Down, Ireland (B.19151.2651/1) are barely discernible to the naked eye, but when viewed at 50 times magnification it is clear that one half is opacified using white crystals (lead stannate?), which are dispersed in the matrix, while the other half is rendered optically opaque by virtue of a multitude of extremely small bubbles, indicating that the glass was deliberately whipped or overheated to obtain this effect (Illus 14).



ILLUS 12 Pontil scars: (a) Dun Fhinn toggle roughly polished (9×); (b) Balure toggle incompletely polished (16×); (c) Balure toggle polished flat (8×); (d) Kilninian unpolished (10×). (© Argyll Archaeology)



Illus 13 Multiple fragments: (a) Culbin Sands toggle showing the different fragments (20×); (b) Braust toggle showing bubble interfaces marking the different fragments used (7.5×). (© Argyll Archaeology)



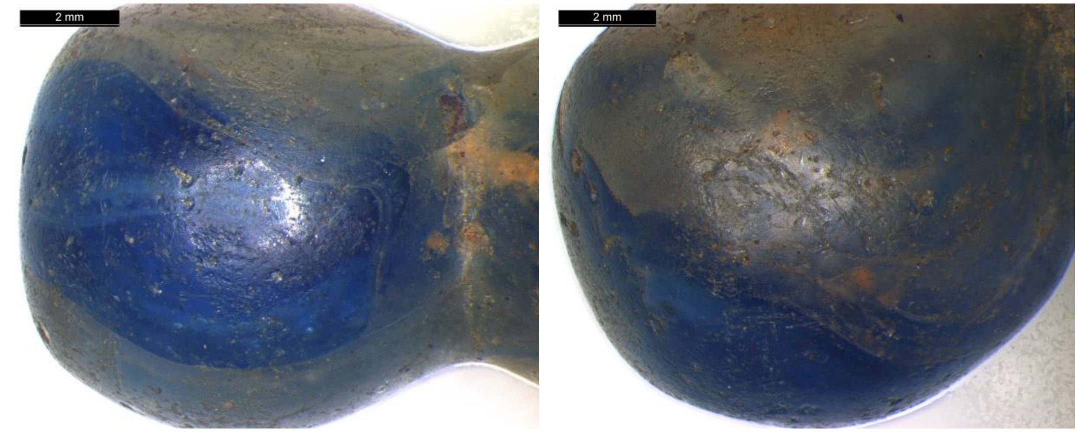
Illus 14 Scrabo Hill toggle (dark blue): (a) white particles; (b) microscopic bubbles (50×); (c) complete toggle with the two different fragments visible. (© Argyll Archaeology)

Blue glass was much less common than 'ordinary' blue-green glass; it would have been much more difficult to procure and therefore was probably more desirable. All the blue toggles appear to have a mixture of blue glass in them, indicating that no glass was wasted, however small the fragment. Interestingly, the Dun Raisaburgh toggle has a core of blue glass which is coated with transparent glass. This possibly reflects the scarcity of blue glass, where the blue appearance of the bead is clearly of paramount importance (Illus 15).

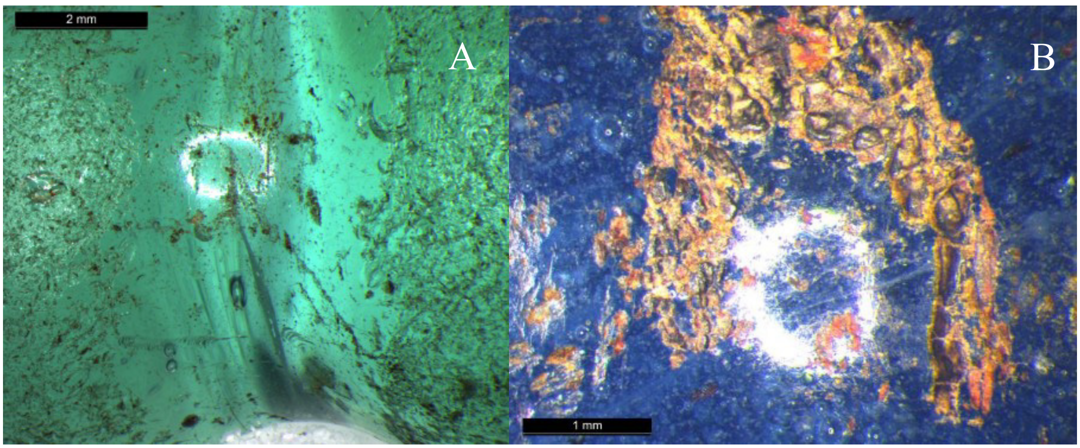
Some of the toggles had worn middle sections that appear to have been polished by wear (Illus 16a). This, together with an undefined residue adhering to the middle section of the Dun Fhinn toggle (Illus 16b), may indicate that material or leather was wrapped around the waist of the toggle in order that it could be attached to a necklace, clothing or hair.

CONCLUSIONS

This study has demonstrated that the glass used for the manufacture of the Kilninian toggle was probably obtained from shards of recycled glass traded from the Mediterranean as cullet. The most likely hypothesis is that it was acquired via a complexity of trade routes, including Atlantic sea lanes and subsequent more localised gift and exchange routes. The glass appears to have been traded or acquired in very small amounts, ensuring the prestigious nature of the material to the



Illus 15 The Dun Raisaburgh toggle (12×). (© Argyll Archaeology)



Illus 16 (a) Braust toggle 1985-00121/1c levigated middle section (18×); (b) Dun Fhinn toggle residue on the midsection (30×). (© Argyll Archaeology)

local Iron Age communities along the western seaboard. In spite of the apparent difference between the two toggles fully analysed, the glass recipe and the trace element chemistry of the glass of the Kilninian toggle are equivalent to those of the toggle bead from Buchan, Aberdeenshire, and compatible with the composition of many Class 13 and 14 beads (Bertini et al 2011; Bertini 2012). Further analysis on thirteen other toggles confirmed this pattern. This is not surprising, as towards the Roman period the production of glass in the Mediterranean became a large-scale industry, based upon the use of beach sand as a glass former and natron as a flux. The source of the raw materials for the production of glass seems to have remained constant for a rather long time and indicates an east Mediterranean source and place of refinement (Davis & Freestone 2021: 216). Furthermore, recent studies suggest that primary glass-making workshops using imported natron may have had a larger distribution across the Mediterranean basin than initially thought (Wedepohl & Baumann 2000; Jackson 2005; Freestone 2005; Freestone et al 2005; Foster & Jackson 2009; Ganio et al 2012). Also, although the set of Class 13 and 14 beads is traditionally supposed to be later than the toggle bead studied (1st and 2nd century AD according to Guido 1978), more work (Foulds 2014) and recent radiocarbon dates now also place them anywhere between the later 2nd century BC and the 2nd century AD (Hunter 2021: 200).

The morphological examination of the external and internal features of the Kilninian toggle bead point to less-than-ideal working conditions for its manufacture. The overall quality of the glass and the use of small, contaminated scraps of broken or waste glass indicate that glass must have been scarce and very precious to the glass worker and the final recipient. The working temperatures must have been relatively low and clearly compatible with the wood-fuelled hearth where the toggle was found. The presence of an unpolished pontil scar and the fact that the black residue stuck to the toggle (a residue that was present before the toggle was manufactured and not picked up post-depositionally) was not cleaned off suggest that the toggle was accidentally dropped in the hearth while it was being made and for whatever reason was not retrieved.

In conclusion, these analyses have revealed the existence of indigenous and firmly pre-Roman production of glass toggle beads from traded glass in the Middle Iron Age in western Scotland. The recovery of this single toggle bead has enormous implications for understanding the social and communication networks existing in the Iron Age along the western seaboard of Scotland and further afield into Ireland and the Isle of Man.

Supplementary material: appendix available at https://doi.org/10.9750/PSAS.152.1352

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