



# Origins of Standing Stone Astronomy in Britain: New quantitative techniques for the study of archaeoastronomy



Gail Higginbottom<sup>a,b,\*</sup>, Roger Clay<sup>a</sup>

<sup>a</sup> Department of Physics, School of Physical Sciences, University of Adelaide, Adelaide, South Australia 5005, Australia

<sup>b</sup> School of Archaeology & Anthropology, The Australian National University, Canberra, ACT 0200, Australia

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## ABSTRACT

By c. 3000 BCE, in the late Neolithic, there had been a significant change in the way people materialized their cosmology across Scotland with the introduction of free-standing stones that continued to be erected almost until the end of the Bronze Age (Burl, 1993, 2000). Significantly, a series of astronomical patternings have been empirically verified for many Bronze Age monuments that were erected in the latter Bronze Age (Higginbottom et al., 2000, 2001, 2015). Further, two series of complex landscape patternings associated with the monuments and their orientations have been identified (Higginbottom et al., 2015; Higginbottom and Clay, in press). However, when and where these patterns were first associated with standing-stone structures was unknown. *Through innovative statistics and software* we show that visible astronomical-landscape variables found at Bronze Age sites on the inner isles and mainland of western Scotland were actually first established in stone nearly two millennia earlier, likely with the erection of two of the earliest dated British 'great circles': Callanish on the Isle of Lewis and Stenness on the Isle of Orkney. In particular, we introduce our new statistical test that enables the quantitative determination of astronomical connections of stone circles. It is seen that whilst different standing-stone monuments were created over time (Burl, 1993, 2000; Higginbottom et al., 2015) with a mixture of landscape variables (Higginbottom et al., 2015), we nevertheless see that highly relevant landscape markers and other aspects remained unchanged through these years. This suggests that there is some continuity of this cosmological system through time, despite the various radical material and social changes that occurred from the late Neolithic to the Late Bronze Age (Lynch, 2000; Mullin, 2001; Owoc, 2001).

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## 1. Introduction

In Higginbottom et al. (2015), it was argued that free-standing megalithic monuments at likely Bronze Age (BA) sites were "the materialization of (people's) cosmology" and that such created places, as indicated by the stones' locations and their concomitant surrounding environs, are an acknowledgement of belief in specific cosmological forces (Fig. 1A and B; Higginbottom et al., 2015: 639–40). Here, cosmology means "how people understood the way the Universe worked in relation to all things, or the properties of the experienced Universe as a whole". This same paper argues that the study of such indicators could potentially reveal something of these past cosmological beliefs.

In Higginbottom et al. (2015) and earlier works, it was shown that astronomy or the study of the visible objects in the sky, played a primary role in the location of the megalithic monuments of Scotland, where specific astronomical bodies are some of the most essential and consistent

visible environmental markers required for deciding where to place a monument. In particular, we found greater statistical evidence for an interest in orientating monuments towards astronomical phenomena in western Scotland than did Ruggles and his colleagues (e.g. Higginbottom 2000, 2001, 2002; Patrick and Freeman, 1985; Ruggles, 1984; Ruggles and Martlew, 1992; Ruggles et al., 1991), a development linked to a new approach that includes detailed topographical information of the surrounding landscape, which was impossible in the early days of computer analyses. Further, through the observation of over 50 3D-landscapes of monument surrounds to date, the astronomical phenomena seem tied to specific landscape characteristics along the entire 360° horizon (Higginbottom, in preparation-a, in preparation-b; Scott et al., 1988–1989; Higginbottom and Clay, in press; Higginbottom et al., 2015). This is critical and has emphasized for us that other interpretations of meaning that we can give the standing stones that do not include these environmental markers or landscape considerations, are secondary, or entangled within other ideologies, though will hopefully still be discovered as we, and others, do more work.

Having closely reviewed BA sites in 2015, we were curious as to the origin of such environmental markers and possible associated cosmologies, and wondered whether or not Neolithic standing stones held any

\* Corresponding author at: Department of Physics, School of Physical Sciences, University of Adelaide, Adelaide, South Australia 5005, Australia.

E-mail addresses: [gail.higginbottom@anu.edu.au](mailto:gail.higginbottom@anu.edu.au) (G. Higginbottom), [roger.clay@adelaide.edu.au](mailto:roger.clay@adelaide.edu.au) (R. Clay).



**Fig. 1. Examples of Bronze Age standing stone monuments.** **A**, Camas nan Geall in north Argyll (2.3 m high by 0.9 m by 0.2 m), displayed here with one side of the amphitheatre created by close hills in view. It was found in Higginbottom in preparation-a, that the horizons of the standing-stone monuments in this area and on Mull have characteristics that would emphasise the Moon illusion (where the moon looks larger nearer it is to the horizon). The sites usually stand in a small and semi-enclosed amphitheatre, created by a relatively close horizon either north or south of the site, sometimes to within 50–100 m as at this site or Totsarie on Mull). At others an open amphitheatre is created by the entire visible sections of a valley, like at Uluvalt (see Fig. 4). This is a slab and so onsite orientations were taken along the horizontal axis of the long side. Photograph taken by Douglas Scott. Copyright © Douglas Scott. **B**, Balliscate is made up of three stones of basalt were erected in an approximately straight line running N and S, 5 m. long. The furthest stone (A on plan of RCAHMS, 1980, fig. 39) is 1.8 m in height by 0.65 m, by 0.6 m at the base. It is a slab in line with the major axis of the 3 stones. Stone B is prone, half-embedded in peat, and is 2.8 m long by 0.7 m, and 0.4 m thick. The tallest of the stones (C), closest to viewer, stands within a ruined turf-and-stone bank and measures 2.5 m in height by 1.1 m in breadth, by 0.8 m thick (q.v. RCAHMS, 1980, no 90). Photograph taken by Gail Higginbottom. Copyright © Gail Higginbottom.

firm evidence of an interest in astronomical phenomena. We noted that non-empirical work on Neolithic megalithic sites suggested that they, too, were ‘places of astronomical connection’ by association or directly, and that such astronomical phenomena were also transformative like those found at BA sites, i.e. indicating a change in the direction of travel for an astronomical body (such as at the time of the solstice; q.v. Higginbottom et al., 2015: 585, 601–04). However, our review also showed that nothing was empirically proven for any standing stone site in the Neolithic. We present here an empirical methodology to deal with this lack, but most importantly, we test the earliest (radio-metrically dated) great circles in Scotland, Callanish and Stenness, currently two out of four of the earliest dated standing stone sites in Scotland. As implied above, due to the availability of Ordnance Survey elevation data in the years since Ruggles and his colleagues looked at these sites, it has been possible to create exceptional visual aids, 3D-models that allow us to view the entire landscape in conjunction with the astronomical phenomena for each site. We will now provide some necessary information on astronomy before proceeding with the descriptions of our Late Neolithic (LN) and BA case-study sites. A discussion of our previous work on the BA sites follows on from these to be able comparison with our most recent results presented in this paper.

## 2. Understanding basic observational astronomical information

The celestial sphere (CS) is an imaginary sphere as viewed from earth against which the celestial bodies appear to be projected. The CS’s axis is the extension of the earth’s own axis. The apparent dome of the visible sky forms half of this sphere. The position of an object on the celestial sphere is specified by its equatorial coordinates: right ascension and declination. To an observer standing on the surface of the earth, the celestial sphere appears to rotate about the celestial poles because of the earth’s rotation. Objects fixed to the celestial sphere therefore appear to follow circular paths about the celestial pole. Some of these paths will cross an observer’s local horizon twice a day (once for rising and once for setting). The exact circumstances of these *observed events* are a function of the associated object’s celestial coordinates, the geographical latitude of the site and the local horizon profile at that site. The *declination* of the object determines *the points on the*

*local horizon* at which rising and setting occur (if at all). The right ascension of the object then determines the times at which rising and setting occur.

Given that a particular declination path always intersects a given horizon profile at the same point, and that every horizon point is intersected by one and only one declination path, and always the same one, it follows that there is a unique, one-to-one mapping between points on a given horizon and an astronomical declination. This mapping will vary according to site latitude and horizon profile. So, given an alignment direction (azimuth), the elevation of the local horizon in the direction of the alignment and the geographical latitude of the site, we can calculate the astronomical declination of a (hypothetical) celestial body that would cross the visible horizon in the direction of the alignment. It is hypothetical because we don’t yet know if a real celestial body actually moves along this declination path. At some point in our statistical assessments we can use such calculated declinations to see whether or not they coincide with the astronomical declination co-ordinate of any known celestial body.

Fixed stars (celestial objects whose apparent motion is so slow they do not appear to be moving in relation to us on earth) have constant declinations and cross the horizon profile at fixed alignments. However, planets, along with our Moon and Sun, vary their declinations, and therefore their alignments, over cycles of time. Nevertheless, as these changing declinations are a function of a planet’s cycle they can be calculated for any particular ‘time’ and ‘place’. For example, we can calculate what the declination of the Sun should be at its most northern and southern rising and setting points (summer and winter solstices) for any specified year (it is currently approximately 23.5°). It is important to know that the Sun takes 1 year to complete its cycle where, in the northern hemisphere, a cycle is roughly equivalent to the Sun moving away from its most northern rising and setting points (summer solstice), rising further and further southward, until it reaches its furthest point south along the horizon (winter solstice), finally returning to its most northern rising and setting points. The Moon, which has a more complicated form of movement, takes approximately 18.6 years to complete its cycle.

For more detailed information on the astronomy used in this study see our *Supplementary Material 1*, section 2. *Understanding basic observational astronomical information*.

### 3. Case study sites

The main aim of the initial stages of this western Scotland project was to develop new methodological procedures for the study of archaeoastronomy and to compare the outcomes with Ruggles' earlier results. Therefore, we used the same sites as well as Ruggles' raw data, which included specific site locations, plus the azimuths (orientation measurements) and the declinations of the horizon points towards which the sites were oriented. Detailed site selection procedures can be found in Ruggles (1984; Section 2) and an overview of this, along with other related matters, is located in the *Supplementary Material*, section 1. *Methodological considerations past and present*.

The chronology, archaeological associations and various possible functions of standing stone monuments, discussed at length in Higginbottom et al., 2015, reveal a number of informative points on the archaeology of standing stones in Scotland. These monuments seemed to appear suddenly and grandly, or modestly, in the Late Neolithic (LN), and were likely built until the end of the Bronze Age (Ashmore, forthcoming; Barber, 1977–78; Gibson, 2010; Ritchie, 1974; Ritchie, 1976; Sheridan, 2006, 2008; Martlew and Ruggles, 1996; Schulting et al., 2010). The first great circles of Callanish and Stenness were likely constructed c. 3000–2900 cal BCE, using thin, tall slabs (Ashmore, in press, Ashmore, 1999; Barber, 1977–78; Gibson, 2010; Ritchie 1974, Ritchie, 1976; Schulting et al., 2010; Sheridan, 2008). Also likely built c. 3000 cal BCE is the more modest low stone circle (SC) Balbirnie in Fife (Gibson, 2010: 57, 59, 68 & 73) along with the stone pair (SP) at Orwell in Perth and Kinross, dated to 2890–2630 cal BCE (Ritchie, 1974: 8; Sheridan, 2008: 201; or possibly part of a SC or a row). All built in close chronological proximity yet great distances apart. The later recumbent stone circles (RSC) could date from the Early BA (EBA) or the Late BA (LBA) (Welfare, 2011: 88, Bradley, 2005). Single standing stones (StS) are associated with, or part of, monuments dating from the LN to the LBA, such as at Callanish SC (Ashmore, forthcoming) or Forteviot, Stirling (a possible single StS marking a burial within a cemetery, the latter dated to 3090–2638 cal BCE; Noble and Brophy, 2011: 790). Fascinatingly, linear StS sites in Scotland have been dated to the LBA only, for instance at Ardnacross, Mull (a pair of stone rows (SR)) has dates of 1260–900 cal BCE and 1130–810 cal BCE (Martlew & Ruggles, 1996: 126). Dated single StS that are associated with linear sites have also only been dated to the LBA, such as Ballymeanoch in Argyll, a single StS next to a SR and dated to 1370–1040 cal BCE (Sheridan in Roberts, 2008: 61; Sheridan, 2006). Notably, there is a possible building hiatus between about 1800 and 1400 BCE, as no StS monument in Scotland has been dated between these times.

Intriguingly, both Neolithic and BA circles, along with the simpler BA StS monuments, are usually directly associated with death, fire, cremations, burials, and pale/white/shiny stones or pebbles (Barber, 1977–78: 107; Bradley, 2000, 2005, 2011; Duffy et al., 2007: 53–54; Ritchie, 1976: 1–60; Higginbottom et al., 2015: 4–15, 17–22; Mackie, 2009; Martlew and Ruggles, 1996; Richards (a) in Richards, 2013a; Schulting et al., 2010: 35–36; Wright, 2007). The finds that date the simpler StS are usually cremated human bone and/or charcoal from deposits set against the base of the standing stone and often sealed under packing stones, as at Ballymeanoch, or buried next to the stone as part of setting it up, as at Dunure Road, (Duffy et al., 2007: 87). The dating of more complicated monuments is more complex, and we refer you to the associated literature mentioned so far for such sites.

The LN great circles studied in this paper, the Stones of Stenness and the Stone Circle of Callanish, are located on the isles of Orkney and Lewis, respectively (Fig. 2). It appears that the regional group, or groups, of Orkney built the following: the settlements of Skara Brae and Barnhouse, Maeshowe-type chambered cruciform passage tombs, and carved spiral motifs, as well as the large Ness of Brodgar 'temple complex', followed closely by the great circle and henge of Stenness (Fig. 3A). The nearby single StS are not yet dated. Stenness, with its slabs measuring 4.57 to 5.2 m high, has dates for the henge and its

hearth (Burl, 2000: 211; Higginbottom et al., 2015: 3; Ritchie, 1976: 10, Appendix 9; Royal Commission of Ancient & Historical Monuments (RCAHMS) – CANMORE – under site name; Schulting et al., 2010: 35–36.). Schulting et al.'s Bayesian model of these dates shows that it was likely built between c. 3000 and 2900 cal BCE (3020–2890 cal BC at 95.4% or 2940–2900 cal BC at 68.2%; Schulting et al., 2010: 35–36).

We note that neither such a Neolithic temple complex nor sizable settlements as found near Stenness have yet been found for Callanish or in western Scotland. However, on the west coast of the Isle of Lewis there is a complex of at least eight stone settings, including circles, that are visually dominated by Callanish (often referred to as Callanish 1) with its thin slab-like menhirs, 3–4 m in height, and central 5 m tall monolith. Three SR and a stone avenue (SA) extend from the Callanish circle (Fig. 3B; Burl, 1993: 148–151). Also on Lewis are at least a further 30 StS sites of prehistoric origin. Most of the circles are associated with small internal cairns. Whilst we do not yet know when the surrounding SC and StS sites near Callanish were erected, nor the associated SR and SA, its circle and central monolith were built around 3000–2900 BCE and its internal tomb during the EBA (Ashmore, in press). These date ranges are inferred through the combination of the sequence of erection events at Callanish and 32 radiocarbon-dated samples from excavation (Ashmore, in press, Ashmore, 1999; RCAHMS – CANMORE digital database). Thus Callanish was built in very close chronological proximity to Stenness. This, and their similar structural elements relating to circularity and the dead (Higginbottom et al., 2015; Richards (a) & (b) in Richards, 2013a, 2013b), are directly relevant here. All the stone holes at Stenness have been recovered and current StS positions for both Stenness and Callanish confirmed through excavation (Ritchie, 1976; Ashmore, in press). No empty stone holes in the perimeter of Callanish have been discovered (Ashmore, in press). Furthermore, the Callanish excavations revealed that the erection of the perimeter stones and the central stone occurred during the same stage of construction. Site visits by Higginbottom have confirmed that none of the upright stones are leaning (Fig. 3A and B).

### 4. Archaeoastronomy and standing stones of Scotland

#### 4.1. Bronze Age standing stones – previous work

Our statistical re-analyses of Ruggles' work showed that megalithic monuments as a regional group were deliberately clustered in orientation towards (initially) unknown directions (Higginbottom and Clay, 1999, S44, Tables 3 and 4, Higginbottom et al., 2001a, 2015: 25). These directions were either internal alignments of monument elements, like the axis of the standing stones of a SR, a thin, wide slab, or external alignments created by two monuments, such as a small SC and a StS. This was statistically confirmed for four out of six sub-regions, namely Uist, Argyll/Lorn, Mull/Coll/Tiree, and Islay/Jura (Higginbottom and Clay, 1999; Higginbottom et al., 2001a, 2015). Upon examination, Kintyre appears to have two separate orientation distributions, one that is more northerly and one that is more southerly within the peninsula (Higginbottom, 2003: 194). Lewis/Harris did not display statistical support at that time but is now being re-examined following current findings.

Statistical reassessment of the works of Ruggles and colleagues (e.g. Patrick and Freeman, 1985; Ruggles, 1984; Ruggles and Martlew, 1992; Ruggles et al., 1991) showed that a greater number of standing stone monuments than previously thought are deliberately orientated to the extreme rising and setting points of either the Sun's or the Moon's cycles across Mull, Coll, Tiree and Argyll, and that those findings extend to Islay and Jura in western Scotland (Higginbottom, 2003: 126–132; Higginbottom et al., 2001a; Higginbottom and Clay, 1999). Further, sites in areas like Kintyre, Uist and Lewis also appear to contain similar phenomena (Higginbottom, 2003).

Specifically, these are the Moon's rising and setting points most close to the major and minor standstills both in the southerly and northerly directions, as well as the Sun at the winter solstice (see *Supplementary*



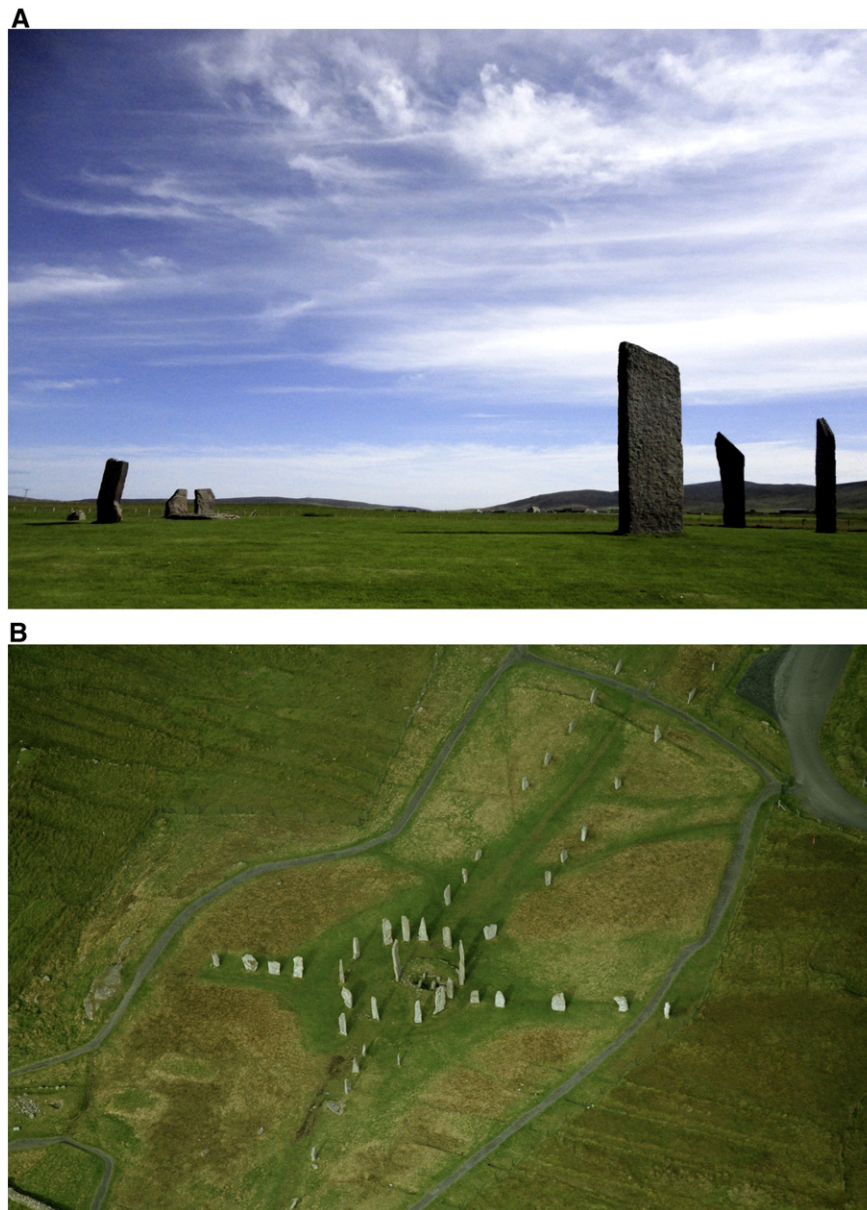
**Fig. 2.** Map of region and case-study sites. Scale 1:350,000; north arrow indicates grid north. Modified Ordnance Survey map: Ordnance Survey © Crown Copyright 2013. All rights reserved.

Material 1, section 2. Understanding basic observational astronomical information, for explanations of these astronomical events). We should point out that, whilst no statistical support was found for the Sun at the summer solstice by region, a small number of sites were oriented in this direction across western Scotland (9/276 orientations). However, the summer solstice becomes important in other ways (see below for further discussion). As part of our reanalysis and extension of Ruggles et al.'s work in western Scotland, our next steps were to generate horizon profiles for sites in the above regions both numerically and graphically from digital elevation data (Higginbottom et al., 2015; see

Supplementary Material 1, section 3. The 3D Horizon program settings, as well as Smith (2013) for more details of how the software operates).

#### 4.1.1. Standing stone landscapes in Bronze Age western Scotland (3D landscapes)

Past statistical findings, along with the examination of our 3D landscape reconstructions of each BA site, revealed that the sky and land are woven together to create a complex series of interactions at very particular times of the lunar and solar cycles (Higginbottom et al., 2015). Fig. 4 is an example of the 3-D rendering of landscape and labels all the



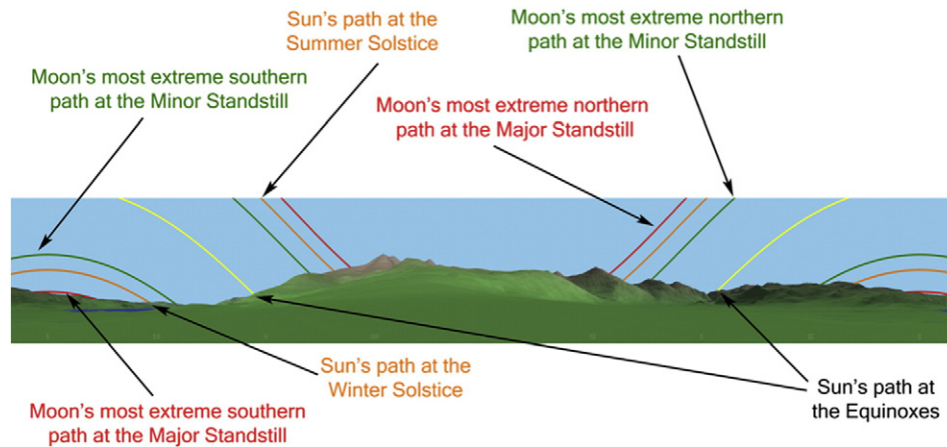
**Fig. 3. The great circles. A (top)**, Stenness, Mainland, Orkney. (Canmore ID 2105. National Monuments Record of Scotland (NMRS) Site Number HY31SW 2) The circle of the Stones of Stenness is 32.2 m by 30.6 m (Burl, 2000: 210). Its earthen henge is 45 m in diameter, over 7 m wide and over 2 m deep and the circumference is 141.37 m (Burl, 1976: 210; Ritchie and Ritchie, 1991: 47–50). Photograph Douglas Scott, © Douglas Scott. **B (bottom)**, Callanish (Canmore ID 4156, NMRS Site Number NB23SW 1) on Lewis is 13 m in diameter with a long stone avenue running north-southwards (southwards is towards the circle) and single long stone rows radiating outwards towards the other three cardinal points. SC\_1023422, © RCAHMS (Aerial Photography Collection). Licensor [www.rcahms.gov.uk](http://www.rcahms.gov.uk)

astronomical phenomena that were of interest. Note that the z-coordinate for elevation has been multiplied by 1.5 for the following supplementary figures (SM Fig.): 3 to 5 and 6 & 7. These figures were also used to make the composite figure in the text of the article (Fig. 5). However, the z-co-ordinate of Dunamuck was multiplied by 1.5 for the composite figure only (Fig. 5A), but not for its 3D landscape used for SMFig. 2. Relevantly, all the analyses of the 3D landscapes were done prior to any exaggeration of the vertical axes.

Examining the 3D landscapes, we found two horizon landscape patterns that were the topographical reverse of each other. Either one or the other pattern surrounded every site for Coll, Tiree and Mull. For Coll and Tiree ( $n = 6/6$ ) and the majority of sites on Mull ( $n = 9/16$ ) there is a combination of specific visual cues, regardless of whether the sites are linear, single slabs, or small circular settings (Higginbottom et al., 2015: 47–53; Higginbottom and Clay, in press; Higginbottom, in preparation-a). We called these ‘classic’ sites, as they

contained the first pattern we recognised. The usual dominant cues for classic sites are (Figs. 5A–D & SMFigs. 1–4; see Fig. 2 for locations of these sites):

1. water occurs in the south (e.g. Figs. 4 and 5A & SMFig. 1);
2. the northern horizon is closest, the southern most distant;
3. the northern horizon has a higher general profile or the highest vertical extents in the profile; the southern horizon has a very distinct dip (concave) or a lower general profile than the northern;
4. the highest areas of the northern and southern horizons focus around the four ordinal directions of NW, NE, SW and SE; occasionally the highest area is more northern if a single mountain or range fills the northern horizon (e.g. Figs. 4 and 5A & SMFig. 1);
5. the highest points of the horizon profiles are usually made up of distinct mountains or hills; where there is no mountain or hill range, a single hill or higher ground is usually located near, or at, these



**Fig. 4. Example of 3-D rendering of the landscape** using the classic site of Uluvalt on Mull. (Canmore ID 22219, NMRS site number NM52NW 3, national grid reference (NGR) NM5469 2997), along with key to reading the paths of the Sun and the Moon on the other such figures below. N = north, S = south. Note there is landscape overlap in the S for easier viewing. Software created by Andrew Smith. Based upon the Ordnance Survey 1:50,000 Landform PANORAMA map with permission of the Controller of her Majesty's Stationery Office © Crown Copyright.

compass points. Whilst most sites have relative peaks near all four ordinal points, some have only three (e.g. Hough: NW, SW and SE, Fig. 5C & SMFig. 3);

6. the summer and winter solstitial Sun and standstill Moon tend to rise out of, and set into, these ranges, hills or high ground.
7. a site most often forms an alignment internally, or with another site, at a lunar or solar orientation (the majority of which fall within the statistically supported declination ranges). For the Moon this is the Major or Minor Lunar Standstill (LS), and for the Sun it is the winter or summer solstice (WS, SS). A few are aligned N-S; no sites are aligned near or on the equinox, nor the midpoint along the horizon between the solstices).

Those sites that do not reveal the landscape pattern above reveal a combination of reverse landscape traits, namely (Fig. 5E & SMFig. 5):

1. water is usually seen in the north;
2. the southern horizon is closest, the northern most distant;
3. the southern horizon has the highest point(s) in profile; the northern horizon has a very distinct dip or overall lower horizon profile compared to the southern.
4. the highest areas of the northern and southern horizons focus around the four ordinal directions of NW, NE, SW and SE; occasionally the highest area is more southern if a single mountain or range fills much of the southern horizon (e.g. Figs. 4 and 5A & SMFig. 1);

We call these simply 'reverse sites'. Their remaining astro-horizon qualities remain the same as in points 5–7 above, except that Argyll has one alignment focused within a few degrees of the equinox (not a statistically supported event). For the 21 sites investigated so far, we now know that Argyll (with Lorn) has ten reverse sites (Higginbottom, in preparation-b; Higginbottom and Clay in press). These astro-landscape patterns, the occasional summer solstice alignment and the particulars found in section 2 of *Supplementary Material 1* (that a full Moon at the major standstill in the south – the direction the majority of statistically supported orientations face – can only occur around the time of a summer solstice) suggest that the event of the summer solstice is likely just as firmly entrenched in the consideration of monument placement as are the statistically indicated alignments mentioned in the previous section.

## 5. The first great circles of Scotland: Callanish and Stenness

### 5.1. The orientation foci of Callanish and Stenness

Looking along the entire 360° horizon of Fig. 4, it can be seen there are eight possible extreme rising and setting LS targets and four extreme solstitial targets. To understand how we determined orientations within a single circle see *Supplementary Material 1*, section 4.1 *Determining orientations* in section 4. *Understanding how the new statistical tests work*.

Callanish has 13 stones making up the circle and three close outliers (i.e. within 3.3–6.7 m but not part of the external linear stone rows). Altogether, the orientations of the large flat central slab (N-S axial alignment) plus those created from the alignments of this central stone to all the stones, contain five LS targets out of the possible eight and three out of four possible solstitial targets (total = 8/12), along with the north and south cardinal points (Table 1). Of these, all the risings and settings of the Major LS in the north and the south are accounted for (4/4), to which the majority of western Bronze Age StS sites on Mull, Coll, Tiree and Argyll are also aligned (Higginbottom et al., 2000). Interestingly, Mull, Coll and Tiree together showed a statistical preference for the Major LS both in the southerly and northerly directions ( $p = 0.025$  and  $p = 0.077$ , respectively) and Argyll the northern Major standstill ( $p = 0.026$ ), as well as the winter solstice ( $p = 0.062$ ). Stenness, with its 12 stones and monument axis (the entrance with the central stone setting which creates a north/south cardinal axis), contains 4/8 significant LS targets and two solstitial targets on opposite sides of the circle ( $n = 2/4$ ): the rising Sun at the SS and the setting at the WS. Together, Stenness and Callanish contain 7/8 LS targets and 3/4 solstitial targets. Notably, the BA sites as a group on Mull contain 7/8 possible rising and setting LS targets (Higginbottom, in preparation-a, in preparation-b, 2003) and Argyll contains all possible rising and setting LS targets (8/8); both regions have all solstitial targets (4/4; Higginbottom, 2003). What we must determine now is the likelihood of these Callanish and Stenness results being due to chance.

### 5.2. Probability analyses of the orientations

We devised two cross-correlation tests which compared the stone directions with the direction of astronomical phenomena crossing the horizon. These tests assess the same basic enquiry, and though one is a more

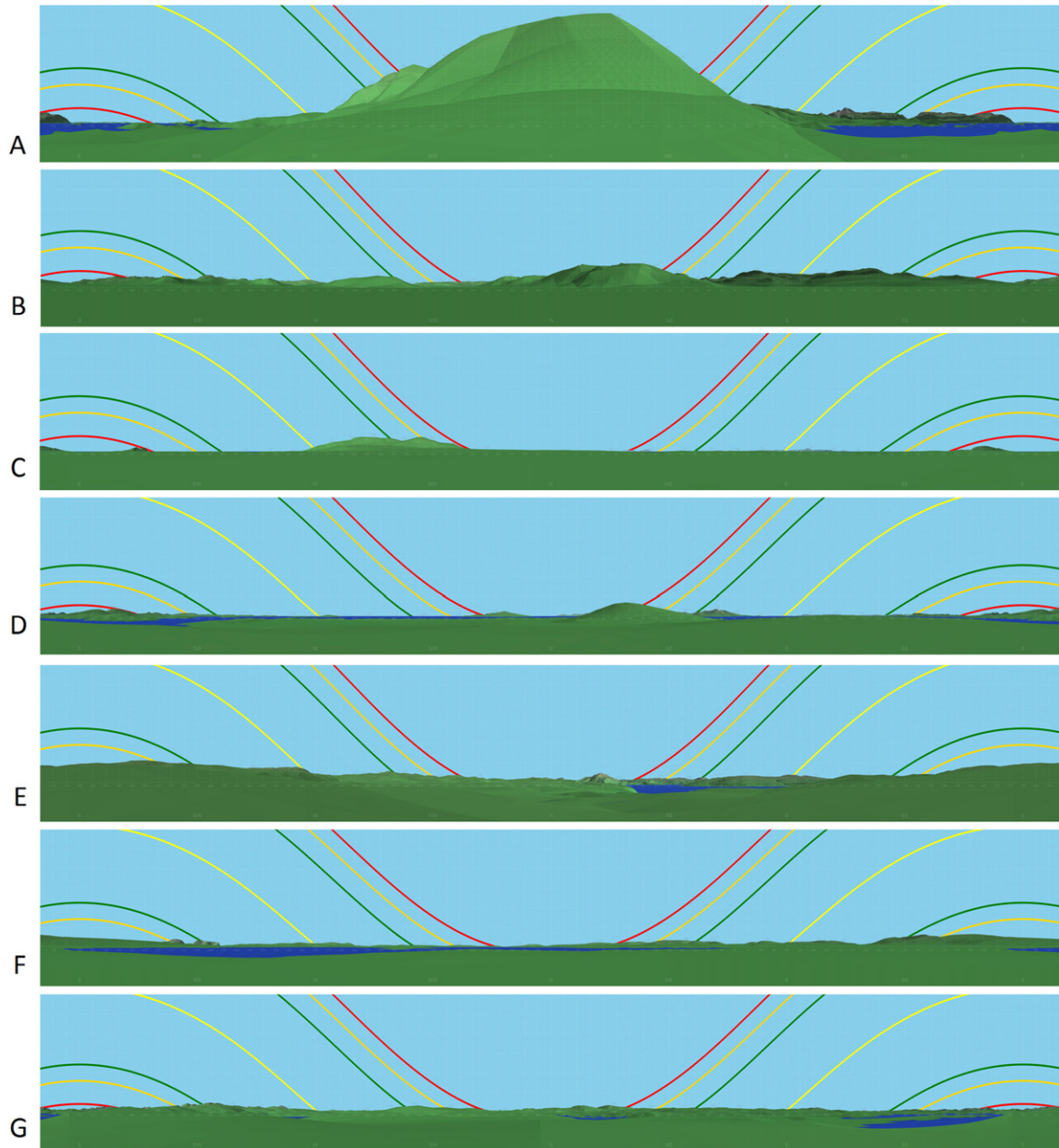
conservative version of the other, both incorporate the same appropriate errors in the construction of the data to be tested (See *Supplementary Material 1*, section 4.2 for *Assumptions and Procedures underlying the tests*). The less conservative test determines the probability that the overall monument is *not designed with astronomical considerations* (Test 1) and the more conservative test determines the probability that the overall monument is *designed with astronomical considerations* (Test 2).

The results for Test 1 are  $p = 0.0125$  for Callanish and  $p = 0.0375$  for Stenness. Thus the likelihood of the number of ‘hits’ coming from random chance is 1.25% ( $p = 0.0125$ ) and 3.75% ( $p = 0.0375$ ). This means that the probability that the circles are not astronomical is low. For Test 2, the results are  $p < 0.97872$  for Stenness and for Callanish, 0.97867 ( $p = 0.97867$ ; where 1 = true and zero = not true). To put

this another way, the likelihood of the monuments being astronomical is above 97.87% for Stenness and 97.87% for Callanish. For details about how the tests work and how we got these results, read the *Supplementary Material 1*, section 4.3 *The Tests and SMFig. 6 for Callanish and SMFig. 7 for Stenness* (for information on earlier versions of this work found on ArXiv and SSRN see *Supplementary Material 1*, section 5. Differences from early preprint version).

### 5.3. 3D landscape reconstructions of Callanish and Stenness

Applying our 3D landscape models to the great circles of Callanish and Stenness, we find that they share a combination of the astronomical and landscape cues found at BA sites more than 1500 years later, where



**Fig. 5.** 3D landscapes of the Bronze Age example sites and the Neolithic great circles (S = south; N = north; sw = southwest etcetera; see SMFigs. 1–5 & 8–9 for higher resolution and greater detail, as well as Figs. 6 & 7). **a.** Craigaig, Mull (NGR NM4028 3901): a pair standing stones, approximately 4 m apart. One is a 1.3 m tall, the other is 1.6 m. **b.** Dunamuck, Argyll (NR8470 9290). Stone row of 4.4 m made up of three menhirs up to 3 m high. **c.** Hough, Tiree: 2 small stone circles 90 m apart and 40 m in diameter. **d.** Blashavel, Uist (NF9122 8068): a thin, tall slab 2.5 m high by 2 m wide. Our pilot study on Uist has begun to find the same patterns as discovered elsewhere to date. **e.** Balliscate, Mull (NM4996 5413): a stone row of 3 irregular menhirs: 5 m in length and 1.8 m to 2.8 m in height. This is a reverse site. **f.** The Neolithic Stenness stone circle, on Orkney (HY3067 1252), is a reverse site. **g.** Neolithic Callanish I stone circle, Lewis (NB2130 3300). A.G.K. Smith, created all landscapes with the software Horizon, © A.G.K. Smith. Also created with Terrain 50. Contains Ordnance Survey data Crown copyright and database right (2012). HYPERLINK <http://www.ordnancesurvey.co.uk/docs/licenses/os-opendata-licence.pdf> Also see Supplementary Material.

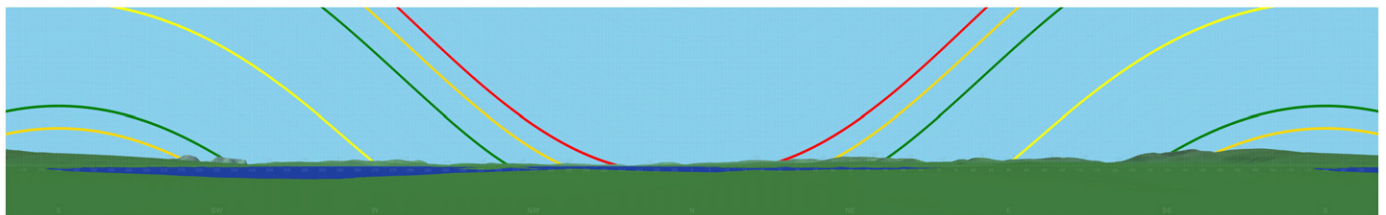
**Table 1**  
Observed data used for probability calculations testing the astronomical associations of the great circles, Callanish and Stenness. Note that whilst Stone 3 of Stenness was 0.3 degrees outside of the orientation error we included it in our assessment (See caption for SMFig. 6). There are no other orientations this close outside of the  $\pm 3$  degree orientation error range.

	Megalith number from plan	Orientation from central feature to vertical centre of stones within the ring	Astronomical phenomenon range (astronomical error)	Possible astronomical phenomenon (target)	Target 'hit' (within orientation error)
Callanish		In degrees	In degrees		
Central slab axis*	29	0	0	'True North'	
	53	5			
	41	27	28.2–30	MajLS rise (nth)	Yes
Close outlier	34	40	39.6–41.5	SS rise (nth)	Yes
	42	52	55–56	MinLS rise (nth)	Yes
	43	77			
	44	98			
	45	122	128.9–130	MinLS rise (sth)	
	46	142.5	140.1–141.4	WS rise (sth)	Yes
Close outlier	35	162	163.5–166	MajLS rise (sth)	Yes
Central slab axis	29	180	180	South	
	47	183			
Close outlier	9	196	188.2–194.2	majLS rise (sth)	Yes
	48	214	215–216.5	Ws set (sth)	Yes
			226.2–227	MinLS set (sth)	
			303.2–304.4		
	49	253			
	50	292			
	51	328	317.9–319.2	SS set (nth)	
	52	349.5	331–334.3	MinLS set (nth)	Yes
Stenness		In degrees	In degrees		
Axis of entrance + hearth		2	0	'True North'	
	8	10.5			
			24.8–27	MajLS rise (nth)	
	9	42	40–42	SS rise (nth)	Yes
			55–56	Min LS (nth)	
	10	74			
	11	104.5/105			
	12	138	136–137.6	MinLS rise (sth)	Yes
			147.2–151	Ws rise (sth)	
	1	162			
Axis of entrance + hearth		178	173	MajLS rise-glimmer	
	2	191	180	South	
	3	218	192	MajLS-glimmer ends	Yes
			213.8–214.7	WS set (sth)	Yes (3.3)
			225–226.5	MinLS set (sth)	Yes
	4	251			
	5	282			
	6	310	306.1–307.5	MinLS set (nth)	Yes
			321.5–323	SS set (nth)	
	7	339.5	336–338.8	MajLS set (nth)	Yes

Callanish on the western Isle of Lewis is a 'classic' site and Stenness in the north on Orkney is a 'reverse' site. Despite Stenness having an almost flat horizon, the builders engineered very particular horizon views (Figs. 5F and 6 & SMFig. 8). The northern cardinal point is closely marked with a horizon notch, with the rising and setting Major Standstill Moon placed very close to 25° either side of this. The SS Sun and northern Major Standstill Moon both rise out of a northern slope of the high ranges in the NE and set into the high points in the NW; the Minor Moon at the LS in the north rises out of the top of a hill in the highest range in the NW. The WS Sun rises out of the closest and highest range in the SE and sets in one of two very distinctive ranges in the SW;

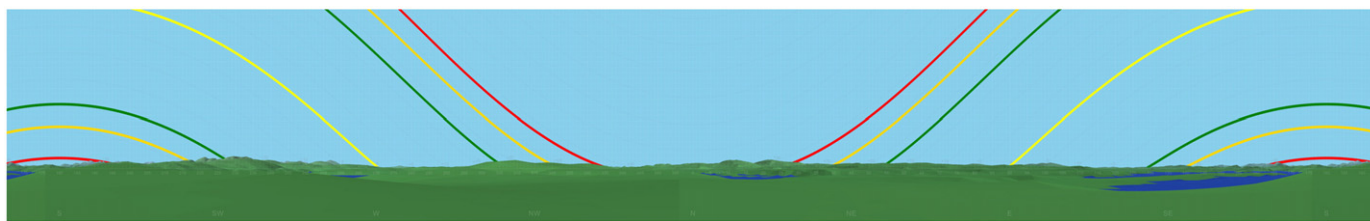
the Minor Moon at the LS in the south does the same, setting into the only other significant peak in the SW. Also in the south, the 'top' rim of the Moon of the Major LS lies just below the horizon within 0.5° in declination, and travels along this declination below the horizon, from 178° to 187°. What is important, here, is that its glow would travel above the horizon for nearly 10°. The equinox Sun rises out of, and sets into, ranges east and west of the site.

For Callanish, the highest points in the distant north sit NW and NE, as expected (Figs. 5g and 7 & SMFig. 9). The Major Standstill Moon rises out of the slopes of the NE range at the LS and begins to set into one of the peaks in the NW before rolling down its slope. Both the SS Sun and



**Fig. 6.** 3D landscape of Neolithic Stenness, Orkney (see SMFig. 8). Created with the software **Horizon** by A.G.K. Smith, © A.G.K. Smith. Created with Terrain 50. Contains Ordnance Survey data Crown copyright and database right (2012). <http://www.ordnancesurvey.co.uk/docs/licenses/os-opendata-licence.pdf>





**Fig. 7.** 3D landscape of Neolithic Callanish, Lewis (see SMFig. 9). Created with the software **Horizon** by A.G.K. Smith, © A.G.K. Smith. Created with Terrain 50. Contains Ordnance Survey data Crown copyright and database right (2012). <http://www.ordnancesurvey.co.uk/docs/licenses/os-opendata-licence.pdf>

Minor Moon at the LS rise out of an undulating horizon. The SS Sun again sets into the highest point in the NW. In the south the Major Standstill Moon rises out of the closest and highest horizon in the SSE and sets into ranges in the SSW. The WS Sun and the Minor Moon set in one of two very distinctive ranges in the SW. These late Neolithic landscapes of the great circles (Fig. 5F and G) have a strong resemblance to those from the BA (Fig. 5A–E). Their landscape and astronomical choices in relation to horizon distances and direction, horizon profile and the astronomical phenomena associated with each of these are clearly consistent, as are the monument alignments.

## 6. Discussion

From the beginning, our Western Scotland Megalithic Landscape Project involved innovatively devising and developing new statistical tests from a broader suite than is common in archaeoastronomy, and applied rigorous, computer-intensive determinations of confidence limits when the tests were applied to archaeoastronomical situations. Significantly, the tests are more appropriate for the data being tested (e.g. Higginbottom et al., 2002; Higginbottom, 2003; Higginbottom and Clay, 1999; Higginbottom et al., 2001b), leading to well-defined and convincing advances in the study of megalithic astronomy in the British Isles.

Now, for the first time statistical tests have been constructed to test the astronomical potential of *single* standing SC, which has been problematic due to the large amount of potential random errors and background noise, plus the inherent number of statistical trials. The latter being a particular worry. Increasing the number of stones there are in a circle means an increase in the likelihood that an observed pattern is due to chance. Our version of a cross-correlation test factors in all of these trials, allowing us to test for significant structural design properties in standing SC and then test those against the possibility that they may be astronomically-related, taking into account the actual horizon viewing structure at individual sites. This work has involved care in assessing and minimising statistical penalties involved with the selection of hypotheses, and due consideration of the effect of large numbers of possible alignments when many stones are involved. The application of these tests has clarified when and where the use of complex astronomical and landscape patterns were likely *first* associated with standing-stone structures in Scotland, and possibly in all of Britain. The statistical results for Stenness and Callanish are compelling.

Whilst there is a diversity of archaeological expressions in site architecture amongst the sites we have examined in the Neolithic and BA (single StS, SC, SR, stone pairs), as well as varied detailed monument associations (number and kinds of monuments found close together or in sight of one another, including mounds, cairn and cist varieties and burial styles: Armit, 1996, Richards (a) in Richards, 2013a) and possible site activities (burning events, local ritual ploughing: Ashmore, 2002; Ritchie, 1976; Richards and Wright in Richards, 2013a; Richards (b) in Richards, 2013b), there are clearly shared, abiding values to be discovered. Our work has highlighted the repeated use of an interest in solar and lunar extreme risings and settings along the horizon, as well as combinations of astronomical targets, at many BA sites, as at the great circles. For example, opposite directions of a single stone row, or a combination of an internal alignment and an alignment with another site,

can contain two different lunar alignments; or two parallel monuments side-by-side or close-by might contain solar or lunar alignments (Higginbottom et al. 2015; Higginbottom, in preparation-a; in preparation-b; Ruggles, 1985). Relevantly, Bronze Age sites can cluster such that a larger number of targets are covered within a small local region, such as in the Kilmartin Valley (Burl, 2000). In this way, perhaps, a small area may have a similar function to one of the past great circles. Further, there is a consistent association of these constructed locales with the dead, most usually cremations.

Regarding astro-landscape features only (i.e. without considering orientation), it can be argued that localised variations (such as three prominent hills/ranges/elevations instead of four in the ordinal directions of NW, NE, SW and SE) may result from finding landscapes with as many of the key features as possible. So, whilst “we observe the physical residues of a series of ‘highly localised’ social encounters of ritual” (Barrett, 1994: 72), they are clearly “organised within a framework of wider cultural motifs” (Duffy et al., 2007: 54), and through their chosen astronomical emphasis within regions, “manifest as a distinct entity of local time, place and experience” (Duffy et al., 2007: 54).

In relation to the possibility that Neolithic sites were altered during the BA to ‘fit to the needs and perceptions’ of the BA population, we note that many Neolithic sites have complicated biographies and have undergone often-dramatic structural changes in the BA. Pitnacree and Callanish are excellent examples (Ashmore, 1995: 31; Brophy and Noble, 2012: 32–33; Coles and Simpson, 1965; Henley 2005:270 in Wright, 2007:224; Higginbottom et al., 2015: 591 & 601; Noble, 2006; Sheridan, 2010: 46–47). Both sites are dealt with differently and it seems that, whilst at Pitnacree there is a distinct feeling of dominating and controlling the past through its proliferation of mounding and burying structures, at Callanish, such as through the addition of the cruciform tomb inside the eastern wall of circle in the BA, it is much more about “channelling” the past and, in many senses, re-instating or regaining the power of the past (Higginbottom et al., 2015: 588 & 595). Regardless, for Callanish at least, we can say fairly categorically, due to Ashmore’s excavation, that the stones of the circle and the central StS that we used for this study were not altered in the BA. Whilst Stenness has been damaged, the current standing stones and the original stone holes of the circle (regardless of whether a stone stood in them or not) were determined via excavation, thus any later alterations, will not have affected the outcome of this particular study either (Ritchie, 1976).

## 7. Conclusion

The local visual dominance of the likely first great circles in the north of Britain seems to have led to a cultural transformation that connected StS to the local landscape and the orderly arrangement of the Universe, across Scotland. By the end of the BA (approximately 800 BCE), hundreds of settings existed (Burl, 1993, 2000; Higginbottom et al., 2015: 3–8, 16–18). The number of these monuments, and the fact that they were likely constructed over a far longer time-frame than any other megalithic monument type (Burl, 1993; Richards, 2013a), highlights their continual relevance for Neolithic and Bronze Age cultures. Significantly, the later monuments continued the tradition of connecting with a cosmological-landscape ideal that was first set in standing stone

around 2000 years earlier demonstrating the longevity and relevance of this cosmological system, despite other cultural changes through time (Lynch, 2000; Mullin, 2001; Owoc, 2001).

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.jasrep.2016.05.025>.

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