The Broch – Observatory (and Tsunami Shelter?)

Figure 1 Mousa Broch Shetland

Introduction

There are remains of ancient monumental circular stone towers called Brochs throughout the North of Scotland, but mainly located in Caithness, Shetland and Orkney. These stone towers are unique to Scotland and are very numerous but their purpose remains unknown. Brochs are impressive, massive structures that have the appearance of prehistoric drystone cooling towers and stand like crumbling sentinels from a bygone era in some of the more remote areas of the northern lands, in many other places they have been razed to the ground or have had courses of stones removed and used as a ready source of building materials for more recent building projects. The oldest brochs have been dated to around 700BC but brochs continued to be built for up to almost a thousand years afterwards and although it is commonly assumed that the towers were inhabited, based on the premise that such a Herculean task of construction could only be justified if they were inhabited, perhaps by a warrior class, their true function remains unknown.

Most of the brochs were built close to the shore, often on promontories and sometimes on little holms in lochs close to the shore. The brochs consist of massive double concentric drystone walls tied together by flagstones forming passages and a spiral stairway in the space between the walls that rises to the top of the tower and exits onto an annular paved walkway sunk between the internal and external wall heads. external

walls of the broch are extremely wide at the base and taper as they rise. Inside, the broch consists of an open circular courtyard, surrounded by near vertical internal walls which rise to the annular wall head that frames the open sky. There are vertical lines of lintelled openings on the internal wall which may have allowed sunlight to light up the otherwise pitch-black spiral stairway and floors enclosed in the space between the inner and outer walls. The entrance to the broch usually has a massive lintel and the passageway through the broch's wide walls to the courtyard is several metres in length and has a rebate for a door about half-way along the passage. Near the rebate on the inside are often bar holes, the holes being long on one side and short on the other consistent with the idea that the door was not hinged but could be secured by way of a long wooden bar. There are usually three or four bee-hive cells constructed at ground floor level within the very thick broch walls that may have provided a sheltered space for storage or habitable small rooms perhaps for sleeping. There is a stone scarcement or ridge around the internal wall at a few metres height above the courtyard that may have supported a roof and/or floor with wooden pillars or posts arranged as a ring supporting the inner edge of the annular floor leaving an open space for the smoke of the central courtyard hearth to escape.

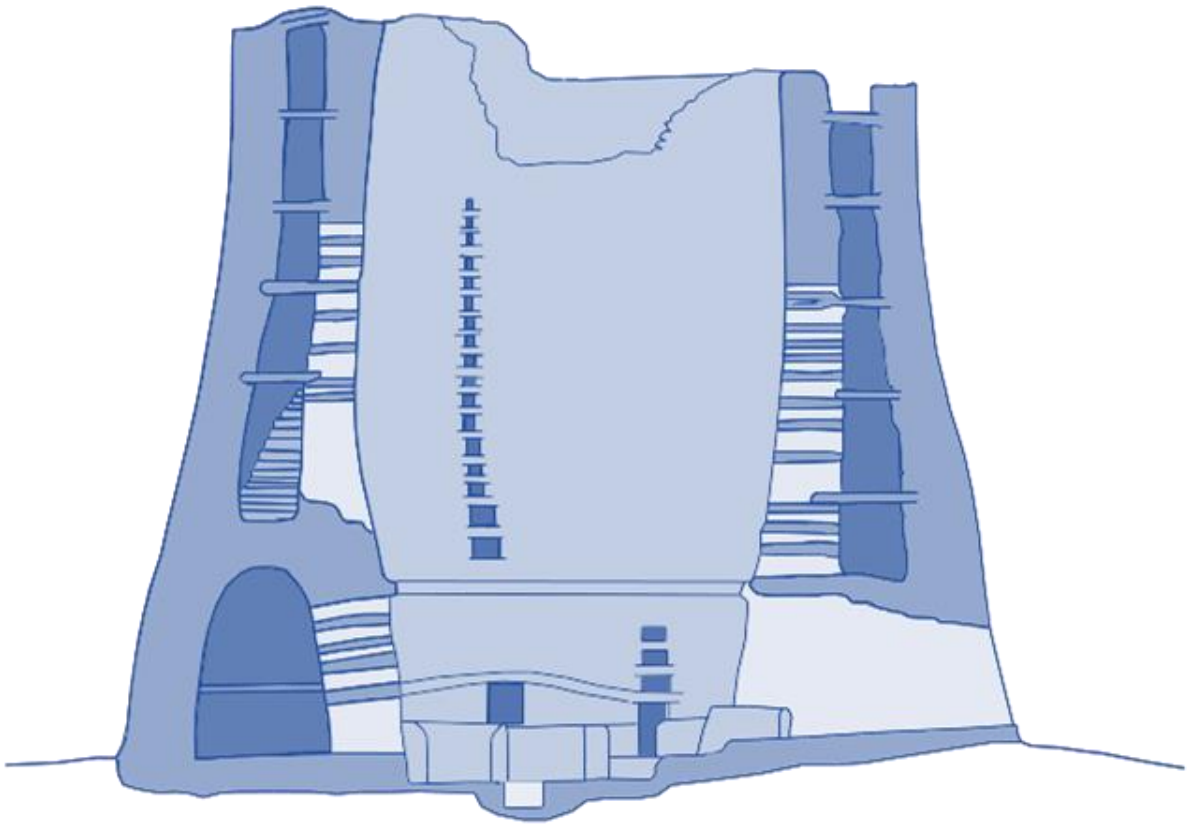


Figure 2 Mousa Broch Cross Section based on the drawings by H.Dryden 1852

Bottom Left vaulted space is a bee-hive cell with a shelf and lintelled openings (in white) allowing some light into the cell from the courtyard. Above the cell in the space between the inner and outer broch walls there is a spiral staircase formed from long flat slabs that help tie the two walls together, along with flagstone ties above the staircase. The stairway spirals from ground level to the top of the broch and out onto the wall head to a sunken annular walkway that runs around the broch between the inner and outer wall heads which is no longer at its full height around the entire perimeter of the broch. Three vertical lines of lintelled openings are shown, two in profile in white and the other full on in black which allow light into the stairway space between the double broch walls from the open roof structure. The only opening in the outer wall is the small doorway at the right-hand side. In the centre of the courtyard there was a sunken water tank and a rectangular hearth. The double horizontal line shown a quarter way up the broch represents the scarcement that runs around the broch at this level and may have supported a floor at the wall and posts on the inner edge of the ring, leaving an open space above the hearth.

Figure 3 Mousa Broch lintelled openings in internal wall that allow light from the open roof into the spiral staircase

Inside Mousa Broch showing lines of lintelled openings or "windows" on the internal walls that allow light from the open roof to light up the stone spiral staircase situated between the internal and external wall that rises to the wall head. The continuous horizontal line of stones indicated at the bottom of the drawing represents the scarcement, a ring-shaped stone ledge extending out from the internal wall that may have served to support an annular floor and possible roof to the ground floor courtyard space beneath it.

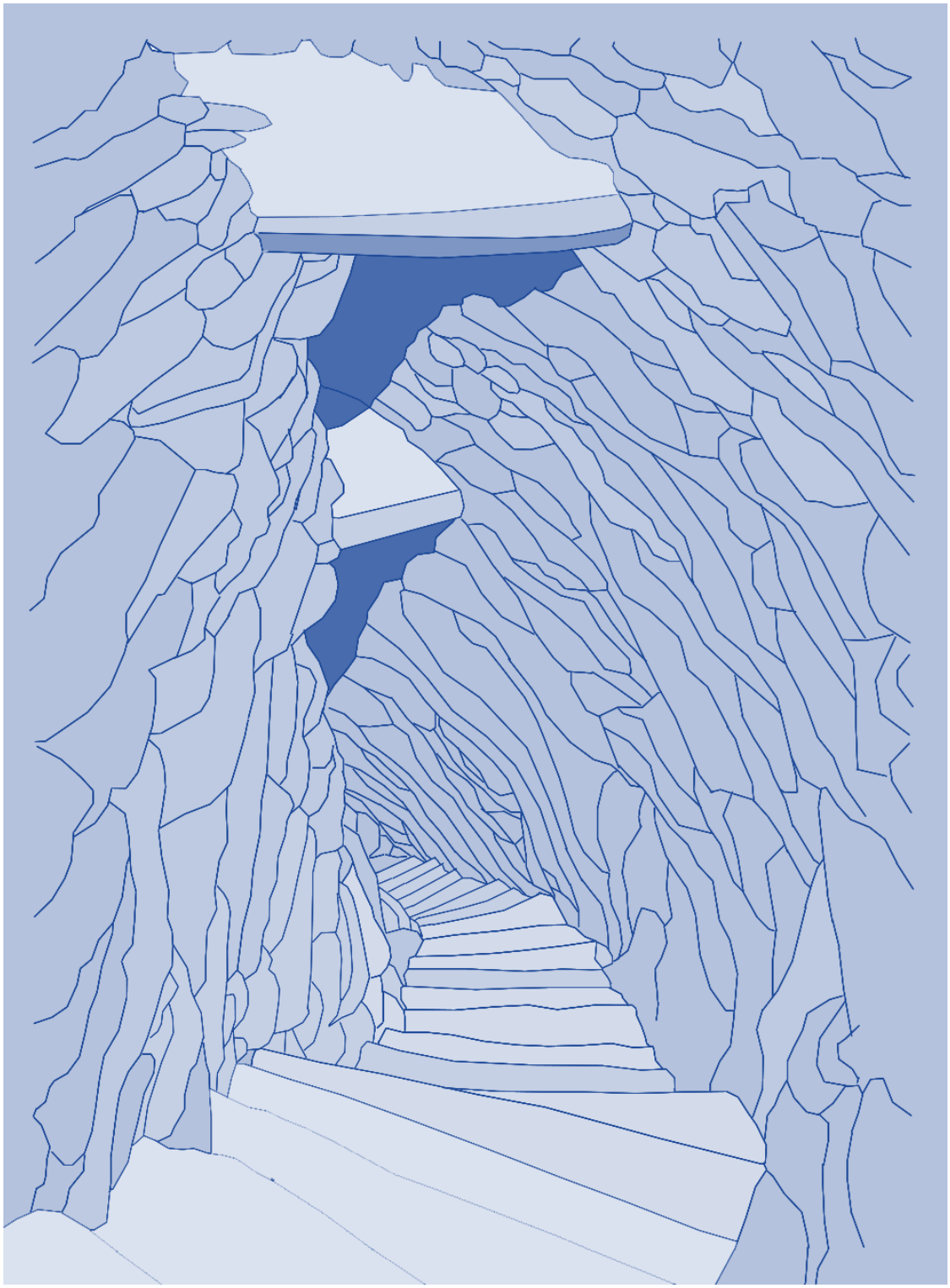
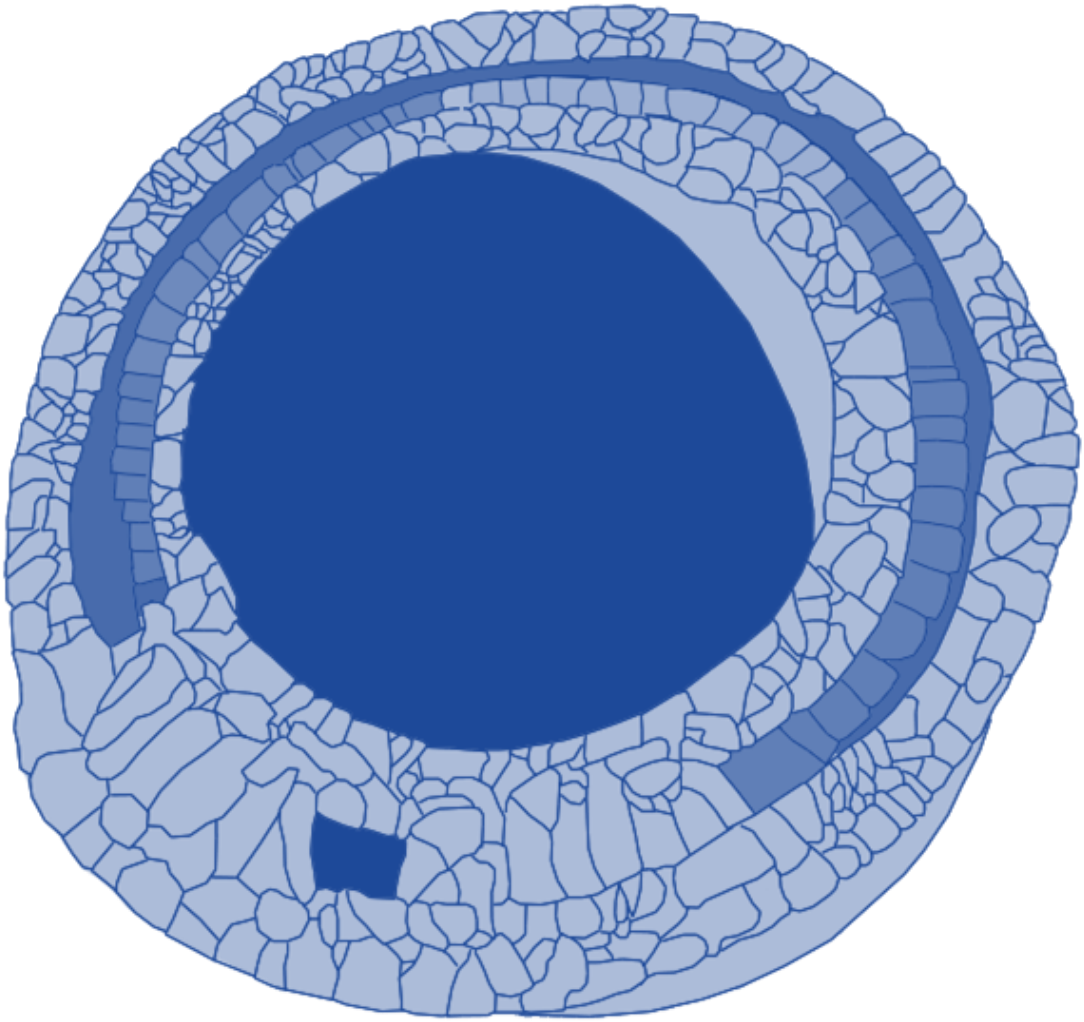


Figure 4 Drawing of spiral stairway and flagstone ties between the internal and external Broch walls

There are often three or four bee-hive chambers of stones within the thick walls where stones were laid horizontally and each successive layer, over-hanging the course below, raised in a stepwise manner until the sides were close enough to be closed with a slab. These vaults are around 6ft wide and around 12 ft long and may have provided dry living or sleeping areas and/or storage spaces. Often there is such a cell located beside and

connected to the broch entrance passage in which case it is often referred to as a “guard cell”.



Fi gure 5 View looking down onto Mousa Broch showing the spiral staircase rising up from the lower left to the sunken annular walkway sandwiched by parapet external and internal walls

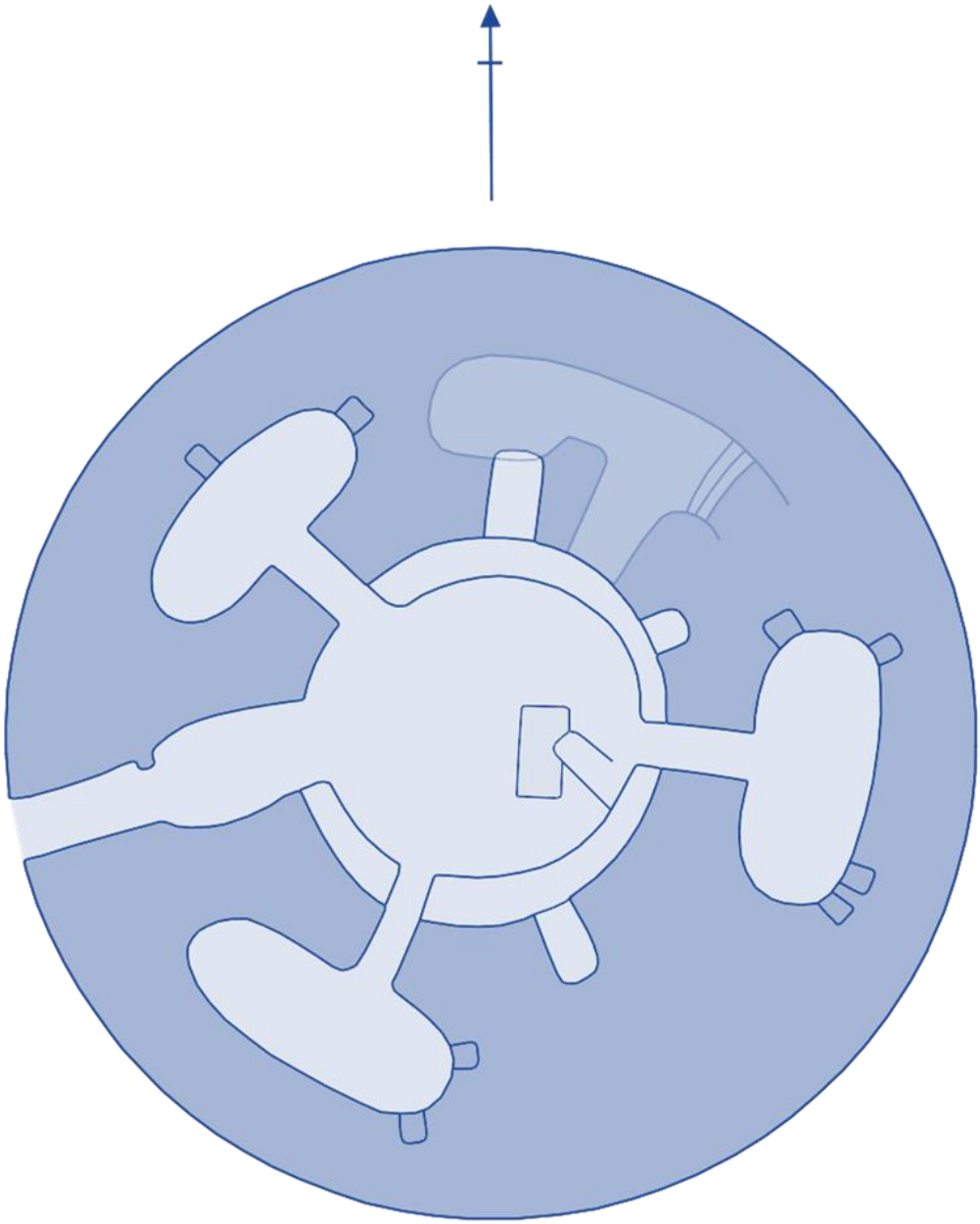


Figure 6 Ground Floor Plan of Mousa Broch showing entrance, three ground floor beehive cells, water tank and elevated entrance to small cell and spiral stair. Drawing copied from Dryden's plan. A central courtyard hearth may also have been present

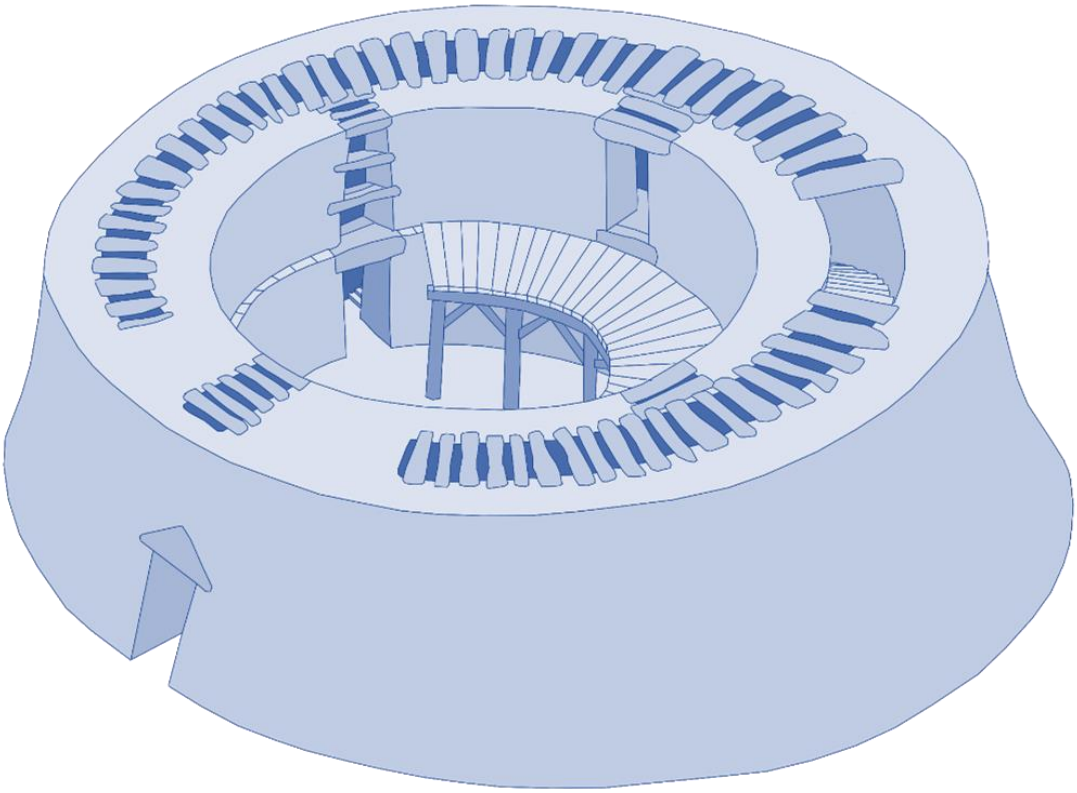


Figure 7 Diagram of Mousa Broch cut away to show ground floor and first floor levels. The spiral stairway continues to rise within the broch walls exiting at the roof onto a sunken gallery.

The entrance to the broch through the opening with the triangular lintel leads to the inner courtyard. The courtyard had a central hearth and small water cistern. A circular arrangement of wooden posts may have supported an annular wooden floor, supported on the internal wall by a scarcement or stone ridge fitted into the wall. If the broch was open to the elements this annular floor may also have served as a roof so that the courtyard space under the annular roof was sheltered and being warmed by the central hearth could have provided a comfortable living area. There are doorways that allow entrance to the bee-hive vaulted cells constructed within the massive broch walls, however the entrance seen in the diagram accesses the spiral stone staircase constructed of flagstones that tie the inner and outer broch walls together and ascend to the higher levels of the broch. The first flight of stairs reaches a short passageway which has a doorway through the internal wall onto the first-floor annular floor proposed as being constructed of wood. It may be that this level was a useful level given that it is accessible via a doorway. Going back through the doorway into the internal passageway the spiral stairs continue to rise. The spiral staircase can be seen in the diagram rising up in the space between the broch walls. The flagstones tying the internal and external concentric walls are shown in the diagram as a ring-like arrangement of horizontal flat stones. The other feature shown in the diagram is the arrangement of lintelled openings situated one on top of the other in a vertical line that allows light from an open roof to light up the otherwise pitch-black spiral stairway and passageways.

What purpose did Brochs serve?

Structural Evidence

Perceptions work in large part by expectation and it is easier to make sense of the world using preconceived ideas than to form entirely new ideas from scratch. But in the case of the broch we really are, or perhaps more pertinently should be, forced into starting afresh with our interpretation of what purpose the broch served because cold logic tells us that a tower with walls that let no light in from the outside, fitted with a roof would leave the inside space in total darkness and completely reliant on the provision of lighting provided by oil lamps for instance and would be unsuitable as a comfortable useable living space. Furthermore, a stone spiral stair that led to the top of the tower and openings on the inner wall that allowed sunlight from an open roof to light the stairway space between the double walls would become redundant once a roof had been fitted. In other words, architecturally, the design of the broch has major issues if it was simply a "tower house".

There is only one broch that survives to its approximate finished height around its entire circumference, Mousa Broch in Shetland and that broch shows absolutely no evidence of any roof structure ever having been fitted. The archaeologist H. Dryden in 1890 concluded that Mousa Broch had never had a roof. However, there are those who argue that Mousa broch must therefore have been the exception to the rule and indeed in some ways it is the exception because it is the only broch left standing to its almost full height. But this is a weak argument because there is no evidence that any of the other brochs, had had a roof in their original form, and the "rule" is nothing more than an overpowering expectation that a tower is a habitable dwelling and therefore a watertight building that would therefore have been roofed.

Such is the strength of this expectation that it is difficult to consider the possibility of a roofless tower and in any case what purpose for such an unusual building could possibly justify the effort involved in its construction.

It is evident that the construction of the brochs would have involved many months of labour and colossal amounts of stone to be skilfully assembled by masons to provide the massive, impenetrable dry-stone walls of the broch towers. The Brochs are believed by many to have served as fortified buildings for the habitation of the leaders of the tribe or warrior lords in a similar way to which much later, castles and fortified towers were built to house powerful mediaeval lords. The brochs may also perhaps have served as safe havens for the community against the attacks of invading tribes like the stone towers built by the Phoenicians in the Pitiusas islands in the Mediterranean but there is the practical problem to the idea that the brochs primarily served as places of habitation in that as already stated, there is no evidence that the brochs were ever constructed with a roof, at least in the form that they were originally constructed and the idea of a roofless structure in Scotland providing a comfortable living space is to most people inconceivable.

Structural Evidence for a Roofless Broch

It is not clear what design of roof could be fitted to a drystone tower that didn't put excessive outward pressure on the broch walls. In terms of evidence for a roof there is no structural evidence on any of the tall remaining sections of broch walls that can be interpreted as features that would have been associated with a roof structure, conical or otherwise. There are however openings, or windows, on the inside walls of all brochs that survive to a reasonable height, that are features that seem to provide evidence that a roof was never fitted to the brochs. It seems a logical possibility that these openings may have been constructed to allow light from the central space, open to the sky, to illuminate the stairway, landings and gallery space sandwiched between the inner and outer walls of the broch. The openings are configured as vertical strings of lintelled openings of varying lengths extending from either the courtyard at ground level or somewhere beginning above the scarcement to a height a few metres below the top of the broch. The strings of windows taper and narrow as they rise and number approximately 10-20 openings stacked one above the other, like a ladder separated by flat stones that form both the lintel of a window and the sill of the window above it. There are usually three or four long lines of lintelled windows radially spaced around the internal walls and they each penetrate the inner broch wall to the stairway and gallery space between the inner and outer broch walls. This fact is strong evidence for the proposal that the brochs never had a roof and were meant to be open to the sky, assuming of course that the openings served the purpose of windows. There is also evidence in many brochs of courtyards that have drains supporting the idea that brochs were roofless, because why would you need drains inside a broch that had a roof? Though it is uncertain whether the drains are original features or are the result of later occupation. There is also the question of how a roofed broch would allow people to use the spiral stairway to access the top of the tower, to some the idea of fitting a roof to the broch would make the spiral stair's exit to reach the wall head redundant, but there is still the possibility that the roof may have only covered the internal wall head leaving the sunken walkway and outer wall head uncovered but the problem then becomes one of having to prevent water from the roof flooding the annular walkway. We cannot say categorically that the broch had no roof, but the problems of explaining away the issues that would come with a roof and the fact that the structures as built are inherently unsuited to having a roof suggests the likelihood that brochs were originally constructed without a roof. Far from being the exception to the rule, Mousa broch is probably a typical example of what all brochs would have looked like had they also survived the ravages of time. It is though for us now to explain why we believe the broch could never have had a roof if it was to function in the way it was designed to.

This leaves the question as to what function could such an impressive open-top construction serve. Perhaps the construction of other monumental buildings that served no "useful" function, at least as living spaces, might be considered such as the Neolithic stone circles and much later, the Mediaeval Churches, monumental structures that would similarly have been constructed by the community to serve a common higher purpose

for the people but were not primarily built to house people rather they were considered as “houses of God”.

Figure 8 View looking up through the roofless broch at Mousa

ROOFLESS TOWER = OBSERVATORY

It is our proposal that the tower was deliberately constructed to be open to the sky and that this was an essential feature of its purpose as an observation tower or more accurately an astronomical observatory. The broch may have been used in a similar manner to the Neolithic stone circles and the skyward extension of the stone ring was a development of the simple circular ground level arrangement of megaliths upwards that provided an artificial horizon at the wall head and some welcome protection from the elements by providing a courtyard sheltered from the wind and warmed by a central hearth. The comfort afforded by the construction of the broch would have been particularly useful for night time observations and the measurement of stellar alignments with the aim of studying the changing patterns of the heavens and perhaps the bigger challenge of understanding the gods associated by the people with the constellations. The development of a simple ring of megaliths into an observatory constructed of stone represented a massive improvement on the conditions endured by their Neolithic forefathers who had made their observations in the exposed conditions of the megalithic circles. The broch would allow druids and their apprentices to comfortably spend the night in the broch observing and measuring alignments and resting beside the comfort

of a central hearth and sleeping in the nest-like oval chambers. The stone circle perimeters were punctuated by megaliths that marked solar alignments on stellar festival days, the brochs however appear to have had a continuous flat wall-heads or internal and external parapets separated by a sunken walkway that enabled eye level alignments to be made at wall head level across the broch to the horizon and measured on graduated parapets allowing a full range of alignments to be made at any position around the broch and measured.

It may have been that markers were placed on the parapets to allow alignments of the Sun and stars on the horizon to be made like a castellated tower or once alignment markers were positioned on the wall head, the positions of the markers may have either been made at the wall head of perhaps within the broch itself by hanging weighted strings from the markers down the inside walls of the broch. Many round stones drilled with holes have been found during excavations in brochs that have been described as loom weights but if the brochs were primarily concerned with observation and making alignments, then there is the possibility that the positions of the markers could have been measured from inside the broch by hanging strings with these “loom weights” hanging down from the wall head markers and measuring the bearings of the vertical strings on the internal broch wall. at the floor level provided by the proposed wooden annular floor sitting 2-3 metres above the courtyard. The main advantage of this idea is that given that these observations are taking place at night, it would be much easier to light the inside of the broch walls with oil lamps and the light provided by the central hearth than to try and make accurate measurements at the wind-exposed and dark conditions of the wall head. The idea of a flat horizontal annular wall head used for observation lends itself to the possibility that the wall head itself may have been calibrated. The alignments provided a calibratable raised artificial horizon in the form of the broch’s wall head and observed from below, a circular window framing the sky to observe the rising and setting of stars and the Sun. Taken in isolation, the proposal that these prehistoric stone towers were observatories seems like a far-fetched idea, a technology before its time, but considering the evidence that the people inhabiting Scotland from Neolithic times had an advanced knowledge of astronomy, the proposal is consistent with these other findings. The beehive cells constructed within the base of the wall may have served as sleeping areas for the skywatcher druid and apprentice and as shelters during inclement weather and for dry storage of food supplies and for the astronomical tools they would have used such as quadrants and pendulums

There is no doubt that these immensely strongly built, impenetrable structures served several secondary purposes and later on, many of the brochs were adapted to be used for many other more mundane purposes as needs changed, and these later uses may have added further confusion to archaeologists as to their original intended use.

As supporting evidence for the proposal that the brochs were ancient observatories there are examples of similar ancient tower structures constructed in mediaeval times in the sixteenth century in Turkey.

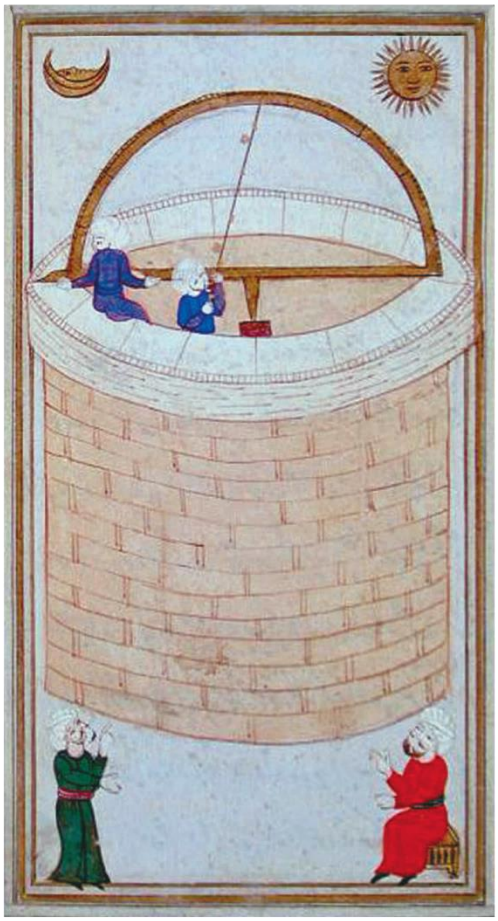


Figure 9 Astronomical Tower built in Istanbul by Taqi-al-Din to measure the declination and hour angle of stars and planets using a large copper quadrant and a calibrated wallhead

The image of the Taqi-al-Din tower shares many similarities with the Scottish brochs despite the fact that there could be 2000 years or more separating their construction. However, the fact we know that this and other towers were constructed in this form for the dedicated observation and measurement of stars allows us to consider the possibility that the ancient brochs served a similar purpose albeit at a much earlier time and in many ways a vastly more sophisticated stone structure. There may be ways of analysing the dimensions of the brochs, particularly the wall head dimensions, to determine whether the circumferences may have been preferentially chosen to enable the perimeters both of the internal and external walls to be easily divided into useful angles equivalent to known pendulum lengths allowing the wall head to be conveniently calibrated and facilitate the bearings of stars and the Sun on the horizon to be measured.

If the broch did represent the development of the simple stone circle, then it might be expected that the brochs circular foundations and walls were based on the same pendulum lengths used in the construction of the stone circles. Furthermore, if the broch was used as an observatory, it might be especially important that the dimensions chosen for the internal radius of the broch resulted in a wall head whose circumference allowed angles of arc to be easily measured using pendulum lengths to equate to angles of arc. It is interesting to consider that any alignments using the wall head as an artificial horizon,

especially if made from high up inside the broch would have to be made either from a walkway sunk in the top of the wall or from annular platforms fixed to the inner wall face. The observation across the broch to make alignments may have involved similar positioning to that proposed for the recumbent stone circles. A walkway around the wall head still survives and can be accessed by visitors at the best-preserved broch on Mousa Island in the Shetland Islands

Analysis of Broch Ground level Internal and External Diameter

1) What Measurement Lengths were used to draw out the foundations of the Brochs?

Analysis of Broch Ground level Internal and External Diameters

Many brochs have been surveyed by archaeologists over the past 150 years and their dimensions reported. Sometimes the external diameters of the brochs have been measured in isolation whilst others have included the measurement of the internal diameter of the courtyard and/or the measurement of the base wall thickness. There is a wide variation in the accuracy of measurements made of the diameters, either because the condition of the broch remains prevented accurate measurement, or because it was not the intention of the archaeologist to obtain a precise measurement because he may not have considered that the precise measurement would have had any significance and therefore estimated diameters to the nearest foot or so. Some archaeologists have not only surveyed the broch dimensions accurately but have also included estimates of the order of accuracy attained during their measurement and also made measurements of diameters along both the North-South and East-West axes of the broch for instance.

The measurements of 109 brochs reported in BAR 342, 444 (I and II) compiled by Euan McKie that include both the internal and external diameters of the broch at ground level have been analysed to determine whether the dimensions coincide with multiples of the pendulum lengths used to draw the ground plans of the Scottish Stone Circles surveyed by Alexander Thom. Those pendulum lengths consist of the following lengths; 35.96cm, 41.12cm, 45.75cm, 46.35cm, 50.0cm, 52.36cm, 56.48cm, 58.25cm, 63.66cm, 80.9cm, 116.5cm and 161.8cm.

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
22	Loch of Huxter	9.68	5.98x80.9	18.21	19.90x45.75
40	West Burra Firth	8.2	9.97x41.12 8.96x45.75 7.04x58.25	17.68	19.07x46.35 10.93x80.9
45	Sae Breck	7.92	11.01x35.96 7.01x56.48	16.76	18.08x46.35 16.00x52.36
94	Mousa	5.64	4.99x56.48	15.22	13.06x58.25 11.95x63.66
98	Scalloway	7.8	6.91x56.48	19.60	6.05x161.8
99	Clickhimin	9.1	9.95x45.75 8.06x56.48	19.80	24.08x41.12 18.91x52.36
153	Stackrue	9.2	10.05x45.75	17.20	20.91x41.12
158	Oxtrow	13.66	18.99x35.96 **13.04x52.36**	21.00	22.95x45.75 21.00x50.00 **20.05x52.36** 18.03x58.25
169	Ingshowe	10.1	14.04x35.96 **11.04x45.75**	18.30	**20.00x45.75**
174	Netlater	10.1	14.04x35.96 **11.04x45.75**	17.40	**19.02x45.75** 14.94x58.25
176	Redland	8.2	9.97x41.12 **8.96x45.75** 7.04x58.25	13.70	19.05x35.95 **14.97x45.75** 13.08x52.36
179	Burgar	10.4	(9.93x52.36 8.93x58.25)	18.30	20.00x45.75 10.93x80.9
188	Midhowe	9.64	5.96x80.9	17.69	19.08x46.35
193	Lingro	9.2	10.05x45.75	18.00	25.03x35.96 18.00x50.00 15.93x56.48
195	Bernstane	10.07	14.00x35.96 **11.01x45.75**	18.30	**20.00x45.75** 13.01x63.66
212	Castle of Bothican	8.33	8.96x46.35 7.95x52.36	16.57	23.03x35.96
226	Dingieshowe	10.1	14.04x35.96 **11.04x45.75**	17.40	**19.02x45.75** 14.94x58.25
234	Burroughston	10.21	**11.01x46.35** 9.04x56.48 **8.02x63.66**	17.70	**19.09x46.35** 16.90x52.36 **13.90x63.66** 10.94x80.9
260	Burrian	9.4	8.98x52.36	18.30	20.00x45.75
272	Howe of Hoxa	9.06	11.02x41.12 8.02x56.48	17.68	19.07x46.35 10.93x80.9

Table 1(i)

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
280	Ousedale Burn	6.66	(**2.06x161.8**)	16.01	16.01x50.00 **4.95x161.8**
313	Dunbeath	8.24	10.02x41.12 9.01x45.75	16.77	18.09x46.35 16.01x52.36
368	Appnag Tulloch	10.7	13.01x41.12	18.00	25.03x35.96 18.00x50.00 15.93x56.48
379/380	Camster	10.7	**13.01x41.12**	23.80	33.09x35.96 **28.94x41.12** 26.01x45.75 21.07x56.48
382	Acharole	9	9.00x50.00 7.97x56.43	17.39	19.01x45.75 14.93x58.25
388	Coghill	8.85	**6.95x63.66**	19.22	21.01x45.75 17.01x56.48 **15.10x63.66** 5.94x161.8
405	Hill of Works	8.85	6.95x63.66	16.47	22.90x35.96 18.00x50.00 7.07x116.5 5.09x161.8
419	Brounaban	8.58	(11.93x35.96)	16.00	16.00x50.00 4.94x161.8
424	Loch Watenan	8.24	10.02x41.12 **9.01x45.75**	19.20	**20.98x45.75** 17.00x56.48 15.08x63.66
427	Thrumster	12.26	17.05x35.96	20.00	20.00x50.00 19.10x52.36
428	Thrumster Little	9.4	8.98x52.36	17.00	17.00x50.00 15.05x56.48
434	Yarrows	9.72	6.01x80.9	16.78	16.02x52.36
435	Elsay	8.85	6.95x63.66	18.00	25.03x35.96 18.00x50.00
437	Hillhead	9.2	10.05x45.75	16.80	16.04x52.36
438	Kettleburn	9.15	**10.00x45.75**	18.30	**20.00x45.75**
439	Kilmster	9.91	12.05x41.12	19.06	19.06x50.00 14.97x63.66
440	Norwall	8.24	10.02x41.12 9.01x45.75	16.17	9.99x80.9

Table 1(ii)

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
442	Wester Broch	8.24	**10.02x41.12** **9.01x45.75**	16.47	22.90x35.96 **20.03x41.12** **18.00x45.75** 12.94x63.66 7.07x116.5
445	Everley	8.845	6.95x63.66	17.96	24.97x35.96 17.96x50.00
446	Freswick Links	9.96	**9.96x50.00**	17.00	**17.00x50.00** 15.05x56.48
447	Keiss North	7.93	**11.03x35.96** **7.02x56.48**	15.86	**22.05x35.96** **14.04x56.48**
448	Keiss South	11.68	10.03x58.25	18.90	22.98x41.12 18.90x50.00 18.05x52.36
449	Keiss West	10.36	-	17.40	19.02x45.75 14.94x58.25
450	Ness	6.6	8.03x41.12	15.50	16.94x45.75
451	Nybster	6.42	7.02x45.75 5.04x63.66 3.97x80.9	15.71	16.94x46.35 15.00x52.36 13.91x56.48
452	Skirzahead	6.64	-	15.25	13.09x58.25 11.98x63.66
457	Achiltibuie	9	9.00x50.00 7.97x56.48	16.60	23.08x35.96 3.04x63.66
458	Clachtoll	9.56	2.95x161.8	18.00	25.03x35.96 18.00x50.00 15.93x56.48
459	Loch Ardbhair	7.32	**8.00x45.75** 6.99x52.36	13.72	19.08x35.96 **14.99x45.75**
460	Kylestrome	9.14	9.99x41.12	16.34	14.03x58.25 10.10x80.9
465	Dail Langwell	9.46	(9.03x52.36)	20.74	8.90x116.5
471	Sallachadh	9.9	**12.04x41.12**	18.90	**22.98x41.12** 18.90x50.00 18.05x52.36
475	Dun na Maigh	8.44	(8.06x52.36)	18.61	20.08x46.35 15.97x58.25

Table 1(iii)

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
480	Grum More	8.69	-	16.47	22.9x35.96 20.03x41.12 18.00x45.75 12.94x63.66
481	Langdale Burn	9.15	10.00x45.75	18.91	22.99x41.12 18.91x50.00 18.06x52.36
485	Sandy Dun	9.67	**5.98x80.9**	16.20	13.91x58.25 **10.01x80.9**
489	East Kinnauld	9.61	(5.94x80.9)	18.61	20.08x46.35 15.97x58.25
493	Castle Cole	6.76	**5.98x56.48**	14.79	17.98x41.12 15.95x46.35 **13.09x56.48**
498	Achoillenabargie	8.54	-	17.08	17.08x50.00
499	Allt an Duin 1	9.61	(5.94x80.9)	20.13	27.99x35.96 22.00x45.75
502	Dun Viden	9.15	10.00x45.75	18.91	22.99x41.12 18.91x50.00 18.06x52.36
504	Armadale Burn	7.17	**9.97x35.96**	16.47	**22.90x35.96** 20.03x41.12 18.00x45.75 12.94x63.66
508	Backies	8.24	10.04x41.12 **9.03x45.75**	18.30	**20.00x45.75**
509	Carn Liath 1	10.2	**11.00x46.35** 9.03x56.48 **8.01x63.66**	20.42	**44.06x46.35** **32.08x63.66**
510	Dunrobin Wood	8.04	**8.04x50.00**	15.96	**15.96x50.00**
514	Feranach	11	12.02x45.75 11.00x50.00	20.46	22.07x46.35 16.07x63.66
516	Bunahoun	9.8	(6.06x80.9)	18.80	17.95x52.36 8.07x115.5
517	Forsinain	10.4	(9.93x52.36 8.93x58.25)	19.52	21.06x46.35 12.06x80.9
522	Kintradwell	9.44	**9.01x52.36**	18.91	22.99x41.12 18.91x50.00 **18.06x52.36**
526	Eldrable	7.63	5.99x63.66	14.95	14.95x50.00
529	Kilphedir	10.07	14.00x35.96 11.01x45.75	18.15	22.07x41.12 16.07x56.48

Table 1(iv)

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
533	Achrarsdal Lodge	10.07	**14.00x35.96** 11.01x45.75	18.00	**25.03x35.96** 18.00x50.00 15.93x56.48
543	Castle Spynie	10.8	15.01x35.96	18.60	20.06x46.35 15.97x58.25
550	Dun Alisaig	9.15	10.00x45.75	16.70	18.02x46.35 15.95x52.36
553	Brae	8.1	6.95x58.25 5.01x80.9	18.30	20.00x45.75
557	Dun Boreraig	10.144	8.98x56.48 7.97x63.66	17.40	19.02x45.75 14.94x58.25
558	Dun Colbost	9.6	(5.93x80.9)	15.86	22.05x35.96 14.04x56.48
560	Dun Osdale	10.32	-	18.00	25.03x35.96 18.00x50.00 15.93x56.48
561	Glen Heysdal	11.5	15.99x35.96 13.98x41.12 10.98x52.36 9.03x63.66	17.00	17.00x50.00 15.05x56.48
562	Dun Fiadhairt	9.61	(5.94x80.9)	16.78	16.02x52.36
563	Dun Hallin	10.52	10.05x52.36 **9.03x58.25**	17.39	19.01x45.75 **14.93x58.25**
564	Dun Gearymore	10.75	14.95x35.96	17.40	19.02x45.75 14.94x58.25
565	Dun Barrafiach	10	10.00x50.00	17.40	19.01x45.75 14.94x58.25
568	Dun Sleadale	11.25	9.96x56.48 **6.95x80.9**	17.70	19.09x46.35 16.90x52.36 13.90x63.66 **10.94x80.9**
569	Dun Beag	10.78	14.99x35.96	18.61	20.08x46.35 15.97x58.25 7.99x116.5
572	Dun Garsin	8	8.00x50.00	14.20	6.09x116.5
574	Dun Arkaig	8.54	-	16.50	22.94x35.96 20.06x41.12 18.03x45.75 12.96x63.66
576	Dun Edinbain	10.07	14.00x35.96 11.01x45.75	17.10	17.10x50.00

Table 1(v)

Reference	Broch	Internal Diameter	Pendulum Lengths	External Diameter	Pendulum Lengths
577	Dun Flashader	10.35	-	17.40	19.02x45.75 14.94x58.25
579	Kingsburgh	10.37	-	17.40	19.02x45.75 14.94x58.25
583	Dun Flodigarry	10	10.00x50.00	17.82	17.02x52.36 14.00x63.66 11.01x80.9
586	Dun Grianan	10.75	14.95x35.96	17.10	17.1x50.00
587	Dun Raisaburgh	9.64	**5.96x80.9**	16.24	13.94x58.25 **10.04x80.9**
590	Dun Telve	9.84	11.96x41.12	18.30	20.00x45.75
591	Dun Trodden	8.56	(11.90x35.96)	17.07	17.07x50.00
592	Caisteal Grugaig	9.38	**13.04x35.96** 8.96x52.36 8.05x58.25	16.50	**22.94x35.96** 20.06x41.12 18.03x45.75 12.96x63.66
604	Dun Mor Vaul	9.86	11.99x41.12	17.55	18.93x46.35 15.06x58.25
607	An Sean Dun	9	10.94x41.12 **9.00x50.00** 7.97x56.48	15.00	**15.00x50.00**
620	Dun Carloway	7.32	8.00x45.75 6.99x52.36	14.35	19.95x35.96
621	Dun Stuigh	7.93	**11.03x35.96** 7.02x56.48	13.73	**19.09x35.96** 15.00x45.75
622	Loch an Duna	9.15	10.00x45.75	15.86	22.05x35.96 14.04x56.48
625	Dun Borve	9.61	5.95x80.9	15.60	18.97x41.12 17.05x45.75
632	Dun Lochan Duin	7.63	5.99x63.66	14.95	14.95x50.00
645	Dun an Sticir	12.2	16.96x35.96	18.30	20.00x45.95
647	Dun Torcuill	11.59	9.95x58.25	16.17	9.99x80.9 6.94x116.5
655	Gallow Hill	11.3	10.00x56.48 6.98x80.9	17.40	19.02x45.75 14.94x58.25

Table 1(vi)

Tables 1(i-vi) show that 87 of the 106 brochs can be described in terms of very close to integer multiples of the proposed pendulum lengths. When we say very close that is to say within +/-5% of a whole pendulum length. A further 11 brochs lie within 7% of a pendulum length. The pendulum lengths that can account for the dimensions of the Broch base diameters of the internal and external foundation walls can be analysed to determine which pendulums were used most frequently. The reference numbers are those used by McKie in BAR 342, 444 (I and II).

Conclusions

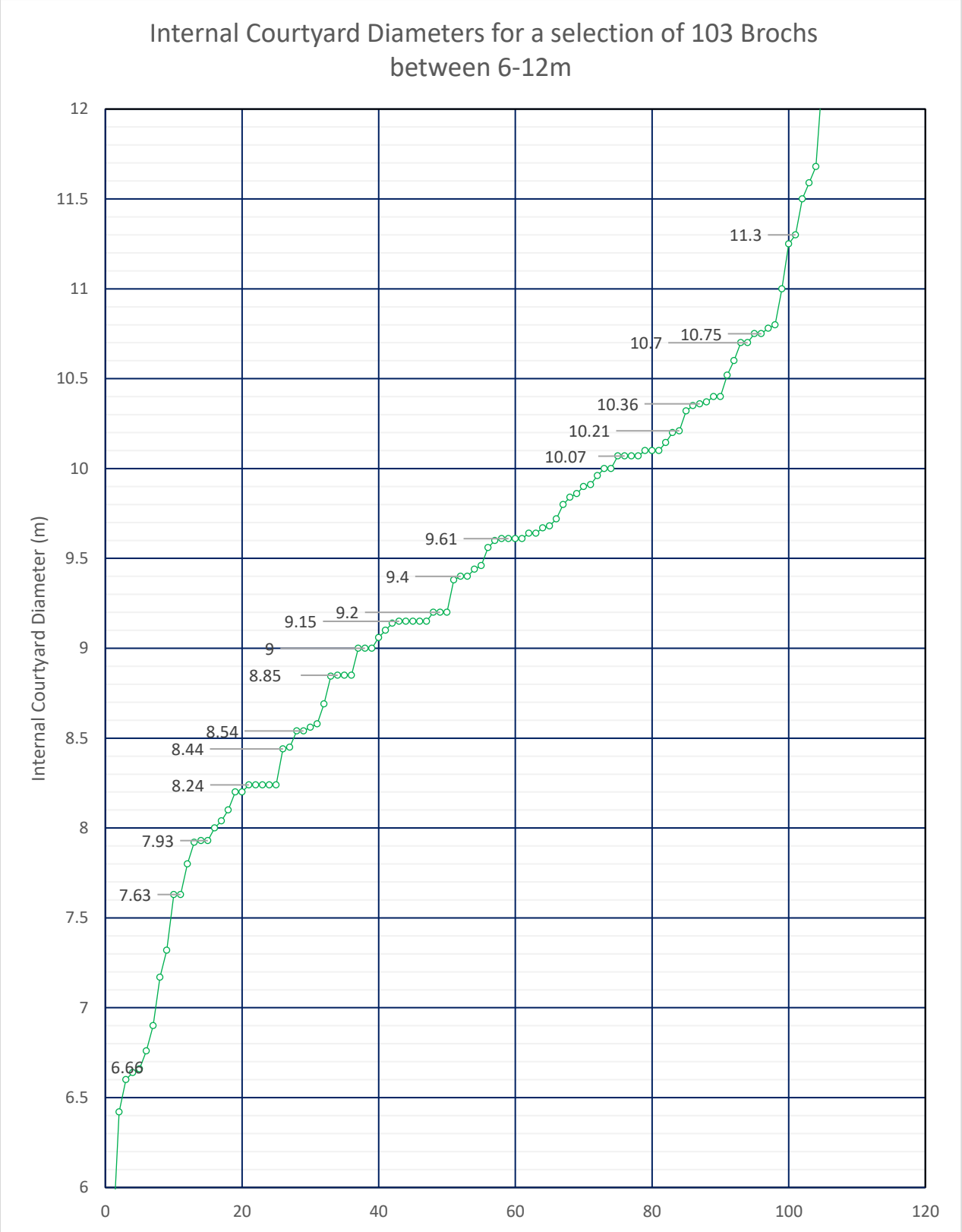
The Broch plans seem to have been drawn out using the same pendulum lengths that had been used in Neolithic Scotland to draw the plans of the stone circles around 3000BC. This suggests that the same measurement system was used by the Picts and their ancestors for a period of over three millennia. 30 of the brochs have plans for their internal and external wall plans that can be described in terms of multiples of the same pendulum length.

Broch	Internal Radius as Pendulum Lengths	External Radius as Pendulum Lengths
Redland	9 x 45.75	15 x 45.75
Loch Ardbhair	8 x 45.75	15 x 45.75
Dun Stuigh	11 x 35.96	19 x 35.96
Castle Cole	6 x 56.48	13 x 56.48
An Sean Dun	9 x 50.00	15 x 50.00
Keiss North	11 x 35.96 7 x 56.48	22 x 35.96 14 x 56.48
Dunrobin Wood	8 x 50.00	16 x 50.00
Ousedale Burn	2 x 161.8	5 x 161.8
Sandy Dun	6 x 80.9	10 x 80.9
Dun Raisaburgh	6 x 80.9	10 x 80.9
Armadale Burn	10 x 35.96	23 x 35.96
Wester Broch	10 x 41.12 9 x 45.75	20 x 41.12 18 x 45.75
Freswick Links	10 x 50.00	17 x 50.00
Dun Hallin	9 x 58.25	15 x 58.25
Caisteal Grugaig	13 x 35.96	23 x 35.96
Netlater	11 x 45.75	19 x 45.75
Dingieshowe	11 x 45.75	19 x 45.75
Burroughston	11 x 46.35 8 x 63.66	19 x 46.35 14 x 63.66
Dun Sleadale	7 x 80.9	11 x 80.9
Achrarasdal	14 x 35.96	25 x 35.96
Backies	9 x 45.75	20 x 45.75
Kettleburn	10 x 45.75	20 x 45.75
Bernstane	11 x 45.75	20 x 45.75
Ingshowe	11 x 45.75	20 x 45.75
Sallachadh	12 x 41.12	23 x 41.12
Loch Watenan	9 x 45.75	21 x 45.75
Coghill	7 x 63.66	15 x 63.66
Kintradwell	9 x 52.36	18 x 52.36
Oxtrow	13 x 52.36	20 x 52.36
Camster	13 x 41.12	29 x 41.12

Table 2 Brochs whose Internal and External diameters can be described using the same pendulum length. 10 of the brochs measurements can be described as 45.75cm pendulum lengths. The significance of the 45.75 cm length of radius is that its use allows the circumference of the circle to be easily divided into eight equal parts using a 35.96cm length. This allows the perimeter of the wall head to be easily be marked and calibrated as North, North-East, East, South-East, South, South-West, West and North-West.

Internal dimensions of the Courtyard

The measurement of the internal diameter of the broch courtyards is in many ways much simpler that the measurement of the external diameter of the broch. Firstly, it is a shorter length, is much easier to measure the distance between two wall surfaces facing each other and the internal courtyard walls are more vertically inclined than the outer sloping wall. However, the internal wall diameters are not now perfectly circular in many cases and it is not known whether, the internal diameters were made at ground level, corresponding with the base of the original broch or higher up the internal walls and even in some cases above the scarcement where the diameters are likely to be greater than that at ground level. It must be remembered that the brochs and their ruins are the remnants of drywall monuments constructed up to 2700 years ago and that some movement of the stones is likely to have occurred over the millennia distorting the perfectly circular shape, (where that was the original plan) of the towers and of course in cases where the broch has collapsed or been dismantled, the remaining broch foundation stones particularly the external stones may have spread outwards increasing the apparent diameter of the broch. The movement of the inner walls is likely to be a less significant factor particularly at ground level though movement of the walls higher up are more likely to have experienced movement and distortion of their shape, as evidenced by the fact that whilst the bases of hundreds of brochs survive, only a handful remain that have walls approaching their original height. Relatively few brochs can be considered to have been accurately measured by archaeologists, where the diameters have been determined along at least two axes, such as the North-South axis and the East-West axis and even fewer that have included estimates of the accuracy of the measurements made. In many cases it probably was not considered particularly important to determine the dimensions of the brochs accurately as there was probably no thought that the dimensions were intrinsically important to the function of these towers. In some cases, it might be considered that the diameter we observe as 9.15m which may imply a diameter to be an accurately determined measurement to within 1 or perhaps 5 cm is in fact a conversion of the original measurement determined in feet and inches. In this case the measurement would have been exactly 30 feet, and the level of accuracy of this measurement is unknown and possibly likely to be at best to the nearest foot. Furthermore, it is not easy to measure the remains of the brochs to a high degree of accuracy particularly of the external diameters at ground level where the best method would probably involve measuring the circumference of the broch at ground level with a tape, where this was possible and dividing that length by pi to obtain the diameter. The problems here are that the lowest course of stones of the broch walls may not be accessible, the length of circumference is very large and may require a 50metre tape to encircle the broch, the diameter calculated will be the average diameter of an imperfect circle and may suffer from the division by pi estimated in pre-calculator times as 22/7.



Graph 1 shows the step-like pattern of distribution of Broch Courtyard diameters, suggesting a series of common preferred diameters for the broch courtyard dimensions.

Internal Diameter (m)	Pendulum Lengths	Frequency
6.66	-	2
7.63	12 x 63.66	2
7.93	22 x 35.96, 14 x 56.48	3
8.24	20 x 41.12, 18 x 45.75, 13 x 63.66	5
8.44	15 x 56.48	2
8.54	-	3
8.85	11 x 80.9	4
9.0	25 x 35.96, 18 x 50.0, 16 x 56.48	3
9.15	20 x 45.75	6
9.2	-	3
9.4	18 x 52.36, 8 x 116.5	3
9.61	21 x 45.75, 17 x 56.48	5
10.07	28 x 35.96, 22 x 45.75	4
10.21	22 x 46.35, 16 x 63.66	2
10.36	-	4
10.7	26 x 41.12, 19 x 56.48	2
10.75	19 x 56.48	2
11.3	20 x 56.48, 14 x 80.9, 7 x 161.8	2

Table 3

Of the 57 brochs that have internal diameters that occur two or more times, 48 can be accounted for by considering the diameters as pendulum lengths. Of the pendulum lengths, the 45,75cm and 56.48cm pendulum between them account for 34 of the preferred internal diameters.

There are 4 preferred diameters accounting for 12 brochs that cannot be described as pendulum lengths. The significance of these preferred “steps” seen in the graph can be seen when the circumferences of the circles formed by these diameters is examined and the arc lengths examined in terms of pendulum lengths.

Diameter (m)	Circumference(cm)	Arc Length(cm) Pendulum	Angle Megalithic Degrees
666	2092.3	1 x 56.48	10
854	2682.9	2 x 35.96	10
920	2890.3	3 x 52.36 1 x 46.35	20 6
1036	3254.7	1 x 52.36	6

Table 4

Three of the preferred diameters give rise to circumferences that describe multiples of 10 Megalithic Degrees of arc length as whole numbers of pendulum lengths. Two of the diameters give circumferences where 6 Megalithic Degrees of Arc can be described as a

pendulum length. The way in which these circles may have been drawn could have involved the broch combs to convert the circumference of the circles giving rise to the desired arc lengths to radii lengths that could be drawn as circles of the required circumferences.

For instance, the arc lengths corresponding to 6 Megalithic Degrees if multiplied 61 times gives the circumference of the circle (equivalent to 366 MD) which can then be wound through a 43-tooth comb, a 11 tooth comb or a 5 or 10 tooth comb to produce the required loop divisions (see Comb Section) to give the desired division by 2xPi that results in the required radius length.

The pendulum lengths equivalent to multiples of 10 Megalithic Degrees can similarly be converted to radial lengths using the same broch combs to draw the circles of the required size.

As an example, the 56.48cm pendulum representing 10 Megalithic Degrees can be divided into 11 loops using a 5-tooth comb or 10 tooth comb section). Take 8 loops of the 11 equal length loops formed between the teeth, this length can be converted to the radius by doubling this length three times (2^3 = 8x) to give the ratio 64/11 which is a good approximation of the radius of the circle whose circumference give arc lengths equivalent to pendulum lengths that describe 10 degrees of arc of that circle.

It is intriguing that some of the broch courtyard diameters could have been calculated in reverse by choosing a circumference that could be usefully divided into megalithic degrees and then obtaining the required radial length using a comb. The radius being unusual in not representing a multiple of one of the pendulum lengths but producing a significant arc length that was a pendulum length.

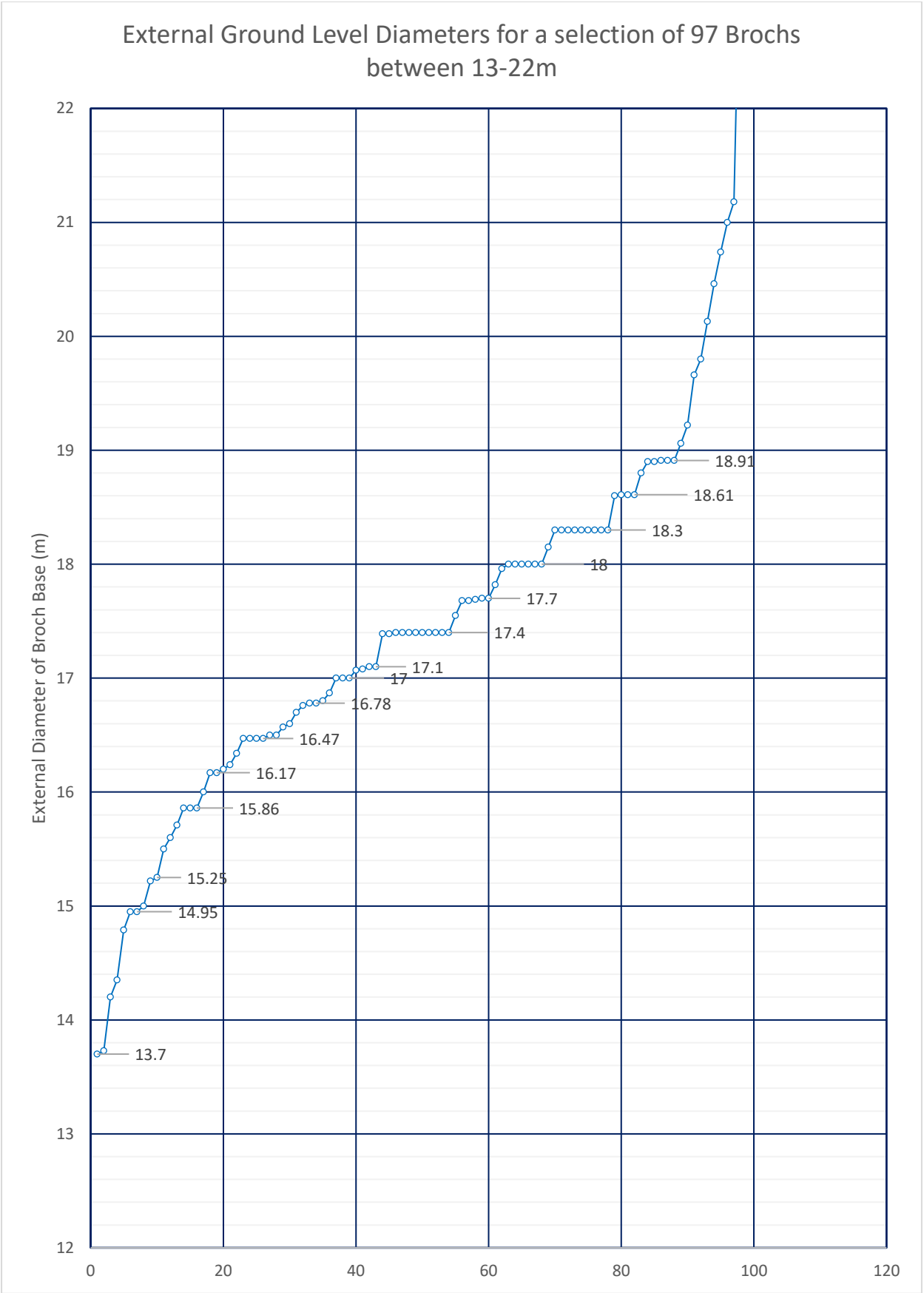
Diameter (cm)	Circumference(cm)	Arc Length(cm) Pendulum	Angle Megalithic Degrees
1495	4696.68	1 x63.66 2 x 63.66	5 10
1710	5372.12	5 x 58.25	20

Table 5

The pendulum arc lengths can be converted to the radius required to give a circumference of the required length by dividing the arc length by 11 and multiplying by 64 for 10 Megalithic Degrees, multiplying by 32 for 5 MD and by 128 for 20MD. This is most easily achieved by taking 8 of the 11 loops and doubling this twice for 5 MD (2^2 x 8/11), three times for 10MD (2^3 x 8/11) and four times for 20MD (2^4 x 8/11).

It is unclear why the internal or external circumferences of the brochs should be designed with a view to describing pendulum lengths as multiples of megalithic degrees especially at ground level where it is difficult to see how any meaningful alignments could have been made. The problem is that externally there is no viewing position at ground level where alignments with the Sun or stars on the horizon could be made. Internally it is possible that alignments made at the top of the broch around the wallhead on the inner wall

circumference could be extended down the walls to the ground level using weighted strings from the wallhead, but if the scarcement, which is situated several meters above the ground level supported an annular floor it would block any weighted lines from reaching the ground and it is more likely that any such marking of alignments extended to the internal walls above the scarcement level and it can be seen that the internal diameter of the broch walls from the scarcement is greater than the diameter at ground level in the courtyard. The business end of the broch must have been at the wall head where alignments with the Sun and stars on the horizon could be made standing in the sunken walkway between the raised internal and external wall heads across the broch, marking the positions of alignment from a viewing point on one side of the wall head with a marker on the other side of the wall head coinciding with an alignment of the Sun or star on the horizon. Alternatively, or additionally the alignment of stars and the Sun at points marked along the inner wall head, as viewed from a position or positions inside the broch.



Graph 2 shows the distribution of Broch external diameters.

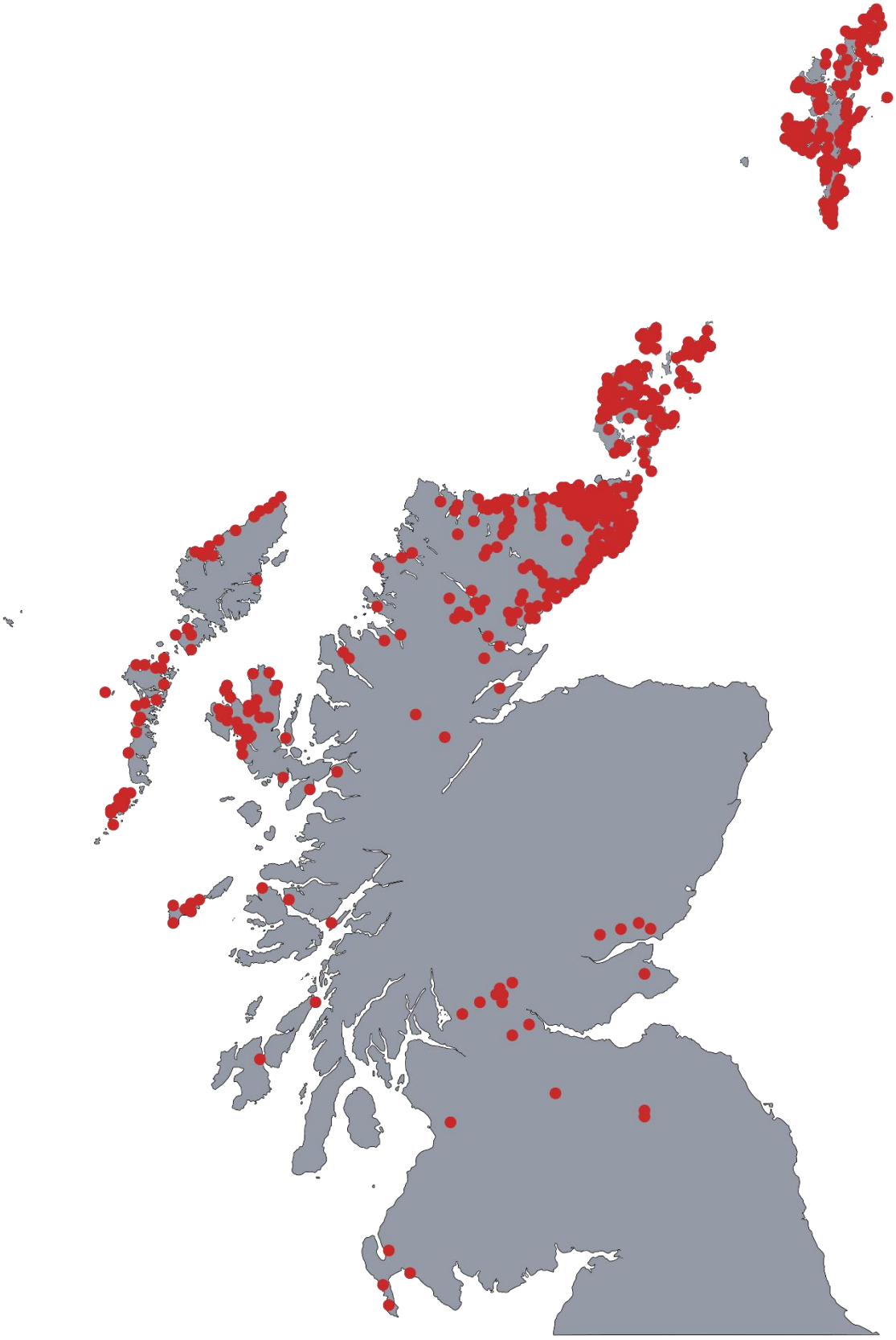
The step-like appearance of the curve suggests that particular lengths of diameter were selected and that many brochs incorporated the same pendulum lengths in their ground plan, in one case 11 brochs had the same measured external diameter (45.75cm x 38).

External Diameter (m)	Pendulum Lengths	Frequency
13.7	30 x 45.75, 17 x 80.9	2
14.95	-	3
15.25	27 x 56.48, 24 x 63.66	2
15.86	28 x 56.48	3
16.17	45 x 35.96, 20 x 80.9, 10 x 161.8	2
16.47	40 x 41.12, 36 x 45.75	4
16.78	32 x 52.36	4
17	34 x 50.0, 30 x 56.48, 21 x 80.9	3
17.1	-	2
17.4	38 x 45.75	11
17.7	43 x 41.12	5
18	50 x 35.96, 36 x 50	6
18.3	40 x 45.75, 35 x 52.36	9
18.61	33 x 56.48, 32 x 58.25, 23 x 80.9, 16 x 116.5	4
18.91	46 x 41.12	5

Of the 65 brochs corresponding to brochs that share an external diameter with at least one other broch, 60 can be described as having diameters equivalent to multiples of pendulum lengths. Of the 60, 38 can be described in terms of two pendulum lengths, 45.75cm and 56.48cm. The most commonly used pendulum length for the external diameter is the 45.75cm pendulum which accounts for 26 of the selected brochs.

There are two diameters shared by five brochs that have external diameters that cannot be described as pendulum lengths. When the circumference of the circles resulting from these non-pendulum diameters are analysed, once again it can be seen that pendulum lengths representing arc lengths around the circumference are equivalent to arc angles of 5, 10 and 20 Megalithic Degrees.

Distribution of Brochs or Ruins likely to have been Brochs throughout Scotland



674 Broch (75), probable broch (249) and possible broch (350) Sites were plotted using their reported grid reference locations.

Shetland Island Brochs

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
1	Pigeon Hellie	Yell	HP/485062			+
2	Breiwick	Yell	HP/531053			+
3	Greenbank	Yell	HP/539050		+	
4	Kirks	Yell	HP/505049			+
5	Cruness	Yell	HP/52450505			+
6	Brough Holm	Unst	HP/566059		+	
7	Hoga Ness	Unst	HP/558005		+	
8	Kirkaby	Unst	HP/566064			+
9	Musselburgh	Unst	HP/593011			+
10	Sna Broch	Unst	HP/568027		+	
11	Underhoull	Unst	HP/575044		+	
12	Ness of Wadbister	Unst	HP/56200180			+
13	Baliasta 1	Unst	HP/596103			+
14	North Geo of Brough	Unst	HP/571125			+
15	Baliasta 2	Unst	HP/603098			+
16	Balta	Unst	HP/660090		+	
17	Brough Taing	Unst	HP/633049			+
18	Sandwick	Unst	HP/623021			+
19	Burgar Stack	Unst	HP/611144			+
20	St. John's Church	Unst	HP/652141			+
21	Ura Geo	Unst	HP/634177			+
22	Loch of Huxter	Shetland	HU/173570		+	
23	Loch of Watness	Shetland	HU/175507		+	
24	Muckle Heogan	Shetland	HU/183599			+
25	North Bank	Papa Stour	HU/18376097			+
26	Burraland	Shetland	HU/222496			+
27	Burrastow	Shetland	HU/224478			+
28	Culswick	Shetland	HU/254448	+		
29	Footabrough	Shetland	HU/200495		+	
30	Pinhoulland	Shetland	HU/255498			+
31	Wester Skeld	Shetland	HU/297438			+
32	Bay of Garth	Shetland	HU/216528			+
33	Brousta	Shetland	HU/223575			+
34	Brindister	Shetland	HU/285572		+	
35	Burga Water 2	Shetland	HU/234540			+
36	Culeryin Loch	Shetland	HU/279543			+
37	Heglibister 1	Shetland	HU/288515			+
38	Nounsborough	Shetland	HU/295577			+
39	Stoura Brough	Shetland	HU/209512			+
40	West Burra Firth	Shetland	HU/256572		+	
41	West Houlland	Shetland	HU/275503		+	

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
42	Heglibister 2	Shetland	HU/288515			+
43	Hillswick	Shetland	HU/281770			+
44	Loch of Houlland	Shetland	HU/214792	+		
45	Sae Breck	Shetland	HU/211781		+	
46	West Hogaland	Shetland	HU/279177 01			+
47	The Hamars	Shetland	HU/220780			+
48	Hamnavoe	Shetland	HU/239806		+	
49	Jarlshof	Shetland	HU/399096	+		
50	Loch of Brow	Shetland	HU/383156			+
51	Lunabister	Shetland	HU/378164		+	
52	Old House of Brow	Shetland	HU/383139			+
53	Old Scatness	Shetland	HU/390107	+		
54	Scouseburgh	Shetland	HU/377217 81			+
55	Skelberry	Shetland	HU/391164			+
56	Byrelands	Shetland	HU/381016 00			+
57	West Burra	West Burra	HU/379350			+
58	Burland	Shetland	HU/390370			+
59	Gruna Sound	Shetland	HU/373333			+
60	Linga	Shetland	HU/359397			+
61	Skeo Hill	Shetland	HU/376312			+
62	Sound of Meal	Shetland	HU/374354			+
63	Burwick Holm	Shetland	HU/386240 22			+
64	Burra Holm	Shetland	HU/386458		+	
65	Burwick	Tingwall	HU/388406			+
66	Hogaland	Tingwall	HU/395469			+
67	Houllands	Sandsting	HU/309443			+
68	East Burra Firth	Sandsting	HU/358580			+
69	Heglibister 1	Tingwall	HU/389516			+
70	Houlland	Sandsting	HU3449538 9		+	
71	Semblister	Mainland	HU/339050 50			+
72	Burgastoo	Delting	HU/345660			+
73	Burravoe 1	Delting	HU/359669			+
74	Isleburgh	Northmavine	HU/337692			+
75	Burgan	Northmavine	HU/344775			+
76	The Cumlins	Northmavine	HU/308770			+
77	Loch of Burraland	Northmavine	HU/344750			+
78	Marki Ness	Northmavine	HU/354721			+
79	Orbister	Northmavine	HU/310768			+
80	Burra Voe	Northmavine	HU/373892			+
81	Fethaland	Northmavine	HU/375943			+
82	Sumburgh Head	Dunrossness	HU/407079			+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
83	Clevigarth	Dunrossness	HU/407129		+	
84	Clumlie	Dunrossness	HU/404181		+	
85	Dalsetter	Dunrossness	HU/408158		+	
86	Eastshore	Dunrossness	HU/402113		+	
87	Levenwick	Dunrossness	HU/415197		+	
88	Southvoe	Dunrossness	HU/400147		+	
89	Burraland	Dunrossness	HU/447232	+		
90	Clodie Knowe	Dunrossness	HU/441294		+	
91	Knowe of Houlland	Sandwick	HU/426240			+
92	Mail	Dunrossness	HU/432280			+
93	Everglades North	Mainland	HU/43002930			+
94	Mousa	Mousa	HU/457237	+		
95	Aithsetter	Dunrossness	HU/447304			+
96	Burland	Dunrossness	HU/446361		+	
97	Loch of Brindister	Lerwick	HU/432370		+	
98	Scalloway	Dunrossness	HU/406399		+	
99	Clickhimin	Dunrossness	HU/464408	+		
100	Hawkness	Tingwall	HU/461490			+
101	Heogan	-	HU/475435			+
102	Burrian 2	Nesting	HU/467540		+	
103	Corn Holm	Nesting	HU/481549			+
104	Burrian 1	Nesting	HU/478545		+	
105	Gletness	Nesting	HU/470512			+
106	Housabister	Nesting	HU/487578		+	
107	Holm of Benston	Nesting	HU/463537		+	
108	Loch of Stavaness	Nesting	HU/490590			+
109	Railsburgh	Nesting	HU/456523			+
110	Wadbister Ness	Tingwall	HU/447504			+
111	Burga Water 1	Nesting	HU/480641		+	
112	Chapel Knowe	Nesting	HU/48556910			+
113	Vidlin	Nesting	HU/479655			+
114	Fugla Ness	Delting	HU/438777		+	
115	Infield	Delting	HU/454747		+	
116	Holm of Copister	Yell	HU/472779	+		
117	Head of Brough	Yell	HU/446850		+	
118	West Sandwick	Yell	HU/440887		+	
119	Windhouse	Yell	HU/48809191		+	
120	Graveland	Yell	HU/463967			+
121	Aith	Bressay	HU/515435			+
122	Brough 1	Bressay	HU/519412			+
123	Cullingsburgh	Bressay	HU/521423			+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
124	Noss Sound	Bressay	HU/528410		+	
125	Brough 3	Whalsay	HU/554651			+
126	Stavaness	Whalsay	HU/508602			+
127	Symbister	Whalsay	HU/540626			+
128	Burravoe 2	Yell	HU/519793		+	
129	Gossabrough	Yell	HU/534833		+	
130	Loch of Kettlester	Yell	HU/511806			+
131	Stoal	Yell	HU/546873			+
132	Burra Ness	Yell	HU/557957	+		
133	Brough Lodge	Fetlar	HU/581927			+
134	Sna Broch 2	Fetlar	HU/578933			+
135	Head of Grunay	Mainland	HU/69477168			+
136	Ruir Taing	Fetlar	HU/616873			+
137	Feal	Fetlar	HU/629902		+	
138	Houbie	Fetlar	HU/620904	+		

Map to show distribution of Brochs and possible Brochs in the Shetland Islands

Map of Shetland Islands with Brochs, probable Brochs and possible Broch marked 1-138

The concentration of brochs in the Shetland Islands is really quite astounding as there are 138 brochs in a total land area of 1466km^2 this is equivalent to one broch for each 10.6km^2.

Orkney Brochs

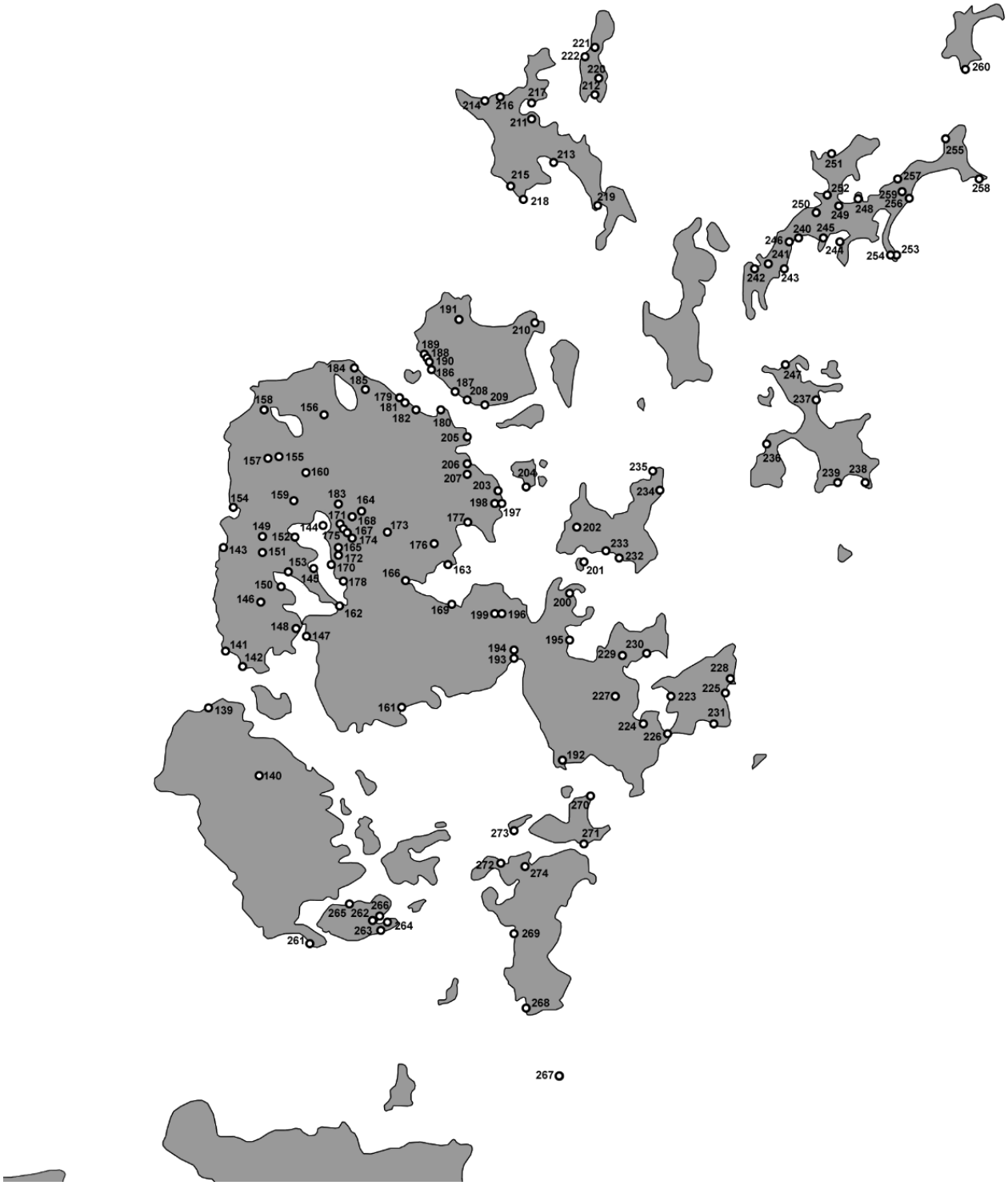
Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
139	Braebister	Hoy	HY/213052			+
140	Green Hill 2	Hoy	HY/250003		+	
141	Breckness	Stromness	HY/22470928		+	
142	Warebeth Cemetery	Stromness	HY/23780818		+	
143	Borwick	Sandwick	HY/22411628	+		
144	Burrian 2	Harray	HY/29611834	+		
145	Burrian 5	Harray	HY/28881538	+		
146	Castle Bloody	Stromness	HY/251129			+
147	Cummi Howe	Stenness	HY/28241039			+
148	The Howe	Stromness	HY/27591092		+	
149	Howans	Sandwick	HY/252176			+
150	Knowe of Redland	Stromness	HY/26591385		+	
151	Loch of Clumly	Sandwick	HY/25171649		+	
152	Scarrataing	Sandwick	HY/276176		+	
153	Stackrue	Sandwick	HY/27051512		+	
154	Verron 2	Sandwick	HY/231198			+
155	Knowe of Skogar	Birsay Harray	HY/26392340			+
156	Loch of Hundland	Birsay	HY/297264			+
157	Loch of Isbister		HY/257233			+
158	Oxtrow	Harray	HY/25372678		+	
159	Skeabrae	Sandwick	HY/275202			+
160	Taft	Birsay	HY/28362226		+	
161	Hillock of Breckna	Orphir	HY/353051			+
162	Big Howe	Stenness	HY/308125			+
163	Burness	Firth	HY/38811556		+	
164	Burrian 3	Harray	HY/32351937		+	
165	Burrian 4	Birsay	HY/308168			+
166	Finstown	Firth	HY/361142			+
167	Harray Church	Harray	HY/318175			+
168	Howen Broch	Birsay	HY/318191			+
169	Ingshowe	Firth	HY/39031277	+		
170	Kirk of Cleaton	Birsay	HY/30191565			+
171	Knowe of Bosquoy	Birsay	HY/309186			+
172	Knowe of Gullow	Birsay	HY/307163			+
173	Nether House		HY/336179			+
174	Netlater	Harray	HY/32321741		+	
175	Overbrough	Harray	HY/314179			+
176	Redland	Firth	HY/377171	+		
177	St Mary's Kirk 1	Evie	HY/39971872			+
178	St Mary's Kirk 2	Birsay	HY/311143			+
179	Burgar	Evie	HY/352277		+	

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
180	Gurness	Mainland	HY/382269	+		
181	Knowe of Ryo	Evie	HY/356273			+
182	Knowe of Stenso	Evie	HY/36382675		+	
183	Mithouse	Birsay	HY/308200			+
184	Verron 1	Evie	HY/319299			+
185	Vinquin	Evie	HY/327283			+
186	Knowe of Swandro	Rousay	HY/375297			+
187	Viera Lodge	Rousay	HY/392281			+
188	Midhowe	Rousay	HY/37163061	+		
189	North Howe	Rousay	HY/37043074			+
190	South Howe	Rousay	HY/37273036		+	
191	The Burrian	Rousay	HY/395334			+
192	Ayre	Holm	HY/47020136		+	
193	Lingro	Kirkwall	HY43450878		+	
194	Tofts	Kirkwall	HY/436094			+
195	Berstane	Kirkwall	HY/47521002		+	
196	Hatston	St Andrews	HY/426120			+
197	Knowe of Dishero	Evie	HY/42561998		+	
198	North Ettit	Evie	HY/421200			+
199	Wideford Hill	Firth	HY/421120			+
200	Work	Kirkwall	HY/475135			+
201	Helliar Holm	Shapinsay	HY/48591579			+
202	Loch of Westhill	Shapinsay	HY/480183			+
203	Hall of Rendall	Evie	HY/425210			+
204	Ness of Boray	Evie	HY/443212			+
205	Ness of Woodwick	Evie	HY/40072486			+
206	Tingwall	Evie	HY/401229			+
207	Wass Wick	Evie	HY/401220			+
208	Knowe of Burrian	Rousay	HY/401275			+
209	Knowe of Hunclett	Rousay	HY/41442722		+	
210	Scockness	Rousay	HY/450331		+	
211	Brough	Westray	HY/448479			+
212	Castle of Bothican	Westray	HY/49264972		+	
213	Hodgalee	Westray	HY/464447		+	
214	Hoor Ness	Westray	HY/414492		+	
215	Knowe of Burristae	Westray	HY/43174293	+		
216	Kno. Queen of Howe	Westray	HY/42504948			+
217	Knoll of Skulzie	Westray	HY/447490			+
218	Knowe of Skea	Westray	HY/44144181			+
219	Tafts	Westray	HY/49634171			+
220	St Tredwell's Chapel	Westray	HY/49645088		+	

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
221	Kirk of Howe	Westray	HY/493531			+
222	St Boniface Church	Westray	HY/48775271		+	
223	Braebuster	St Andrews	HY/54900611		+	
224	Campston	Holm	HY/52880411			+
225	Deerness Church	Deerness	HY/589063			+
226	Dingieshowe	St Andrews	HY/54760330		+	
227	Howe of Langskaill	St Andrews	HY/50780593		+	
228	Riggan of Kami	St Andrews	HY/593074		+	
229	Tankerness 1	St Andrews	HY/514090			+
230	Tankerness 2	St Andrews	HY/532091			+
231	Backland	St Andrews	HY/58040402			+
232	Howe Hill	Shapinsay	HY/512160			+
233	Steiro	Shapinsay	HY/50191635		+	
234	Burroughston	Shapinsay	HY/54042100	+		
235	Ness of Ork	Shapinsay	HY/53562238			+
236	Hillock of Baywest	Stronsay	HY/61902425		+	
237	Hunton	Stronsay	HY/65342754		+	
238	Lamb Head	Stronsay	HY/69042146		+	
239	Benni Cuml	Stronsay	HY/67152142		+	
240	Backaskaill	Sanday	HY/64173919		+	
241	Braehowar	Sanday	HY/620374			+
242	Lamaness	Sanday	HY/61.37.app			+
243	Nebister	Sanday	HY/63163701		+	
244	Elsness	Sanday	HY/672390			+
245	How Farm	Sanday	HY/660392			+
246	The Knowes	Sanday	HY/635390			+
247	Green Hill 1	Stronsay	HY/63223008			+
248	Colli Ness	Sanday	HY/685421			+
249	Icegarth	Sanday	HY/671416			+
250	Marygarth Manse	Sanday	HY/654412			+
251	Scar	Sanday	HY/666454			+
252	Westbrough	Sanday	HY/663424			+
253	Hangie Head	Sanday	HY/712380			+
254	Wasso	Sanday	HY/70923794		+	
255	Brace Garth	Sanday	HY/749465			+
256	Newark	Sanday	HY/722422	+		
257	Peterkirk	Sanday	HY/714436			+
258	Point of Buryan	Sanday	HY/77244340		+	
259	Chapel of Anston	Sanday	HY/717426			+
260	Burrian 5	N.Ronaldsay	HY/76275138		+	
261	The Skeo	Hoy	ND/286880		+	

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
262	Burrowstone	Hoy	ND/333898			+
263	Green Hill of Hestigeo	Hoy	ND/33758904		+	
264	Outer Green Hill	Hoy	ND/343896			+
265	Green Hill 3	Hoy	ND/315910			+
266	Green Hill of Scarton	Hoy	ND/337890005			+
267	Muckle Skerry	S.Ronaldsay	ND/468785			+
268	Brough Farm	S.Ronaldsay	ND/443833			+
269	Weems Castle	S.Ronaldsay	ND/434889		+	
270	Burray East	Burray	ND/489798881	+		
271	Kyelittle	Burray	ND/485953			+
272	Howe of Hoxa	S.Ronaldsay	ND/425293936		+	
273	Hunda	S.Ronaldsay	ND/434962			+
274	Smiddybanks	S.Ronaldsay	ND/442936			+

136 brochs 990km^2 1 per 7.28km^2 almost the same number of brochs as Shetland but the land area is only about two thirds that of Shetland.



Map to show distribution of Brochs and possible Brochs in the Orkney Islands

Caithness and Sutherland

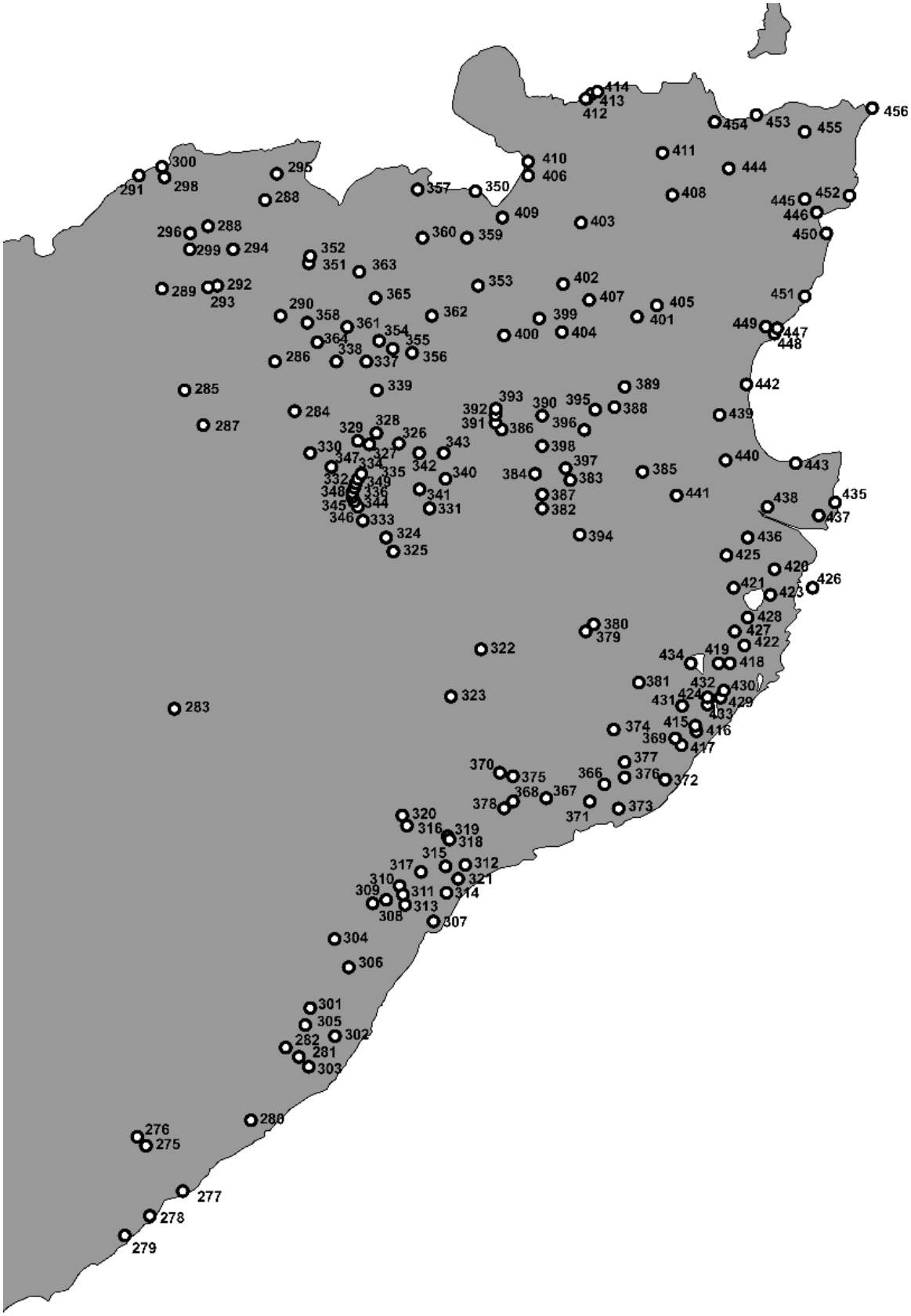
Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
275	Caen Burn 1	Sutherland	ND/015174			+
276	Caen Burn 2	Sutherland	ND/0118app.			+
277	Cnoc Chaisteal	Sutherland	ND/03101525			+
278	Dun Phail	Sutherland	ND/01481387	+		
279	Midgarty	Sutherland	ND/00081279	+		
280	Ousedale Burn	Caithness	ND/07131881	+		
281	Langwell Tulloch	Caithness	ND/09742231		+	
282	Tulloch Turnal	Caithness	ND/09042286		+	
283	Dalnawillan	Caithness	ND/03024094			+
284	Scotscalder	Caithness	ND/09645686			+
285	Tota an Dranndain	Caithness	ND/037579		+	
286	Tulloch of Achavarn	Caithness	ND/08545962			+
287	Tulach Gorm	Caithness	ND/04675608			+
288	Brimside Tulloch	Caithness	ND/04956696		+	
289	East Shebster	Caithness	ND/02506339			+
290	Framside	Caithness	ND/08906199			+
291	Green Tullochs	Caithness	ND/01316964		+	
292	Knockglass 1	Caithness	ND/05476358	+		
293	Knockglass 2	Caithness	ND/04896345		+	
294	Oust	Caithness	ND/06326552		+	
295	Scrabster Mains	Caithness	ND/08676969			+
296	Stemster 2	Caithness	ND/04006642			+
297	Thing's Va	Caithness	ND/08086824		+	
298	Tulloch of Lybster	Caithness	ND/02686947		+	
299	Tulloch of Stemster	Caithness	ND/03996548			+
300	Crosskirk	Caithness	ND/02487012	+		
301	Berriedale 1	Caithness	ND/10332492		+	
302	Berriedale 2	Caithness	ND/11682335		+	
303	Burg Langwell	Caithness	ND/10262181		+	
304	Burgh Ruadh	Caithness	ND/11602852	+		
305	TulachBad a'Choilich	Caithness	ND/10052404			+
306	Upper Borgue	Caithness	ND/12432708		+	
307	Poll Gorm	Caithness	ND/17032949			+
308	Achorn	Caithness	ND/13693050			+
309	Ballentrath	Caithness	ND/14393072		+	
310	Ballentink 1	Caithness	ND/15083135			+
311	Ballentink 2	Caithness	ND/15323098		+	
312	Burn of Latheronwheel	Caithness	ND/18653260		+	
313	Dunbeath	Caithness	ND/15533044		+	
314	Knockinnon	Caithness	ND/17643105			+
315	Latheronwheel	Caithness	ND/17623251			+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
316	Minera	Caithness	ND/15583461		+	
317	Achnagoul	Caithness	ND/16273233		+	
318	Smerral	Caithness	ND/17803379		+	
319	Smerral Wood	Caithness	ND/17733396		+	
320	Tiantulloch	Caithness	ND/15243522		+	
321	Upper Latheron	Caithness	ND/18243186			+
322	Ballachly	Caithness	ND/19564423			+
323	Greysteil Castle	Caithness	ND/17954167		+	
324	Tulach Beag	Caithness	ND/14594980			+
325	Tulach Mor	Caithness	ND/14854940			+
326	Achanarras	Caithness	ND/15115515			+
327	Achies 1	Caithness	ND/13645506			+
328	Achies 2	Caithness	ND/14005565			+
329	Achies 3	Caithness	ND/13055522			+
330	Achingoul	Caithness	ND/10475463			+
331	Achkeepster	Caithness	ND/16805158			+
332	Achlochan Moss	Caithness	ND/14185306			+
333	Carn na Mairg	Caithness	ND/13315103	+		
334	Cnoc Donn	Caithness	ND/14005330			+
335	Dale 1	Caithness	ND/13205304			+
336	Dale 2	Caithness	ND/12975227			+
337	Halkirk	Caithness	ND/13475951			+
338	Housle Cairn	Caithness	ND/11905960		+	
339	Houstry	Caithness	ND/14045801			+
340	Knockglass 3	Caithness	ND/17615329			+
341	Mybster	Caithness	ND/16195280			+
342	Spital 1	Caithness	ND/16325473			+
343	Spital 2	Caithness	ND/17565438		+	
344	Tulach an Fhuarain	Caithness	ND/12875208			+
345	Tulach Lochain Braiseal	Caithness	ND/12825203			+
346	Westerdale 2	Caithness	ND/12995186			+
347	Leosag	Caithness	ND/11625384			+
348	Aisle	Caithness	ND/130525ap			+
349	Dale House 1	Caithness	ND/12975232			+
350	Castlehill	Caithness	ND/19366876			+
351	Geise 1	Caithness	ND/10366480			+
352	Geise 2	Caithness	ND/10546514			+
353	Ha' of Duran	Caithness	ND/19516359			+
354	Hoy	Caithness	ND/14166062		+	
355	Hoy Station	Caithness	ND/14996011			+
356	Knockdee	Caithness	ND1660app			+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
357	Murkle	Caithness	ND/16266881			+
358	North Calder	Caithness	ND/10356160			+
359	Olrig House	Caithness	ND/18906628			+
360	Sibmister	Caithness	ND/16516622			+
361	Skinnet	Caithness	ND/12576136			+
362	Stemster 3	Caithness	ND/1762ap			+
363	Tulloch of Shalmstry	Caithness	ND/13166443		+	
364	Upper Sour	Caithness	ND/10856056			+
365	Carsgoe	Caithness	ND/1463app			+
366	Achavar	Caithness	ND/26173697			+
367	Achow	Caithness	ND/23033617			+
368	Appnag Tulloch	Caithness	ND/21213591		+	
369	East Clyth	Caithness	ND/29953923			+
370	Golsary	Caithness	ND/20573749			+
371	Lybster	Caithness	ND/25293597			+
372	Mid Clyth	Caithness	ND/29453732			+
373	Occumster	Caithness	ND/26933565			+
374	Roster	Caithness	ND/26643986			+
375	Rumster	Caithness	ND/21253725			+
376	Upper Clyth	Caithness	ND/27303727			+
377	Upper Lybster	Caithness	ND/27243811			+
378	Usshilly Tulloch	Caithness	ND/20753552			+
379	Camster 1	Caithness	ND/25204518			+
380	Camster 2	Caithness	ND/25554558			+
381	Toftgun	Caithness	ND/27984241			+
382	Acharole	Caithness	ND/22815171		+	
383	Achingale	Caithness	ND/24345353		+	
384	Banks of Watten	Caithness	ND/22605348			+
385	Bilbster	Caithness	ND/28175381			+
386	Cairn of Dunn	Caithness	ND/20655605			+
387	Carn a' Chladha	Caithness	ND/23135233			+
388	Coghill	Caithness	ND/26705708		+	
389	Gearsay Cairn	Caithness	ND/27265819			+
390	Lynegar	Caithness	ND/23045662			+
391	Old Hall of Dunn 1	Caithness	ND/20415613			+
392	Old Hall of Dunn 2	Caithness	ND/2026/5670			+
393	Old Hall of Dunn 3	Caithness	ND/20355694			+
394	Scorriclet	Caithness	ND/24855051			+
395	Scottag	Caithness	ND/25665699			+
396	Tulach Gorm 2	Caithness	ND/25105604			+
397	Watten	Caithness	ND/24105397			+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
398	Wester Watten	Caithness	ND/22995502		+	
399	Bowertower	Caithness	ND/22796179			+
400	Camster 3	Caithness	ND/20936098			+
401	Gunn's Hillock 1	Caithness	ND/27926201			+
402	Ha' of Bowermadden	Caithness	ND/23986369		+	
403	Ha' of Greenland	Caithness	ND/24906709			+
404	Halcro	Caithness	ND/23896119			+
405	Hill of Works	Caithness	ND/29036255		+	
406	Links of Dunnet	Caithness	ND/222696		+	
407	Murza	Caithness	ND/25386290			+
408	Scoolary	Caithness	ND/29826847			+
409	Thurdistoft	Caithness	ND/20786731		+	
410	Dunnet	Caithness	ND/22147028			+
411	Hollandmay	Caithness	ND/29307083			+
412	Rattar	Caithness	ND/25047378			+
413	Rattar Burn	Caithness	ND/25257398			+
414	Scarfskerry	Caithness	ND/25647420			+
415	Brouan 1	Caithness	ND/31023949			+
416	Brouan 2	Caithness	ND/31083946			+
417	Gunn's Hillock 2	Caithness	ND/30293904			+
418	Borrowstone	Caithness	ND/32884353			+
419	Brounaban	Caithness	ND/32314347		+	
420	Cairn of Humster	Caithness	ND/35294848			+
421	Cairnquoy	Caithness	ND/33094743		+	
422	Gansclet	Caithness	ND/33624441			+
423	Hempriggs	Caithness	ND/35114717			+
424	Loch Watenan	Caithness	ND/31714114		+	
425	Old Stirkoke	Caithness	ND/32754928		+	
426	Tannach	Caithness	ND/37364748			+
427	Thrumster	Caithness	ND/33194505		+	
428	Thrumster Little	Caithness	ND/33844583		+	
429	Ulbster 1	Caithness	ND/32434149			+
430	Ulbster 2	Caithness	ND/32714171			+
431	Warehouse	Caithness	ND/30344124		+	
432	Watenan North	Caithness	ND/31804146	+		
433	Watenan South	Caithness	ND/317411			+
434	Yarrows	Caithness	ND/30834349	+		
435	Elsay	Caithness	ND/38715198		+	
436	Hill of Stemster	Caithness	ND/33845029			+
437	Hillhead	Caithness	ND/37625140		+	
438	Kettleburn	Caithness	ND/34975191		+	

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
439	Kilmster	Caithness	ND/32345655		+	
440	Norwall	Caithness	ND/32665445		+	
441	Thuster	Caithness	ND/30045254			+
442	Wester Broch	Caithness	ND/33855831		+	
443	Shorelands	Caithness	ND/36475425			+
444	Brabstermire	Caithness	ND/32856993			
445	Everley	Caithness	ND/36996828		+	
446	Freswick Links	Caithness	ND/37616761		+	
447	Keiss North	Caithness	ND/35416120		+	
448	Keiss South	Caithness	ND/35316108		+	
449	Keiss West	Caithness	ND/34886151		+	
450	Ness	Caithness	ND/38146665		+	
451	Nybster	Caithness	ND/37026314		+	
452	Skirza Head	Caithness	ND/39406844		+	
453	Canisbay	Caithness	ND/34347285			+
454	Gills	Caithness	ND/32047238			+
455	Stemster 1	Caithness	ND/36917194			+
456	Duncansby Head	Caithness	ND/40547326			+



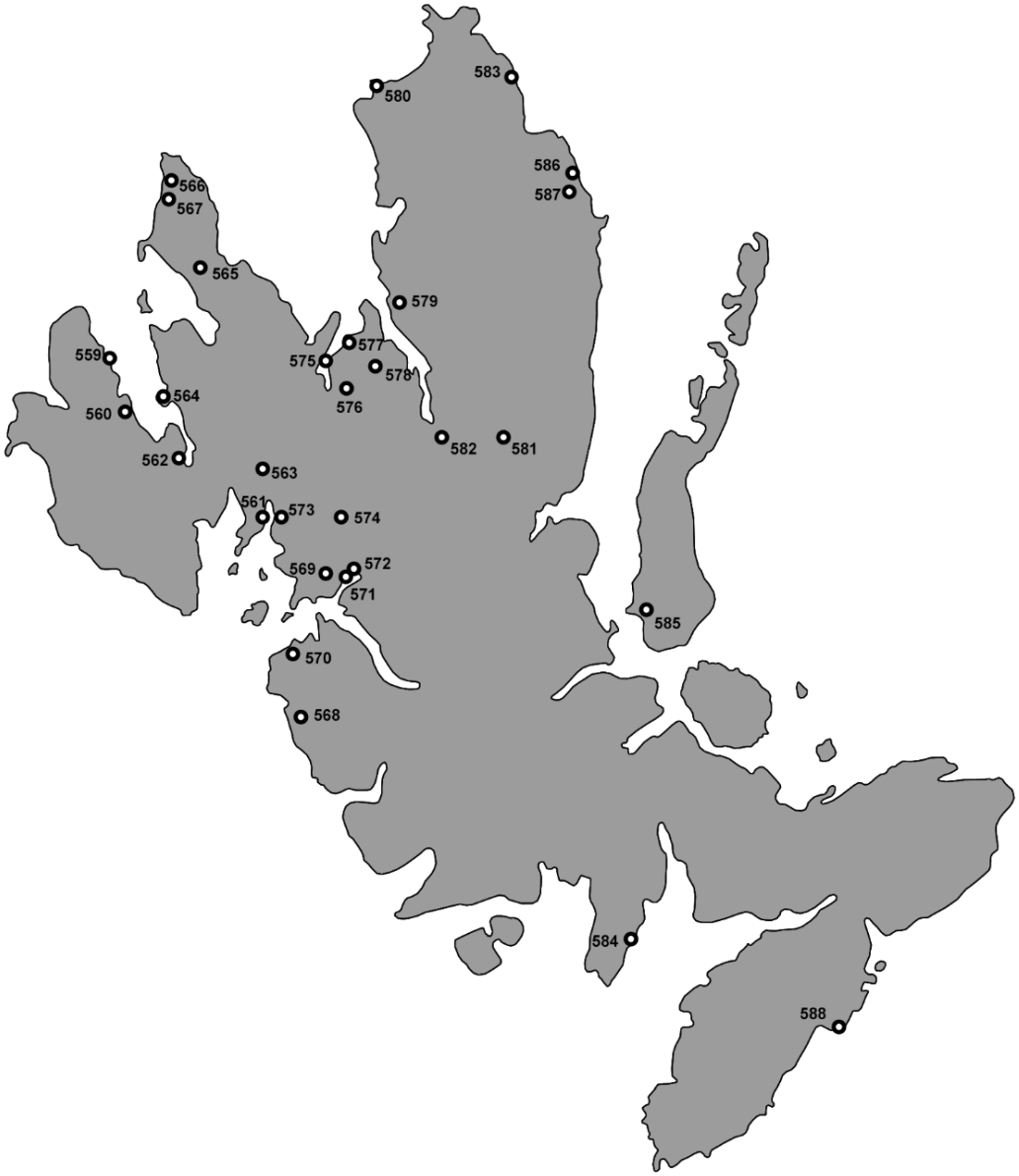
Caithness distribution of Brochs

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
457	Achiltibuie	Ross&Cromarty	NC/02890694	-	+	-
458	Clachtoll	Sutherland	NC/03662784	+	-	-
459	Loch Ardbhair	Sutherland	NC/16883323	-	+	-
460	Kylestrome	Sutherland	NC/21703411	-	+	-
461	River Dionard	Sutherland	NC/36336200	-	+	-
462	Achaneas 1	Sutherland	NC/47010253	-	-	+
463	Achaneas 2	Sutherland	NC/46860273	-	-	+
464	An Dun	Sutherland	NC/44450085	-	-	+
465	Dail Langwell	Sutherland	NC/41161121	+	-	-
466	Dun Dornaigil	Sutherland	NC/45724501	+	-	-
467	Camas an Duin	Sutherland	NC/44595797	-	+	-
468	Ach an Duin	Sutherland	NC/46016053	-	+	-
469	Durcha	Sutherland	NC/50170239	-	+	-
470	Loch Shin	Sutherland	NC/57190679	-	+	-
471	Sallachadh	Sutherland	NC/54910922	+	-	-
472	Allt Breac	Sutherland	NC/59111035	-	+	-
473	Dalchork	Sutherland	NC/57251116	-	-	+
474	Shiness	Sutherland	NC/52731526	-	-	+
475	Dun na Maigh	Sutherland	NC/55235303	+	-	-
476	Dun Buidhe 4	Sutherland	NC/56456401	-	+	-
477	A'Mheirle	Sutherland	NC/30000484	+	-	-
478	Coilt ach a'Chuil	Sutherland	NC/65853815	-	+	-
479	Dun Creagach	Sutherland	NC/60463558	+	-	-
480	Grum More	Sutherland	NC/61073669	+	-	-
481	Langdale Burn	Sutherland	NC/69264496	+	-	-
482	Borgie Bridge	Sutherland	NC/66535871	-	+	-
483	Pallcharn	Sutherland	NC/62105875	-	-	+
484	Kyle of Tongue	Sutherland	NC/60365977	-	-	+
485	Sandy Dun	Sutherland	NC/69736097	-	+	-
486	Scullomie	Sutherland	NC/615610	-	-	+
487	Torrisdail	Sutherland	NC/67736185	-	-	+
488	Carn Mor 1	Sutherland	NC/6090	-	-	+
489	East Kinnauld 1	Sutherland	NC/74380159	+	-	-
490	East Kinnauld 2	Sutherland	NC/74210145	-	-	+
491	Mearlig	Sutherland	NC/7303	-	-	+
492	Sallachie	Sutherland	NC/7603	-	-	+
493	Castle Cole	Sutherland	NC/79571337	+	-	-
494	Coich Burn	Sutherland	NC/78801087	-	+	-
495	Eilean Garbh	Sutherland	NC/72014732	-	+	-
496	Inshlampie	Sutherland	NC/71594657	-	+	-
497	Skail	Sutherland	NC/ 71354744	-	-	+
498	Achoillenaborgie	Sutherland	NC/71395942	-	+	-
499	Allt an Duin 1	Sutherland	NC/72355752	-	+	-
500	Dun Carnachaidh	Sutherland	NC/72135269	-	+	-

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
501	Dun Chealamy	Sutherland	NC/71995140	-	+	-
502	Dun Viden	Sutherland	NC/72655188	-	+	-
503	Skelpick	Sutherland	NC/72305620	-	-	+
504	Armadale Burn	Sutherland	NC/79946266	-	+	-
505	Cai Dun	Sutherland	NC/7161	-	-	+
506	Clerkhill	Sutherland	NC/71756338	-	-	+
507	Loch Swordly	Sutherland	NC/729628	-	-	+
508	Backies	Sutherland	NC/83450261	+	-	-
509	Carn Liath 1	Sutherland	NC/87040137	+	-	-
510	Carrol	Sutherland	NC/84620646	+	-	-
511	Duchary	Sutherland	NC/85500520	-	+	-
512	Dunrobin Wood	Sutherland	NC/84070176	-	+	-
513	Kilbrare	Sutherland	NC/82290987	-	-	+
514	Killin	Sutherland	NC/86730761	-	+	-
515	Allt an Duin 2	Sutherland	NC/80972605	-	-	+
516	Feranach	Sutherland	NC/84412730	+	-	-
517	Suisgill	Sutherland	NC/88752530	-	+	-
518	Bunahoun	Sutherland	NC/89405233	-	+	-
519	Forsinain	Sutherland	NC/89935095	-	+	-
520	Trantlemere	Sutherland	NC/89185338	-	+	-
521	Upper Bighouse	Sutherland	NC/88965752	-	+	-
522	Bighouse	Sutherland	NC/89846387	-	-	+
523	Loch Mor 2	Sutherland	NC/88896344	-	+	-
524	Kintradwell	Sutherland	NC/92930807	+	-	-
525	Allt a' Choire Mhoir	Sutherland	NC/92161887	-	+	-
526	Balvalich	Sutherland	NC/94521898	-	-	+
527	Carn Bran	Sutherland	NC/94201220	+	-	-
528	Eldrable	Sutherland	NC/98331816	-	+	-
529	Gylable Burn	Sutherland	NC/94871823	-	+	-
530	Killowan	Sutherland	NC/92931882	-	-	+
531	Kilphedir	Sutherland	NC/99431891	-	+	-
532	Stronrunkie	Sutherland	NC/97641117	-	-	+
533	Ach an Fhionnfhuraidh	Sutherland	NC/90202396	-	-	+
534	Achunabust	Caithness	NC/99436463	-	+	-
535	Achvarasdal	Caithness	NC/98346469	-	+	-
536	Isauld	Caithness	NC/97676504	-	-	+
537	Knock Urray	Caithness	NC/98386630	-	-	+

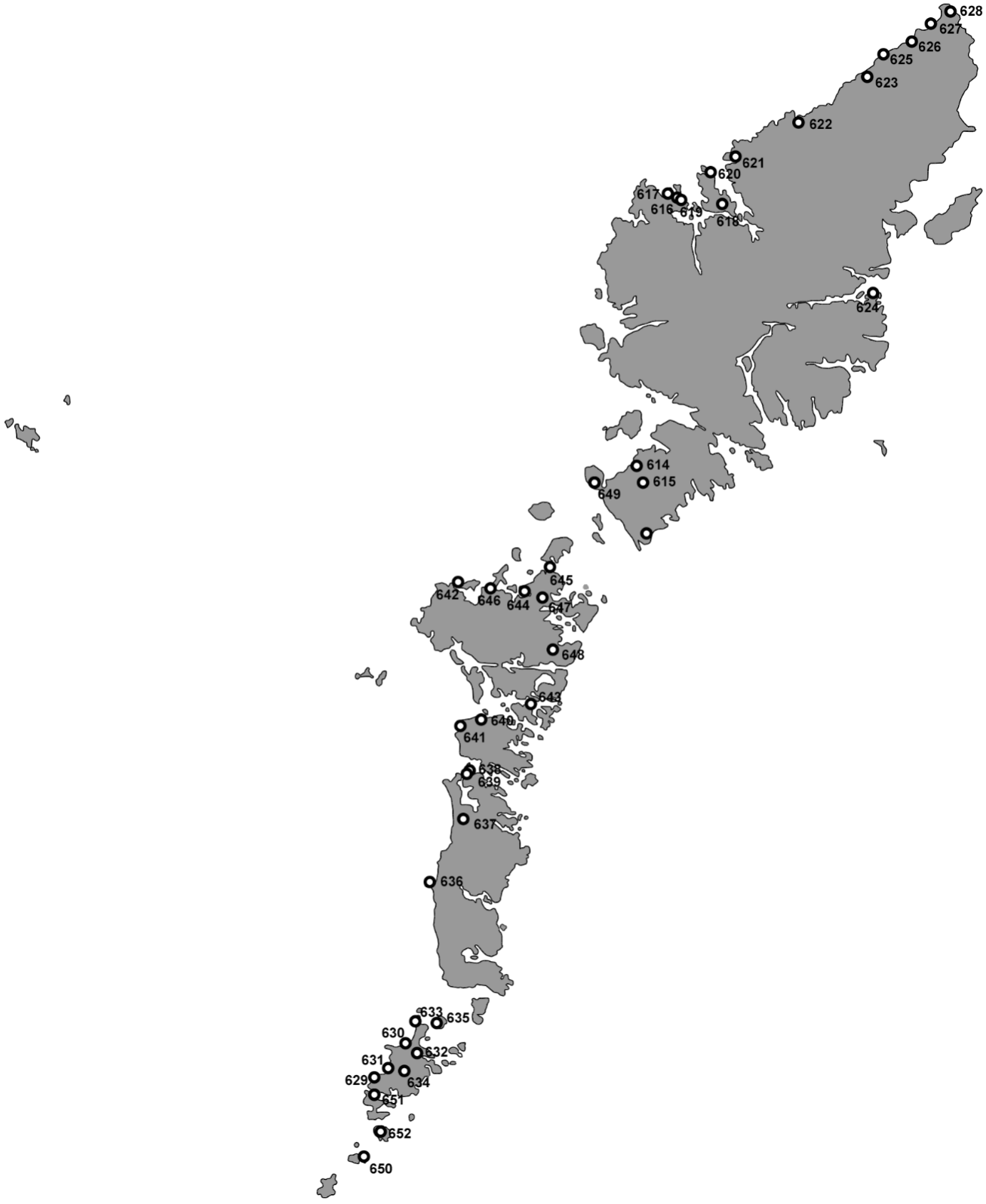
Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
538	Little Loch Broom	Wester Ross	NH/0888	-	-	+
539	Allt Raon A' Chroisg	Wester Ross	NH/16959008	-	-	+
540	Carnoch	E.Rosshire	NH/252507	-	+	-
541	Allt Dail a' Bhraid	Wester Ross	NH/21369494	-	+	-
542	Dun Coille Struy	Invernessshire	NH/39643976	-	+	-
543	Carn Mor	Sutherland	NH/49039926	-	+	-
544	Croick	Sutherland	NH/45649143	-	+	-
545	Castle Spynie	Invernessshire	NH/54144204	-	+	-
546	Carn Deasgan	Invernessshire	NH/5990	-	-	+
547	Carn Liath 3	Invernessshire	NH/56699098	-	-	+
548	Carn Mor 3	Invernessshire	NH/50399853	-	-	+
549	Gruinards	Invernessshire	NH/549908	-	-	+
550	Invershiel Station	Invernessshire	NH/57953	-	-	+
551	Resolis	Invernessshire	NH/679655	-	-	+
552	Dun Alisaig	Invernessshire	NH/65698682	+	-	-
553	Lechanich	Invernessshire	NH/68128546	-	+	-
554	Struie	Invernessshire	NH/600800	-	-	+
555	Brae	Sutherland	NH/70509903	-	+	-
556	Skelbo Wood	Sutherland	NH/78209443	-	-	+
557	Thor's Tower	Sutherland	NH/75379920	-	+	-
558	Castle Corbet	Sutherland	NH/90268326	-	-	+
559	Dun Boreraig	Skye	NG/19485311	+	-	-
560	Dun Colbost	Skye	NG/20554947	+	-	-
561	Dun Feorlig	Skye	NG/29934235	-	+	-
562	Dun Osdale	Skye	NG/24124641	+	-	-
563	Glen Heysdal	Skye	NG/29874537	-	+	-
564	Dun Fiadhairt	Skye	NG/23115042	-	+	-
565	Dun Hallin	Skye	NG/25665927	+	-	-
566	Dun Gearymore	Skye	NG/23686490	-	+	-
567	Dun Borrafiach	Skye	NG/23556371	+	-	-
568	Dun Sleadale	Skye	NG/32382920	+	-	-
569	Dun Beag	Skye	NG/340386	+	-	-
570	Ard an t' Sabhail	Skye	NG/31803333	-	+	-
571	Dun Diarmaid	Skye	NG/35453816	-	-	+
572	Dun Garsin	Skye	NG/36093878	-	+	-
573	Dun Alighlinn	Skye	NG/30984260	-	-	+
574	Dun Arkaig	Skye	NG/34994251	+	-	-
575	Dun Borve	Skye	NG/34265257	-	-	+
576	Dun Edinbain	Skye	NG/35355092	-	+	-
577	Dun Flashader	Skye	NG/35115349	-	+	-
578	Dun Suledale	Skye	NG/37445255	+	-	-
579	Kingsburgh	Skye	NG/38915688	-	+	-
580	Dun Bornaskitaig	Skye	NG/37267161	-	-	+
581	Dun Borve 2	Skye	NG/45914772	-	+	-
582	Dun a' Cheitechin	Skye	NG/41754785	-	-	+

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
583	Dun Flodigarry	Skye	NG/46397196	-	+	-
584	Dun Liath 2	Elgol	NG/54331427	-	-	+
585	Dun Borrodale	Raasay	NG/55473633	+	-	-
586	Dun Grianan	Skye	NG/50556529	-	+	-
587	Dun Raisaburgh	Skye	NG/50326427	-	+	-
588	Dun Choinnich	Skye	NG/68290834	-	-	+
589	Borrodale	Ross & Crom	NG/71184432	-	-	+
590	Dun Telve	Ross & Crom	NG/82901725	+	-	-
591	Dun Troddan	Ross & Crom	NG/83381723	+	-	-
592	Caisteal Grugaig	Ross & Crom	NG/86692508	+	-	-
593	Dunan	Ross & Crom	NG/88242645	-	-	+
594	Lag an Duin	Ross & Crom	NG/83624044	-	-	+
595	Craig Bran	Ross & Crom	NG/865796	-	-	+
596	Kernsary	Ross & Crom	NG/8979	-	-	+
597	Thumaig	Ross & Crom	NG/8782	-	+	-
598	Killilan	Tiree	NG/9430	-	-	+
599	Dun Hiader	Tiree	NL/964389	-	+	-
600	Dun Boraige Moire	Tiree	NL/94684756	-	+	-
601	Dun Heanish	Tiree	NM/039434	-	-	+
602	Dun Ibrig	Tiree	NM/026444	-	-	+
603	Dun Mor a' Chaolais	Tiree	NM/08324767	-	+	-
604	Dun Mor Vaul	Tiree	NM/04234927	+	-	-
605	Dun Aisgean	Mull	NM/37744524	+	-	-
606	Dun Nan Gall	Mull	NM/43314313	+	-	-
607	An Sean Gall	Mull	NM/43105624	+	-	-
608	An Sean Chaisteal	Mull	NM/55104988	+	-	-
609	An Dfun 7	Mull	NM/81133768	-	+	-
610	Tirefour Castle	Mull	NM/86754291	-	+	-
611	Dun Bhoraraig	Islay	NR/41646578	+	-	-
612	Barnhill	Jura	NR/705968	-	-	+
613	Dun Rodil	Harris	NG/05018330	-	+	-
614	Dun Borve 3	Harris	NG/03259400	-	+	-
615	Dun Borve 4	Harris	NG/04329161	-	-	+
616	Dun Bharabhat	Lewis	NB/09873530	-	+	-
617	Traigh Na Clibhe	Lewis	NB/08363606	-	-	+
618	Dun Baraglom	Lewis	NB/16773435	-	+	-
619	Beirgh	Lewis	NB/10343516	+	-	-
620	Dun Carloway	Lewis	NB/18994122	+	-	-
621	Dun Stuigh	Lewis	NB/15404025	-	+	-
622	Loch an Duna	Lewis	NB/28544740	+	-	-
623	Loch an Duin	Lewis	NB/39285435	-	+	-
624	Dun Cromore	Lewis	NB/401206	+	-	-
625	Dun Borve 5	Lewis	NB/41855803	-	+	-
626	Loch Baravat	Lewis	NB/462597	-	+	-



Distribution of Broch remains on the Isle of Skye

Ref.	Name	Location	Grid	Broch	Probable Broch	Possible Broch
627	Dun Airnistean	Lewis	NB/48866266	-	-	+
628	Dun Smirvig	Lewis	NB/5264	-	-	+
629	Dun Ban 2	Barra	NF/63110037	-	+	-
630	Dun Chlif	Barra	NF/68190528	-	+	-
631	Dun na Cille	Barra	NF/64770167	-	-	+
632	Dun Loch an Duin	Barra	NF/69320316	-	+	-
633	Dun Scurrival	Barra	NF/69540810	-	+	-
634	Dun Sleibhe 1	Barra	NF/66020116	-	-	+
635	Dunan Ruadh 1	Barra, Fuday	NF/72520818	-	-	+
636	Dun Vulan	South Uist	NF/71402980	+	-	-
637	Dun Aligarry	South Uist	NF/76553917	-	+	-
638	Dun na Buaile Uachdraich	South Uist	NF/77774646	-	+	-
639	Dun Buidhe 3	South Uist	NF/77354629	-	+	-
640	Dun Buidhe 2	South Uist	NF/79425458	-	+	-
641	Dun Torcusay	South Uist	NF/76185313	-	+	-
642	Dun Thomaidh	North Uist	NF/759758	-	+	-
643	Dun Ban 1	North Uist	NF/871569	-	+	-
644	Dun na Mhairbhe	North Uist	NF/86277474	-	+	-
645	Dun an Sticir	North Uist	NF/897777	+	-	-
646	Dun Skellor	North Uist	NF/80757507	-	+	-
647	Dun Torcuill	North Uist	NF/889737	+	-	-
648	Loch Hunder	North Uist	NF/90466525	-	+	-
649	Toe Head	Harris	NF/97009134	-	+	-
650	Dunan Ruadh 2	Barra, Pabbay	NL/61288760	-	+	-
651	Dun a' Chaolais	Barra, Vatersay	NL/629971	-	+	-
652	Dun Sandray	Barra, Sandray	NL/638914	-	+	-
653	Auchinsalt	Stirlingshire	NN/65330099	-	-	+
654	Boquhapple	Stirlingshire	NN/65920203	-	-	+
655	Gallow Hill	Perthshire	NN/74580374	-	-	+
656	Little Dunsinane	Perth & Kinross	NO/22253252	-	+	-
657	Hurly Hawkin	Angus	NO/33213279	-	+	-
658	Drum Carrow Craig	Fife	NO/45931321	-	+	-
659	Craighill	Angus	NO/432358	-	-	+
660	Laws Hill	Angus	NO/491349	-	+	-
661	Camp Castle	Ayrshire	NS/42793272	-	+	-
662	Craigievern	Stirlingshire	NS/49509025	-	+	-
663	Buchlyvie	Stirlingshire	NS/58569425	-	+	-
664	Coldoch	Perthshire	NS/69639812	-	+	-
665	Leckie	Stirlingshire	NS/69269399	-	+	-
666	Auchincloich	Stirlingshire	NS/7679	-	-	+
667	Torwood	Stirlingshire	NS/83338498	+	-	-
668	Calla	Lanarkshire	NS/99114884	-	-	+
669	Torwoodlee	Selkirkshire	NT/46553847	-	+	-
670	Bow Castle	Midlothian	NT/46144172	-	+	-
671	Crammag Head	Wigtownshr.	NX/08913404	-	+	-
672	Ardwell Point	Wigtownshr.	NX/06704468	-	+	-
673	Teroy	Wigtownshr.	NX/09926410	-	+	-
674	Stairhaven	Wigtownshr.	NX/20905335	-	+	-



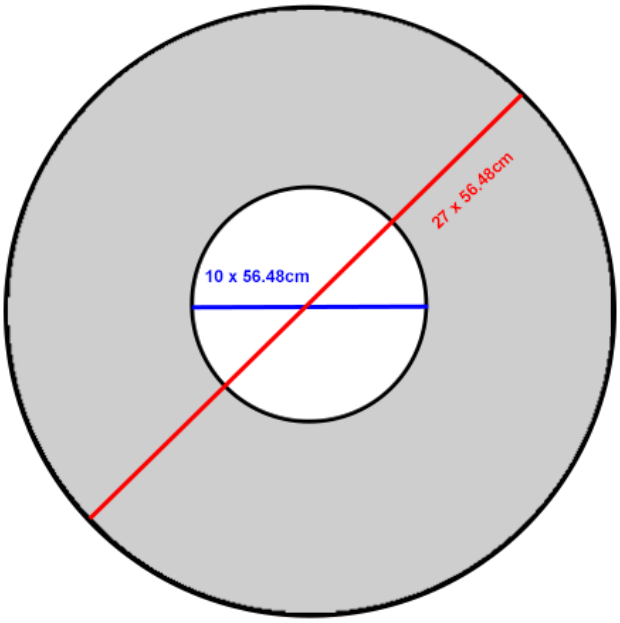
Distribution of Broch remains in the Outer Hebrides

Planning and constructing Mousa Broch

Mousa Broch was first accurately surveyed by H.Dryden between 1852-1866 those measurements and those detailed in feet and inches have been converted into metric measurements and then divided by the pendulum measurement lengths to determine which lengths were used to mark out the circles that became the outer wall and the inner courtyard wall. The first stage of the construction involved the marking of the two concentric circles on the bedrock that marked the outer and inner circumferences of the base of the broch. The outer diameter of the broch at ground level was degermined to be about 50ft 9" corresponding to 15.22m, the internal courtyard diameter measured by Dryden was 18'6" (5.64m).

The 56.48cm pendulum length could have been used to draw these two circles on the ground.

The inner circle corresponding to the inner courtyard has a diameter equivalent to 10 x 56.48cm whilst the diameter of the outer wall can be described as 27 x 56.48cm.



Mousa Broch Base Dimensions

The broch walls were then built up as a tight fitting dry stone wall allowing openings for a door and passageway and three corbelled chambers of approximately 14-16 ft length, 5ft 6" -6ft 10" width and 9ft 3" – 10ft 6" height.

The outer walls are built to taper inwards as they rise so that at the level of the scarcement around the internal wall, the outer diameter given by Dryden is 44ft 7" (1358.9cm) which can be described using the same 56.48cm pendulum length that was used to draw the

base external and internal circular plans (24 x 56.48cm). The internal diameter of the wall above the scarcement increases to 21ft 3" (647.7cm) allowing a possibly annular wooden floor/roof to be supported on the inner wall, supported centrally perhaps by a ring arrangement of wooden columns. The new increased diameter of the inner wall could have been measured using the 80.9cm pendulum with 8 lengths describing the new diameter. Perhaps a temporary central pole was used as the walls were built upwards so that the circularity and radius of both the internal and external wall could be maintained as each layer of stone was added. The wall at the scarcement floor level is interesting because although the pendulum length used to describe its diameter has changed from the 56.48cm pendulum, the circumference of the circle can now be described in terms of the 56.48cm pendulum as 36 x 56.48cm. This change perhaps reflects a change in the purpose of the walls above the level of the scarcement and when the circumference of the wall at this level is examined as a function of the other pendulum lengths it can be seen that when the circumference is divided into arc lengths corresponding to Megalithic Degrees (where 366 Megalithic Degrees is equivalent to 360 Degrees) 9 Megalithic Degrees can be described as a 50.0cm pendulum. The 50cm pendulum could be easily divided into 9 parts using a long-handled broch comb with 9 teeth so that each 5.55cm length represented 1 Megalithic Degree. It is interesting that a pendulum length of 50cm, a pendulum associated with the measurement of solar time is implicated at this level near the base of the tower where visibility of the Sun would be extremely limited (assuming the broch had an open roof) and perhaps it directs our attention to the top of the broch where the alignment of the Sun on the horizon could be viewed. The walls continued to be built up more or less vertically on the inner wall face and tapering slightly on the external wall to the top of the wallhead as a double wall separated by a staircase consisting of stone slabs which tie the two walls together and spiral their way up to the top of the broch wallhead. The tapering of the external wall reduces as the height increases to become almost vertical. The internal wall appears to be slightly concave and it increases in diameter before closing in again to realise an internal diameter of 21ft 8" close to that above the scarcement (21ft 3"). It is not known whether the slight concavity results from movement of the walls over the millennia, whether the curvature simply reflects the difficulty in maintaining a perfectly vertical wall as the wall was being constructed or whether the shape of the wall imparted some advantage in terms of structural strength or perhaps allowed weighted strings suspended from the wallhead to hang freely down the walls allowing alignment positions made at the wall head to be studied and measured in the comfort of the broch standing on the scarcement annular floor. In this way any string with a stone weight tied onto its end could be more easily suspended vertically without the possibility of the inner wall contacting it and deflecting its true position.

It is proposed that the wall-head of the broch is the most important feature of the broch because here it is finally possible to make alignments with the Sun and stars on the horizon as they rise and set. Perhaps marker stones for viewing and alignment were placed across the wallhead in a similar manner to the way in which alignments were made

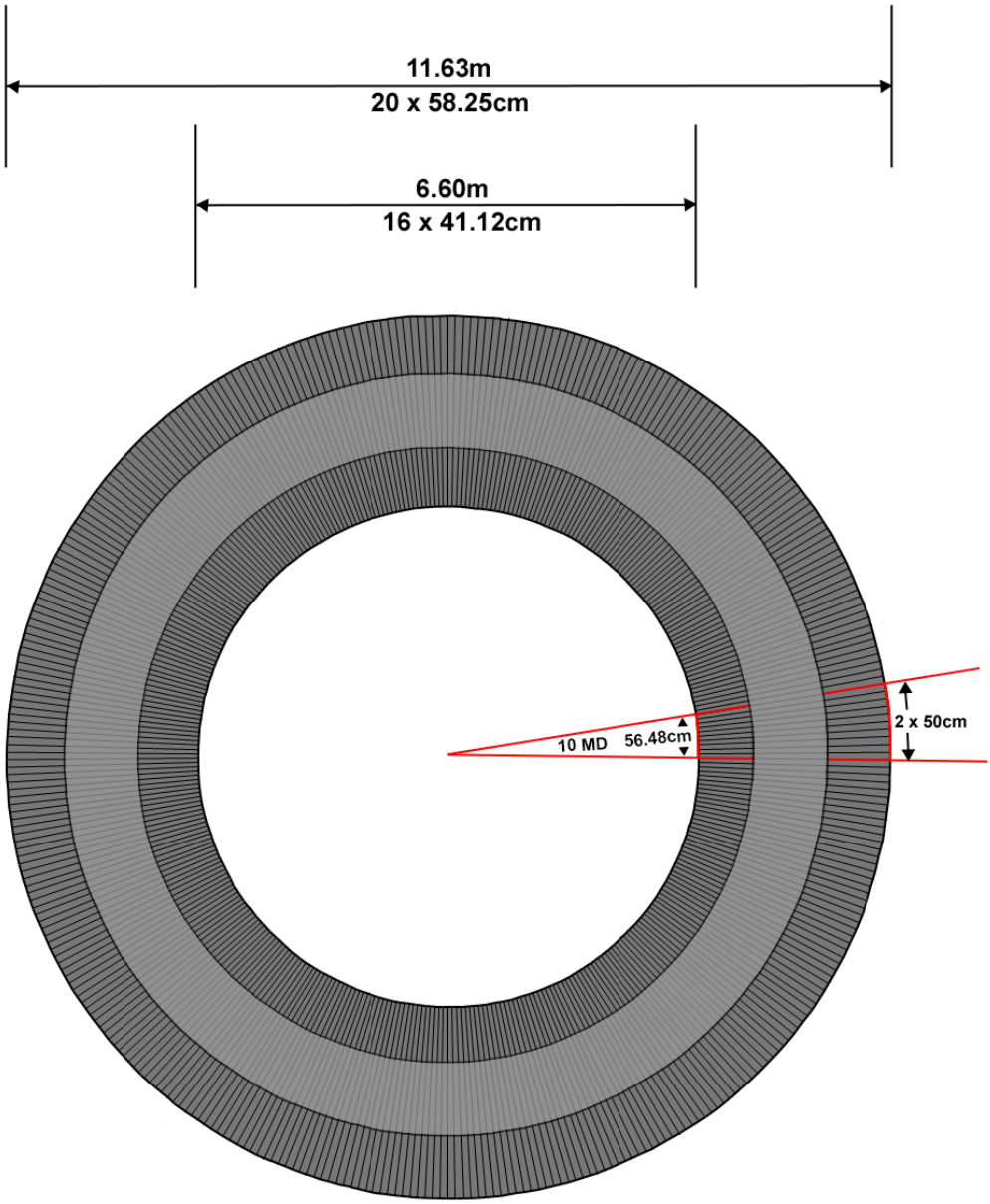
with the stone circles. Furthermore, the broch provides an opportunity to calibrate the wallhead as Megalithic Degrees to facilitate the measurement of angles directly at the wallhead. The question is whether the particular dimensions of the wallhead would enable the calibration of the wall as Megalithic Degrees.

Calibration of Outer Edge of Wall-head

The outer diameter of the Mousa Broch wall-head has been measured as 38ft 2" equivalent to 1163.32cm or 20 x 58.25cm. The choice of the 58.25cm to describe the outer diameter of the wallhead is perfect because an integer number of 58.25cm for the radius of the circle will give that integer number multiple of megalithic degrees because a circle of 58.25cm has a circumference of 366cm and as there are 366 Megalithic degrees in a circle, 1cm of arc length on the circles circumference describes 1 Megalithic Degree of angle measured from the centre of the 58.25cm radius circle. Mousa Broch having a wallhead outer radius of 10 x 58.25cm means that the circumference is 36.6m, equivalent to 366 x 10cm. The 50 cm pendulum therefore as an arclength represents 5 Megalithic Degrees and when divided by five using a 5 tooth or 9 tooth long handled bone comb gives 10cm lengths equivalent to I Megalithic Degree.

Calibration of the Inner Edge of the Wall head

The inner and outer edges of the broch wall head are separated by the annular walkway that is sunk between the two circular walls. Whilst it is the outer edge of the wall that may have been used for alignment of say the Sun on the horizon, it would have been the inner wall diametrically opposite, on the other side of the broch's wall head that would have been used to make the alignment. The internal diameter of the wall head was measured as 21 ft 8" (660cm) which can be measured using the 41.12 cm pendulum length as 16 x 41.12cm. This time the pendulum used to draw out the base dimensions of the pyramid, the 56.48cm pendulum as an arc length described exactly 10 Megalithic degrees. Once again, the pendulum length can be divided by 10 to describe 1 Megalithic Degree as an arc length, this time as 5cm using a 5 or 9 or 10-tooth comb. There is no evidence on the wall head of any calibrations but it is doubtful that the original wall head stones remain in position for both the inner wall head and outer wall head could be carved into the inner and outer wall heads as lines every degree or half a degree aligned with each other and with the cardinal positions. It would also be possible to carryout measurements inside the broch by having long strings with stone weights at either end. With the viewing point the stone attached to one end of the string is placed in the sunken walkway with the string going up over the inner wall head and into the calibrated notch carved into inner wall head and the string with the other weight is lowered vertically down inside the broch to reach the scarcement floor. The alignment string could be similarly lowered by



Mousa Broch Wallhead Divided into 366 Megalithic Degrees (MD)

The internal and external diameter of the broch's wall head measured as 16 x 41.12cm pendulum lengths and 20 x 58.25cm pendulum lengths respectively allows the internal and external circumferences to be divided into arcs lengths corresponding to 10 Megalithic degrees that can be described by one 56.48cm pendulum length on the inner circumference and two 50.0cm pendulum lengths on the outer circumference.

References

Details of every currently known, probable and possible broch in Scotland is collected in 1426 pages of three volumes of British Archaeological Reports. Many of these brochs were personally visited, surveyed and excavated by Professor Euan MacKie himself over many decades of dedicated research.

MacKie E. W, 2002 The Roundhouses, Brochs and Wheelhouses of Atlantic Scotland c.700BC – AD500, Architecture and material culture Part 1 The Orkney and Shetland Isles, British Archaeological Report, British Series 342

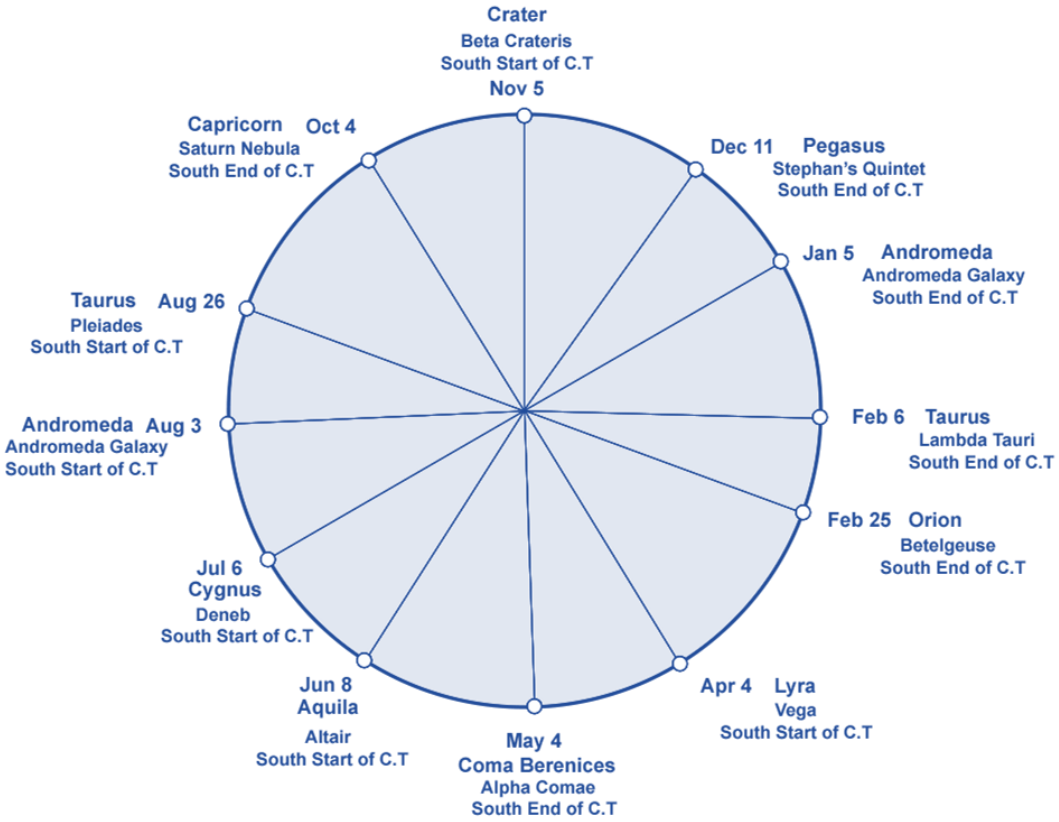
MacKie E. W, 2007 The Roundhouses, Brochs and Wheelhouses of Atlantic Scotland c.700BC – AD500, Architecture and material culture Part 2(I) The Northern and Southern Mainland and the Western Islands, British Archaeological Report, British Series 444(I)

MacKie E. W, 2007 The Roundhouses, Brochs and Wheelhouses of Atlantic Scotland c.700BC – AD500, Architecture and material culture Part 2(II) The Northern and Southern Mainland and the Western Islands, British Archaeological Report, British Series 444(II)

Euan MacKie personal communications.

Festivals and Calendar for 300BC

The possible Pictish festivals celebrated in Shetland around 300BC can be postulated by considering the festival days indicated by the stone alignments of the Neolithic stone circles and the festivals indicated by the Class I Pictish symbol stones. Some of the most important stellar alignments involved the constellations of Crater, Taurus, Coma Berenices and Capricorn representing the Pagan festivals of Samhain, Imbolc, Beltane and Lunasadh. The stars in the Summer Triangle, Deneb, Altair and Vega and Betelgeuse in Orion were also seen to be aligned due South at Civil Twilight (C.T) on important festival days. The alignment of deep space objects such as the Saturn Nebula (NGC7008) in Capricorn, Stephan's Quintet in Pegasus, the Dumbell Nebula (M27) in Cygnus, the Andromeda Galaxy (M31) in Andromeda, the Cone Nebula (NGC2264) in Monoceros, the Pleiades (M45) in Taurus and the Triangular Galaxy (M33) in Triangulum. By calculating the days on which the deep space objects were aligned due South at Civil Twilight, either at the Start of Civil Twilight at dawn or the End of Civil Twilight at dusk, the year can be found to be divided into twelve fairly evenly spaced festival days when displayed as a "Wheel of the Year" calendar with the spokes of the wheel representing the stellar festival days.

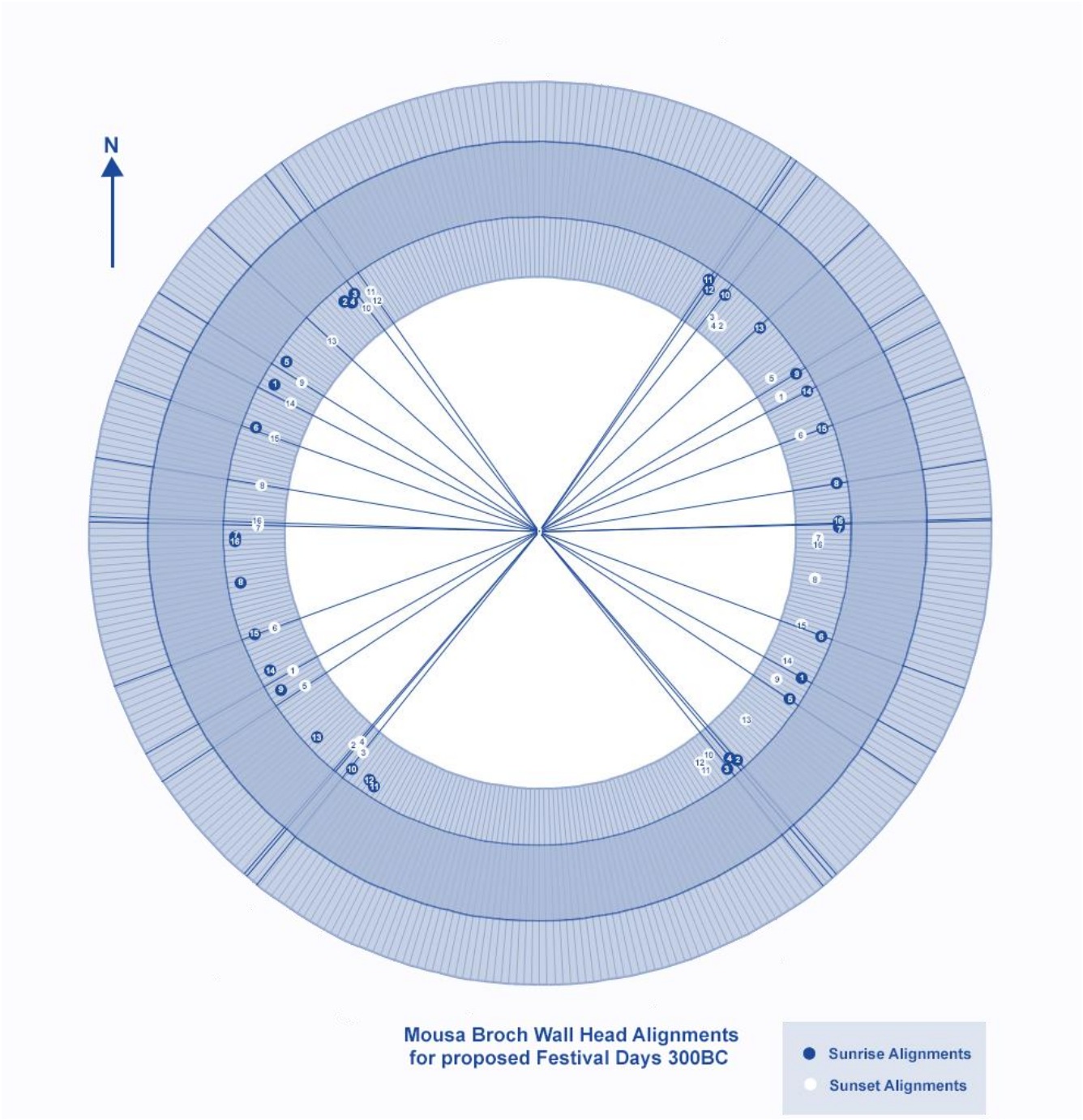


Possible Pictish Calendar for 300BC represented as a Wheel of the Year

The solar festival days represented by the Winter Solstice, Spring Equinox, Summer Solstice and Autumn Equinox can also be included in the calendar. These solar festival days are constantly changing with time and any alignment of stars with cardinal positions can be regarded as coincidental but where they do occur, they may have been used themselves as markers for the solar festival. One such example of this is the Winter solstice festival which occurred on the 24th December when the Fried Egg Nebula (NGC7742) lying directly beneath and bisecting the constellation of Pegasus was aligned due South at the End of Civil Twilight.

The days of these festivals can be marked by the position of the Sun on the horizon either at sunrise or sunset. The bearing of the Sun on these days some 2300 years ago can be calculated using the archaeo-astronomy program Sky Map Pro II. The bearings of the solar alignments corresponding to the festival days have been plotted onto the parapet wallheads of Mousa Broch in the diagram below to show how alignments could have been made from the galley walkway at the top of the broch across the wallhead to the Sun on the horizon and those actual alignments marked using bone pointers in stone bases and then perhaps indicating those alignments on the vertical walls within the broch using weighted strings from the wallhead down the internal broch wall.

Reference	Day	Festival Day	Sunrise Bearing (degrees)	Sunset Bearing (degrees)	Alignment South at Civil Twilight
1	5th Nov	Start of Winter Samhain	118.92	240.82	β-Crateris
2	11th Dec	αα	139.10	220.82	Stephan's Quintet
3	24th Dec	Winter Sol.	141.24	218.76	
4	5th Jan		139.74	220.32	Andromeda Galaxy
5	6th Feb	End of Winter Imbolc	123.73	236.49	
6	25th Feb		110.15	250.16	Betelgeuse
7	25th Mar	Spring Equ.	88.55	271.85	
8	4th April		80.76	279.66	Vega
9	4th May	Start of Summer Beltane	58.31	302.16	A-β Coma Berenices
10	8th Jun		37.86	322.43	Altair
11	27th Jun	Summer Sol.	33.88	325.12	
12	6th Jul		34.76	325.08	Deneb
13	3rd Aug	End of Summer Lunasadh	47.06	312.49	Andromeda Galaxy
14	26th Aug		62.32	297.20	Pleiades
15	4th Oct	Lunasadh	69.97	289.56	Saturn Nebula
16	27th Sep	Autumn Equ	88.33	271.26	



Procedure to make alignments with the Sun on the horizon.

1) Make alignment across the broch to the Sun on the horizon using the Central Pointer for alignment and place weighted pointer on inner parapet wall head from viewpoint.
2) Go round galley walkway and place a second weighted pointer on the inner parapet wall to align with the central pointer and the first weighted pointer just positioned on the opposite side of the inner parapet
3) Return to the first weighted pointer to check that the two weighted pointers on the parapet wall head align with the central pointer and that all three align with the rising or setting Sun on the horizon.

Suggestions for the way in which alignments with the Sun and Stars could have been made using the Artefacts that have been found during Broch excavations

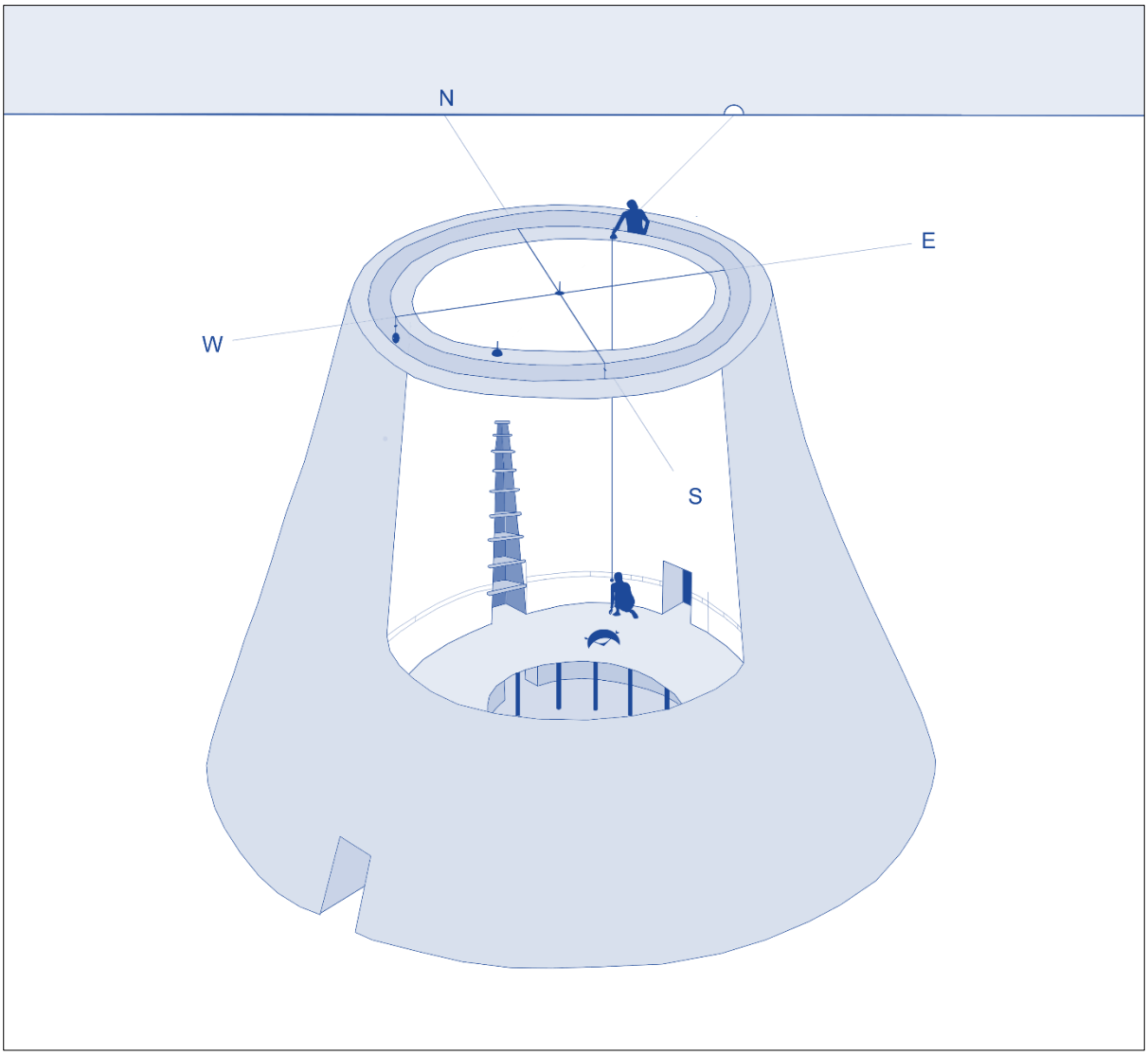
The first requirement is to establish the North-South and East-West axes as reference points to allow other alignments to be made.

The North South axis could have been marked on the parapet walls for reference using the fact that a vertically placed stick in the Sun casts its shortest shadow when the Sun is at its highest azimuth which occurs when the Sun is due South in the sky. This would allow the North-South axis to be established and marked by grooves on the stone slabs forming the wall head of the broch. The East-West axis could then be determined by simply bisecting the half circumference length between the North and South marks and carving marks corresponding to due East and due West.

The alignment of the Sun on the horizon measured as a bearing can be made across the Broch wall head but given that care appears to have been taken to construct the wall heads inner and outer circumferences as lengths that were readily divided into arc angles corresponding to pendulum lengths it is apparent that the wall heads were in effect calibrated in Megalithic degrees in much the same way as a protractor is calibrated in degrees. In this case the measurement of a bearing relative to North has to be made relative to the origin of the protractor or in this case the centre point of the broch. The difficulty here is that the centre-point of the broch occupies the centre of an open space and is not accessible. It would seem unlikely that the broch builders would have erected a very long central pole up through the broch reaching and extending slightly above the level of the wall head to allow alignments between a viewer on the walkway, the central pole and an object on the horizon, marked by the level of the broch wall head. There is a much simpler solution to marking the centre-point with a physical pointer using nothing more than twine, a stone with a hole in its centre and a stick or bend reed.

The method involves first attaching a string across the broch corresponding with the North and South marks on the wall head. The next part involves taking a small round flat stone with a hole drilled, say with a bow drill, through its centre. Standing at the North end of the North-South fixed string the round stone can be held on top of the string and the East-West axis twine threaded down through the hole in the stone under the North-South string and back up through the hole in the stone. In this way the North-South string is under the round stone and the East-West string lies across the top of the stone but forms a loop around the North South axis string beneath the stone. The East West axis string can then be held by a person at either end and by walking around the sunken walkway slide the assembly until the string ends correspond with the East and West position marked on the wall head. The circular stone now lies at the centre point of the broch. The East-West Axis string can once again be fixed in position by attaching the string to a wedge in the wall at the appropriate position or perhaps just using stone weights in the walkway heavy enough to keep the sting taught. It might be reasonably questioned as to why would you need to complicate the procedure by involving a stone with a hole in the procedure, as it would be easy to just have wedges in the wall head marking the

cardinal points and it would be easy to simply attach two separate strings to the wedges independently to form a N-S and E-W cross of strings. The problem here is that although the centre of the broch and reference point for bearings to be made is marked by the point at which the strings cross, that reference point is just that, a point and is practically useless for alignment purposes. The use of a stone with a hole at its centre offers the possibility of taking a stick or reed and bending it to fit into the hole in the stone so that either end protrudes through the stone either side of the North-South axis string. This is done after the stone has been coupled to the N-S and E-W strings and results in a flat stone sandwiched between two perpendicular strings and having an upright vertical stick or reed that can be used for alignment purposes when the stone occupies the centre point. The weight of the stone provides a stable base that allows the stick to remain vertical.



Cut away diagram to illustrate one possible way in which alignments could be made at the wall head and measured and marked inside the broch using stones with drilled holes and bone pointers as alignment markers and twine with weights. Aligning the position of the rising Sun around the time of the summer solstice.

To make an alignment with the Sun for instance the viewer would move around the walkway looking across the internal parapet wall head until the Sun on the horizon was aligned with the central reed and his eye. He would then place a marker on the inner wall head corresponding to the position of his eye. He could the walk around the parapet to position a second marker on the wall head corresponding to the alignment of the Centre Point marker and the wall head marker he had just put in position. The position of the sun on the horizon could be measured and marked on the wall head itself or given the exposure more comfortably measures and recorded by hanging down weighted strings inside the brochs so that they corresponded with the wall head marker positions and hung over the wall head and vertically down the internal broch wall to the level of the first floor platform where the alignment could be measured accurately using pendulum lengths and quadrants and perhaps marked around the circumference of the internal walls.

Examining the Broch Finds

There are thousands of artefacts that have been recovered from brochs. The challenge was to think how such a structure could have been used as an observatory using only the artefacts found during excavations. The finds consistently found in the brochs are Round flat stones with holes drilled through their centres that have been identified as loom weights or spindle whorls, combs made of bone some consisting of many fine teeth, assumed to be for combing hair, another class of comb, called “broch combs” are much more common and are more substantial consisting of long handled combs carved from a single piece of bone with a relatively small number of strong teeth. Large numbers of bone needles and larger bone pointers have also been found. The broch builders would also have had string and ropes and wooden items but these unlike those constructed in stone and bone have perished over the past one and a half thousand years or so.

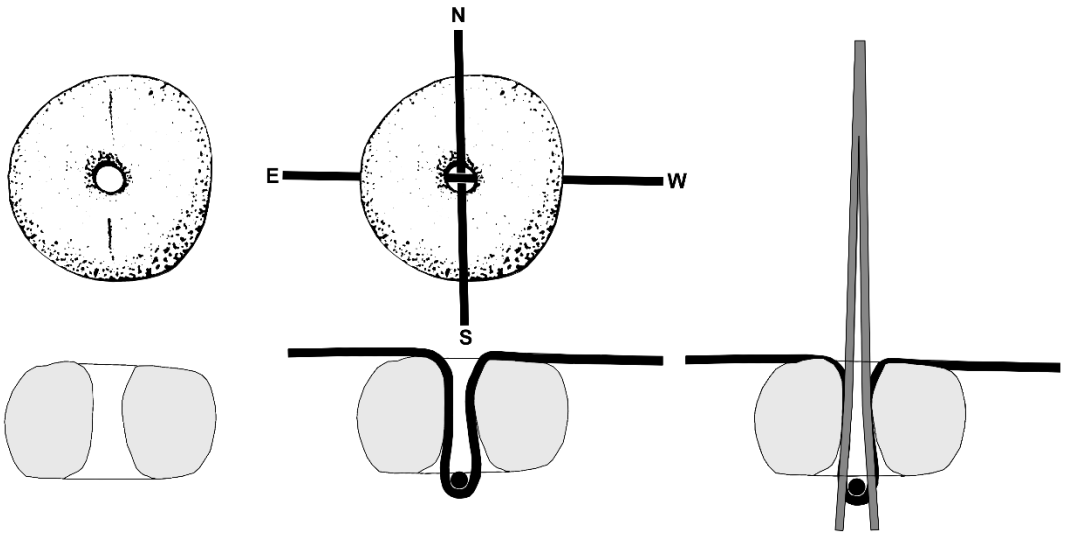
Drilled Stones

Many hundreds of stones drilled with holes through their centres have been found during archaeological excavations. Most are quite small, round and flat and are typically referred to as loom weights, used to keep strands of wool taught during weaving, but may equally have been used as pendulum bobs or as weights at the end of strings lowered from the broch inner parapet to mark the positions of alignment made at the wall head on the inside wall of the broch. Some of these small drilled stones may have been used to connect the N-S and E-W axial strings and support a wooden or bone pointer used to mark the centre point of the Broch at wall head level.

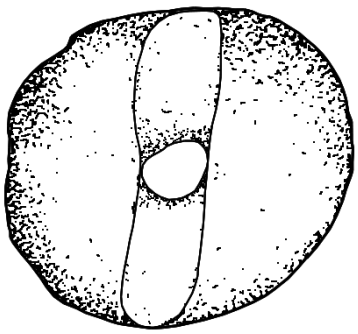
Other drilled stones are heavier and have a dome shape on one side and a flat side on what is presumed to be the bottom of the stone. These stones are often referred to as spindle whorls that have a wooden spindle fitted into the hole and used to spin wool fibres into a thread. There is the possibility that these stones fitted with wooden or bone

spindles were used on the wall head parapets as markers, their weight and flat bottoms being enough to allow a short vertical pointer to be aligned with an object on the horizon.

There are also drilled stones that are significantly larger that are described as weights. These weights could have been used to keep strings, used to mark the North – South axis and the East – West axis, taught. Thereby allowing the centre-point marker to be maintained at wall head level and its central position stable and less likely to be affected by gusts of wind.



Possible Broch Wall head Centre-Point Marker Point with E-W and N-S String Configuration and Reed Alignment Pointer. Stone with groove found at Dun an Rhiroy.



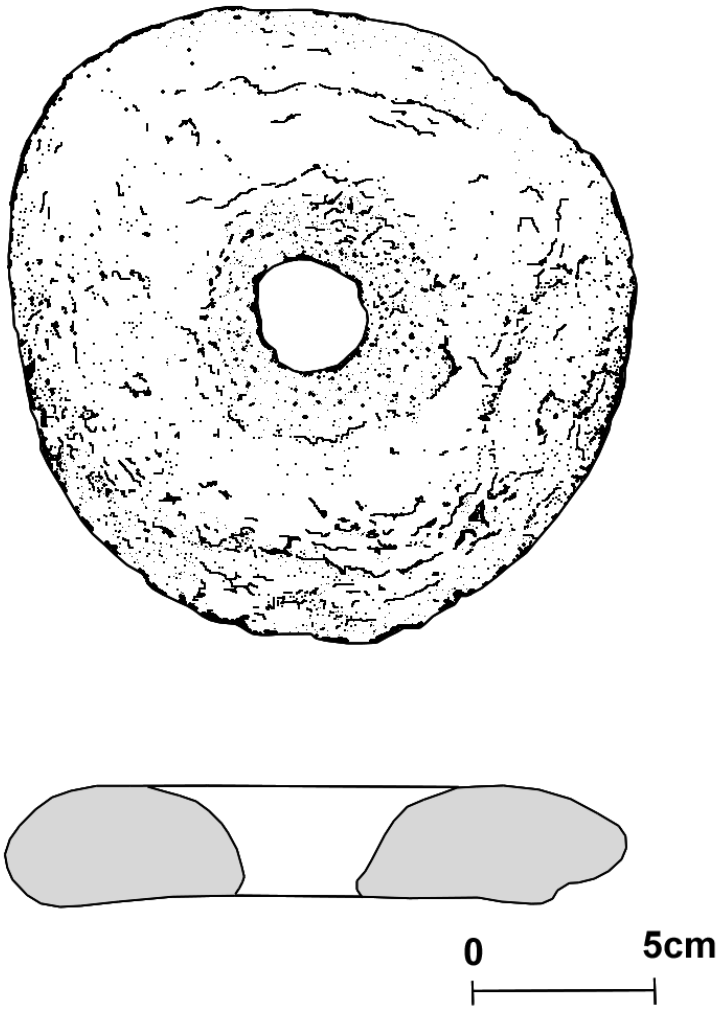
Stone with hole and groove from Gurness Broch

Proposed method of positioning the stone with upright alignment reed is to fix a string across the broch wallhead aligned North – South. The stone with the groove is placed groove down onto the N-S Axis String. Standing at the parapet say at the North position, a second string is placed acoss the top of the stone and then threaded down through the hole from above forming a loop around the N-S string and back up through the hole and across the top the top of the stone. This string will correspond with the East – West axis

of the Broch wall head but first a reed or stick is bent in two and pushed through the hole in the stone with the ends of the pointer going either side of the N-S string. Either end of the E-W string is then pulled taught by two people and they pull the string as they walk around the parapet sliding the stone and alignment pointer southwards along the N-S axis string until the E-W string aligns with the due East and due West points on the broch wall head. The pointer is then positioned at the centre-point of the broch and can be used to make alignments of the Sun or stars on the horizon from any position around the walk way around the wall head.

There is another example of a stone with a hole drilled through it that also has a single groove bisecting it from Gurness Broch as illustrated below.

The position of alignment can be marked using a weighted alignment pointer made of bone or stick fitted into a flat-bottomed stone weight such as the one illustrated below. Once the first alignment has been made on the wall head opposite the deep space object on the horizon, the position of the deep space object itself can be marked with a second movable marker by aligning that marker with the centre-point marker and the marker just positioned on the wallhead forming a straight line between the two wall head Parapet movable markers and the fixed centre-point pointer.



Stone Weight found at Gurness Broch

Combs

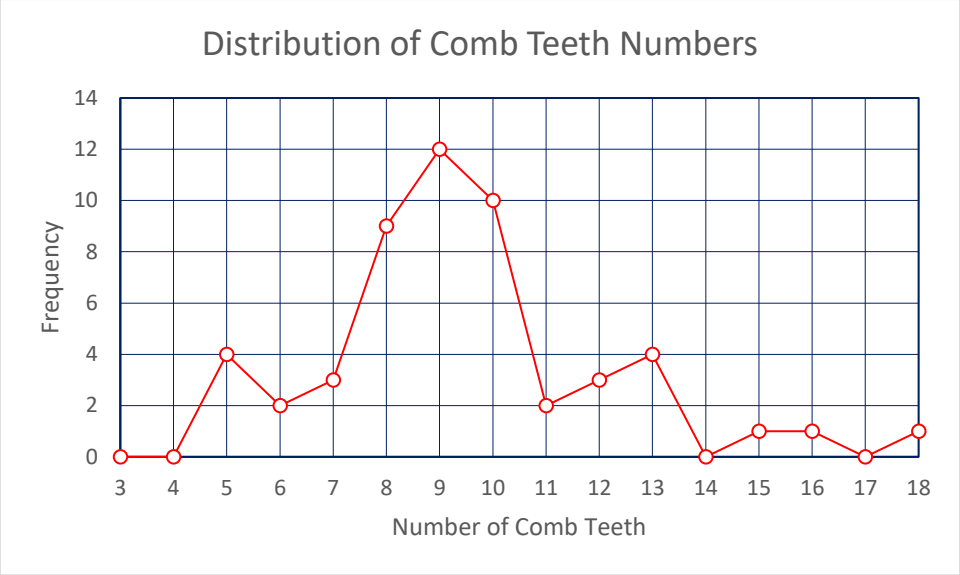
The second class of finds that represents the most common artefact of worked bone are the long-handled combs called “broch combs”. It is interesting that so many of the artefacts can be associated with weaving. There is the consistent theme of loom weights, spindle whorls and combs and maybe the brochs were used for the purpose of making cloth. There is also the possibility that these artefacts were seen as familiar tools that could equally usefully be used in making alignments and measuring the position of deep space objects in the broch observatories.

Broch Long-Handled Combs

A large number of long-handled bone combs have been found during archaeological excavations at broch sites. A selection of those combs included in the BAR British Series 343,444(I) and 444(II) by Euan MacKie have been examined to determine the number of teeth present on those in a sufficiently good state to determine whether there are preferred numbers of comb teeth or if the designs are more or less random.

Broch	Reference, Location	Number of Teeth	Total Number Combs found	Page
Oxtrow		7, 9	2	283
Burray East		7, 9, 10	4	283
Gurness		12, 9,10, 13, 9, 9, 11	10	309
Midhowe		8, 11, 8, 8, 13, 9, 9, 10, 9	11	315
Burrian		8, 10, 16, 12, 15, 10, 8, 12,	12	350
Howemae Wheelhouse		13, 6, 9, 10	4	357
Thrumster	Caithness	8	1	503
Wester Broch	Wick, Caithness	5	1	553
Elsay	Wick, Caithness	5	3	564
Kettleburn		8, 6	4	565
Keiss South		10, 8	2	591
Keiss West		5	1	597
Nybster		9, 9	3	612
Carn Liath		9	1	736
Balevulin Hut Site		13, 18	3	1025
Bac Mhic Connain		10, 10, 8	4	1251
Foshigarry		7, 5	7	1264
Garry Lochdrach		10	1	1271

74 bone comb artefacts of which 52 were sufficiently complete to determine the original number of teeth. The average number of combs found during the 18 excavations was just over four indicating that these combs were probably used in some activity that was carried on inside the broch.



Graph to show the pattern of number of comb teeth found on the 52 combs.

There appear to be a preferred number of teeth on the combs which may relate in part to the dimensions of the pieces of bone used in their construction but there are three main peaks which can be examined to see whether there is any possible significance to the number of teeth carved in the bone pieces.

A number of combs were found that had either 22 teeth or 43 teeth which were seen to allow 22 loops of twine to be threaded through the teeth allowing 7 of these loops to be selected to allow a desired circumference length to be converted into a radius length that could be used to draw the circle with the desired circumference. In other words, these combs may have been used as pi-calculators rather than domestic combs.

Perhaps the long-handled more robust bone combs with fewer and fatter teeth could have been used to serve a similar purpose dividing a known length into a number of equal parts that had some significance to the inhabitants of the brochs.

The idea is that at the wall head of the broch the outer circumference can be described where certain pendulum lengths relate to arc angles, measured as Megalithic Degrees, that can be described as whole integers. It is proposed that the number of parts that the pendulum length requires to be divided into is related to the number of teeth on the comb used to divide that length using the method of forming equal lengths of loops of twine between the teeth. It should also be remembered that the pendulum lengths chosen were those that gave whole thousands of swings corresponding to special numbers of Megalithic Degrees, related to the hypotenuse lengths of Pythagorean Triplet Right angle triangles. These numbers are 13, 16, 17, 23, 27, 29, 32, 34,37 and 41. In this way perhaps a pendulum length that represented say 13 Megalithic degrees of arc at the wall head could be passed through the teeth of a 13 tooth comb as a series of 12 loops

and two lengths at either end of the same length that could be used to calibrate the wall head circumference in Megalithic Degrees by using the length of one of the thirteen loops to represent One Megalithic degree. This length could then be used to describe the outer circumference as 366 Megalithic degrees. The ways in which the combs with "preferred" numbers of teeth could be used to divide Megalithic Arc Lengths to provide unit Megalith Degrees is illustrated below.

The Pi-Calculator Comb

It has been shown how pendulum lengths used as integer multiple lengths could account for the radial dimensions of the Neolithic stone circles of Scotland. It has also been shown how these multiple lengths could be obtained by winding a twine around stone geodesic spheres. Whilst the measurement lengths used formed a series of lengths related through circular geometry, so that one measurement unit used as a radius automatically produced a circle whose length of circumference was an integer multiple of one of the other measurement units, there may have been occasions when a particular length of circumference was required and the radius that produced a circle of that circumference was needed in order to draw that circular circumference on the ground. Today of course it is known that the relationship between a radius of a circle and its circumference is given by

$$C = 2\pi r$$

Where **C** is the circumference

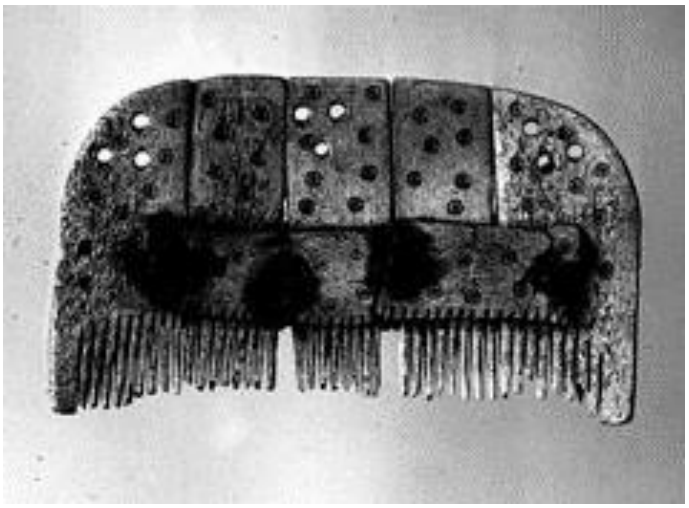
r is the radius and

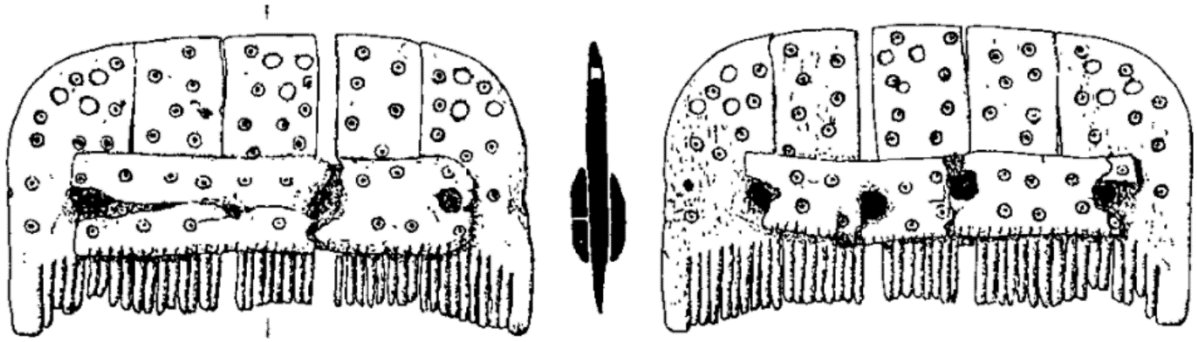
π is approximately 3.1427

Today the radius that gives a desired circumference can be calculated by division and then measured using a ruler onto a length of string or a tape measure and then scribed into the earth to form a circle. The question is whether in pre-historic times man had the ability to make such arithmetic calculations and if not, how he might have achieved such a mathematical procedure using some other practical method. The circle was of central importance to Neolithic people inhabiting Scotland some five thousand years ago and it has been shown how the hundreds of stone circles were constructed as calendrical devices and how megaliths placed on the circumference were used for alignment purposes with the Sun on the horizon. Many circles had circumference lengths that could be divided into arc lengths that were equivalent to integer multiples of one of the measurement lengths whose length in turn corresponded to an integer multiple of Megalithic Degrees of arc angle. This allowed the movement of the Sun and the stars rising and setting from and into the horizon to be conveniently measured.

There is an interesting class of artefact that has been found that has the appearance of an everyday object whose purpose has never been questioned. The comb. Whilst most

comb artefacts found did serve the primary purpose of combing hair either human or sometimes wool, there are some combs that appear to be different in certain respects. The first thing is they have a relatively large number of teeth, which might be accounted for if they were used as nit combs, the second common feature is that these combs have in common is the pattern of decoration that adorns their spines which consists of arrangements of dots and circles that form triangular and square shapes in line with the patterns of stars in the Summer and Winter Triangles and the Square of Pegasus. The third and most important feature of the combs is that they have precisely the same number of teeth, namely forty-three. This number of teeth could of course be coincidental but it is interesting to consider why such an apparently random number of teeth could be useful if the comb served some other purpose.





Comb recovered from Burrian Broch, North Ronaldsay Scotland showing pattern of circles and dots and three sets of holes arranged as triangles. National Museum of Scotland

There is a particularly interesting comb made from bone that was found at Burrian Broch in North Ronaldsay in Orkney. The first remarkable thing about this comb is the pattern of decoration on the comb with cup and circle-type carved images all over the comb, a symbol that we are confident represents stars, much in the style of the ancient stone megaliths decorated with similar cup and ring marks and indeed the way in which our

Sun today is symbolised. There are 44 of these circular patterns over the main body of the comb on one side and sixteen along the comb's spine that keeps the five pieces of bone that comprise the combs needles together. There are three triangular arrangements of three holes that pierce through sections 1, 3 and 5, that is, the two end pieces and the central section. This appears to represent the Summer Triangle moving across the night sky through the seasons. The Summer triangle consists of the three bright stars Deneb in Cygnus (the Goose), Altair in Aquila (the Eagle) and Vega in Lyra (the Horseshoe) so their position on the comb seems to replicate their position in the sky remarkably well for these three main festival dates and this appearance is heightened by the elliptical curve shape of the "comb" handle

The three stars comprising the Summer Triangle are precisely aligned with cardinal positions on the following days:

Festival	Date 1200BC	Star	Alignment
Mid Winter	Dec 21st	Vega	Due East Dawn
Spring Equinox	Apr 1st	Altair	Due South Dawn
Mid Summer	Jun 21st	Deneb	Due South Dawn
End of Summer	Aug 6th	Deneb	Due West Dawn
Autumn Equinox	Oct 3rd	Deneb	Due South Dusk

The pattern of three stars on the comb can therefore be interpreted as representing the position of the Summer Triangle at dawn as the seasons move from the Mid-Winter Festival when it is due East (as portrayed on the left-hand position on the comb) to the Spring Equinox when it is due South at the central position on the comb, to the End of Summer Festival when the Summer Triangle is due West (depicted on the right-hand side of the comb) and then back to its central position on the comb due South at the Autumn Equinox but now at dusk rather than dawn.

Whilst the decoration is beautiful, its astronomical portrayal of the passing of the year may suggest that the comb could have had a more serious use than as a means of combing hair. The question is how a comb might be used as a mathematical tool.

If a person had a long length of a fine twine consisting of a multiple number of pendulum lengths that he wished to form a circumference of a circle, and he wanted to know what radius length was required to make a circle of that circumference, he could wind the length of twine through the teeth of the 43-tooth comb in such a way as to form twenty-one long loops between alternate teeth and have the ends of the length of the twine hang down as a two single strands at the first and last gap of the comb. The 21 loop ends could be threaded onto a straight bone needle and gently pulled down to form a common length of loop, whilst at the same time the single strands of twine hanging down at the end of the comb rise up shortening as the loop lengths increase, until the strands and loops all form the same length. Once the two ends of twine and the twenty-one loops are the same length, the circumference has in effect been divided into 22 equal parts consisting of 21 loops and 2 half loops consisting of the two end strands. It is now a simple procedure to find the radius of the circle that results in a circumference of the desired length of twine, by taking the seven middle loops of the comb and using that length as a

radius to draw a circle. The reason for this is that the comb is a good tool to allow the very near approximation of pi (22/7) to be achieved.

$$\pi = 3.141593.$$

$$22/7 = 3.142857 \ (1.0004 \times \pi)$$

There are a couple of other good examples of combs that could have been used as pi-calculators in converting circumference lengths to radii. One again was recovered from the ruins of a broch at Buckquoy and the third example is a Coptic wooden comb from Egypt dating from the 6th-7th Century AD.

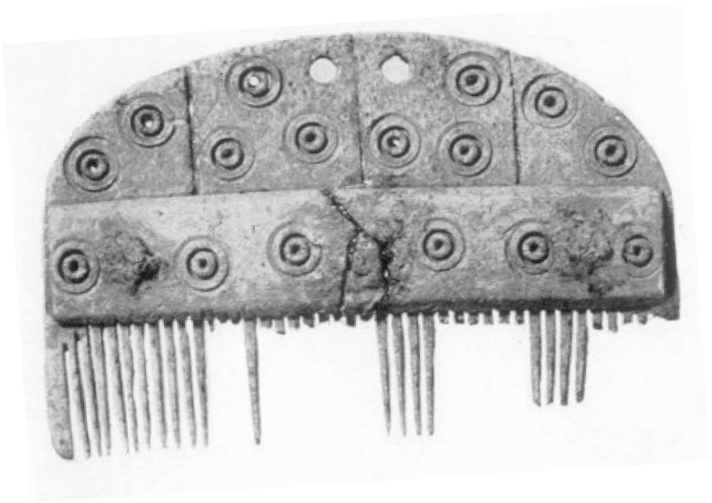
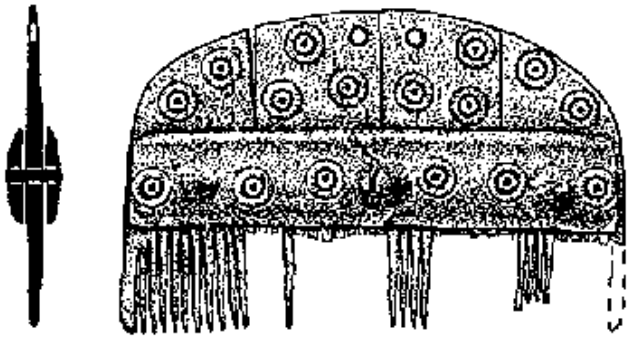


Image of the Buckquoy comb from the paper by Anna Richie describing the archaeological excavation at the Buckquoy Pictish-Norse farmstead in 1976. The comb shows evidence that it originally had 41 teeth, 43 teeth including the outer teeth.



Drawing of Buckquoy Comb showing its construction from four pieces of bone cut with teeth sandwiched and pinned between two horizontal lengths of bone

The Buckquoy comb was recovered from a Pictish and Viking-age farmstead in Buckquoy, Orkney. This distinctive type of comb has been found on three other sites in Orkney: the Broch of Burrian, North Ronaldsay (as already illustrated)

This distinctive type of comb has been found on three other sites in Orkney; the Broch of Burrian, N Ronaldsay, the Broch of Berwick (Anderson 1883, fig 213) and the Brough of Birsay. It would appear to have been a local Orcadian fashion, most probably among the

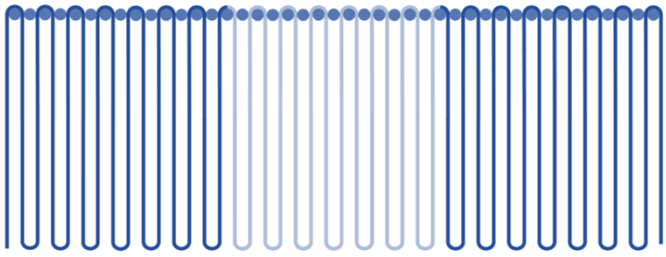
Pictish population, and does not appear to have been found outside Orkney (thus militating against MacGregor's suggestion (1974, 80) that the form may have been derived from one-piece combs found in S Scotland). The other comb-fragments from this phase belong to the more common double-sided composite type, again of native origin; nos 55 and 56 show linear incised decoration

Comb found at Dun Cuier, Barra, Outer Hebrides 600-800AD National Museum of Scotland

The Dun Cuier comb is a beautifully decorated example of a single edge arched comb decorated with 21 dotted circles and a further ten dotted circles on its connecting bar. There are intricately cut patterns in the comb but most importantly there appear to once more have been 43 teeth in the original comb.

Method of Winding Twine between the Comb Teeth

The 43 teeth could be used to form 21 loops and 2 single strands at either end in the way proposed so that 7 loops give the radius length corresponding to the circumference length of twine wound between the comb teeth. However the other side of the combe which has only 11 teeth could also be used to form 10 loops with 2 single strands and three loops and one single strand taken from either end of the comb is equivalent to the radius of the circle as the length corresponds to 7 single strands whilst the 10 loops and 2 strands

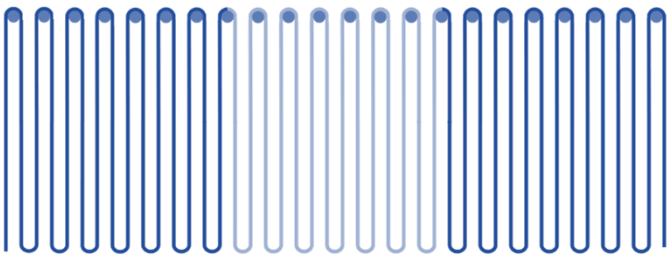


Pattern of Winding loops of twine through a 43 tooth comb to produce the Radius of the circle that gives rise to this length of circumference.

There is another common style of Pictish comb that consists of a double-edged comb constructed from sections of bone sandwiched and pinned together between two horizontal lengths of bone. This double-edged style of Pictish comb is the one commonly represented as the Comb Symbol on Pictish Stones dating to 1200BC.

This comb has 22 teeth along one edge and appears to have had 43 teeth along the other edge

Double sided bone comb from Freswick Links, Caithness dated to 800-1100AD. National Museum of Scotland



Twenty-two tooth comb showing winding of twine to produce 21 loops and 2 half-loops. The seven loops shown in the centre of the comb are equivalent to the radius of the circle that has a circumference equivalent to the length of 22 loops.

It is evident that any comb with a sufficient number of teeth could be used to create the required number of loops, that is a comb with more than 11 teeth but in this case the comb would not lend itself so elegantly to the required division and the person using the comb would have to know to form either ten loops plus two half loops or 21 loops and two half loops.

As an example, the comb shown below, which is a Pictish comb found at Buiston Crannog, a round house made on a man-made island in a loch, is decorated with the usual pattern of triangular dots and circles but has 35 teeth on the bottom edge which seems to go

against our theory about such combs being used as pi calculators, but it can be seen in this example how the central 22 teeth appear to be conveniently separated from the teeth on either side by intentionally carved larger gaps

Bone double-edged Comb from Buiston Crannog, Ayrshire 600-800AD

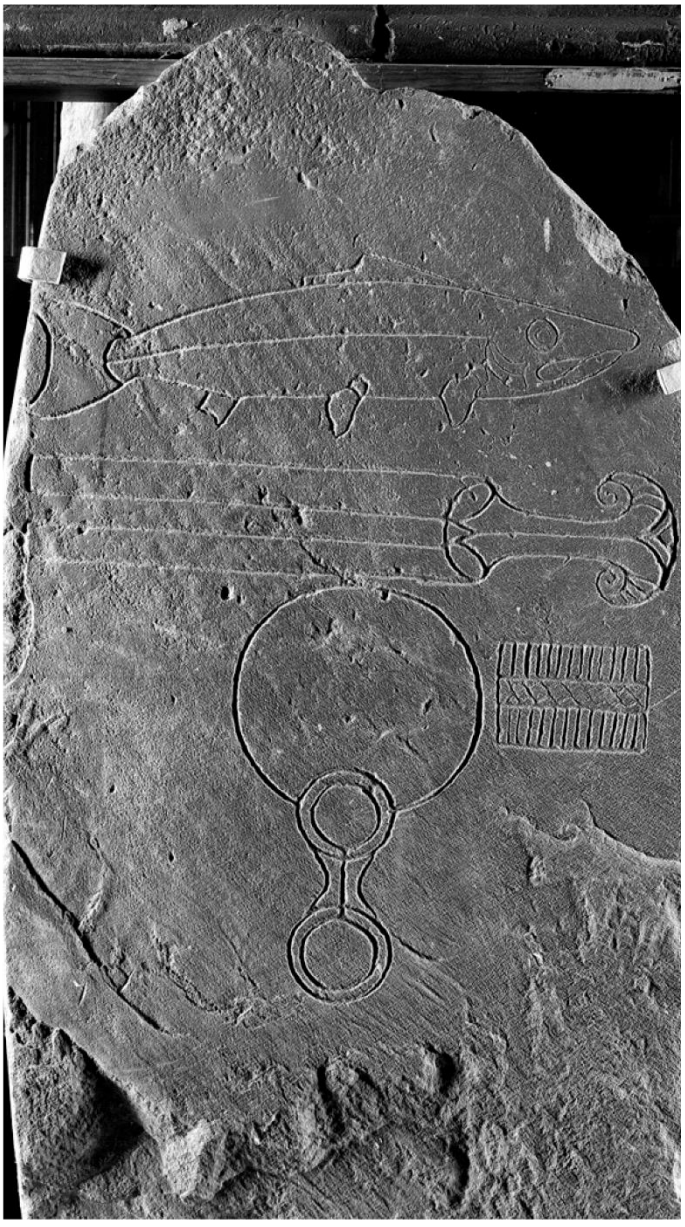
National Museum of Scotland. Note the 22 central teeth on the bottom edge

The fact that there are combs with 22, 31 and 43 teeth which are quite often decorated with patterns of the “summer triangle” of dotted circles suggests that there were some combs that were designed with the main purpose of being useful tools in determining the lengths of radii of circles that had a desired circumference.

It is also interesting that on the other edge of the comb there are 34 teeth which is one of the Pictish special numbers (Pythagorean Triplet Number), There is also some evidence that there are two sections of teeth that appear to be separated based on their slightly different lengths and the presence of three slightly larger gaps separating the teeth into a group of 5 central teeth and a group of 9 teeth to the right.

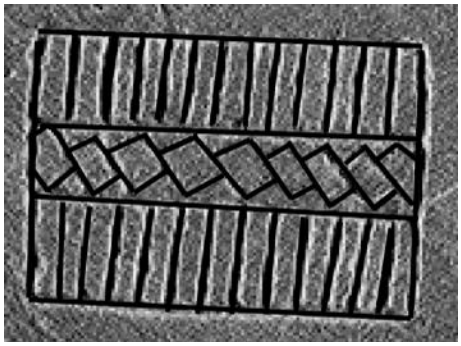
Evidence of Combs Carved on Class I Pictish Symbol Stones

There are very few combs that have survived the passing millennia, and fewer still that have survived in a sufficiently intact condition to enable the determination of the number of teeth originally cut. There are however combs that have been carved as symbols on the Class I Pictish stones and they can be examined to see whether there is any indication of their use as potential pi-calculators. Previous analysis of the Class I Pictish stones has revealed the date they were carved as being around 1200BC.



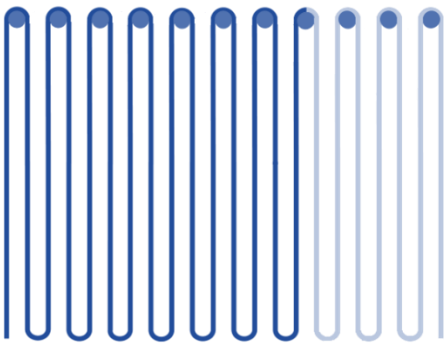
It appears that the level of detail employed in carving teeth on a Pictish comb symbol is usually quite basic. The Pictish Comb symbol is relatively small in comparison to other symbols, reflecting the relatively small size of the constellation of Coma Berenices compared with, for instance the constellation of Virgo depicted by the Pictish Mirror

symbol which lies directly beneath Coma Berenices. It is impossible to carve a realistic representation of comb teeth on a granite stone when the carved lines themselves are about 5mm thick and it is not unreasonable that a general, readily identifiable representation of a comb's shape was made. Indeed, it seems like the detail included in the Pictish Comb's design was more often directed towards portraying the constellation of Coma Berenices either through the representation of the comb's spine as a right angle replicating the pattern of stars in the constellation or more commonly the inclusion of a pattern of nine lozenges decorating the comb replicating the occurrence of a cluster of nine stars known as the Nine Maidens or MEL 111.



Detail of the Dunrobin Pictish Comb showing the 9 Lozenges and 11 teeth on both edges

There is a good example of a carved comb on the Class I Pictish Stone from Dunrobin. The symbol of the comb carved on the Dunrobin stone is a particularly good example of its association with the constellation of Coma Berenices with Nine lozenges representing the nine MEL 111 cluster in Coma Berenices. Furthermore, eleven teeth have been carved on either side of the comb, or rather twelve gaps between the teeth which allow ten loops and two single end strands to be formed that can be used to divide a length of twine equivalent to a desired circumference to be divided into 22 equal parts. Seven of those parts made up as a single end strand plus three loops can be used as a radius to draw a circle that gives a circumference equivalent to the length of twine wound through the comb teeth.



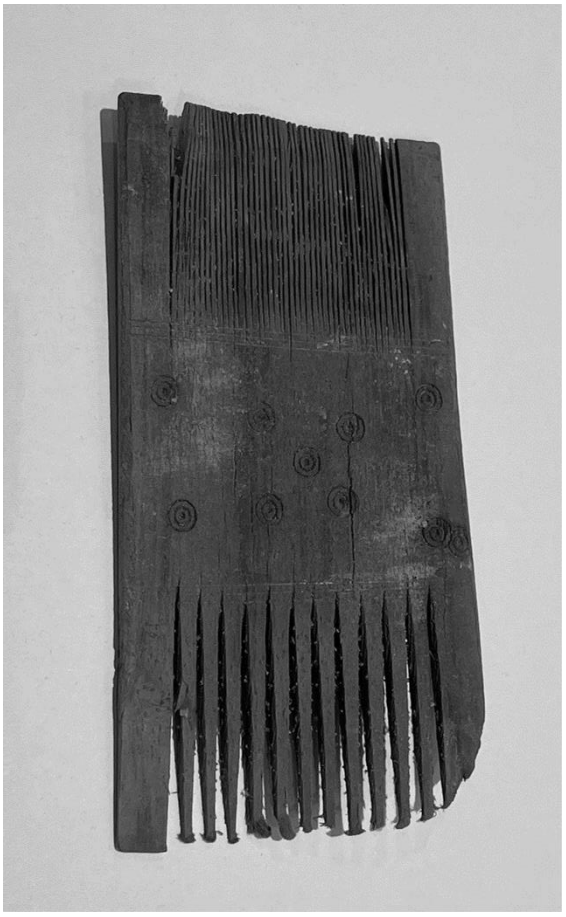
Pattern of Winding a Twine of the Circumference length around Eleven Comb teeth to obtain the Radius that gives a Circle of the desired circumference.

The eleven teeth winding gives 10 loops and 2 single end strands of the same length. The end three loops and single strand give the required radius length or alternatively seven loops can be taken and folded in two to obtain the radius.

The idea that in Scotland over a thousand years and possibly over two thousand years ago the inhabitants of Scotland used a comb to divide circle circumference lengths into 22 parts which could then be used as a radius by taking seven of those parts to draw a circle with the desired circumference is at first a strange idea to our modern way of thinking. The possibility that an object we take completely for granted as a comb for hair could possibly serve a mathematical function seems ridiculous until we look at the way in which the number of teeth cut on these combs and the way in which loops can be formed between the teeth so perfectly serves the purpose of replicating the division of a length by pi to obtain a radius.

The question arises as to whether similar combs were made in other areas of the world.

Egyptian Coptic Comb dated between 600-800AD



This comb, has eleven teeth on one side and forty-three three teeth on the other side allowing both suggested methods of dividing a circumference into 22 parts and then selecting 7 of those parts to form a radius length.

Perhaps the different comb edges allow different thicknesses of twine to be used with the 43 teeth allowing only very fine twine to be used whilst the 11 teeth have much larger gaps between them allowing twine of thicknesses of around 3mm to be wound between the teeth. In many respects the comb is similar to the double-edged bone combs of Scotland even to the extent of the decoration of the comb with dots and circles, in this case there are nine dots within nine double circles (perhaps again related to the Nine Maidens associated with the cluster Mel 111 in Coma Berenices) with the central five dots forming a square with a central dotted circle. The Egyptian comb is taller than it is wide and is formed from a single piece of cedar wood, a material that would not have survived the ravages of time in the Scottish climate.

Ritchie, A 1976, Excavation of Pictish and Viking-age farmsteads at Buckquoy, Orkney, Proc Soc Antiq Scot, 108 (1976-7) 174-227

MacGregor, A 1974 The Broch of Burrian, North Ronaldsay, Orkney, Proc Soc Antiq Scot 105 (1972-4) 63-118

Broch Comb Pendulum Length Dividers

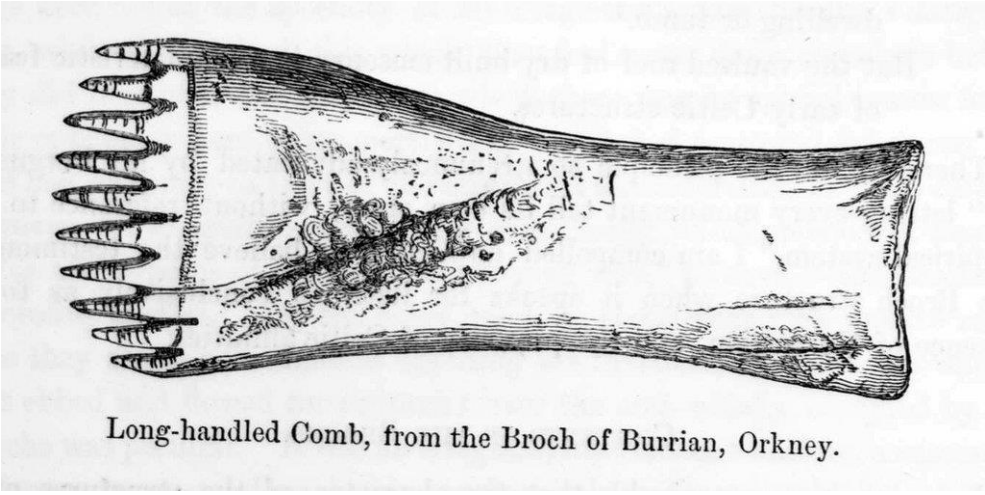
Megalithic Degree Arc Lengths

There are a surprising number of long-handled bone combs that have been found during archaeological excavations of the Scottish brochs. The combs have been described as weaving combs and the presence of many round stones with a central hole in the same finds, many identified as spindle whorls and some as possible loom weights have helped to legitimize the sense of the long-handled combs as weaving combs used to brush wool before spinning it to form threads to weave into cloth. This makes sense in terms of our experience of similar objects still used today to spin and weave wool but we should ask ourselves whether the brochs were particularly involved in these activities or whether the "combs" served some other purpose.

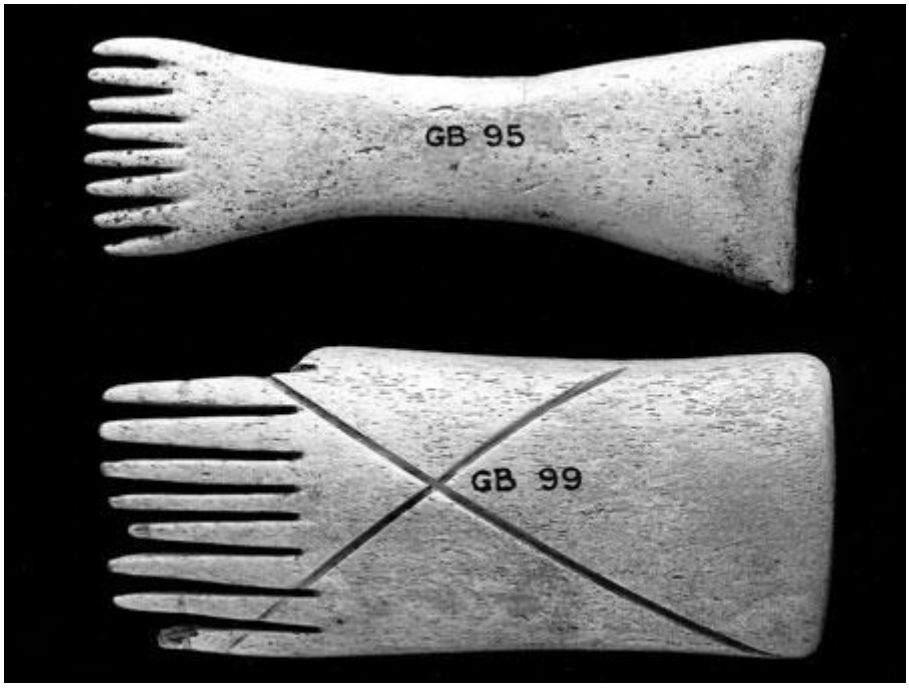
Survival of bone combs in the brochs.

It seems remarkable that so many bone artefacts have survived between 1500-2500 years buried in the ground in Scotland in such a remarkable state of preservation. This may have something to do with the fact that these objects were found inside the broch towers and that despite the fact that the brochs are open to the sky, they are much drier inside due to the high walls of the original towers and the fact that rain is usually accompanied by some degree of wind which means that the rain rarely falls completely vertically. This means that the walls of the broch act as a barrier which prevents much of the rain from entering the inner courtyard of the broch. As an example, we can look at Mousa Broch which stands at a height of approximately 13.05m (max) and has an opening at the wall head of approximately 6.5metres. The base of the broch is approximately 15.2m in diameter and the wall head has an approximate width of 2.5m. On top of this there is in Mousa, in common with all the brochs a scarcement, a ring of stones protruding from the inner wall that was believed to support an annular platform around the courtyard at a height of around 8'6". The middle of the courtyard has a rectangular hearth and it is likely that the area above the hearth would have been open to allow smoke from the fire to exit the broch.

Broch Comb from North Ronaldsay and Gurness



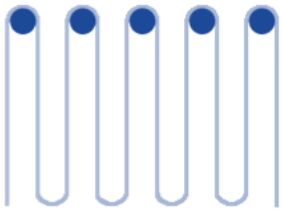
Long-handled Comb, from the Broch of Burrian, Orkney.



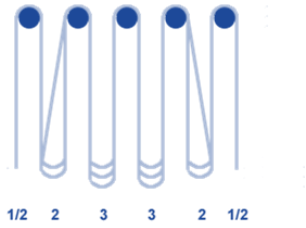
Broch of Burrian 8 and 9 tooth combs

Nybster Broch

5 Tooth Comb



Division of a length into 10 equal parts using a 5-tooth comb

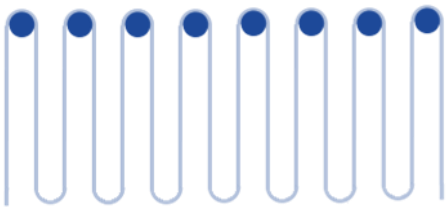


Division of a circumference length of a circle to give the radius of the circle

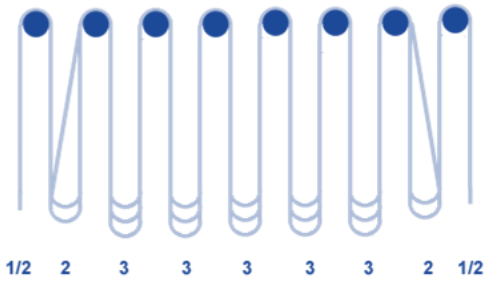
Take 3 and a half loops of 11 loops (10+(2x1/2)) using a 5-tooth comb

The five tooth comb can be seen as the simplest comb but can provide two very useful operations of division and conversion

8 Tooth Comb

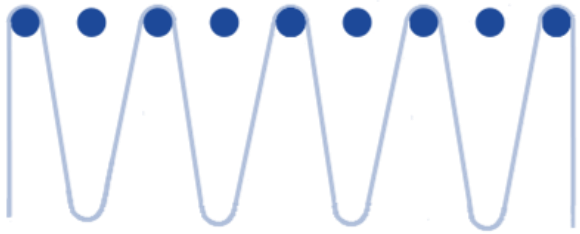


Division of a length into 8 or 16 equal parts using an 8-tooth comb

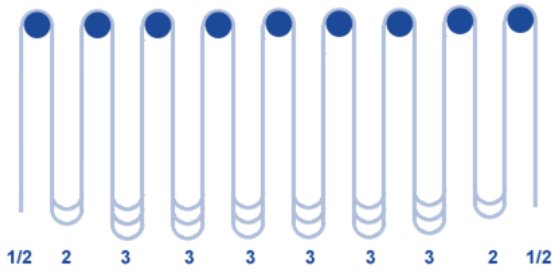


Division of a length into 20 equal parts using an 8-tooth comb

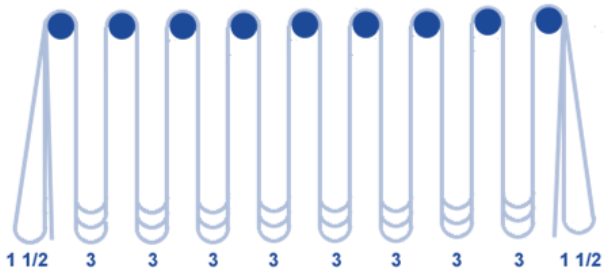
9 Tooth Comb



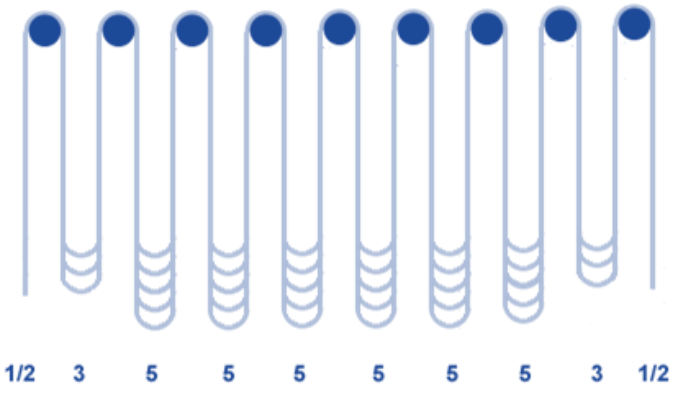
Division of a length into 5 or 10 equal parts using a 9-tooth comb



Division of a length into 23 equal parts using a 9-tooth comb



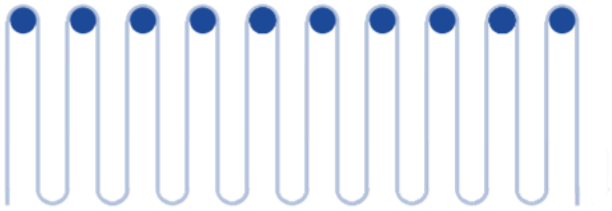
Division of a length into 27 equal parts using a 9-tooth comb



Division of a length into 37 equal parts using a 9-tooth comb

The nine-tooth comb is the most useful comb in dividing a length into the important Pictish numbers of 23, 27 and 37. Perhaps this is reflected in their frequency of occurrence

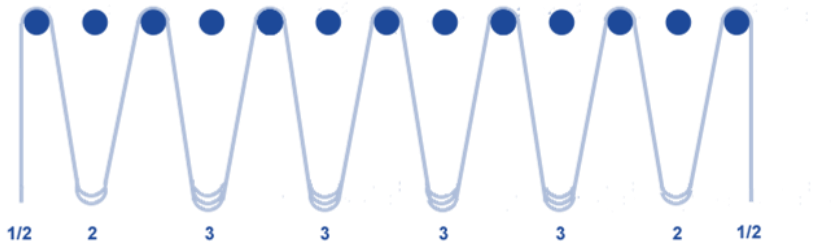
10 Tooth Comb



Division of a length into 10 equal parts using a 10-tooth comb

13 Tooth Comb

Division of a length into 13 equal parts using a 13-tooth comb



Division of length into 17 or 34 equal parts using a 13-tooth comb

The 13-tooth comb is useful in obtaining important Pictish numbers of 13, 17 and 34. Perhaps this reflects the frequency of occurrence of 13-tooth combs along with the 5-tooth comb and 9-tooth comb that was seen in the graph on page 69.

Possible uses of the Brochs and Historical Evidence to support these ideas

The conventional association with a stone tower is that of a fortified house that allows its inhabitants panoramic views of the surroundings to identify possible advancing threats and an impregnable stronghold to ensure security against that threat. The towers generally have very thick walls and limited openings in the walls to make access and destruction impossible. The brochs however did not have roofs so the conventional idea of a habitable stronghold is not so obvious. The broch has been proposed as an observational tower, or observatory where alignments with the Sun and stars could be made from the broch's wall head across the open roof to the horizon but whilst this idea has merit in terms of the way in which the dimensions of the broch's inner and outer wall radii appear to have been specially chosen to be easily divisible into arc angles described by arc lengths consisting of the pendulum lengths used at the time to measure both length and time, the question is why would such tall walls be required to make the proposed alignments? Furthermore, if the height of the broch towers had been less, the requirement for really thick walls at the base of the broch would have been significantly diminished and therefore a building that fulfilled the requirements of an observatory would have been more easily met. There is of course the advantage in having a high tower that the horizon in all directions is more easily viewed from a more elevated position especially where the broch is situated in a hilly or undulating landscape. There is also the possibility that low brochs were built that we know as Duns and perhaps these also fulfilled an observational function. It is also possible that many of the collapsed brochs were not all as relatively high as those brochs that have sections of their wall surviving to a significant height. The question then is if the brochs were not all built to a significant height why were the base walls of these ruined brochs constructed to such a thickness that would not be necessary in terms of both engineering nor for access. It is also evident from the remains of relatively well preserved brochs that tall brochs were constructed where there was no absolute requirement for height in terms of visibility of the horizon. One possible reason why the brochs were constructed as high towers may relate to the fact that the broch's purpose as an observatory did not allow for the construction of a roof and therefore the courtyard of the broch was exposed to rain, hail and snow. Usually, precipitation is accompanied by wind or at least a breeze so that any precipitation tends not to fall vertically but at an angle. The provision of a tall open-roof tower minimizes the amount of rain that will enter the broch and reach the courtyard floor as at a critical height and angle of fall all the rain drops that enter the open roof will impinge the vertical inner wall and the courtyard floor itself will be in effect a dry rain shadow area. This is an interesting conceptual idea as it provides a dry open habitable space that removes the presumed condition of having a roof. In the instance where rain falls vertically, the provision of the annular floor at the scarcement would also provide a shelter beneath it as the floor doubled as an annular roof that was only open at the centre to allow smoke from the central hearth to escape.

There is another even more surprising possible reason for the construction of brochs and their design that was unrelated to its purpose as an observatory. Shetland, Orkney and

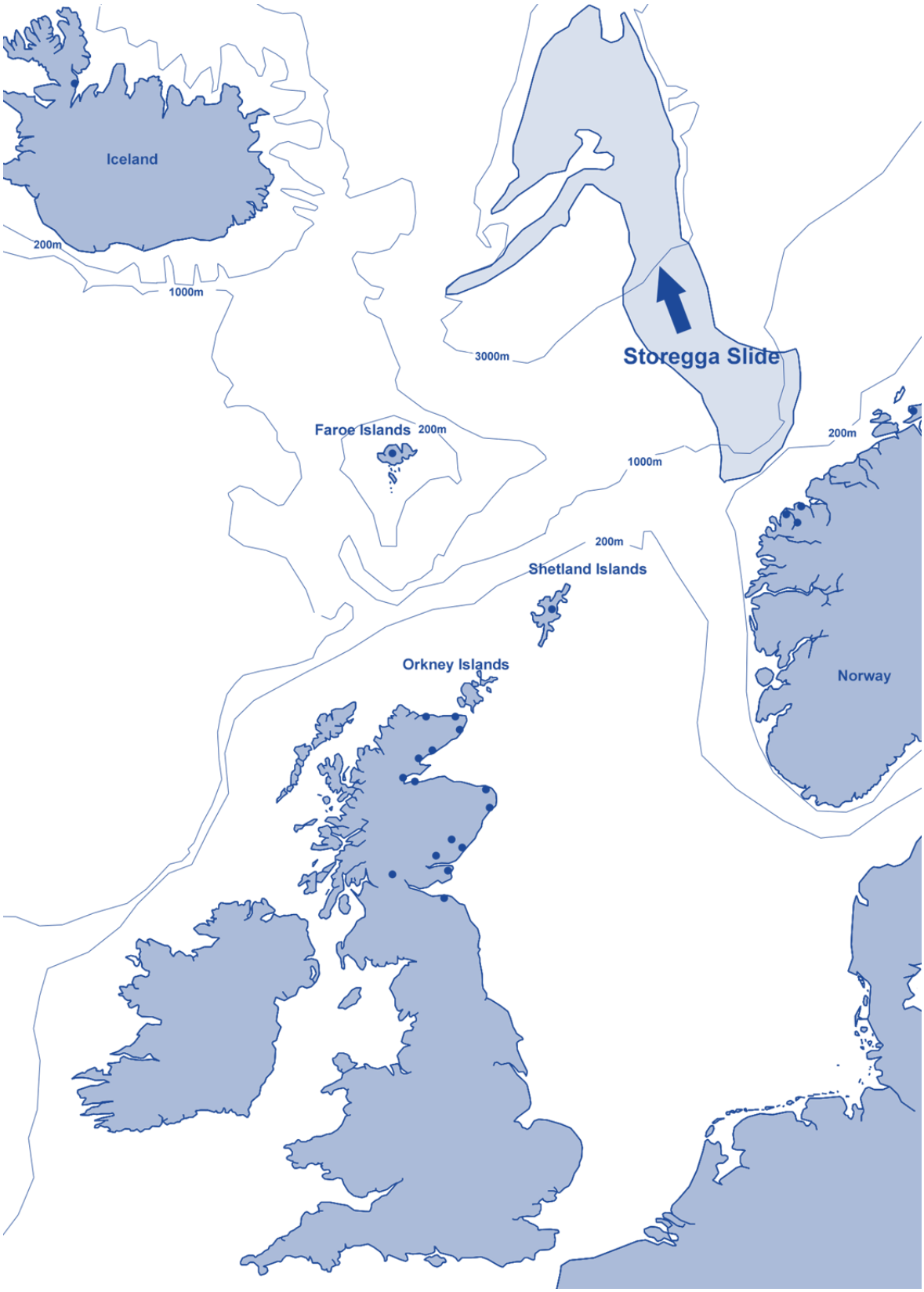
the mainland of Scotland particularly the East coast of Scotland have been subjected to serious tsunami events throughout prehistory. A tsunami is initiated by the sudden displacement of a volume of water. For a tsunami to occur, a source that causes such a such a displacement to occur is required. Three mechanisms can cause a tsunami to occur

1) A sudden vertical movement of the sea floor as the result of a geological fault that usually results from an earthquake that causes a fault rupture that extends to the sea bed.
2) Sudden movement of a large amount of sub-sea material such as in an underwater landslide that can be triggered by either an earthquake when the slope is unstable or which can be triggered by evolution of gas from gas hydrates or underwater volcanic eruptions.
3) A large amount of material entering the sea rapidly usually caused by terrestrial landslides involving a coastal landslide, a volcanic slope collapse or the collapse of a cliff.

A further cause of a tsunami is the impact of a significantly sized asteroid with the sea but this event is considered to be an extremely rare occurrence. Although we are aware of the devastating effects that tsunamis have on places and people where they occur, these events do not directly affect us because they happen in other parts of the world. Small tsunamis have however been experienced and documented by historians in the South of Wales and the South West of England in recent history caused mainly by earthquakes west of Portugal. These tsunamis have tended to have involved wave surges of a metre height or less. Serious devastating tsunamis however involving waves of tens of metres in height have also occurred in prehistoric times in Scotland their occurrence which are likely to have been passed down through generations of the people who survived them through stories of the great floods that destroyed vast areas of land and took the lives of thousands of people, forgotten. The evidence for their occurrence back in the mists of time though remains through deposits of seabed sediment consisting of sand and microfossils sucked up by the tsunami wave and thrown into suspension with the wave and deposited far inland as the giant waves hit the land. These deposits often form layers of seabed material several centimetres thick and where organic material such as twigs have been entrained within that material, carbon dating can establish the likely date of the tsunami event and sometimes even the season of the year can be identified by the presence of seeds or pollen within the same deposit.

Possibly three such tsunami events have been recorded in the British Geological Survey published in "A catalogue of tsunamis in the UK" (Marine, Coastal and Hydrocarbons Programme Commissioned Report CR/07/077[N]) in Scotland dating to 6150BC, 3500BC and 500AD. The discovery of deposits so far inland in Scotland illustrates the volume of water that must have been involved in some of these tsunami events and the devastation that must have ensued particularly in island and coastal communities. There would no doubt be evidence of tsunami-generated deposits along the eastern coast of England were it not for the fact that much of that coastline has disappeared through erosion and rising sea levels in England whereas Scotland is rising following the end of the ice age when the massive mass of ice covering the North of Britain sometimes over a kilometre

thick, melted producing a slow fulcrum effect with the North rising and the South of England sinking.



Onshore evidence of the Storegga tsunami shown by blue circles.

Is it possible that the brochs were designed in part as a response to the historical threat posed by known tsunami wave events with a view to offering people a defense against this ever-present threat? The design of the broch apart from being ideally suited as an observatory also is perfectly suited, as far as any building can be suited to protection from a tsunami. The broch is a round enormously thick-walled tapering structure that provides the strongest resistance to waves, much in the same way as a lighthouse on a rock reef whose base is buffeted by waves is designed as a tapering tower. The round shape is also useful where the precise direction of the incident wave is unknown and the energy of the wave can be dispersed effectively around the circular walls. The broch walls are constructed as drystone walls which are massively thick and their mortarless construction affords further protection against the impact of a large wave or series of waves because the wall is not completely solid and allows some of the impacting water to pass through the wall thereby absorbing a significant proportion of the waves impact energy. It should be remembered that tsunami events though devastating pose a short-lived danger, as the series of high energy waves tend to last for no more than a matter of hours before the wave water retreats and the sea becomes calm again. The broch as a stronghold against a tsunami only has to protect anyone inside the broch from being crushed or swept away and drowned by the incoming wall of water. It is unlikely that someone was charged as a permanent watchman at the top of the broch keeping a look-out for signs of such a rare event as a tsunami. However, given that brochs are mainly located along the coast on low-lying land, where a tsunami would take its greatest toll on life, it is likely that the people living in these coastal areas would be constantly aware of the sea state and would be looking out for the characteristic warning sign of an approaching tsunami when the seabed, usually covered by seawater, was exposed far beyond the low water mark as the shoreline seawater was sucked away into the distant approaching wave. This event would allow the alarm to be raised so that communities could take to the hills or take shelter inside their broch and await the impact of the tsunami and wait for the retreat of its waters. Perhaps the safest place in the broch at the time of the initial impact would be the beehive cells situated at the base of the broch within the walls at their greatest thickness and strength. Inside the courtyard depending on the height of the tsunami's wall of water, that could exceed 10 metres, it is quite likely that the upper section of the broch walls being narrower could be damaged and cause stones from the wall head or sections of the wall impacted by the wave to collapse and to fall down inside the broch. Positioned in small extremely strong vaulted chambers within the base walls would avoid the danger of any collapse but would then be subject to the dangers of flooding as the water penetrated the broch through, or over the drystone walls following the initial impact. At this stage there is likely to follow a succession of waves of decreasing height and depending on the conditions in the broch it may be desirable to move from the beehive chambers and enter the intra-mural wall space occupied by the spiral stair case and flagstone ties allowing those seeking protection in the broch to climb above the water level in the broch, keeping to the side opposite the approaching waves. In the event that a significant amount of water entered the inner space of the broch, the water would be static and the people inside in no danger of being swept away. This might be

considered a fanciful speculation but given a history of devastating floods causing untold numbers of deaths it is perhaps logical that steps would be taken to protect families and this role might in some ways provide a more logical explanation for the hundreds of brochs built throughout Scotland rather that a requirement for hundreds of astronomical observatories many times more numerous that the number of stone circles that were built in Neolithic times for that same purpose.

Light band of deposit from the Storegga tsunami in Shetland

Speculative accounts of the Brochs as Observatories

The early brochs predate history and Christianity by hundreds of years and the earliest written reference to them appears in a Norse story contained in Egil's Saga where a couple eloping to Iceland from Norway were shipwrecked and used a broch as a temporary refuge. The saga however dates to around 850-1000AD when the broch was already over a thousand years old and had long since stopped being used in the manner we have suggested. Earlier in history, the Romans undoubtedly encountered the brochs during their ultimately unsuccessful campaigns in Scotland and some considered that Leckie broch in Stirlingshire may have been burnt down and destroyed by them around 100AD but once again the earliest brochs predate the Romans by hundreds of years and

there is no surviving mention of the brochs and their use in writings of Roman historians. In order to get back to the heyday of the brochs requires us to enter prehistoric times and there is of course by definition of prehistory no surviving written record from these times. There is however an ancient Hebrew apocalyptic religious text known as the Book of Enoch, the great grandfather of Noah whose older sections, believed to date from 300-200BC, refer to an intriguing group of people or angels referred to as the "Watchers" or more specifically as "Watchers of heaven or heavenly Watchers" which would be a reasonable description of a group of astronomers or astrologers. There are also references in the book of Enoch relating to "towers" such as at 87.2 where Enoch recounts

"*And I raised mine eyes again to heaven, and I saw in the vision, and behold there came forth from heaven beings who were like white men: and four went forth from that place and three with them. 87.3 And those three that had last come forth grasped me by my hand and took me up, away from the generations of the earth, and raised me up to a lofty place, and showed me a tower raised high above the earth, and all the hills were lower. 87.4 And one said unto me: ' Remain here till thou seest everything that befalls those elephants, camels, and asses, and the stars and the oxen, and all of them.'*

So, there is a description of Enoch being escorted to a tower by heavenly beings "like white men". The tower was raised high above the earth, or ground and Enoch was told to remain there until he had seen everything that happened to a group of a wide range of animals comprising elephants, camels, asses and oxen and stars. Perhaps the inclusion of stars, and the fact that these animals are unlikely to actually occur together outsides the confines of a zoo, suggests that the animals described are actually the stellar identities of particular constellations of stars, which by contrast would be visible together in the sky, and Enoch is being encouraged to stay in the tower and "watch the heavens" as the constellations rise in the East, move across the night skies before setting in the West whilst other circumpolar constellations revolve around the Celestial Pole never rising nor setting.

Although the towers described in the book of Enoch match our interpretation of the brochs as observatories and the term Watchers similarly is consistent with the idea of prehistoric astronomers, the location of these towers so far North in Scotland seems to be way outside the area considered to have been visited by Enoch. However, the hundreds of these tall and massive towers called brochs that were built in Scotland, and only existed in prehistoric Scotland at this time, if they were used as observatories the people who built these amazing monumental structures are likely to have been considered by other people as a people apart and as "the Watchers of the Heavens". The connection is of course very tenuous but remains as an intriguing possible association

between ancient, pre-Christian, religious texts and prehistoric people and their observations and interpretations of the night skies.

The interpretation of what brochs were suffers from many difficulties in that they are unlike any other group of surviving buildings. Furthermore, the brochs are amongst the oldest surviving buildings in Europe and are present in such huge numbers despite their monumental nature. The fact that the brochs are unique to Scotland and have no indication of ever having had a roof provides further difficulties in their interpretation.

The suggestion that these towers were built as observatories is consistent with the fact that in Neolithic times hundreds of stone circles, again more than anywhere else in Europe, were built as calendrical monuments by the forefathers of the same people who appear to have been so interested in following and celebrating the movement of the stars and deep space objects.

The other thing that differentiates the people inhabiting Scotland from the rest of Britain and Europe is the fact that the people had suffered the devastating effects of natural disasters that had wiped out thousands of people over the generations dating back to the first settlers moving into the lands of the North following the retreating glaciers covering Scotland. Two devastating tsunamis resulting from subsea landslides off Norway hit Scotland around 6150BC and 3500BC that involved walls of water in excess of 10 metres in height then around 1150BC Mount Hekla in Iceland erupted over an extended period of years resulting in clouds of dust and ash blocking the Sun and causing a perpetual winter that may have lasted for up to 28 years according tree growth ring analysis of bog oak from Scotland and Ireland. The people inhabiting Scotland around 500-700BC would have been intimately aware of the stories of such cataclysmic floods experienced by their forefathers before the construction of the Neolithic Stone circles and the more recent calamitous darkening of the night skies and failure of crops. The people had carved symbol stones as votive offerings to the stellar deities to clear the skies and once again be able to see the stars representing their star gods.