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1 Handaxe Types, Colonization Waves, and Social Norms in the British 2 Acheulean

3
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9

10 Abstract

11 The handaxes of north-western Europe are some of the most varied in the Acheulean world,
12 with the meanings of that variation debated since the late nineteenth century. To reassess
13 handaxe form in this region, we performed a 3D morphometric analysis of 150 handaxes
14 from five British Acheulean assemblages: Boxgrove, High Lodge, Hitchin, Swanscombe
15 Middle Gravels, and Broom. Regression analyses indicate the importance of the effects of
16 allometry and the assemblage to which the handaxe belongs on shape variation. Marine
17 Isotope Stage (MIS) 11c assemblages Hitchin and Swanscombe occupy significantly different
18 shape space from both the MIS13 assemblages Boxgrove and High Lodge, and the MIS9
19 assemblage of Broom. Handaxe types such as ovates, cordates, limandes, triangular, and
20 ficrons occupy unique areas of shape space in plan form. Twisted-profile and plano-convex
21 handaxes are distinctive in their profile forms from handaxes with similar plan forms. We
22 suggest that the distinctive and difficult to produce handaxes types that characterize the
23 British Late Acheulean were reproduced according to normative expectations of what
24 handaxes should look like. Different occupation phases in MIS13, MIS11c, and MIS9 are
25 characterized by different suites of handaxe types, likely as the result of different waves of
26 colonization with different normative social traditions.

27
28 **Keywords:** Normativity; 3D morphometrics; Boxgrove; Hitchin; Swanscombe;
29 Plano-convex; Twisted symmetry
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35 Introduction

36 Archaeological 'cultures' are defined by suites of co-occurring traits with temporal and
37 geographic localization. The maintenance of such cultures over generations is enhanced by
38 the human propensity for normativity: the societal level way of making, doing, or saying
39 things, that ensures greater uniformity of behaviour than would otherwise derive from the
40 cultural ancestry and connections of individuals (Claidière and Whiten, 2012). Normativity is
41 not merely of concern for archaeological inference, it is a uniquely human trait with a critical
42 role in a range of behaviours including language and morality (e.g. Roughley and Bayertz,
43 2019; Tomasello and Vaish, 2013). Determining when and why it emerged is a significant
44 goal for human evolutionary studies but one with which researchers are only just beginning
45 to engage (Finkel and Barkai, 2018; Shipton, 2019b; Sterelny, 2014, 2019). In this paper we
46 explore what may be an early expression of normativity; handaxe types and different
47 archaeological cultures in the British Late Acheulean.

48 Acheulean handaxes are perhaps the most ubiquitous and recognisable shaped tool in
49 prehistory, although as a group they are far from homogenous in technology or form.
50 Within-site variation is wide, but nonetheless almost all Acheulean localities show one or
51 more modal shapes, some highly characteristic. Handaxe form can thus be understood
52 hierarchically: there are general modal shapes in terms of which all assemblages may be
53 described (Schick and Clark, 2003; Shipton, 2013), and in some assemblages there are
54 distinctive technological or morphological features that warrant the use of specific named
55 types. Experimental evidence confirms the intuitive observation that the variation seen in
56 handaxe form goes beyond functional requirements (Bordaz, 1970; Key and Lycett, 2017).
57 There is a limited shape space in which the constraints of knapping will allow the tool to
58 vary, so there is inevitable convergence and overlap in the range of handaxe types at
59 regionally and temporally disparate sites. Nonetheless, several contrasting examples of
60 handaxe types are to be found in the Acheulean of south-eastern Britain, which are rare or
61 absent in the rest of the Acheulean world.

62 South-eastern Britain lay at the north-western extremity of the Acheulean world. Different
63 shapes of Acheulean handaxes have long been recognized as characterizing different
64 assemblages in the British Acheulean (Roe, 1968; Wymer, 1968). Early attempts to make
65 sense of these shapes as either *fossile directeurs* of linear chronological stages (e.g.
66 Commont, 1912; de Mortillet, 1873) or as cultural markers of different 'ethnic' groups
67 (Breuil, 1932) were ultimately unsuccessful, principally due to inadequate chronological
68 frameworks. A morphometric analysis to systematize British handaxe variation was first
69 attempted in the 1960's by Derek Roe (Roe, 1964, 1968). Using the ratios of width to
70 length, of tip width to base width, and of base length to total length, Roe divided British
71 handaxes into pointed versus ovate types and assigned assemblages into seven groups
72 (Table 1). However, an overall chronological pattern of a shift from pointed to ovate (or vice
73 versa) over time did not emerge.

74 Explanations of handaxe shapes instead shifted to focus on the influences of initial clast
75 form (White, 1998), and the extent of reduction (McPherron, 1999). Experimental tests of
76 these hypotheses have shown that while they may influence handaxe form, these effects

77 are not strong enough to produce the diversity that is visible in the archaeological record
78 (Eren et al., 2014; Shipton and Clarkson, 2015b).

79 In light of improved dating of river terrace sequences in southern Britain, chronological
80 patterning in handaxe types has recently come to the fore again (Bridgland and White, 2014,
81 2015; Wenban-Smith, 2004; White et al., 2018). White and colleagues propose a schema
82 whereby successive waves of colonization introduced different handaxe forms to Britain in
83 different temperate periods between Marine Isotope Stages (MIS) 15 and 9 (621,000 -
84 300,000 years ago) (Table 1 and Figure 1). They further suggest that in the sub-stages of
85 Marine Isotope Stage 11 there are geographical differences within south-eastern Britain
86 that are related to cultural traditions rather than clast form (White et al., 2019) (Table 1).
87 The dating at many of these sites remains imprecise and may conflate different sub-stages,
88 while temperate periods would have lasted several thousand years. However, primary
89 context open-site assemblages typically represent short-lived occupations, and continuity in
90 knapping traditions has been demonstrated over tens of thousands of years in Acheulean
91 sites with multiple occupation layers (Sharon et al., 2011). That Britain was periodically
92 abandoned during cold periods is perhaps one reason why handaxe form is particularly
93 distinctive between assemblages here, as individual sites were not usually occupied for
94 extended periods.

95 Table 1 includes both broad characterization of assemblages on a pointed-rounded
96 spectrum as well as the proportions of specific types. A Multinomial Logistic Regression
97 analysis of this data (model fit $\chi^2=52.112$, $df=15$, $p<0.001$) indicates it is effective in assigning
98 assemblages to marine isotope stages, with 100% of assemblages correctly classified. In this
99 paper we propose to test the hypothesis of different handaxe traditions in different isotope
100 stages using a more powerful quantification and statistical analysis of shape, on a sample of
101 handaxes from five of the assemblages in Table 1. If occupation in different stages
102 represents different waves of colonization, we should be able to detect significant
103 differences in shape between stages, and sites within the same temperate period should be
104 more similar to each other than those from different stages.

105 Several factors might explain why different assemblages are characterized by different
106 handaxe shapes. Conformity to the most common model and random drift of that model
107 over time could lead to divergence between assemblages. Prestige bias resulting in the
108 copying of a handful of experts each with their own idiosyncratic style might explain
109 multiple types. An alternative hypothesis is that handaxe forms might be maintained by
110 normativity (Finkel and Barkai, 2018; Shipton, 2019b), the uniquely human tendency to
111 conform to the particular behavioural modes of a social group that exist independently of
112 dyadic relationships (Anderson and Dunning, 2014).

113 *Table 1. Key British Acheulean sites; their probable marine isotope stage; the percentage of*
114 *pointed versus ovate by Roe metric and their group according to Roe; and the percentage of*
115 *distinctive types for which data is available – twisted, ficrons, cleavers, and tranchet. Data*
116 *from White (unpublished; White, 1996, 1998; White and Plunkett, 2004), Roe (1968),*
117 *Cranshaw (1983), and Hosfield and Green (2013).*

Site	Probable Age	% Metrical Pointed: Rounded Handaxes	Roe Group	% Twisted	% Ficrons	% Cleavers	% Tranchet	N	Reference for dating
Baker's Farm	MIS9	56:44	I	0	8.5	14.5	15.8	152	(Bridgland, 1994)
Stoke Newington	MIS9	75:25	I	0	8.6	12.9	3.6	63	(Green et al., 2006)
Cuxton	MIS9-8	60:40	I	0	10	8.5	8	183	(Wenban-Smith, 2004)
Furze Platt	MIS9	74:26	I	0.4	7.5	5.6	5.6	107	(Bridgland, 1994)
Wolvercote	MIS9	67:33	III	0	3.5	1.8	2.1	47	(Bridgland, 1996)
Broom	MIS9-8	61:39	IV	3	2.6	2.7	7.5	997	(Hosfield and Green, 2013)
Swanscombe UL	MIS11a	30:70	VI	22	0	5	39	18	(White et al., 2019)
Bowman's Lodge	MIS11a	24:76	VI	33	0	3.3	47	30	(Bridgland, 1994)
Wansunt	MIS11a	19:81	VI	28	0	0	43	32	(Bridgland, 1994)
Elveden	MIS11c	26:74	VI	36	0	0	42	74	(Ashton et al., 2005)
Foxhall Road Grey Clay	MIS11c	33:67	VI	39	0	5	50	18	(White and Plunkett, 2004)
Hitchin	MIS11c	68:32	VI & II	16	0	1	11	64	(Boreham and Gibbard, 1995)
Hoxne	MIS11a	67:32	II	3.5	0	0	13.5	111	(Ashton et al., 2008)
Dovercourt	MIS11	68:32	II	4	1.8	0	2	165	(Bridgland et al., 1990)
Foxhall Road Red Gravel	MIS11c	70:30	II	5	0	0	11	17	(White and Plunkett, 2004)
Swanscombe MG	MIS11c	82:18	II	0	3.6	1.8	0	159	(Conway et al., 1996)
Highlands Farm	MIS13/12	15:78	VII	0	0	4	32	200	(Wymer, 1999)
Warren Hill Fresh	MIS13	13:85	VII	1.6	0	1.3	30	642	
High Lodge	MIS13	12:82	VII	3	0	7.6	38	68	(Lewis et al., 2019)
Boxgrove	MIS13	15:85	VII	0	0	10	72	81	(Roberts and Parfitt, 1999)
Fordwich	MIS13+	67:33	V	1	0.7	5.1	2	139	(Bridgland et al., 1998)

118

119

120 Samples

121 To address hypotheses about the sources of British handaxe shape variation, this paper will
122 compare handaxe form between marine isotope stages and between types. To do this we
123 sampled handaxes from five assemblages chosen to reflect the diversity of the British
124 Acheulean: Boxgrove, High Lodge, Hitchin, Swanscombe Middle Gravels, and Broom. These
125 assemblages are from three different regions of south-eastern Britain – eastern England, the
126 Thames Valley, and the southern coast; they are dated to three different marine isotope
127 stages - 13, 11c, and 9 (Figure 1); they feature several distinctive handaxe types such as
128 tranchet-flaked, twisted-profiles, ficrons, and cleavers; and in Broom they include one of the
129 few British assemblages that is not dominated by flint (Table 1). Handaxes were selected at
130 random from collections housed in the British Museum. As post-discard damage will affect
131 analyses of shape (Grosman et al., 2011), any handaxes with more than minor damage were

132 excluded. In the rare instances of typological ambiguity, such as a handaxe versus a
133 discoidal core, or questionable provenance, pieces were excluded.

134 Boxgrove, West Sussex, is an MIS13 site on the south coast, with handaxes made on primary
135 nodules of chalk flint (Roberts and Parfitt, 1999). Handaxes were sampled from localities
136 1B, 1BD, BDL, and L30. Boxgrove handaxes tend to be rounded, falling on a spectrum from
137 ovate to the classic cordate tear-drop shape. A distinctive feature of the Boxgrove handaxes
138 is the high proportion of tranchet flaking on the tip whereby the distal tip is removed in a
139 single oblique or transverse blow at the end of reduction to leave a sharp straight tip edge
140 (Bergman and Roberts, 1988) (Figure 2). Notably Boxgrove was occupied for less than 150
141 years (García-Medrano et al., 2018), an archaeological instant in comparison to most Lower
142 Palaeolithic sites, with its handaxes the products of a few generations at most.

143 High Lodge, Suffolk, is a probable MIS13 site in East Anglia with handaxes made on both
144 fresh flint and secondary clasts from the valley sides of the (now-extinct) Bytham river
145 (Ashton, 1992; Lewis et al., 2019). Handaxes were sampled from both late 19th century
146 antiquarian collections and the 20th century excavation campaigns at the site. High Lodge
147 handaxes tend to be rounded like those of Boxgrove, but also feature some limande forms
148 which are elongate with the edges running parallel around the midpoint (Figure 2).

149 Hitchin, Hertfordshire is an MIS11c site on the north-eastern edge of the Chiltern Chalk
150 downlands, with handaxes on primary cobbles and large flakes of flint (Ashton et al., 2006;
151 Boreham and Gibbard, 1995). Handaxes were sampled from antiquarian collections of the
152 late 19th and early 20th centuries. Handaxes from Hitchin are sub-pointed and feature a
153 variety of forms. Some of the more distinctive are plano-convex pieces with a pronounced
154 profile asymmetry between a flat and a domed surface, typically on more pointed
155 specimens (Figure 2); and twisted pieces which have a remarkable twisted profile, typically
156 on more rounded specimens (White et al., 2019) (Figure 2). There is a possibility that
157 Hitchin is a palimpsest of two assemblages belonging to two Roe Groups (Table 1), one with
158 more pointed forms and another with more cordates including twisted profile pieces (White
159 et al., 2019).

160 The Middle Gravel at Swanscombe, on the right bank of the river Thames in Kent, has
161 produced a large MIS11c assemblage of handaxes (Conway et al., 1996). These were made
162 on secondary clasts of flint deposited by the Thames and occasionally large flakes struck
163 from those clasts. Handaxes were sampled from the Barnfield Pit locality recovered by
164 excavations in the early 20th century. The Swanscombe handaxes are some of the most
165 pointed, in plan view some are triangular (Figure 2) while others have the concave edges
166 associated with the British definition of a ficron (Roe, 1982).

167 Broom, Devon is an MIS9-8 site in the south-west, with handaxes on near-primary chert
168 nodules and large flakes, with occasional secondary flint clasts (Hosfield and Chambers,
169 2009; Hosfield and Green, 2013). Handaxes were sampled from the antiquarian collections
170 of the gravel pits. There is a great variety of handaxes from Broom and it was once
171 supposed that the site was a palimpsest, however recent work indicates that the majority of
172 handaxes were deposited over single occupation phase (Hosfield and Chambers, 2009).

173 Several of the types mentioned above are evident at Broom, as well as asymmetrical pieces
174 and cleavers. The distinctive asymmetrical pieces are large with an unflaked area on one
175 side of the butt, possibly a grip. Cleavers have a broad bit at their tip and elsewhere in the
176 Acheulean world are undoubtedly a distinct tool, often made using blanks obtained from
177 prepared cores. In Britain and adjacent regions of northwestern Europe, the cleaver has no
178 such technological definition, and is sometimes regarded as just another type of handaxe
179 (White, 2006) (Figure 2).

180

181 **Method**

182 Geometric morphometrics is a method of analysing objects as a series of landmark co-
183 ordinates occupying the same shape space. It has the advantage over linear morphometric
184 measurements of retaining relationships between different parts of the object during
185 analysis. Geometric morphometrics is well suited to the analysis of shaped artefacts and
186 has been used on handaxes, in particular, for a number of years. Two dimensional
187 geometric morphometrics have been applied to bifaces, including handaxes since the late
188 2000s (Buchanan, 2006; Costa, 2010). Lycett and colleagues (Lycett et al., 2006; Lycett et
189 al., 2010) used a bespoke tool to measure 3D landmarks on the most worked hemisphere of
190 bifaces, following Wynn and Tierson's (1990) morphometric method in using a radiating
191 array of measurements. Subsequent methods employed a Microscribe with the same
192 orthogonal configuration (Archer and Braun, 2010), and with orthogonally oriented
193 configurations more akin to the Roe measurements, that took landmarks from both surfaces
194 of the bifaces (Shipton, 2008, 2013). Data collection was then done on 3D scans of
195 handaxes (Shipton and Clarkson, 2015b). The most laborious part of all these methods is
196 taking the co-ordinates of landmarks on the handaxe.

197 Recently, Herzlinger and colleagues (2017) developed automated software to collect
198 landmarks from 3D scans, allowing magnitudinal increases in the number of datapoints, and
199 thereby finer details of shape variation to be analysed. This AGMT3D program (version
200 3.01) was used throughout the following analyses (Herzlinger and Grosman, 2018), except
201 for the regression analyses and General Linear Model which were conducted in SPSS.

202 The AGMT3D program begins with the automated positioning of handaxe scans (Grosman et
203 al., 2008). The protocol positions handaxes so that the plane of intersection between its
204 two largest opposed surfaces is parallel to the XY plane and perpendicular to the Z axis. It
205 then rotates the object so that its maximum length in the XY plane is parallel to the Y axis.
206 For more symmetrical handaxes this protocol closely matches others that maximize the
207 symmetry of the objects (Shipton and Clarkson, 2015b). However, for handaxes with
208 protrusions on the butts or asymmetrical tips there is a disagreement between the
209 protocols, with the AGMT3D program orienting some pieces 'diagonally'. Any handaxe that
210 was oriented by the AGMT3D program more than 5° off the axis of maximum symmetry in
211 the XY plane was eliminated from the analysis. This resulted in the initial sample of 160
212 handaxes being reduced to 150 pieces (Table 2). Handaxe models were further oriented so
213 that the most domed surface was always designated as the same surface (Shipton and

214 Clarkson, 2015b), and if neither surface was more domed, then orientation was so that any
 215 asymmetries in the tip were protruding in the same direction.

216 To extract the landmarks, the AGMT3D places a 3D grid on the surface of the object
 217 (described in detail in Herzlinger et al., 2017). The maximal length of the handaxe forms the
 218 prime meridian of the grid, with either end the poles. Equidistant latitudes are taken at
 219 fixed intervals along the maximum length out to the edge of the handaxe, and equidistant
 220 longitudes are taken parallel to the maximum length out to the maximum breadth of the
 221 handaxe. Semi-landmark co-ordinates are then obtained from the crossing points of the
 222 latitudes and longitudes. The user is able to specify the number of latitudes and longitudes,
 223 and in this case we chose 50 of each resulting in a total of 5000 landmarks for every
 224 handaxe scan (50x50 for each surface). Our previous 3D geometric morphometric study of
 225 these same scans used just 18 landmarks per handaxe (Shipton and Clarkson, 2015b).

226 To compare between assemblages, a Generalized Procrustes Analysis was performed to
 227 scale each object to a unitary size, so that the following analyses look at shape in isolation
 228 from size. A Principal Components Analysis (PCA) was then performed to determine the
 229 main parameters of shape variation among the objects, the results of which are discussed
 230 below.

231 *Table 2. Breakdown of samples used in this study by handaxe type. Note that we used a*
 232 *broad definition of ficron as any handaxe with bilateral convexity in plan.*

Site	N	Ovate	Limande	Cordate	Triangular	Ficron	Twisted-profile	Plano-convex	Cleaver	Asymmetrical
Boxgrove	34	13		18					3	
High Lodge	28	11	6	11						
Hitchin	31		3	4	5	2	5	12		
Swanscombe	26			4	15	7				
Broom	31	3	2	10	3	4			7	2
Total	150	27	11	47	23	13	5	12	10	2

233

234 Results

235 The PCA extracts N-1 principal components, in this case 149. We first examined assemblage
 236 variability in terms of the mean distance of the multi-dimensional principal components of
 237 individual handaxes from the assemblage centroid (Herzlinger and Goren-Inbar, 2019)
 238 (Table 3). Results show that Boxgrove is the least variable of all the assemblages, with a
 239 Wilcoxon rank-sum test indicating that it is significantly different from the other MIS13
 240 assemblage High Lodge, which is also the next most homogenous (rank-sum=896, p=0.01).
 241 This is in keeping with the short duration of occupation at Boxgrove. Hitchin meanwhile is
 242 the most variable assemblage, significantly different from the other MIS11c assemblage,
 243 Swanscombe (rank-sum=1058, p=0.01), though not significantly different from Broom
 244 another assemblage noted for its variability (rank-sum=1050, p=0.3). This provides for
 245 support for the suggestion that Hitchin is a palimpsest of two different occupations (White
 246 et al., 2019).

247 *Table 3. Assemblage variability expressed as the mean distance of principal components for*
248 *each handaxe from the assemblage centroid.*

Site	N	Variability
Broom	31	302.1
Hitchin	31	313.2
Swanscombe	26	275.8
High Lodge	28	249.5
Boxgrove	34	211.6

249

250 The first two principal components explained around half the variability, 37.57% and 11.5%
251 respectively. For our second analysis we examined the scores for the first principal
252 component (PC1) which, like our previous study on these specimens (Shipton and Clarkson,
253 2015b), essentially distinguishes between pointed (negative values) and rounded (positive
254 values) handaxes.

255 To test what is driving the variation in PC1 we conducted regression analyses against three
256 variables: length, to test for allometric variation related to ergonomic constraints (Gowlett
257 and Crompton, 1994); the proportion of cortex remaining (as measured from 3D scans), to
258 test for constraints of clast size (White, 1998); and the Scar Density Index (SDI) (Shipton and
259 Clarkson, 2015a), to test for the influence of reduction intensity (McPherron, 1999).

260 All three variables produced significant correlations (Table 4) with more rounded handaxes
261 being shorter, with less cortex, and higher scar densities. There are multiple explanations
262 for such correlations. For instance, a life history trajectory from pointed to rounded through
263 resharpening phases could explain concomitant reductions in length and cortex, as well as
264 increases in scar density (McPherron, 2006). Alternatively, making a rounded handaxe may
265 necessarily entail greater reduction, with the butts on such pieces being more extensively
266 worked than those of pointed ones. This might preclude the production of rounded pieces
267 on smaller clasts with limited reduction potential (White, 1998).

268 To tease apart competing explanations, we conducted a General Linear Model using PC1 as
269 the dependent variable, length, cortex proportion, and SDI as covariates, and site as a fixed
270 factor. The resulting model had an adjusted R^2 value of 0.57, indicating these variables were
271 able to explain over half the variation in PC1. With the model taking into account all four
272 variables, the effect of reduction intensity (SDI) disappears, and the effect of cortex
273 proportion becomes very weak, explaining less than 10% of variation in PC1 (Table 5).
274 Length is still an important determinant of PC1 which we think supports the hypothesis of
275 Gowlett (Gowlett and Crompton, 1994) that constraints of hand size were an important
276 influence on handaxe shape, such that longer pieces must necessarily be relatively narrow.
277 By far the most important determinant of PC1 was however the assemblage to which the
278 handaxes belong. This indicates that there are site specific determinants of handaxe shape
279 unrelated to reduction intensity, clast size, or ergonomic constraints.

280

281 *Table 4. Results of Linear Regression Analyses of PC1 against handaxe length, cortex*
 282 *proportion, and SDI.*

	df	F	p	Adjusted R ²
Length	148	29.333	<0.001	0.161
Cortex Proportion	146	39.938	<0.001	0.211
SDI	147	26.649	<0.001	0.149

283

284 *Table 5. Results of General Linear Model of PC1 with length, cortex proportion, SDI, and site*
 285 *as explanatory variables. The model had an adjusted R² value of 0.57.*

	F	p	Partial Eta squared
Length	27.32	<0.001	0.164
Cortex Proportion	9.341	0.003	0.063
SDI	1.2	0.275	0.009
Site	22.815	<0.001	0.396
Total	28.623	<0.001	0.59

286

287 Our subsequent analyses returned to the original geometric morphometric dataset and used
 288 Wilcoxon rank-sum tests to compare interpoint distances between group mean shapes. We
 289 compared the MIS13 assemblages from Boxgrove and High Lodge with the MIS11c
 290 assemblages from Hitchin and Swanscombe Middle Gravels, finding a significant difference
 291 between the two periods (N=120, rank-sum=9610, p<0.01). Figure 3 shows that MIS13
 292 assemblages are more rounded and with their point of maximum thickness close to the
 293 middle of the piece, whereas MIS11 assemblages are more pointed with their point of
 294 maximum thickness close to the base of the piece. In comparing individual assemblages
 295 with the Wilcoxon rank-sum test, no difference was found between the MIS13 assemblages
 296 from Boxgrove and High Lodge, but significant differences were noted between the East
 297 Anglian assemblages from High Lodge and Hitchin, between the primary clast assemblages
 298 of Boxgrove and Hitchin, and between the MIS11c assemblages of Hitchin and Swanscombe
 299 Middle Gravels (Table 6).

300 *Table 6. Results of Wilcoxon Rank-Sum test comparing interpoint distances between MIS13*
 301 *and MIS11 biface assemblages for PCA 1.*

Comparison	N	rank-sum	p
Boxgrove v. High Lodge	62	3668	0.3
High Lodge v. Hitchin	59	2652	<0.01
Boxgrove v. Hitchin	65	2899	<0.01
High Lodge v. Swanscombe	54	1751	<0.01
Hitchin v. Swanscombe	57	2746	<0.01
Hitchin v. Broom	62	3435	0.02
Swanscombe v. Broom	57	2420	<0.01

302

303 Both Boxgrove and High Lodge have a significant proportion of tranchet flaking in their
 304 handaxe assemblages, 19 and 9 pieces respectively in this sample. A Wilcoxon rank-sum
 305 test however showed no significant difference between tranchet and non-tranchet group
 306 means for these two sites (rank-sum=3755, n=62, p=0.48). This suggests that while tranchet

307 flaking is technologically distinct and creates a distinct tip edge, it does not produce a
308 distinctive overall handaxe morphology. This corroborates a morphometric study of the
309 Boxgrove handaxes, which found that most tranchet flaking had no effect on shape (García-
310 Medrano et al., 2018).

311 To further explore the distinction between Hitchin and Swanscombe, we looked at the mean
312 models of handaxes from the two sites. These indicate that they are distinguished by the
313 Swanscombe handaxes being pointier and to some extent by the unusual profiles of the
314 plano-convex and twisted handaxes from Hitchin (Figure 4).

315 Comparing Hitchin and Swanscombe with the MIS9 assemblage from Broom shows
316 significant differences between both MIS11c assemblages and Broom (Table 7), with the
317 cluster analysis further showing the MIS11c assemblages are more similar to each other
318 than either is to Broom (Figure 5). Figure 5 shows that Broom occupies a wide range of
319 variability in its first two components, occupying its own area on the right of the
320 distribution, and overlapping with much of the Hitchin and Swanscombe distributions,
321 including in areas they do not overlap with each other.

322 Next we analysed the shape occupied by biface types rather than assemblages (Figure 6). As
323 there were only two asymmetrical pieces they are not discussed in the following analysis.
324 For the first two principal components there are significant areas of unique shape space
325 occupied by each type except plano-convex and twisted pieces (Figure 6). This is likely
326 because the first two components are concerned with gross morphology and are not
327 discriminating the details of the position of the edge in relation to the profile of the piece
328 which defines plano-convex and twisted handaxes. Wilcoxon rank-sum tests on interpoint
329 distances, (taking into account the entirety of shape space), indicate significant differences
330 between cordate handaxes and the types they overlap with, between triangular handaxes
331 and all the types that they overlap with, and between limandes and cleavers which overlap
332 with each other (Table 7). Plano-convex and twisted handaxes are significantly different
333 from triangular and cordate handaxes respectively, showing that the former types are
334 distinguishable by lower order parameters of shape variation than the first two principal
335 components. Wilcoxon rank-sum tests on interpoint distances showed that neither rock
336 type (flint vs. chert, $N=150$, rank-sum=21844, $p=0.33$), nor blank type (cobble vs. flake,
337 $N=40$, rank-sum=1500, $p=0.25$) were significant factors in explaining shape variation.

338 One explanation for the distribution of shape variation is that the designated types are
339 simply capturing extremes of continuous variation within sites. However, the wide variety
340 of forms at Broom, including both ficrons and ovates from opposite ends of the main
341 spectrum of shape variation, and the presence of asymmetrical pieces not represented in
342 the other assemblages, are difficult to accommodate in variation around a single modal
343 type. The lack of twisted and plano-convex pieces in assemblages with similar ranges of
344 planforms such as Swanscombe Middle Gravels (White et al., 2019), indicates the
345 distinctiveness of these types at Hitchin. The double distinctiveness of planform and edge
346 position in the case of plano-convex and twisted handaxes (overlapping in planform with
347 triangular and cordate handaxes respectively) (Figure 7), shows that these are genuinely
348 different types.

349 *Table 7. Results of Wilcoxon rank-sum tests comparing interpoint distances between biface*
 350 *types for PCA 5.*

Comparison	N	rank-sum	p
Cordate v. Ovate	74	4308	<0.01
Cordate v. Twisted	52	1682	<0.01
Cordate v. Triangular	70	3220	<0.01
Triangular v. Limande	34	662	<0.01
Triangular v. Plano-convex	35	846	<0.01
Triangular v. Ficron	36	946	<0.01
Limande v. Cleaver	21	368	<0.01

351

352 **Conclusion**

353 The meaning of handaxe form has been the subject of debate since the early discoveries of
 354 these objects. In our sample of British Acheulean handaxes, incidental variables have a
 355 varying influence on handaxe morphology. Reduction intensity did not have a significant
 356 effect once other variables were taken into account. Initial clast size had a significant but
 357 very weak effect. There was an allometric effect of handaxe length with longer handaxes
 358 tending to be narrower (and pointier), likely due to the ergonomic constraints of these
 359 handheld objects (Gowlett and Crompton, 1994). The most important determinant of
 360 handaxe shape was however the site to which the specimen belongs.

361 We tested the hypothesis that site-wise differences in handaxe shape reflected different
 362 waves of colonization with divergent traditions of handaxe making in different temperate
 363 periods (Bridgland and White, 2014; White et al., 2018). Our results show strong support
 364 for this hypothesis, with the MIS13 assemblages of High Lodge and Boxgrove not
 365 significantly different to each other, while both are significantly different to the MIS11c
 366 assemblages Hitchin and Swanscombe. This is despite High Lodge and Hitchin both being in
 367 eastern England (Figure 1), and despite Boxgrove and Hitchin handaxes both being made on
 368 primary clasts of flint. Within MIS11c there is a significant difference between Hitchin and
 369 the Thames valley assemblage from Swanscombe, supporting the hypothesis of White and
 370 colleagues (2019) that there were different geographical traditions in Britain at this time.
 371 Part of the distinctiveness of Hitchin may derive from its representing two occupations. The
 372 cluster analysis showed that despite the significant difference, Hitchin and Swanscombe are
 373 still more similar to each other than either is to the MIS13 assemblages. Likewise,
 374 Swanscombe and Hitchin are more similar to each other than either is to the MIS9
 375 assemblage of Broom. This is despite both Broom and Hitchin bifaces being made on
 376 primary clasts, while those from Swanscombe were made on secondary clasts.

377 Acheulean populations recolonizing Britain must have had their origins in the more
 378 continuously occupied regions to the south. The Somme Valley in northern France provides
 379 the nearest well-studied Acheulean sequence (Commont, 1912). Here, the MIS15/14
 380 transition site of Carriere Carpentier has yielded cordate handaxes flaked around the entire
 381 perimeter and with tranchet removals, similar to those from Boxgrove in MIS13 (Antoine et
 382 al., 2016). At the MIS12 site of Cagny-la-Garenne pointed forms and handaxes with clumsy

383 twisted edges are evident, presaging those that occur in the MIS11 sites in Britain; while at
384 MIS10-9 sites in the Somme valley there is a wide variety of handaxe forms and shaping
385 methods (Lamotte and Tuffreau, 2016) consistent with the diversity seen in the MIS9
386 occupation of Broom. That equivalent handaxe assemblages to the British Acheulean occur
387 in the preceding marine isotope stages in France, suggests that the traditions represented
388 by these distinctive handaxes types were maintained over tens of thousands of years,
389 consistent with the longevity in particular Acheulean traditions documented elsewhere in
390 the world (Sharon et al., 2011).

391 The second part of our analysis attempted to morphometrically evaluate the named
392 handaxe types in the British Acheulean. The analysis showed that most types occupy
393 significant areas of unique shape space for the first two principal components and that all
394 types are statistically distinguishable. For plano-convex and twisted pieces, the double
395 distinctiveness of plan shape and edge position indicates these are genuinely different
396 types. Rock type and blank type do not appear to be driving this variation. Elsewhere we
397 have argued for the importance of imitation and over-imitation in maintaining the
398 Acheulean (Nielsen, 2012; Shipton, 2010, 2019a; Shipton and Nielsen, 2015), but such high-
399 fidelity social reproduction of knapping sequences is not enough in itself to explain the
400 distinctive similarities observed here. The relatively small, irregular-shaped, and internally
401 variable flint and chert nodules used to make these British handaxes require dynamic
402 adaptation of reduction sequences to produce the same final forms. Importantly,
403 conceptually different reduction sequences were sometimes used to produce the same
404 types. For example, plano-convex handaxes from Hitchin, triangular handaxes from
405 Swanscombe, and ovate handaxes from Broom were all made on both flake and cobble
406 blanks.

407 Multiple distinct types are apparent in both these assemblages and others in Table 1. While
408 in the case of Hitchin this may reflect a palimpsest, such an explanation cannot hold for all
409 sites. This intra-assemblage variability suggests that handaxe forms were not merely
410 conforming to the most common model with random drift of that model between
411 assemblages. Further analysis, with larger sample sizes, is needed to test whether, for
412 example, MIS13 ovates and cordates occur on a continuum, or if there is a bimodal
413 distribution of different types. The variety of shapes seen in the Broom handaxes, including
414 those not present at the other sites, and which are thought to derive from a single
415 occupation (Hosfield and Chambers, 2009), indicates multiple distinct types.

416 For a knapper skilled enough to produce some of the refined pieces studied here (Figure 2),
417 the morphology of the plan, profile, and edge, would have been salient features of the
418 handaxe (Hiscock, 2014). Between 18 and 24 months old, human children begin to
419 recognize three dimensional shape categories, an ability that appears to emerge from the
420 learning of object names (Pereira and Smith, 2009; Smith, 2009; Yee et al., 2012). We
421 suggest that to be able to make the distinctive forms observed in the British Acheulean,
422 their makers would have needed to recognize them as particular types.

423 Different forms may have appeared as emergent properties of the idiosyncrasies of expert
424 knappers, whose handaxes were preferentially replicated. However, in transmission chain

425 experiments where handaxe-like forms are recreated in mediums that do not require
426 specialized skill, deviation from the initial shape is rapid (Schillinger et al., 2016; Shipton et
427 al., 2018). To maintain the kinds of specific handaxe types seen in Britain from MIS13
428 onwards may have required expected norms of handaxe shapes. Many of the British Late
429 Acheulean handaxes types are difficult to create. Plano-convex and twisted pieces for
430 example, are very rare in the wider Acheulean world (Gallotti et al., 2010), while the
431 distinctive tranchet resharpening technique in use at Boxgrove and High Lodge, is a highly
432 risky knapping strategy that is liable to break or blunt a biface if done incorrectly (García-
433 Medrano et al., 2018). To reproduce such forms may have required the additional
434 motivation of socially resonant behavioural norms.

435 The developmental basis of normativity is to be found in over-imitation, the uniquely human
436 tendency to replicate all intentional actions of a demonstrator, including those that are
437 causally redundant (Nielsen et al., 2014). Over-imitation, we suggest, is evident in the
438 arbitrary conformity seen in complex Acheulean manufacturing sequences from ~1 million
439 years ago (Shipton, 2019a; Shipton and Nielsen, 2015; Shipton et al., submitted). It may be
440 that from this time we begin to see arbitrary normative conformity in handaxe types at sites
441 like Isenya in eastern Africa, which has some distinctive elongate and skilfully made forms
442 (Shipton, 2018).

443 Normativity is an intuitively underappreciated human trait (Cialdini, 2007), yet it underpins
444 diverse aspects of our behaviour including language, co-operation, and morality (Roughley
445 and Bayertz, 2019). Normativity would have conferred key advantages to Acheulean
446 hominins in a niche of co-operative hunting of mega-herbivores in large groups (Domínguez-
447 Rodrigo and Pickering, 2017). Normativity is critical to expectations of particular roles in co-
448 operative tasks (Tomasello and Hamann, 2012), something that would have had selective
449 salience when hunting large and dangerous mammals like elephants (Ben-Dor et al., 2011;
450 Solodenko et al., 2015). To maximise the fitness benefits of large nutritious carcasses and
451 spread the risks of unpredictable procurement, normative rules for sharing throughout a
452 large group would have been advantageous. Such rules would have engendered the
453 transport of carcass elements to group aggregation sites, where the individuals who had
454 incurred the risk of the hunt shared their gains with others (Agam and Barkai, 2016; Moreno
455 et al., 2015), and where freeloading would have been policed and discouraged by similar
456 collectively understood behavioural codes (Boyd et al., 2003). By the late Middle
457 Pleistocene, normativity had perhaps evolved beyond mere conventions to something that
458 carried external social pressure (Anderson and Dunning, 2014). The existence of such social
459 norms would explain why hominins in the British late Acheulean persisted in making
460 handaxes types that were difficult and risky to produce when more generic forms would
461 have sufficed.

462

463

464

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469

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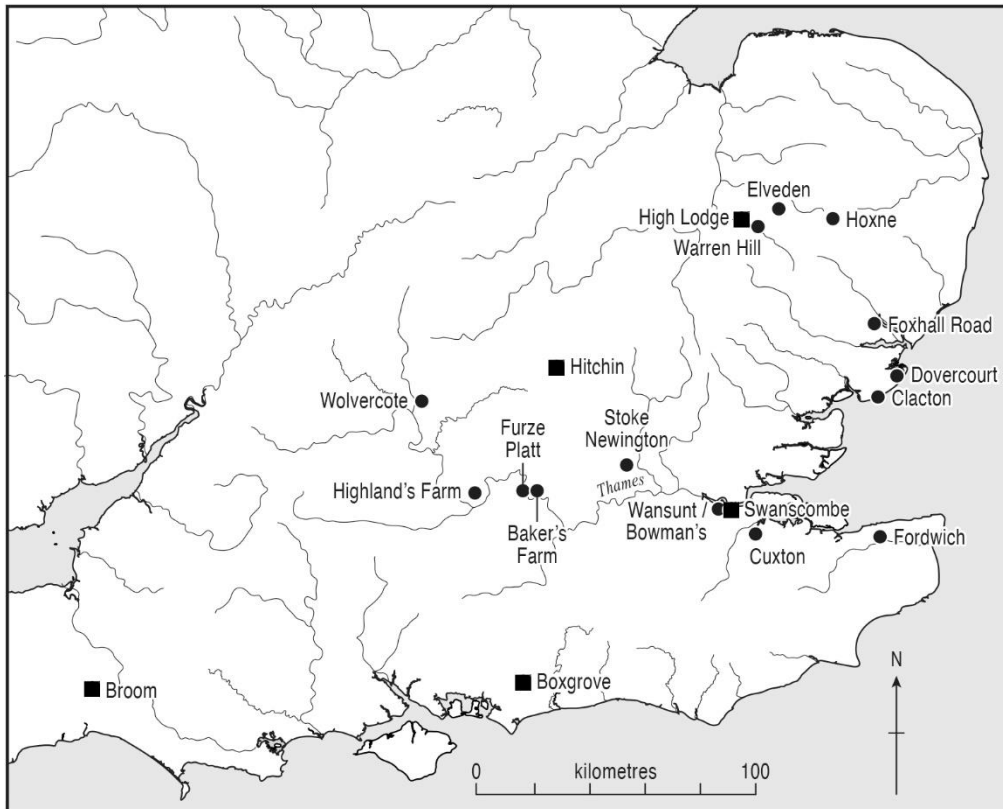
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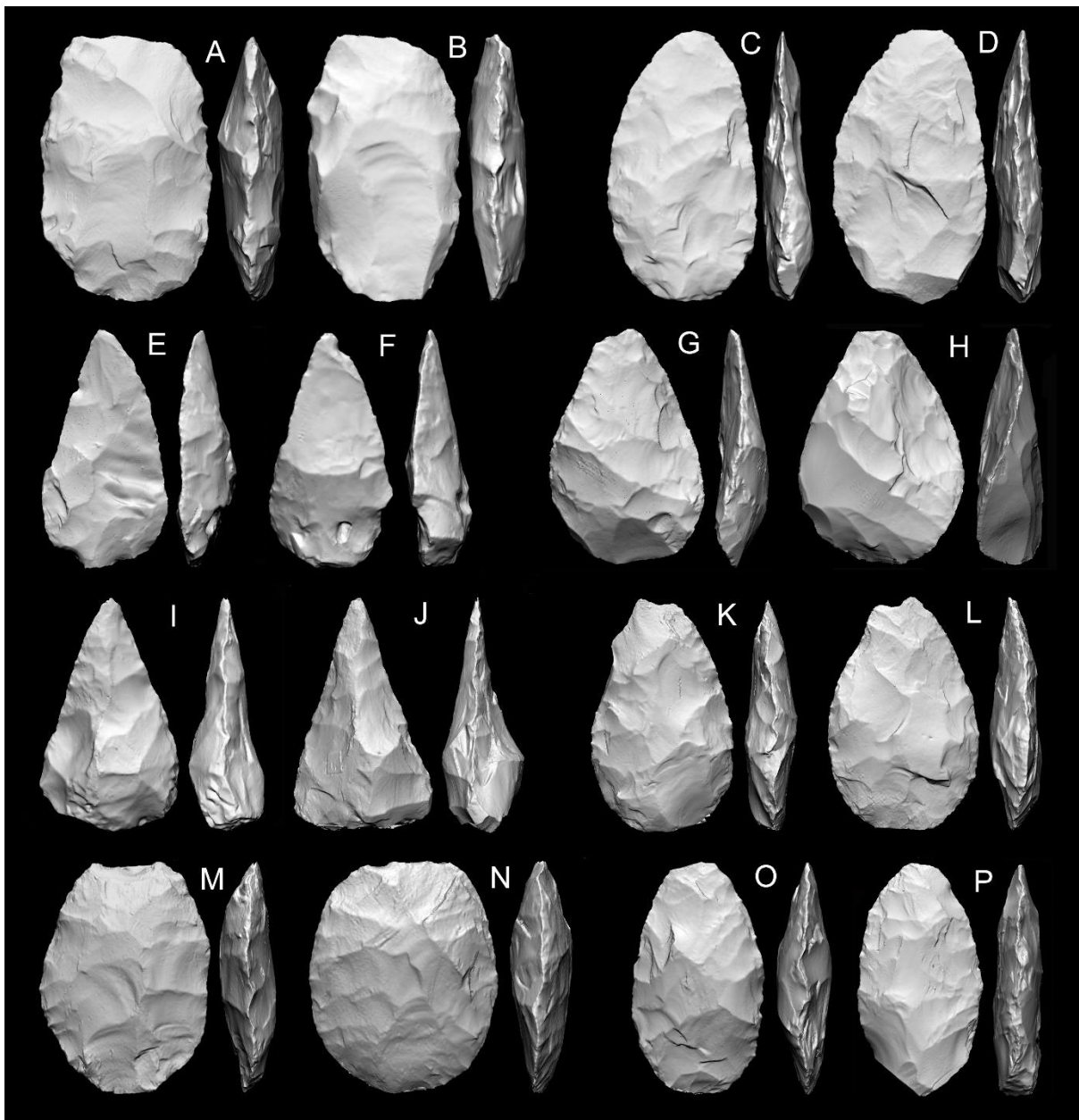
670

671 **Figures**



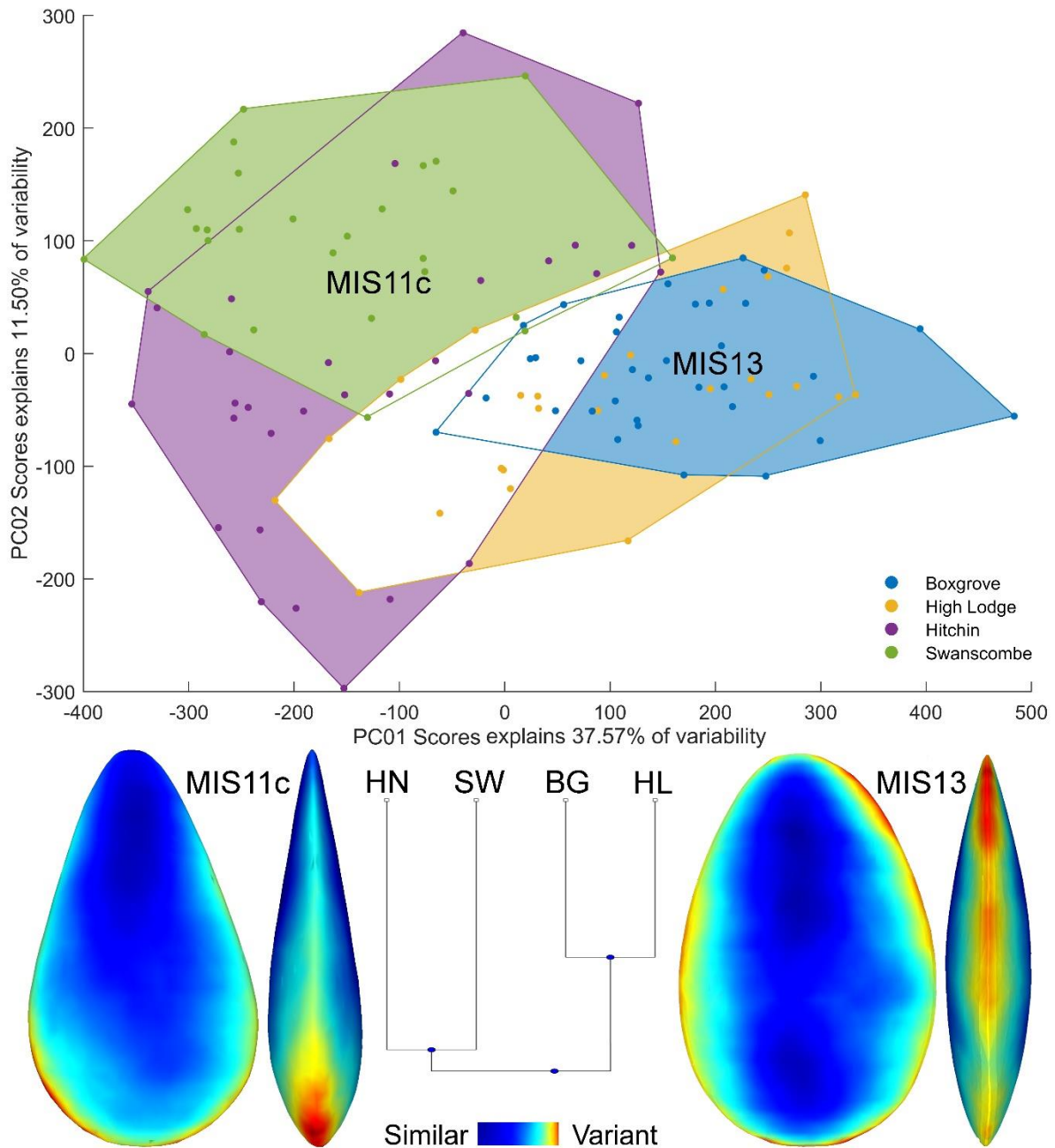
672

673 *Figure 1. The location of the British Acheulean sites shown in Table 1. The sites shown by*
674 *squares were sampled for this study.*



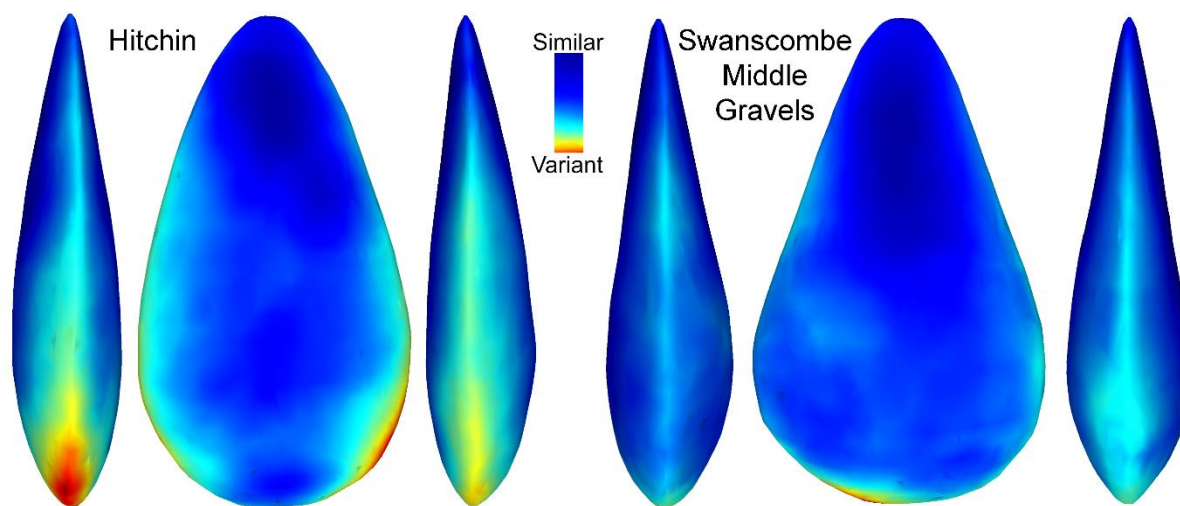
675

676 *Figure 2. Plan and profile views of some of the British bifaces used in this study, showing*
 677 *matched pairs of biface types from each site. A and B are cleavers from Broom; C and D are*
 678 *asymmetrical giants from Broom; E and F are plano-convex handaxes from Hitchin; G and H*
 679 *are twisted handaxes from Hitchin; I and J are triangular handaxes from Swanscombe; K and*
 680 *L are tranchet cordates from Boxgrove; M and N are tranchet ovates from Boxgrove; O and P*
 681 *are limandes from High Lodge. Note that the handaxes are shown at a standardized size to*
 682 *facilitate comparisons of shape.*



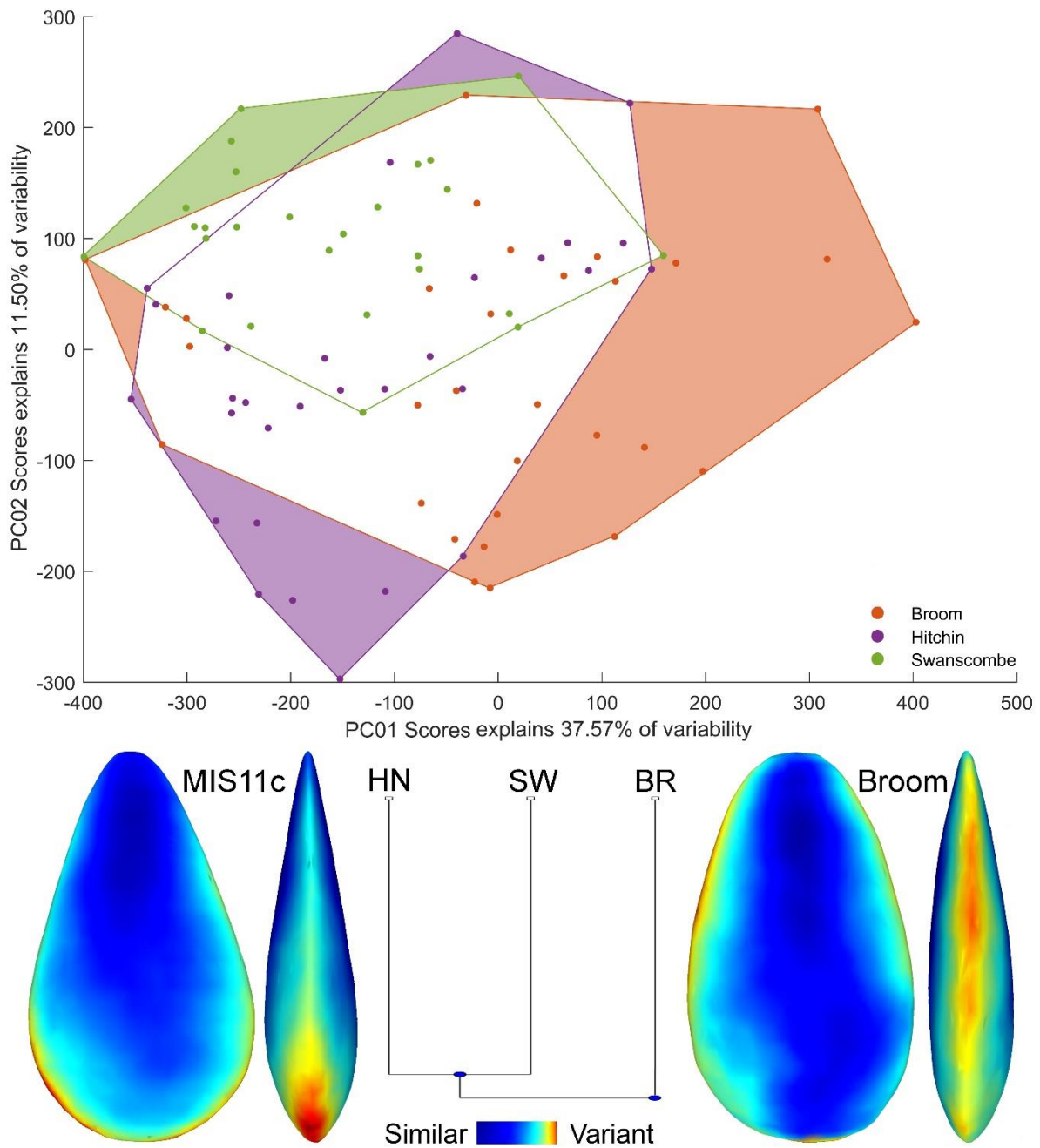
683

684 *Figure 3. Scatter plot showing the distribution of handaxes from Boxgrove (BG), High Lodge*
 685 *(HL), Hitchin (HN), and Swanscombe Middle Gravels (SW) according to the first two principal*
 686 *components. Groups are outlined with convex hulls. Note the Boxgrove convex hull is shown*
 687 *on top of High Lodge, and the Swanscombe convex hull is shown on top of Hitchin. The area*
 688 *of overlap between the two marine isotope stages is left unshaded. Models below show the*
 689 *average form of MIS11c and MIS13 handaxes, with heat maps showing within group*
 690 *variation. Note the contrast in the points of maximum breadth and thickness. The variable*
 691 *right tip on the MIS13 handaxes reflects the presence or absence of tranchet flaking. The*
 692 *dendrogram in the lower middle shows the hierarchical clustering of group mean shapes.*
 693 *Note that Boxgrove and High Lodge are more similar to each other than either is to Hitchin*
 694 *or Swanscombe.*



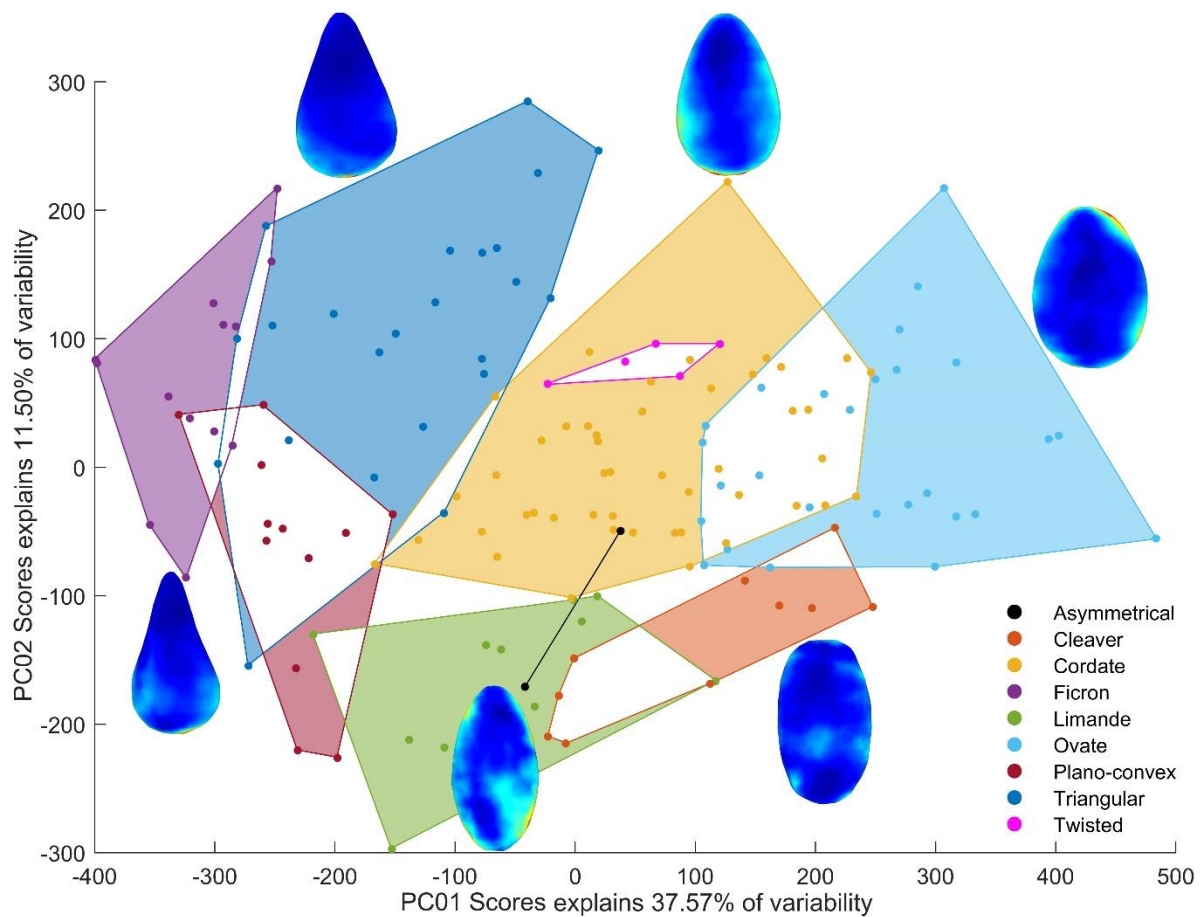
695

696 *Figure 4. Mean forms for Hitchin and Swanscombe. Heat maps show most variable regions*
 697 *within assemblages. Note the convex edge of the Hitchin model in plan compared to the*
 698 *straight edges of the Swanscombe model. Edge morphology is more variable in the Hitchin*
 699 *model.*



700

701 *Figure 5. Scatter plot of the first two principal components of biface morphology for MIS11c*
 702 *assemblages Hitchin (HN) and Swanscombe (SW), and Broom (BR). Convex hulls are drawn*
 703 *around the three distributions with Swanscombe overlain on Hitchin and areas overlap*
 704 *between the MIS11c assemblages and Broom left unshaded. The dendrogram in the lower*
 705 *middle shows the hierarchical clustering of group mean shapes. The model on the lower left*
 706 *show the mean form for MIS11c bifaces and that on the right for Broom. Heat maps show*
 707 *the areas of highest within group variation. Note the point of maximum thickness is*
 708 *proximally located on the Broom model, similar to the MIS11c model, but the tip is rounded*
 709 *unlike the pointed MIS11c model.*



710

711 *Figure 6. Scatter plot of the first two principal components of all bifaces used in this study,*
 712 *grouped by biface type. Convex hulls denote the area of shape space occupied by each type*
 713 *with overlapping areas unshaded. Note that there are large areas of unique shape space for*
 714 *each of the types, except plano-convex and twisted pieces. Planforms of mean type shapes*
 715 *are shown next to each convex hull except plano-convex, twisted, and asymmetrical pieces.*
 716 *Three of the Boxgrove ovates on the bottom left of the distribution are U-shaped with*
 717 *transverse bits formed by a tranchet blow and in some typologies might be considered*
 718 *cleavers.*

719

720

