ORIENTATIONS OF LINEAR STONE ARRANGEMENTS

in New South Wales

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Abstract

We test the hypothesis that Aboriginal linear stone arrangements in New South Wales are oriented along cardinal directions. We accomplish this by measuring the azimuths of stone arrangements described on site cards held in the New South Wales Aboriginal Heritage Information Management System. We find a preference recorded on the site cards for cardinal orientations among azimuths. We then survey a subset of these sites to test the accuracy of the information recorded on the site cards. The field surveys show that the site cards are reasonably accurate, but the surveyors probably did not correct for magnetic declinations. Using Monte Carlo statistics, we show that these preferred orientations did not occur by chance and that Aboriginal people deliberately aligned these arrangements to the approximate cardinal directions. We briefly explore possible reasons for these preferred orientations and highlight the need for future work.

Introduction

This paper represents the first rigorous study of the orientations of stone arrangements in New South Wales (NSW), focusing on linear arrangements ('stone rows'). Specifically, we test the hypothesis that linear stone arrangements have a preferred orientation to cardinal directions. We accessed site cards from the NSW Aboriginal Heritage Information Management System (AHIMS) database and filtered them through a rigorous selection process to reject those with insufficient information from which to determine stone row orientations. We then measured the orientations of each stone row described in the site cards. To test the accuracy of recorded information, a subset of sites was revisited and surveyed (Figure 1). Monte Carlo statistics were used to test whether or not any preferred orientation amongst linear stone arrangements is the result of chance. Finally, we discuss future work and explore the causes for any preferred orientations.

Cardinal Directions in Aboriginal Languages

The concept of cardinal directions is found among several of the hundreds of Aboriginal language groups in Australia (e.g. Breen 1992, 1993; Edmonds-Wathen 2011; Haviland 1996; Kirton 1987; Laughren 1978, 1992; McGregor 1990; Yallop 1977). While many Aboriginal languages contain names or concepts for four cardinal directions, some languages contain as many as five or six (e.g. Laughren 1978; Nash 1980; Spencer and Gillen 1899). Of particular interest with respect to Aboriginal astronomy is whether these directions are based on an abstract concept of relative space, or an absolute concept based on features of the landscape (e.g. Lewis 1976), wind directions, river flow directions or the rising/setting position of the sun.

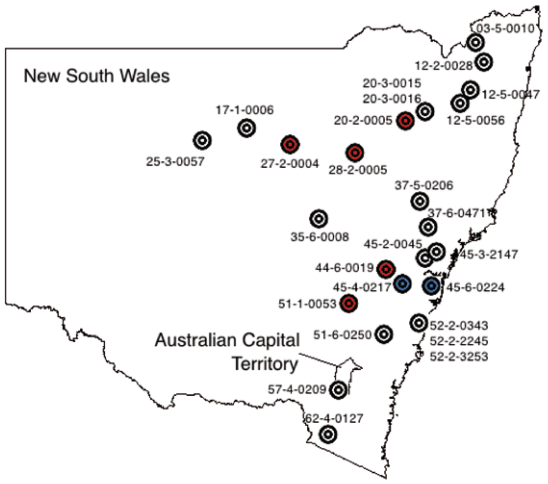

Figure 1 Locations of stone arrangements in New South Wales used in this study. White circles indicate stone arrangements that were recorded in the site cards but were not surveyed by the authors. Red circles indicate sites that were surveyed by the authors. Blue circles indicate sites that were visited by the authors but appeared to be destroyed.

Guugu Yimithirr speakers from Queensland (Qld) describe the relative position of objects or places in terms of root words that represent the cardinal directions in four general quadrants (Haviland 1979, 1993, 1996): north (*gungga*), east (*naga*), south (*jiba*) and west (*guwa*). In terms of gauging directions by solar positions, Kunwinjku speakers of the Northern Territory (NT) may refer to absolute directions according to sunrise and sunset, corresponding to *abalkbang manyij* (east) and *wurrying manyij* (west), respectively (Edmonds-Wathen 2011:222). Several language groups in Central Australia have particular words for the cardinal directions, most notable of which are the Warlpiri, who have an entire culture based on a system of cardinal directions (Laughren 1978, 1992; Nash 1980). Interestingly, Breen (1993) found that an Alyawarr community in the NT that had migrated to a different region altered the names of the cardinal points by 90°. The reason for this is currently unknown, but Breen noted that the Wangkumara (Qld) terms for east and west are based on *mirla*, meaning sun. The linguistic relationship between east/west and the sun is also found in the Yirandhali and other Mayi languages of Qld (Tindale 1938/39). In the Yirandhali language, the term for east is *kunggari*, meaning literally 'sun get up' (Breen 1993; Tindale 1938/39). An identical concept is found near Lake Boga, Victoria (Vic.), where east is *worwalling gnowie*, meaning 'where the sun rises', and west is *purticalling gnowie*, meaning 'where the sun sets' (Stone 1911:451).

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From this, it is clear that the concepts of east and west are denoted by the rising and setting sun amongst Australian Aboriginal groups. However, it is not clear how close these cardinal directions are to scientific definitions based on the rotational axis of the Earth. Breen (1993) tested the accuracy of various words representing cardinal directions in several different areas by asking Aboriginal people and found that the direction, as compared to a compass, ranged rather dramatically—up to 90° in some cases—leading him to suggest that the names for cardinal directions represent a vague area rather than an exact direction, and that it would be unreasonable to expect a person to 'even try to be exact' (Breen 1993:28). Breen also concluded that, if people were placed in a new area with an unfamiliar topography, they would require a view of the sun to determine direction by during the day, or the stars at night. If dropped in an unfamiliar area on a cloudy day, they would essentially be unable to determine the cardinal points (Breen 1993:27). In some regions, cardinal directions play a role in burial rituals. In NSW, for example, graves were found with the dead buried in a sitting position, facing east (Dunbar 1943; Mathews 1904:274).

Stone Arrangements

Stone arrangements of various designs and morphologies, including circles, lines, pathways, standing stones and cairns, were common to many Aboriginal cultures and had purposes that ranged from practical (e.g. fish traps, land boundaries) to mythological and ceremonial/ritual (e.g. initiation or burial; Flood 1999a). These arrangements can vary in size from a few metres to hundreds or even thousands of metres in length or diameter and are typically constructed from local rocks that are small and movable by one or two people, although occasionally they can weigh as much as 500 kg (Lane and Fullagar 1980; Long and Schell 1999). The ages of stone arrangements are unknown, but smaller arrangements are likely to be in the order of hundreds of years old, as sedimentation and disruption by natural processes would likely have buried or destroyed older arrangements.

McCarthy (1940) suggested that stone arrangements used for ceremonial purposes incorporate the surrounding landscape, and may indicate the direction of a landmark or mimic a land feature. The results of the current study indicate that many of the stone arrangements examined were on a hill or a location of higher elevation that commanded a panoramic (full or partial) view of the surrounding landscape. Flood (1999b:239–240) noted that, in NSW, elevated sites were preferred for ceremonies, such as male initiation, or 'bora', ceremonies. Bora sites were generally made of stone or raised earth in the form of two circles connected by a pathway (a project measuring the orientations of bora sites in southeastern Australia is currently underway by the authors).

Some researchers have noted that stone arrangements align to cardinal points in southeastern Australia and Tasmania. Examples include Black (1945:212–213) and Flood (1999b:208), both of whom described linear stone arrangements oriented to a north/south direction, and Bartholomai and Breeden (1961:233) and Winterbotham (1957:38), who described ceremonial stone arrangements oriented to the east/west or north/south. Other examples include the Wurdi Youang and Carisbrook stone arrangements in Vic., which are oriented to the cardinal points (Hamacher and Norris 2011; Massola 1963; Norris et al. under review).

For a further treatise on stone arrangements, the interested reader is referred to Attenbrow (2002), Bannerman and Jones (1999), Black (1950), Campbell and Hossfield (1964), Dow (1939), Enright (1937), Frankel (1982), Kelly (1968), Lane (2009), Lane and Fullager (1980), Long and Schell (1999), Love (1946), Massola (1968), McCarthy (1940), Palmer (1977), Ross (2008), Ross and Ulm (2009), Rowlands and Rowlands (1963), Towle (1939a, 1993b) and Winterbotham (1949).

Methods

Archaeological Site Cards

Aboriginal sites and artefacts in NSW are registered with AHIMS and administered by the NSW Office of Environment and Heritage. Information about each site is stored on archaeological site cards submitted by both professionals and amateurs. These can vary significantly in the quality and quantity of information provided and therefore the accuracy of the data collected is difficult to assess without physically resurveying each site. Not all existing stone arrangements are registered with AHIMS and some site cards are restricted owing to their cultural sensitivity; no restricted sites were included in this study.

We examined 643 stone arrangement site cards from AHIMS, developing a rigorous selection process to cull sites that did not provide useful data. We rejected sites that did not meet all of the following five criteria:

1. The arrangement must be clearly Aboriginal in origin[1];
2. The stones must form an unambiguous linear pattern;
3. The arrangement must consist of at least five stones of comparable size;
4. The linear pattern of stones must not clearly be a smaller component of a larger, non-linear structure, such as a circle, animal motif or other pattern; and,
5. A map or directions and a photo, diagram or a sufficient description of the site must be available.

Of the 643 AHIMS site cards examined, 618 were rejected as not meeting the criteria, leaving 24 sites consisting of 32 stone rows (Table 1); parallel rows ('pathways') were categorised as a single row. Five of the sites contained multiple stone rows (12-2-0028, 12-5-0056, 28-2-0005, 44-6-0019, 45-4-0217). Although site card 44-6-0019 shows a stone circle, the three stone rows within the circle (two parallel rows to the north and one to the east) were included because they were distinct within the arrangement and not merely a straight component of the overall circle. Sketches of the stone rows, as shown in the site cards, are given in Figure 2. Some site cards provided orientations but not sketches.

Site Card Measurements

Using information provided on the site cards, we measured the azimuth of each stone arrangement (Table 2) using the

[1] Rows of stone were sometimes constructed as survey markers or borders by Europeans: these are generally called survey lockspits. These can mimic Aboriginal stone rows (see 45-2-0045 in Figure 2) and some have been identified along the NSW/ACT border. All stone rows in our final dataset were cross-checked against the locations of known lockspits and rejected if they were discovered to be one.

Site Card	Zone	Latitude (°)	Longitude (°)	Elevation (m)	N
03-5-0010	56	–28.8	152.1	960	1
12-2-0028	56	–29.1	152.3	980	2
12-5-0047	56	–29.6	152.2	880	1
12-5-0056	56	–29.8	152.1	1100	2
17-1-0006	55	–30.9	146.6	200	1
20-2-0005	56	–30.4	150.9	820	1
20-3-0015	56	–30.2	151.3	1000	1
20-3-0016	56	–30.2	151.3	1000	1
25-3-0057	55	–31.2	145.4	240	1
27-2-0004	55	–31.3	147.6	160	1
28-2-0005	55	–31.3	149.3	540	5
37-5-0206	56	–32.6	150.9	480	1
37-6-0471	56	–32.9	151.0	160	1
44-6-0019	55	–33.5	149.9	820	1
45-3-2147	56	–33.2	151.1	180	1
45-4-0217	56	–33.7	150.9	460	2
45-6-0224	56	–33.7	151.2	420	1
51-1-0053	55	–34	149.0	700	1
51-6-0250	55	–34.7	150.0	680	1
52-2-2245	56	–34.5	150.7	500	1
52-2-3253	56	–34.5	150.7	460	1
52-5-0343	56	–34.5	150.7	560	1
57-4-0209	55	–35.8	148.9	1660	1
62-4-0127	55	–36.7	148.5	300	1

Table 1 The general locations of the 24 sites in this study. Coordinates provided are for a location within 10 km of the site so as to protect their specific location but give the reader an overall impression of their distribution.

compass azimuth if provided, or by using a protractor and ruler on graph paper. Azimuths are given between 0° and 179°, with 0° representing north/south, and 90° representing east/west. Azimuths measured with a magnetic compass (i.e. that measures direction with respect to the magnetic north pole) in NSW are between 9° and 13° east with respect to true (geographic) north. The difference between true and magnetic north is called 'magnetic declination' ($\mathbf{D}_{mag}$). We used an online program provided by Geoscience Australia (2011) to calculate $\mathbf{D}_{mag}$ using the geographic coordinates provided in the site cards, the elevation taken from Google terrain maps (with a relief of 20 m) and the date of the original site recording as noted on the site card. $\mathbf{D}_{mag}$ was calculated for every site and then corrected the measured azimuth, as described below (Table 2); however, only five of the 24 site cards discriminate between true and magnetic north (the latter by indicating 'MN'). The remaining site cards either labelled north as 'N' or stated the orientation without specifying whether magnetic declination had been corrected for. For this reason, we used only the corrected azimuths for the five sites included in this analysis.

Field Survey Methods

To test the accuracy of site card information, we surveyed a subset of the 24 sites. Of these, we were unable to gain access to 17, either because of their remote location or our inability to contact or obtain permission from the traditional owners, the current landowners or NSW Parks and Wildlife. Sites 12-2-0028 and 45-6-0224 had been previously destroyed, Site 44-6-0019 was damaged, we were unable physically relocate to Site 45-4-0217 (which may have been destroyed since initial recording), and dense vegetation had grown over Site 35-6-0008 such that it was impossible to clearly identify the stones in any of the several arrangements noted on the site card. Accordingly, this site was also excluded from analysis. The sketch for Site 35-6-0008 did not indicate north, but it was assumed to be at the top of the page; however, upon visiting the site this assumption was proved incorrect based on the orientation of a large rock in the centre of the site. As such, Site 35-6-0008 was also excluded from analysis. Given time constraints, we were unable to survey three of the five rows at Site 28-2-0005 in detail. We surveyed five sites (Table 3) using a standard military lensatic compass, a Sokkisha C40 (D10355) automatic level (dumpy), stadia rod, tape measures and a hand-held GPS as follows:

1. The stones on each end of the linear arrangement were identified.
2. The levelled dumpy was placed 1 m from one end-stone along the axis of the end-stones, using a weighted string over the point on the ground to ensure accuracy.
3. The stadia rod was placed on the centre of the opposite end-stone.
4. Using the sight on the dumpy as an alidade, the magnetic azimuth of the stadia rod was measured by aligning the compass sight-wire along the dumpy sight to the edge of the staff.
5. Using the dumpy and stadia rod, the topographic relief was recorded along the stone row.
6. Each stone was numbered and its dimensions recorded.

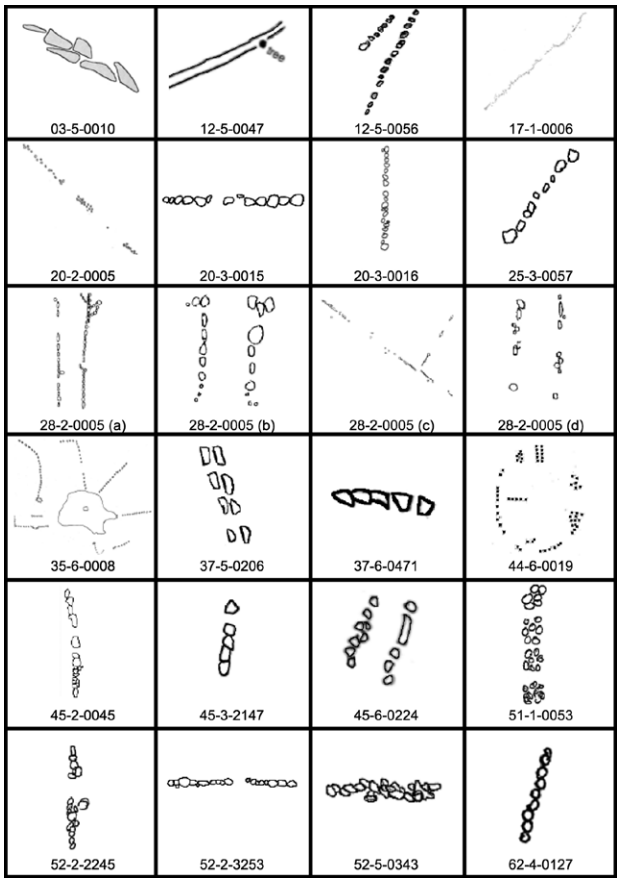

Figure 2 Stone arrangement sketches taken from site cards. Stone rows have been cropped from the rest of the sketch in most cases (except 44-6-0019). Site 45-2-0045 was removed when it proved to be a lockspit and 35-6-0008 was rejected upon visiting the site and finding that the site card orientation was incorrect and vegetation overgrowth concealed the arrangements. Sites that provided only a description or a photo were not included. North (as labelled in the site card) is to the top of the page.

7. The position of the centre of each stone was recorded relative to the line connecting the end-stones.
8. The site was photographed.
9. The presence of Aboriginal artefacts or art in the area was noted.

For the purposes of analysis the azimuths of parallel stone rows were averaged. This data is provided in Table 2, where all measured azimuths are rounded to the nearest degree. Errors are discussed in the following section.

Error Analysis

The two general errors that affected the measurements of stone rows were (1) site card errors and (2) our field survey errors. Site card errors included the accuracy of the original sketch, the accuracy of the survey methods and the skill of the surveyor. These errors were difficult to quantify without visiting the site. Some site card drawings were not to scale and represented only rough sketches. However, if the sketch of the site is taken to be accurate, the main source of error stemmed from physically measuring the azimuth given in the site card using a ruler and protractor. Both the site cards and our field surveys were subject to the same three general errors in measuring the azimuth, as described below.

Errors in Measuring the Magnetic Azimuth

The azimuth of the stone row surveyed in the field was measured by taking several compass bearings and averaging them. The compass bearings varied by a maximum of ~2°, which we consider to be the 'human error estimate'.

Errors in Magnetic Declination

The Earth's magnetic field varies over time, causing the $\mathbf{D}_{mag}$ to shift at any given location by ~0.3° over a 25 year period. The azimuths recorded in the site cards were recorded as early as 1977 (33 years prior to our resurvey), thus giving an azimuthal error of 0.3°. If the location and elevation of the site and the date of the survey are known, the azimuthal error is reduced to only ~0.001°. However, local magnetic anomalies, such as the influence of iron-bearing stone, can cause variations of up to 4° (Goulet 2001).

The Great Dividing Range of eastern Australia, where many of the stone arrangements are found, is volcanic in origin. Volcanic (igneous) rocks, such as basalt, are typically iron-rich and many of the stones forming the arrangements are composed of basalt. Therefore, we use an upper error estimate of 4° to account for this effect.

Errors in Measuring the Dimensions of Each Stone

The dimensions of each stone were recorded, including their maximum width, length and height (with respect to the ground surface). The width and length were relative to the x- and y-axes, as determined by the orientation of the two end-stones. The positions of each stone were recorded with respect to the midpoint of the width and length. Since measurements were taken from the centre of each stone with an accuracy of ±0.02 m, the azimuthal error for an arrangement with an average length of 7.5 m was ~0.3°.

Final Error Estimates

The human error (2°), the error from local magnetic anomalies (4°), the error in magnetic declination (0.001°) and the error in measuring the dimensions of the stones (0.3°) were used to calculate an error of ~5° (±2.5°) for the surveyed azimuth (σ_{mag}). To account for this, azimuths were grouped into 5° bins. Because the value of σ_{mag} is dominated by magnetic anomalies and human error, we applied an error of 5° to orientations of stone arrangements on the site cards. However, we do not know how accurate the surveyors were in recording the azimuths, so this can only be considered approximate based on our quantified estimates.

Results and Statistical Analysis

Site Card Measurements

The site card data consisted of 32 azimuths from 24 sites, mapped as a histogram shown divided into 5° bins centred at 0° (N/S) and 90° (E/W), as shown in Figure 3. As demonstrated, there is an unambiguous preference for cardinal orientations, with nine azimuths in the N/S bin and seven in the E/W bin. To test whether or not these peaks could occur by chance, we used Monte Carlo statistics. Monte Carlo statistics sample probability distributions to produce millions of possible outcomes, which is useful for determining the likelihood of something occurring by chance (Fishman 1995; Vose 2000).

Site Card	Az^{mag} (°)	Dmag (°)	Date
03-5-0010*	120	11.112	Jun-77
12-2-0028	0	11.277	Oct-97
12-5-0047*	90	11.277	
12-5-0056	65	11.388	Nov-95
17-1-0006	27	11.428	Sep-97
20-2-0005	43	11.428	
20-3-0015*	47	10.071	Jan-91
20-3-0016*	134	11.178	May-81
25-3-0057	178	11.301	Aug-79
27-2-0004*	90	11.301	Aug-79
28-2-0005	38	9.738	Jun-79
37-5-0206	90	10.496	Feb-91
37-6-0471	1	11.005	Dec-79
44-6-0019	3	11.005	
45-3-2147	0	11.005	
45-4-0217	32	11.005	
45-6-0224	125	11.005	
51-1-0053	157	11.958	Apr-94
51-6-0250	101	12.101	Oct-90
52-2-2245	0	11.970	Sep-78
52-2-3253	90	11.970	
52-5-0343	2	12.242	Jun-93
57-4-0209	0	12.238	Nov-92
62-4-0127	90	12.238	
45-6-0224	16	12.467	Apr-92
51-1-0053	0	11.801	Dec-93
51-6-0250	90	12.393	Jul-04
52-2-2245	0	12.552	Jul-98
52-2-3253	90	12.552	Jul-98
52-5-0343	90	12.552	Jul-98
57-4-0209	0	12.415	May-06
62-4-0127	15	12.616	Jul-81

Table 2 Linear stone arrangements remaining after the application of selection criteria. The five site cards with an asterisk denoted north as magnetic.

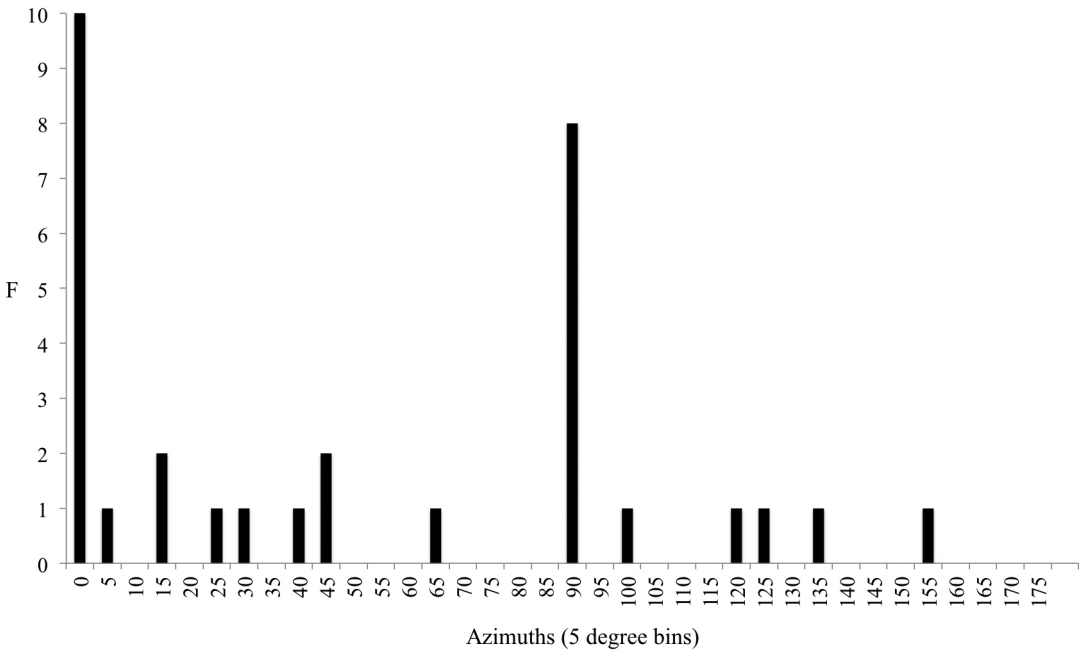

Figure 3 Histogram showing the azimuths of stone rows from the site cards.

Site Card	Accessibility	Cardinal	Surveyed	Condition	MN
03-5-0010	None			Unknown	X
12-2-0028	None	X		Destroyed?	
12-5-0047	None			Unknown	X
12-5-0056	None			Unknown	
17-1-0006	None			Unknown	
20-2-0005	Granted		X	Good	
20-3-0015	None	X		Unknown	X
20-3-0016	None	X		Unknown	X
25-3-0057	None			Unknown	
27-2-0004	Granted	X	X	Good	X
28-2-0005	Granted	X	X	Good	
37-5-0206	None			Unknown	
37-6-0471	None			Unknown	
44-6-0019	Granted	X	X	Damaged	
45-3-2147	None	X		Unknown	
45-4-0217	Granted	X	V	Unidentified	
45-6-0224	Granted	X	V	Destroyed	
51-1-0053	Granted	X	X	Good	
51-6-0250	None	X		Unknown	
52-2-2245	None	X		Unknown	
52-2-3253	None	X		Unknown	
52-5-0343	None	X		Unknown	
57-4-0209	None	X		Unknown	
62-4-0127	None			Unknown	

Table 3 A list of the sites. Sites surveyed = X; sites visited but not surveyed = V; MN denoted sites that recorded magnetic north.

Site Card	AzSC (°)	Dmag (°)	AzS (°)	m (°)	χ^2	θc	AzF	ΔAz
20-2-0005	133	11.2	144	0.0051	0.07	0.3	108	25
27-2-0004	90	10.5	101	–0.0313	0.24	–1.8	87	3
28-2-0005	181	11.0	192	–0.0079	0.24	–0.5	165	16
	183	11.0	194	–0.0182	0.12	–1.0	174	9
44-6-0019	0	12.0						
	90	12.0	102	–0.0064	0.00	–0.4	63	27
51-1-0053	180	11.8	192	–0.0018	0.05	–0.1	143	37

Table 4 Data for all linear stone arrangements surveyed. m = the slope of the linear best fit, χ^2 is the chi-squared distribution, θ_c is the correction angle, and Az_F is final calculated azimuth from the survey, measured with respect to true north. ΔAz is the difference between Az_{SC} and Az_F. All azimuths are rounded to the nearest degree with an error of 5°. The northerly row at site 44-6-0019 had been destroyed by bulldozing, as noted in the site card.

A Monte Carlo simulation was performed in which 39 random angles were assigned to any one of the 36 5° bins from 0° to 180°. After running one million (10^6) simulations, in only 376 of the simulations did any bin contain ten or more azimuths, showing that the probability of getting a peak of nine in any one bin is approximately 0.04%.

The site card azimuths did not attain a peak of ten in any random bin, but in the bin centered at 0°. This occurred in only 148 of the one million simulations, implying that the probability of a peak centered at 0° occurring by chance is 0.015%. In none of the one million simulations were peaks of eight or more obtained in both the 0° and 90° bins. From this, we conclude that if the site cards are accurate, the preferred orientations of the stone rows are not the result of chance alignments.

Field Survey Measurements

To check whether the surveyors corrected for magnetic declination, we surveyed a subset of six stone arrangements at five sites. Table 4 gives the azimuths for these six arrangements. To compare the accuracy of information on the site cards with the resurveyed data, we calculated the mean (θ) and standard deviation (σ_{Az}) of the difference between the surveyed azimuth and the site card azimuth ($\Delta Az = Az_{SC} - Az_F$). Given six data points for ΔAz from Table 4, θ = 11.7° and σ_{Az} = 8.2°.

The magnetic declination at the sites resurveyed ranged from 10.5° to 12.0°, with a mean ($\mathbf{D}_{mag}$) of 11.3° and a standard deviation (σ_{Dmag}) of 0.56°. Because $\mathbf{D}_{mag}$ is within 1-σ of θ, it seems the site cards were probably not generally corrected for $\mathbf{D}_{mag}$ by the surveyors (i.e. most of the surveyors probably recorded the magnetic compass bearing rather than true north). The surveyed azimuths represent a small percentage of the site card azimuths (~15%), so the remaining sites need to be surveyed to determine

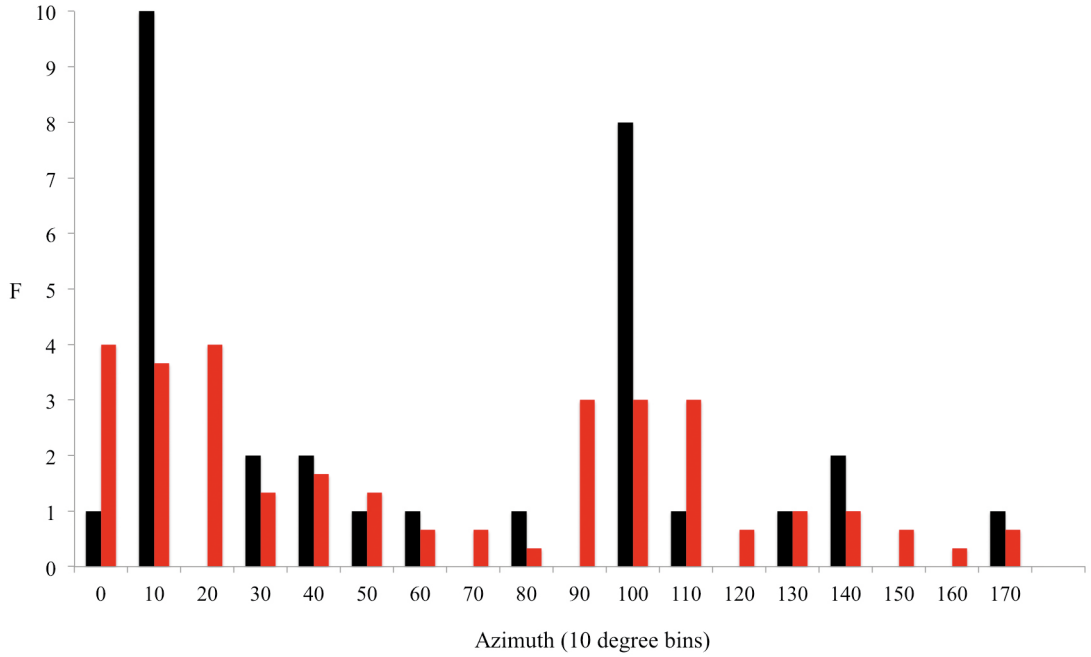

Figure 4 Histogram showing the azimuths (black) and the smoothed data (red) in 10° bins. This represents the entire data set corrected for $\mathbf{D}_{mag}$, assuming all site cards gave magnetic north, as indicated by the analysis. Data is smoothed to account for the uncertainty in θ.

more accurately whether the arrangements are aligned to true or magnetic north.

We now determine whether or not the orientations of the entire dataset can be accounted for by chance. To account for the uncertainty in whether or not the azimuths were given with respect to true or magnetic north, we present here the survey data with the site card data in 10° bins and smooth it using a 3-bin boxcar convolution (to account for uncertainty in whether or not $\mathbf{D}_{mag}$ was corrected), given as:

$$\text{bin n} = \left[\frac{\text{bin (n-1)} + \text{bin (n)} + \text{bin (n+1)}}{3}\right]$$

Here, *n* is each given bin in the histogram. The smoothed data is given in Figure 4. For the unsmoothed (original) data, 10^5 Monte Carlo simulations were performed, of which 650 attained a peak of 10 in the 0° or 90° bins. This gives a chance probability of 0.7%. For the smoothed data, the same number of simulations was performed, with a peak of 4.0 in the 0° bin occurring less than 0.5% of the time. In either case, it is clear that these alignments are not the product of chance; there is a clear preference for these azimuth ranges.

Discussion

From these results it is apparent that there are two preferred orientations for linear stone arrangements: a lesser preference towards east/west and a greater preference towards north/south. To explain the preferred cardinal orientations, we consider three possibilities:

1. The stone rows were constructed by Europeans with a preferred orientation to cardinal points;
2. The stone rows were systematically drawn or described by the surveyors as having preferred cardinal orientations, despite the stone rows not actually having this preference; and,
3. The stone rows were constructed by Aboriginal people with a preferred orientation to cardinal points.

Possibility 1 depends on whether or not the stone arrangements are Aboriginal in origin. The first criterion in selecting stone rows for this study was that they were constructed by Aboriginal people. Some of the site cards identified arrangements that were European in origin (e.g. survey lockspits). These site cards were rejected during the selection process and all of the sites that passed this criterion are argued to be Aboriginal in origin based on their morphology, proximity to other Aboriginal artefacts (such as scarred trees and rock art), or their identification as such by members of the local Aboriginal community. Thus, we reject the position that these arrangements are European in origin.

Possibility 2 depends on the accuracy of information recorded on the site cards. Since the mean Az for the surveyed sites θ is 11.7°, it is within 1-σ of $\mathbf{D}_{mag}$ at the sites surveyed (11.3°). This shows that the surveyors are reasonably accurate in recording their findings, except that they generally did not correct for magnetic declination.

Possibility 3 is that the arrangements are Aboriginal in origin and that Aboriginal people oriented stone rows to cardinal directions, both of which are supported by the site card information and the data analysis. However, we are puzzled as to why these arrangements seem to be oriented to magnetic north. There is currently no evidence that Aboriginal people used any form of magnetic compass. Since we have determined that the arrangements are not European in origin, it indicates that the bias may lie with the surveyors. It is probable that the surveyors used a compass and took a general orientation, but did not place emphasis on high accuracy (which is why we say 'reasonably accurate'). We do not know what percentage of the site cards gave magnetic or true north without revisiting each site. The smoothed data accounts for this uncertainty and

shows us that preferred cardinal orientations are within the error limit.

This paper is a preliminary test to see whether linear stone arrangements have a preferred orientation to the cardinal points. Our analysis suggests that they do, but we were only able to survey a small subset of sites and are not certain of the reliability of the remaining site cards. Future work will involve locating and surveying as many arrangements as reasonably possible to better constrain our estimates. The geographical range of the sites surveyed in this paper is significant, ranging from the northern tablelands near Armidale to the southern slopes near Canberra and from the coast to central NSW. Most of the stone arrangements belong to different Aboriginal language groups. To overcome uncertainties it would be ideal to survey a number of stone arrangements within a particular language group to see whether these orientations remain statistically significant.

Future work should also focus on understanding how the orientations were estimated. It may be that east/west orientations are related to the rising and setting position of the sun in the sky, as noted by some Aboriginal cultures, such as the Wangkumara and Yirandhali. Other stone arrangements in Australia have been found with precise east/west orientations, such as Wurdi Youang (Hamacher and Norris 2011). North and south are 90° to east and west, and the concept of right angle orientations is found in some Aboriginal cultures (e.g. the Warlpiri and Guugu Yimithirr). South can be roughly determined at night by locating the south celestial pole and looking in the direction of the horizon directly below this point. A number of techniques can be used to accomplish this, such as noting the midpoint of a circumpolar star. An Aboriginal man and educator from Port Lincoln, South Australia (SA), said that Venus was a good indicator of west, as it shone brightly at dusk and is near the sun (Pring 2002:9). Another Aboriginal man from SA said he could tell direction at night based on the position of the Milky Way—it would stretch from east to west during the winter, and from north to south during the summer (Pring 2002:9). These techniques are approximations of finding the cardinal directions; they are only accurate to within several degrees. For example, the position of the rising or setting sun on the horizon will vary by nearly 30° either side of due east or west. These extreme rising/setting positions occur at the summer and winter solstice. The only time the sun rises exactly at due east or sets at due west is at the vernal or autumnal equinox.

We cannot currently say with any certainty why these structures were oriented to the cardinal directions but examples across Australia give us clues. The concept of cardinal directions is found in the cultures of several Aboriginal groups and techniques for finding the cardinal points based on the positions of astronomical bodies are known, providing plausible explanations on which to base future work.

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