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Late Acheulean hominins at the Marine Isotope Stage 6/5e transition in north-central India

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Single-grain optically stimulated luminescence dating was applied to Late Quaternary sediments at two sites in the Middle Son Valley, Madhya Pradesh, India. Designated Bamburi 1 and Patpara, these sites contain Late Acheulean stone tool assemblages, which we associate with non-modern hominins. Age determinations of 140–120 ka place the formation of these sites at around the Marine Oxygen Isotope Stage 6–5 transition, placing them among the youngest Acheulean sites in the world. We present here the geochronology and sedimentological setting of these sites, and consider potential implications of Late Pleistocene archaic habitation in north-central India for the initial dispersal of modern humans across South Asia.

Introduction

Much recent discussion has focused on the Late Pleistocene dispersal of *Homo sapiens* out of Africa, with growing archaeological and genetic support for an early South Asian role (Petraglia et al., 2007; Atkinson et al., 2008; Oppenheimer, 2009; Soares et al., 2009; Petraglia et al., 2010; Haslam et al., 2010a,b). However, South Asia was occupied by hominins for several hundred thousand years prior to modern human arrival (Dennell, 2009), as evidenced by abundant Middle and Late Pleistocene stone artefact assemblages (Settar and Korisettar, 2002), and by one – taxonomically ambiguous – pre-modern hominin cranial fragment from the Narmada Valley at Hathnora (Sonakia, 1985). Techno-typologically, most of the lithic assemblages attributable to the Middle Pleistocene occupation of the Indian subcontinent are considered Acheulean, with large flake manufacture accompanied by distinctive large cutting tools: handaxes and cleavers (Petraglia, 1998; Pappu, 2001). The most recent component of these assemblages, the Late Acheulean, is characterised by an increase in smaller flake tools, a decrease in both size and relative abundance of bifaces, continued cleaver manufacture, and the introduction of prepared-core reduction techniques such as Levallois (Misra, 1987; Misra, 1989; Petraglia, 2006). Despite the potential for enlightening comparisons with the replacement of pre-modern hominins elsewhere, issues surrounding the extinction of Acheulean hominins in India are rarely discussed. An important step in redressing this imbalance is to describe and date secure contexts for South Asian Late Acheulean assemblages.

Here we report on Late Acheulean occupation in the Middle Son Valley in Madhya Pradesh, north-central India. We present optically stimulated luminescence (OSL) age determinations and archaeological data for the new site of Bamburi 1, as well as OSL ages for the previously excavated Patpara locality (Blumenschine et al., 1983). Both Bamburi and Patpara date to the terminal component of Marine Oxygen Isotope Stage (MIS) 6 and the subsequent early MIS 5, placing them among the most recent Acheulean sites anywhere in the world (Clark, 2001).

Bamburi 1

The Bamburi 1 archaeological site (N 24° 33.801′ E 82° 13.293′) is named for a nearby village on the north bank of the Son River (Fig. 1). The Son is one of the largest rivers in India, measuring almost 800 km in length from its headwaters on the eastern edge of the Maikala Range in Madhya Pradesh to its confluence with the Ganges River near Patna in

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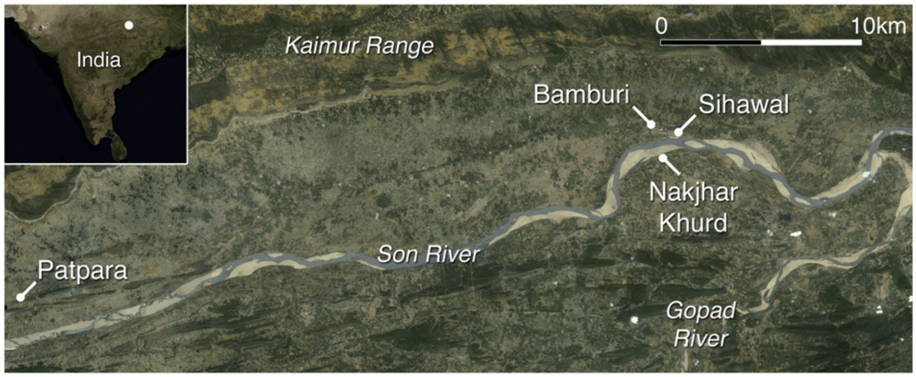

Figure 1. Location of Bamburi, Patpara and other Late Acheulean sites, Middle Son Valley, India. Note the presence of SW–NE trending medial ridges that separate the Patpara locality from the Son River channel.

Bihar. In its middle reaches the Son flows eastwards, parallel to and south of the Kaimur Range (an eastern section of the Vindhya Range), with the Baghelkhand plateau lying to the south of the river. Vindhyan sandstones, siltstones, limestones and minor igneous and metavolcanic rocks crop out in the Middle Son Valley, overlain by younger (Upper Proterozoic) Vindhyan quartzites, sandstones and shales of the Kaimurs. The Kaimur plateau reaches elevations of ~200–300 m above the valley floors of the Son and nearby Belan valleys, forming a steep barrier along the northern margin of the Middle Son (Williams and Royce, 1982). The headwaters of the Son River encompass Tertiary basalts (of the Trap Series); these were the source of agate, chalcedony and jasper pebbles used for artefact manufacture in the Middle Son during the later Pleistocene (Clark and Williams, 1987).

From the time of the first systematic geomorphological work undertaken during the mid-1970s (Sharma et al., 1976), the Quaternary sediments of the Middle Son have been characterised into four sequential alluvial formations, later named after villages located near the type sections. From oldest to youngest these are the Sihawal, Patpara, Baghor and Khetaunhi Formations, with the Sihawal and Baghor Formations sub-divided into lower coarse-grained and upper fine-grained members (Williams and Royce, 1982, 1983; Williams and Clarke, 1995; Misra, 1997). Each of these units has been argued to preserve a distinct techno-typological artefact assemblage, and the generalised characteristics of these deposits and their cultural inclusions are summarised in Table 1. The recent announcement of a fifth formation (Khunteli) (Williams et al., 2006) has proved problematic to reconcile with the established archaeological and sedimentological profiles, as it relies on few occurrences and a questionable chronology that conflicts with the known technological sequence (Jones, 2007; Jones and Pal, 2009).

Excavation and sedimentology

Bamburi 1 lies just over 900 m from the present Son channel, from which it is separated by a low east–west trending medial ridge (Fig. 2). The site was identified from the presence of a finely-crafted, diminutive, silicified limestone biface eroding from a cobble bed in a sandy clay matrix, within a dry nala (tributary stream-bed) south of the Bamburi school. A 2 m wide stepped trench was excavated into the ~5 m high western bank of the nala, with all sediment screened through a 5 mm mesh and all artefacts piece plotted *in situ*. Five steps were cut, leaving a section just over 4 m in height.

The trench exposed two main sedimentary bodies (Fig. 3). The uppermost sediments are comprised of around 2.5 m of beige, pedogenically altered sandy silts, with carbonate nodules becoming larger and more abundant towards the top and mineral-rich granules found throughout. Although not present in the excavation, locally this stratum is overlain by red to orange pedogenically altered sandy silts. A small snake burrow found close to the top of the section indicates that some bioturbation may be expected for the uppermost sediments. The

Table 1
Sedimentary formations of the Middle Son valley.[a]

Formation	Description	Cultural material
Sihawal	*Lower member*: Poorly-sorted gravels (coarse sand to cobble-sized with boulders up to 50 cm) in a matrix of grey and brown silty to fine sandy clay, resting on unconformably on Proterozoic bedrock. *Upper member*: Very well-sorted, massive grey and brown mottled silty clay, generally devoid of both gravel and artefacts. Combined maximum observed thickness ranges from ~1.5 to 4 m. For ages see text.	*Lower member*: Lower Palaeolithic (Acheulean) bifaces, cleavers and flakes
Patpara	Rounded to sub-angular clasts of quartz, sandstone and mudstone, set in a clay-rich matrix. Clast size ranges from coarse sand to cobbles with 1–2 cm pebbles most common. 'Diagnostic' red colour (Williams et al. 2006:2622). Formation is at least 10 m thick and unconformably overlies the Sihawal Formation. For ages see text.	Refined bifaces, cleavers; prepared cores and flakes
Baghor	*Coarse member*: Co-sets of unconsolidated cross-bedded poorly-sorted medium to coarse quartz sands with individual sets 5–85 cm thick, usually bounded by planar horizontal surfaces. Separated from Patpara Formation by an erosional unconformity. *Fine member*: Inter-bedded silts, clays and occasional fine sands, resting conformably on the Baghor coarse member. Evidence of pedogenesis. Combined members are up to ca. 20 m thick. Ages between ca. 8 ka (^{14}C) and 26 ± 5 ka (TL) are reliable, and older ages than this are likely for the coarse member, based on IRSL.	*Coarse member*: rolled and abraded Middle Palaeolithic artefacts *Fine member*: Fresh 'Upper Palaeolithic' artefacts in the upper few metres. Microlithic blades and bladelets
Ketaunhi	Inter-bedded silts, clays and fine sands, forming a still-active alluvial terrace adjacent to the present Son River. Dated to ca. 3–5 ka (^{14}C).	Neolithic and historic period remains

[a] As reported in Williams and Royce (1982); Mandal (1983); Williams and Clarke (1984, 1995); Clark and Williams (1987); Pal et al. (2005); Williams et al. (2006); see also Jones (2007: Table 5.1, Fig. 5.18, Table C.3). TL = thermoluminescence dating; ^{14}C = radiocarbon dating; IRSL = infra-red stimulated luminescence. Note that the problematic Khunteli Formation reported by Williams et al. (2006) is not included here, and neither is an infrared stimulated luminescence age of either ~54 ka (Pal et al., 2005) or ~58 ± 6 ka (Williams et al., 2006) for sample S-1, reportedly from the Patpara Formation but collected at an unspecified location near Sihawal (see Jones and Pal, 2009 for discussion).

Figure 2. The Bamburi 1 site in relation to surrounding eroded landscape features, facing south towards the Son River (which lies just beyond the ridge visible in the background). The trench is 2 m wide.

upper sediment body is subdivided into two sections by an erosive event 0.8 m above the contact with underlying coarser material. This does not indicate a significant break in sedimentation at the site, however, as evidenced by the continued input of similar sediments and the statistically indistinguishable OSL ages obtained either side of the erosive break (see below).

The lower sediments at Bamburi 1 have a significant proportion of pebbles and cobbles within a sandy clay matrix. These clasts are variably rounded to angular. The basal portion of the excavation revealed brecciated stromatolitic limestone amid large boulders weathering from the local bedrock. The presence of a pebbly sandy clay layer just over a metre from the base of the section suggests that this area was subject to input from sheetwash, but there is no evidence that the river has directly deposited any of the sediments at Bamburi other than via floodplain silts. We assign the two components of the Bamburi sequence to the lower and upper members of the Sihawal Formation, based on previous published descriptions and observations at the Sihawal type site approximately 1.4 km to the southeast (Williams and Clarke, 1995). As noted below, the chronometric age of the lower sediments is indistinguishable from the overlying sandy silts.

Lithic technology

Figure 3 includes a simplified aggregated representation of *in situ* artefact counts by stratigraphic context, with artefacts collated that were within 10–20 cm depth of the location marked. Table 2 displays techno-typological data for the Bamburi 1 excavated and surface-context lithic assemblage. Two varieties of quartzite (coarse and fine-grained) were used for the artefacts at Bamburi, with both forms represented evenly at the site. One highly siliceous limestone artefact was recovered *in situ*, and artefacts of these three materials also make up the surface assemblage at the site. Most surface artefacts in the vicinity of Bamburi 1 appeared to be eroding out of the lower Sihawal member, an observation repeated during excavation, when only one quartzite core and a flaked piece were recovered from the basal portion of the upper member. The core possessed differential patination, suggesting it may have been re-used or re-worked from an earlier context. Overall,

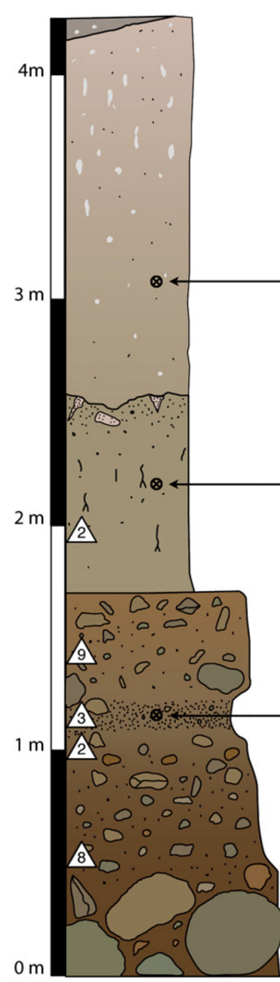

Figure 3. Bamburi 1 sedimentary sequence, with position of OSL ages indicated by crossed circles and aggregated artefact counts indicated by triangles.

Table 2
Lithic technology at Bamburi 1, Sihawal II and Nakjhar Khurd, Middle Son Valley.

Site	Stratum[a]	Typology	Raw material[b]				Total
			CG Qtz	*FG Qtz*	*Qtz/S*	*L*	
Bamburi 1	SUM	Multi-platform core	1				1
		Flaked piece		1			1
	SLM	Multi-platform core	1	2			3
		Uni-directional core	1				1
		Bifacial core		1			1
		Side retouched flake	1	1			2
		End retouched flake	1				1
		Side/double end retouched flake		1			1
		Broken retouched flake	1				1
		Biface		1			1
		Flake	4	3		1	8
		Broken flake		2			2
	SLM	Handaxe				1	1
	(Surf.)	Cleaver		1			1
		Radial core		1			1
		Multi-platform core	2				2
		Side retouched flake	2	1		1	4
		End retouched flake	2				2
		Side/end retouched flake	1	1			2
		Flake		3		5	8
		Broken flake	1				1
		Flaked piece	1	1			2
		Total	*19*	*20*		*8*	*47*
Sihawal II	SLM	Handaxe			1		1
		Chopper			1		1
		Cleaver			1		1
		Knife			1		1
		Bifacially flaked chunk				1	1
		Side scraper			4	1	5
		Double side scraper			1		1
		End scraper			1		1
		Convergent scraper				1	1
		Core scraper			1		1
		Modified flake			9	1	10
		Modified flake fragment			4		4
		Single platform core			3		3
		Biconical core			3		3
		Discoid core			1		1
		Flake core			1		1
		Multi-platform core			1		1
		Blade core				1	1
		Flake			52		52
		Flake fragment			18	1	19
		Chunk			10		10
		Total			*113*	*6*	*119*
Nakjhar	SUM	Flake		1			1
Khurd	SLM	Handaxe					
		Cleaver fragment					
		Flake scraper					
		Core scraper					
		Modified flake	6 × quartzite				21
		Modified flake fragment	15 × silicified limestone[c]				
		Core					
		Flake					
		Flake fragment					
		Chunk					
		Total					22

Sihawal II and Nakjhar Khurd data from Kenoyer and Pal (1983); Misra et al. (1983).
[a] SUM = Sihawal upper member; SLM = Sihawal lower member; Surf. = Surface collected.
[b] FG Qtz = fine-grained quartzite; CG Qtz = coarse-grained quartzite; Qtz/S = quartzite/sandstone; L = silicified limestone.
[c] Precise raw material breakdowns for Nakjhar Khurd Sihawal Formation lower member are unavailable.

however, quartzite artefacts at Bamburi were in an extremely fresh condition, with no sign of edge damage from post-depositional transportation. Further evidence of the site's integrity comes from the surface find, adjacent to the excavated trench just below the top of the Sihawal lower member, of two fine-grained quartzite flakes with a dorsal-ventral refit.

A total of 21 artefacts were recovered *in situ* from the Sihawal lower member, including multiplatform and bifacially-worked cores. One large bifacial quartzite core bears scars from the production of a number of large flakes with prominent bulbs of percussion (Fig. 4a). Both end and side retouched flakes were present in the assemblage, as well as unretouched flakes without evidence of platform preparation. A finely-crafted silicified limestone handaxe (Fig. 4b; no. 40) was found embedded *in situ* in the lower member gravels approximately 1 m south of the excavated trench. One large fine-grained quartzite cleaver (Fig. 4b; no. 18) was also recovered from the lower member. A further 16 quartzite cores and flakes, along with six silicified limestone flakes and the handaxe noted above, were surface collected from the Sihawal lower member within a few tens of metres of the Bamburi 1 site. Retouch is present on some of the flakes (Table 2). The assemblage indicates that reduction at the site included flake production for both expedient use and subsequent transformation of flake blanks into large cutting tools. Raw material at the site displays some selective foresight, as much of the weathered local limestone bedrock tends to crumble or fracture into useless blocky fragments. Nevertheless, all utilised materials were likely available within a few kilometres, as both the Son River and the nearby Kaimur escarpment provide reliable sources of suitable clasts.

Large flake-blank production for handaxe and cleaver manufacture is considered one of the hallmarks of Acheulean technology worldwide (Sharon, 2009), and the presence of this trait alongside large cutting tools at Bamburi securely places the site into the Acheulean tradition. Likewise, there is an absence of the prepared core and flake-based technology that characterises the typical Indian Middle Palaeolithic (Sankalia, 1964; Pal, 2002). However, it has been noted that the so-called 'Early Middle Palaeolithic' of India may have been an autochthonous development (James and Petraglia, 2009), a point discussed further below. One of the key indicators of this transition is a decrease in size and increase in refinement (measured through ratios of width:thickness and calculations of symmetry) in bifacial handaxe technology, together with increased reliance on cryptocrystalline raw materials. Bifaces described as refined, 'evolved' or diminutive occur in Indian assemblages assigned to either the Late Acheulean or Early Middle Palaeolithic, along with the early presence of prepared core technologies at some Acheulean sites (Mishra, 1995; Dennell, 2009; James and Petraglia, 2009). The recovery of a refined biface from the upper portion of the Sihawal lower member at Bamburi 1 provides further evidence of the diminution of handaxe technology prior to the end of the Acheulean in India, and places the site within the Late Acheulean period.

Chronology

OSL dating gives an estimate of the time elapsed since grains of quartz or feldspar were last exposed to sunlight (Huntley et al., 1985; Aitken, 1998). In this study, we measured the ultraviolet OSL emissions from individual sand-sized grains of quartz to exploit the advantages inherent in single-grain OSL dating (Jacobs and Roberts, 2007). The burial age of a grain is determined by dividing the equivalent dose (D_e) – the radiation energy absorbed by the grain since the last bleaching event, which is estimated by measuring the OSL signal – by the environmental dose rate, which is derived mainly from the radioactive decay of ^{238}U, ^{235}U, ^{232}Th (and their daughters) and ^{40}K in the surrounding deposit. For each sample, between 300 and 1000 individual grains were measured using the single-aliquot regenerative-dose (SAR) procedure (Galbraith et al., 1999) to obtain multiple, independent estimates of D_e. From such data, it is possible to assess the adequacy of bleaching of a sample at the time of deposition, as well as any post-depositional complications arising from sediment mixing or grain-to-grain differences in dose rate. Supplementary Information contains

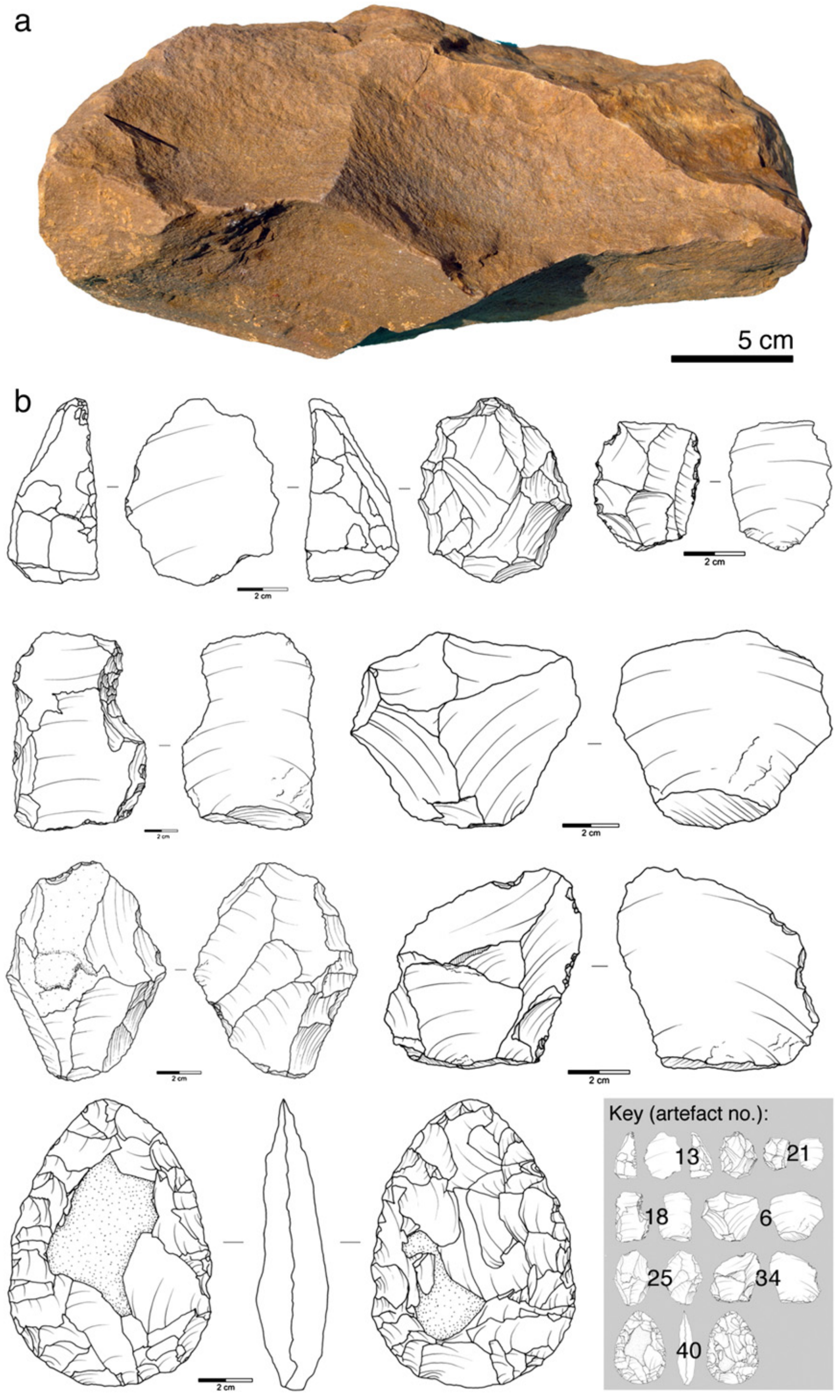

Figure 4. (a) Large bifacial quartzite core, recovered *in situ* from the Sihawal Lower Member, 70 cm above the base of the Bamburi 1 excavation. (b) Surface collected and excavated artefacts from Bamburi 1. All scales 2 cm. See key for artefact numbers (all artefacts from Sihawal Lower Member): (13) fine-grained quartzite multi-platform radial core; (21) limestone flake, surface collected; (18) fine-grained quartzite cleaver; (6) coarse-grained quartzite flake; (25) fine-grained quartzite biface; (34) fine-grained quartzite flake, surface collected; (40) silicified limestone biface.

details of analytical methods and additional discussion of D_e and dose rate data.

Three OSL ages were obtained for the Bamburi 1 sequence, with the sample positions indicated in Figure 3. Sample BAM-1/1 was collected from 125 cm below the top of the excavated section, approximately midway down the Sihawal upper member silts, and sample BAM-2/1 was collected from 223 cm below the top of the section, in the upper member silts that immediately overlie the sedimentary transition to the Sihawal lower member. Sample BAM-3/2 was collected from 345 cm below the top of the section, in the Sihawal lower member that contains *in situ* Late Acheulean artefacts. Two OSL ages were also obtained for sediments collected from a step trench cut into a remnant hillock at the Patpara Formation type locality (32 km WSW of Bamburi; N 24°29′6.7″, E 81°54′38.3″), with sample positions indicated in Figure 5. One of the samples (PAT-4/1) was collected from a dark red pebble conglomerate at the base of the excavated section, 330 cm below the top of the trench (stratigraphically equivalent to the 'dark red-brown gravely clay' of Blumenschine et al., 1983). The other sample (PAT-3/2) was collected from pedogenically modified clay-rich silts overlying the pebble conglomerate, ~40 cm above the first sample location and potentially equivalent to the 'dark red brown clay with Mn inclusions' of Blumenschine et al. (1983).

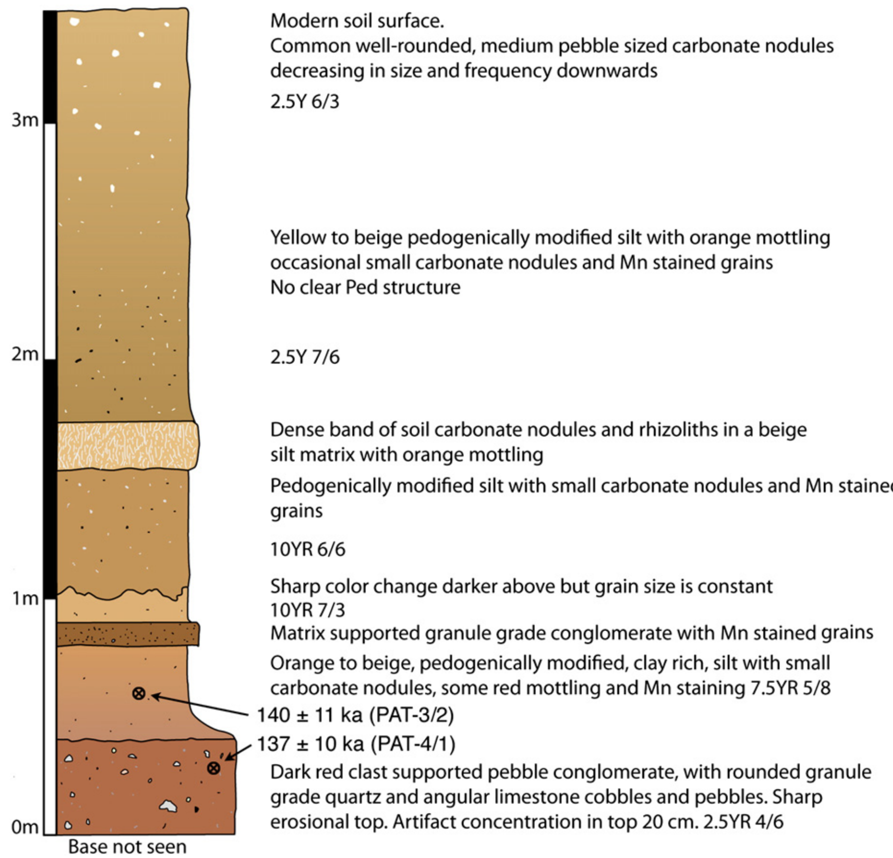

Figure 5. Patpara sedimentary sequence, with position of OSL ages indicated by crossed circles.

The OSL ages and supporting D_e and dose rate information for all five samples are summarised in Table 3. Figure 6 shows OSL decay and regenerated dose–response curves for two individual grains from the upper and lower Bamburi 1 samples, together with the complete D_e distributions for these samples and both Patpara samples. The OSL decay and dose–response data are representative of the grains that were accepted after applying the SAR quality-assurance criteria described in Supplementary Information and in previous publications (Petraglia et al., 2007; Jacobs and Roberts, 2007; Jacobs et al., 2008a). These grains exhibit two properties in common with quartz grains from southern India (Petraglia et al., 2007): a rapid decay in OSL with stimulation (indicative of these grains being dominated by the 'fast' component of quartz OSL, which is a requirement for the reliable application of the SAR procedure), and the continued growth of the OSL signal at high applied doses, which enabled large D_e values to be measured for these samples.

The D_e distributions of all five samples have overdispersion (OD) values of 30–40% (Table 3), which is the relative standard deviation of the D_e distribution after allowing for measurement uncertainties (Galbraith et al., 1999). These values are larger than those obtained for grains of samples BAM-2/1 and PAT-4/1 that were first bleached in sunlight and then given a known dose (5.4 ± 0.8% and 9.9 ± 1.4%, respectively), as well as the OD values of up to ~20% commonly reported for well-bleached samples that have not been mixed after burial or affected by grain-to-grain variations in dose rate (Jacobs and Roberts, 2007; Arnold and Roberts, 2009). The centre-top and lower-right panels in Figure 6 illustrate the extent of scatter in D_e for samples BAM-1/1 and PAT-4/1, which have the most overdispersed distributions. In these

Table 3
Dose rate data, D_e values and OSL ages for sediment samples from Bamburi 1 and Patpara.

Sample code	Water (%)	Carb. (%)	Dose rates (Ga/ka)					Equivalent doses				OSL age (ka)
			Beta	Adjusted Beta	Gamma	Cosmic	Total	No. of grains	OD (%)	D_e (Gy)	% of grains	
Bamburi 1												
BAM-1/1	3.7	8.5	1.55 ± 0.07	1.76 ± 0.09	0.94 ± 0.05	0.17 ± 0.02	2.90 ± 0.18	55/300	37 ± 6	381 ± 19	78 ± 7	131 ± 10
BAM-2/1	3.9	6.8	1.59 ± 0.08	1.72 ± 0.09	1.04 ± 0.05	0.15 ± 0.02	2.94 ± 0.18	90/400	34 ± 4	366 ± 32	85 ± 11	125 ± 13
BAM-3/2	3.7	6.7	1.63 ± 0.08	1.83 ± 0.09	0.80 ± 0.04	0.13 ± 0.02	2.79 ± 0.17	136/1000	35 ± 4	365 ± 14	81 ± 5	131 ± 9
Patpara												
PAT-3/2	2.7	6.2	1.59 ± 0.08	2.15 ± 0.09	1.01 ± 0.05	0.15 ± 0.02	3.34 ± 0.18	215/900	32 ± 3	468 ± 26	59 ± 9	140 ± 11
PAT-4/1	2.5	4.2	1.02 ± 0.06	1.07 ± 0.07	0.77 ± 0.04	0.14 ± 0.02	2.01 ± 0.13	97/1000	37 ± 4	275 ± 11	92 ± 4	137 ± 10

The water and carbonate contents refer to the measured (field) values. For age determinations, a carbonate content of 6% was used for all samples and long-term water contents of 7.5% and 6.5% were used for the Bamburi 1 and Patpara samples, respectively. Each of these was assigned an uncertainty of ± 2% to accommodate (at 2σ) the field values and any likely variations integrated over the period since sample deposition. The dose rates, equivalent dose (D_e) values and OSL ages are expressed as mean ± total (1σ) uncertainty, and calculated as the quadratic sum of the random and systematic uncertainties. The relative spread in the D_e distributions beyond that associated with the measurement uncertainties for individual grains (overdispersion, OD) is included in the uncertainty on the D_e, as is a relative error of 2% for possible bias in the calibration of the laboratory beta source. An internal alpha dose rate of 0.03 ± 0.01 Gy/ka is included in the total dose rate for each sample.

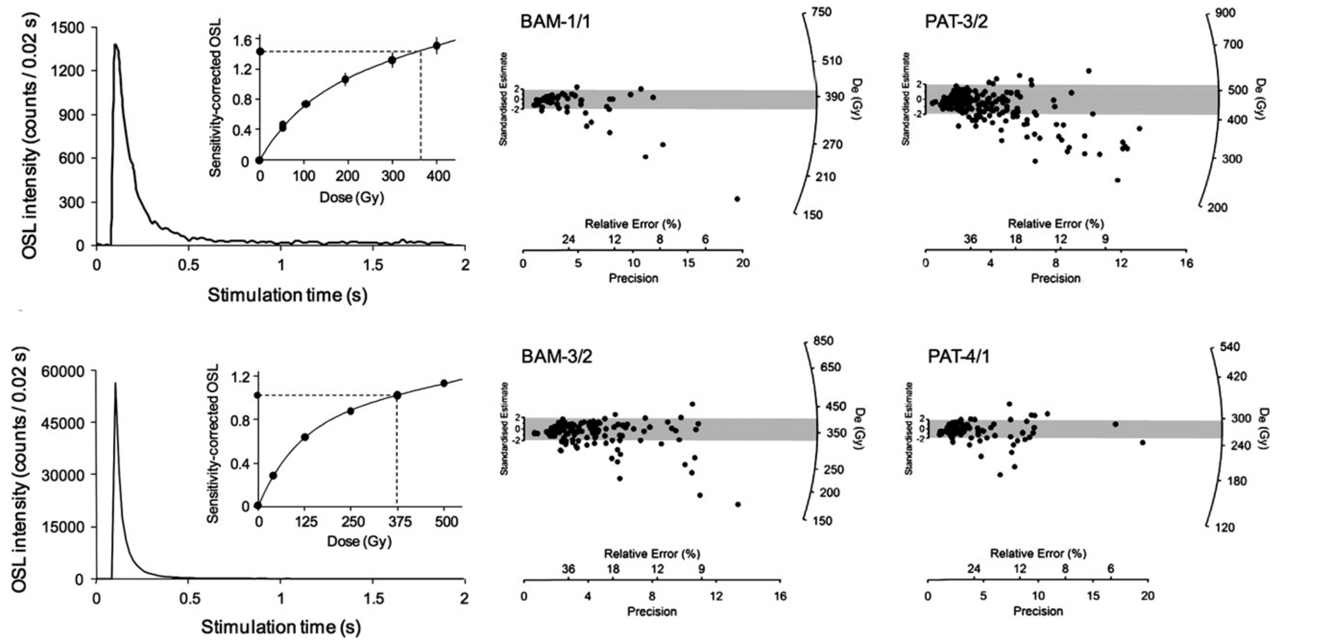

Figure 6. Left-hand panels: natural OSL decay curves and inset dose–response curves for individual grains of quartz from samples BAM-1/1 (top) and BAM-3/2. In the inset plots, the dashed line extends from the natural OSL signal on the y-axis to intersect the dose–response curve at the estimated D_e value, which is read off the x-axis (~360 Gy and ~370 Gy, respectively). Centre panels: D_e distributions for 55 and 136 single grains from samples BAM-1/1 (top) and BAM-3/2, respectively. Right-hand panels: D_e distributions for 215 and 97 single grains from samples PAT-3/2 (top) and PAT-4/1, respectively. In each of the four radial plots, the shaded band is centred on the D_e value of the component that contains the majority of grains, as determined by the Finite Mixture Model. These D_e values were used to calculate the OSL ages (see text and Supplementary Information for details).

radial plots, as well as those shown for the two samples with the most grains (BAM-3/2 and PAT-3/2), any shaded band of ± 2 units projecting from the standardised estimate axis should capture 95% of the points if they are statistically consistent with each other (Galbraith et al., 1999). In all cases, the D_e estimates are spread far too widely to be captured by any single band, with several values falling short of the D_e component that accommodates the majority of grains (shown by the grey band). To determine the OSL age of each sample, the D_e of the latter component was identified using the Finite Mixture Model (Roberts et al., 2000) and divided by the beta-adjusted total dose rate experienced by these grains, following Jacobs et al. (2008b). Details are given in Supplementary Information.

The ages obtained at Bamburi 1 for the upper member silts (131 ± 10 and 125 ± 13 ka) and the underlying Sihawal lower member (131 ± 9 ka) are statistically indistinguishable at 1σ. The two artefacts in the upper member silts may not be in primary context, but the Late Acheulean artefacts in the Sihawal lower member are *in situ* and were deposited, therefore, in MIS 5e or terminal MIS 6. We consider the latter as more likely, based on the statistically consistent ages of 140 ± 11 and 137 ± 10 ka for the dark red pebble conglomerate and overlying clay-rich silts at the Patpara type locality. The associated artefacts at Patpara have been described as 'early Middle Palaeolithic' (Clark and Sharma, 1983; Jones and Pal, 2009) and 'final Acheulean' (Sharma and Clark, 1982), so they should postdate, or be contemporaneous with, the Bamburi 1 assemblages. We argue below that the artefacts recovered from Patpara should be classified as Late Acheulean, in which case both they and the *in situ* artefacts at Bamburi 1 date to around the time of transition from glacial MIS 6 to interglacial MIS 5e.

We have tested the robustness of these OSL age estimates using a range of alternative models for D_e and dose rate determination, as described in Supplementary Information. For example, we also calculated the age of each sample from the weighted mean D_e (obtained using the Central Age Model of Galbraith et al., 1999) and the environmental dose rate for the bulk sample, instead of using the D_e component and beta-adjusted dose rate for the majority of grains. The resulting ages are 8–16 ka younger than those listed in Table 3, but these offsets are not statistically significant, given the size of the associated uncertainties. We consider the ages in Table 3 to be more accurate, because they take into account the known occurrence of carbonate in the Bamburi 1 and Patpara deposits, which will reduce the beta dose rate to adjacent quartz grains and, hence, their D_e values.

We used the carbonate- and water-content correction factors of Nathan and Mauz (2008) to determine the beta and gamma dose rates for the bulk samples, which contained <10% mass of carbonate (determined by loss on ignition). At such low carbonate contents, the ages are insensitive to any time-dependent changes in the dose rate arising from progressive carbonate cementation of the deposit during burial, decreasing by only 6–7 ka if the carbonate content is reduced to zero. Age differences of this magnitude are smaller than the 1σ uncertainties on the OSL ages in Table 3. Long-term water contents and burial depths were chosen to reflect the conditions experienced by the samples since deposition, which includes both humid (interglacial) and arid (glacial) periods, and were assigned uncertainties sufficient to encompass (at 2σ) all plausible alternative scenarios. The calculated ages decrease (or increase) by only ~1% for each 1% decrease (or increase) in water content. So, even if the sample water contents are reduced to zero or are raised to their saturation values (21–22%) for the entire period of burial, the OSL ages still lie within the intervals 120–150 ka at Bamburi 1 and 130–160 ka at Patpara.

Given the insensitivity of the OSL ages to various alternative burial conditions and methods of data analysis, we consider them to reliably constrain the deposition of the sediments and *in situ* Late Acheulean artefacts at Bamburi 1 and Patpara to late MIS 6 or MIS 5e.

Discussion

The Middle to Late Pleistocene OSL ages obtained at Bamburi 1 and Patpara are the first to be directly associated with lithic artefacts in the Middle Son Valley, and are considered here in light of both extensive previous research in the valley (Sharma et al., 1976; Sharma and Clark, 1983; Williams and Clarke, 1995; Jones and Pal, 2005; Pal et al., 2005; Williams et al., 2006; Jones and Pal, 2009), and potential implications for hominin replacement in India.

The Sihawal Formation and its age

Initial and subsequent formulations of the Sihawal Formation (e.g., Williams and Royce, 1982, 1983; Williams et al., 2006) record a maximum exposed thickness of around 1.5 m, a result partly of erosional truncation of the upper member at the Sihawal type section. The discovery of the ~4 m Bamburi 1 section therefore adds considerable potential for more fine-grained sedimentological and chronological analysis of this formation than was previously thought possible.

The early observation (Kenoyer and Pal, 1983; Misra, 1997) that the Sihawal lower member contains *in situ* Acheulean biface tools and flakes is supported by the new findings, as is the observation that the upper member clays are predominantly culturally sterile. Artefacts found towards the base of the Sihawal upper member at Bamburi raise the possibility of sporadic hominin presence during the initial period of this layer's deposition (see also Misra et al., 1983), but further excavations are required to test for post-depositional disturbance. Bamburi also supports the conclusion that the lower Sihawal member is derived predominantly from local bedrock weathering and erosion, with some input from alluvial fans and debris flow (Williams et al., 2006). The upper member has been suggested to be a partially reworked loess deposit, and both members have been posited as dating to a period of reduced summer monsoon and, therefore, reduced flow in the Son River (Williams and Royce, 1982). These observations fit with the evidence from Bamburi 1 if the upper member silts are considered to date from terminal MIS 6, rather than the warmer and wetter interglacial MIS 5 (Clemens and Prell, 2003), but the current precision of our OSL ages is insufficient to place either Sihawal member into one isotope stage or the other. If the hypothesised lack of fluvial control for clast transport in the Sihawal lower member is correct, then the Bamburi ages may indicate its formation during terminal MIS 6, with occupation most abundant as the climate transitioned into MIS 5e.

Two previous chronometric ages have been obtained for the Sihawal Formation. First, a thermoluminescence age of 104 ± 20 ka (Alpha-899) was obtained from near the top of the Sihawal upper member at a step trench (G9) on the south bank of the Son River at Nakjhar Khurd (Williams and Clarke, 1995) (see Fig. 1). This trench was excavated some 20 m east of the archaeological site of Nakjhar Khurd (Misra et al., 1983), which is located across the river from Sihawal. The archaeological record from this site is reviewed below, but the association between the dated trench and the archaeological material is not direct. Furthermore, no assessment of the relationship between the two Sihawal Formation sedimentary bodies is possible at the G9 trench, as the Sihawal lower member is not present.

The second previous chronometric age for the Sihawal Formation also comes from the Sihawal upper member at Nakjhar Khurd (Pal et al., 2005), although no more precise provenance data than these are available at present. The sample (N-1) yielded an age of ~100 ka using infrared stimulated luminescence (IRSL). No error margins are reported. The potential for long-term fading to result in significant age underestimates was not assessed during the analysis (Williams et al., 2006), so this should be considered a minimum age only (see Jones, 2007). With limited information available for this sample, it is not possible to relate this age to any archaeological occurrences, and its sedimentological value is also minimal. It does, however, lend further support to the notion that the largely culturally-sterile Sihawal upper member was deposited during the first half of MIS 5, ~130–100 ka.

The Late Acheulean in north-central India

The co-occurrence at Bamburi 1 of large quartzite flakes and cores with typologically distinct refined handaxes and cleavers permits comparison with the local technological sequence (Sharma and Clark, 1983; Jones and Pal, 2009). The Sihawal II and Nakjhar Khurd sites, excavated in the early 1980s, preserve artefact records within the Sihawal Formation and are located within a few kilometres to the south and southeast of Bamburi 1. In addition, the Patpara locality preserves a significant archaeological assemblage and is located just over 30 km west–southwest of Bamburi, between the Kaimur Range and one of the medial ridges that parallel the course of the Son River (Fig. 1). The separation of Patpara from the main Son River channel is likely to have influenced sedimentary deposition at the site, and the implications of this separation are discussed further below. The technological record of these sites can be considered alongside that of Bamburi to build an initial picture of the Late Acheulean occupation of the Middle Son Valley.

Sihawal II (N 24°33′31.7″, E 82°14′04.2″) was excavated as a 25 m^2 open plan site with a separate 2 m^2 sondage in February 1980, by a joint University of Allahabad/University of California team under the direction of G.R. Sharma and J. Desmond Clark. The main excavation reached shale bedrock ~0.5–1.5 m below the surface, with two overlying sedimentary bodies forming the type locality for the Sihawal Formation lower and upper members (Kenoyer and Pal, 1983). The lower member is 0.5–1 m thick and comprises rolled to angular clasts of quartzite, sandstone, silicified limestone and shale in a clay matrix, with a higher proportion of calcium carbonate and iron/manganese precipitation creating greater consolidation towards the base of the stratum. The upper member is a culturally sterile mottled brown clay loam up to 0.5 m thick, with a high concentration of carbonate nodules towards its base. A total of 114 artefacts was recovered from the less consolidated upper portion of the lower member, while only 5 artefacts (from 5 m^2) were found in the dense lower deposits. Technologically, these artefacts fall into the Late Acheulean as seen at Bamburi, with handaxe and cleaver forms alongside a discoidal core and a range of flake tools (Fig. 7a; Table 2). The site's excavators (Kenoyer and Pal, 1983) suggest that the lower member is a colluvial deposit, and that the fresh nature of many of the recovered artefacts, along with their position high in this stratum, suggests they were primarily deposited during the final stages of the process that led to the formation of the Sihawal lower member.

Nakjhar Khurd (N 24°32′20″, E 82°13′42″) was excavated in February and March 1980 as a 6.6 m high step trench, 3 m wide (Misra et al., 1983). The base of the trench cut into the same shale bedrock seen at Sihawal, overlain by 0.8–1 m of bedded gravels assigned to the Sihawal Formation lower member. This is, in turn, overlain by ~2.8 m of mottled yellow/grey clay, itself unconformably underlying reddish-brown unstructured sandy gravel. The former is equated to the Sihawal upper member, and the latter to the Patpara Formation. The Sihawal upper member produced only a single end-struck flake with a dihedral platform, of fresh fine-grained quartzite, while the lower member produced 21 artefacts (Table 2). This distribution conforms to the pattern seen at both Bamburi 1 and Sihawal II, where occupation debris is concentrated in the upper portion of the lower member gravels and clays, and virtually absent from the upper member. The lower member artefacts at Nakjhar Khurd included a small lanceolate quartzite handaxe, made on a thick flake, and the distal half of a fine-grained cleaver with an oblique bit (Fig. 7b).

The combined records from Sihawal II, Nakjhar Khurd and Bamburi 1 demonstrate that Acheulean occupation in this portion of the Middle Son Valley was largely confined to the period during which the final portion of the Sihawal Formation lower member was being deposited, with lesser evidence for both earlier and later occupation recorded at Bamburi 1 in particular. We hypothesise that this period was a time of reduced southwest monsoon input, most probably at the termination of the glacial MIS 6, on the basis of available age estimates and sedimentological evidence for reduced fluvial activity. South Asia is not directly affected by continental ice sheets, with the result that even during glacial maxima refugia existed across the subcontinent (Kourampas et al., 2009; Petraglia et al., 2009a; Farooqui et al., 2010), and low-density Acheulean populations were clearly able to survive in the Middle Son Valley during these periods.

Differentiating the Indian Late Acheulean from the subsequent, or potentially contemporaneous, early Middle Palaeolithic can be

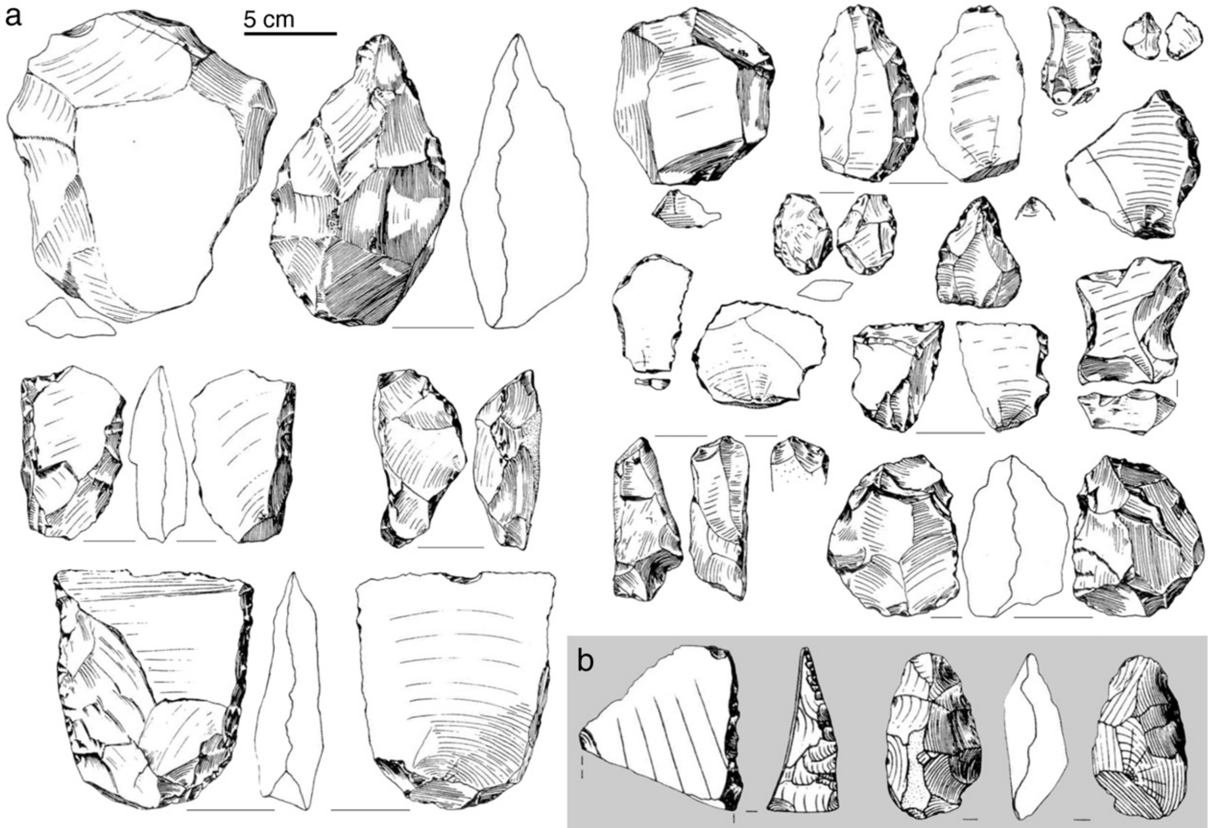

Figure 7. Late Acheulean artefacts excavated from the Sihawal Formation lower member, at (a) Sihawal II (adapted from Kenoyer and Pal, 1983) and (b) Nakjhar Khurd (adapted from Misra et al., 1983).

problematic, as lithic assemblages from both contain refined bifaces and cleavers along with flake removal from prepared cores (Mishra, 1995; Petraglia et al., 2003; Sharma and Misra, 2003). At many sites, the difference between the two phases is only in the frequency with which these elements are present (James and Petraglia, 2009), leaving isolated occurrences in a definitional grey area. In the Middle Son Valley, for example, the early Middle Palaeolithic has been characterised as including increasingly diminutive handaxes and cleavers together with prepared core technologies, and an increasing use of cryptocrystalline materials that then gain greater prominence later in the Middle Palaeolithic (Sharma and Clark, 1982; Jones and Pal, 2009). Here we prefer to diminish terminological ambiguity by including all assemblages with handaxe and cleaver components within the Late Acheulean, as they are demonstrably a continuation of the long South Asian Acheulean tradition. Assemblages at a given site without such technologies cannot automatically be assigned to the Middle Palaeolithic, however, and detailed technological studies are the only presently available route by which archaic and modern human activities may be distinguished.

As an example, both 'final Acheulean' (Sharma and Clark, 1982) and 'early Middle Palaeolithic' (Clark and Sharma, 1983; Jones and Pal, 2009) have been used to describe assemblages from two sites excavated near Patpara village in the early 1980s (Blumenschine et al., 1983; Sharma and Misra, 2003). These Patpara Formation sites contain discoidal core reduction elements and various retouched scraper forms, but quartzite is the dominant raw material and handaxes and cleavers are distinct items in the assemblage (Fig. 8). We therefore consider the Patpara finds as resulting from archaic *Homo*, Late Acheulean occupation. No evidence remains of the archaeological sections excavated in the Middle Son Valley during the early 1980s, but we have attempted to relate the new OSL age determinations to the previous work at Patpara. Blumenschine et al. (1983) reported that 'most if not all of the archaeological material' at the Patpara locality derives from red-brown clays overlying dark red-brown clay with mineral inclusions. Based on sediment colour and texture, the latter may plausibly equate to the clay-rich silts from which OSL sample PAT-3/2 was collected. The two OSL ages from Patpara are statistically indistinguishable, so we suggest that the Late Acheulean artefact accumulation at Patpara was concentrated in the period around and following 140 ka. On the same evidence, initial deposition of the Patpara Formation at its type locality appears to have occurred at or just before the MIS 6 to MIS 5 transition.

There is a discrepancy between the dating of the Sihawal upper member to ~130–100 ka, and evidence that parts of the supposedly succeeding Patpara Formation had accumulated by ~140–130 ka. Even if previously-reported ages of 100 ka for the final Sihawal Formation sediments at Nakjhar Khurd and Sihawal II are too young (Jones and Pal, 2009), it is clear that parts of these two formations were deposited synchronously. Our proposed explanation for this discrepancy is that the Sihawal Formation is a product of activity within the main Son river channel, whereas the Patpara type locality sediments more than 30 km away are derived from local sources, detached from the main river deposition by medial ridges (see Fig. 1). Testing the hypothesis of lateral discontinuity between the two type formations will require reanalysis of (1) the supposed Sihawal Formation clays present in the lower portion of the Patpara sedimentary sequence, and (2) the rubified coarse sands attributed to the Patpara Formation that form the uppermost component of the Sihawal type section.

Hominin replacement in north-central India

Collectively, the Middle Son Valley sites provide evidence that the socio-cognitive and environmental processes driving South Asian hominins towards a greater reliance on flake technology and fine-

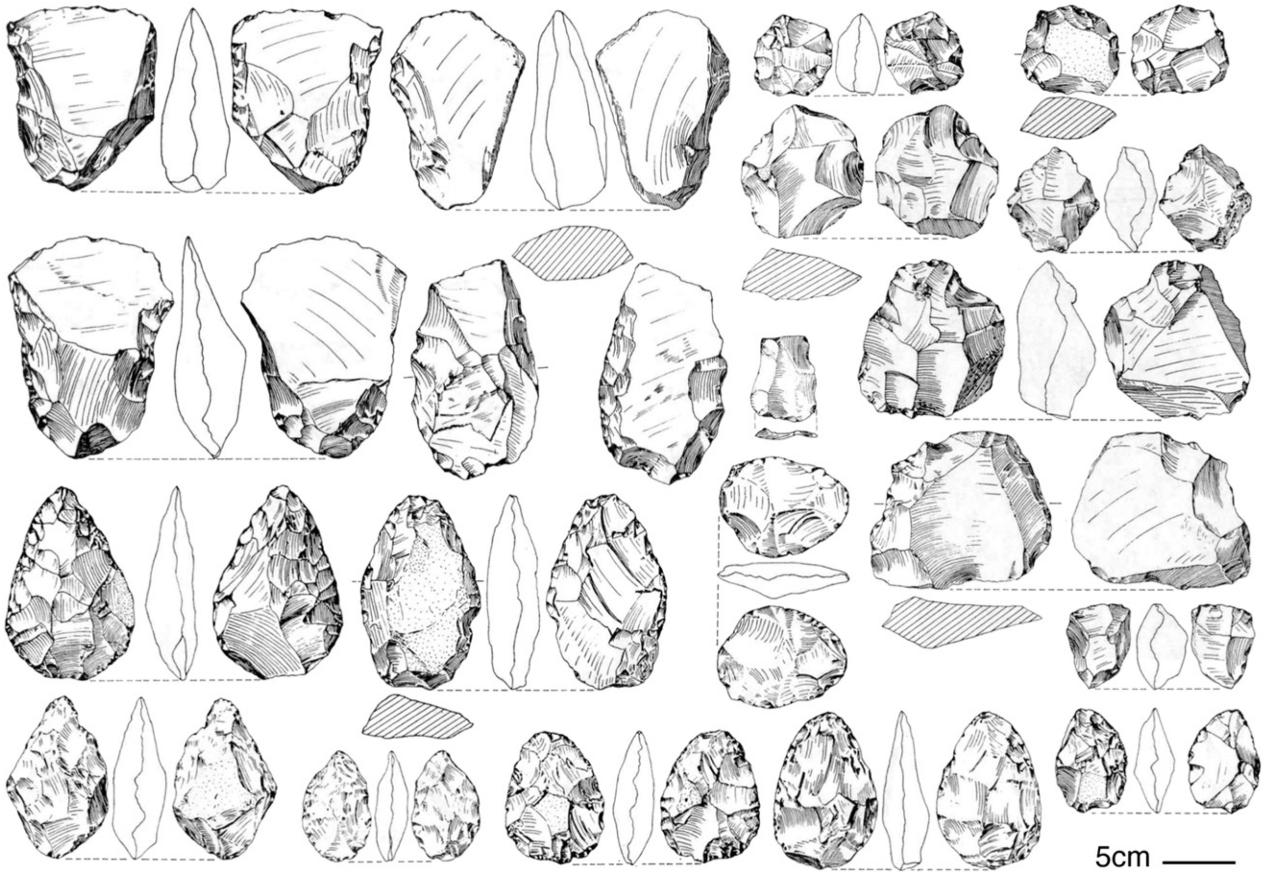

Figure 8. Artefacts excavated and surface collected from the Patpara Formation, at the Patpara I and Patpara II sites (adapted from Blumenschine et al., 1983).

grained materials were underway prior to 120 ka, and potentially occurred through the climatically variable period from MIS 6 into the first half of MIS 5. Table 4 summarises the limited number of available ages for the South Asian Late Acheulean that fall within this glacial–interglacial period. Note that there are, at present, fewer than 30 excavated Acheulean sites in India, and most of these remain undated by chronometric means (Pappu, 2001).

We propose that technological consistency across the Late Acheulean in northern India was a result of biological consistency. Specifically, we suggest that hominin groups represented by the cranial remains from Hathnora on the Narmada River produced the Late Acheulean in the Middle Son Valley. The Hathnora fossil has a variety of anatomical features leading to it being classified at various times as *Homo erectus* (de Lumley and Sonakia, 1985), *H. sapiens narmadensis* (Kennedy et al.,

Table 4
Chronometric ages for South Asian Acheulean sites, MIS 6–MIS 5.

Site	Age (sample code)	Dating method/context[a]
Kaldevanhalli, Hunsgi Valley, Karnataka	174 ± 35 ka 166 + 13/−15 ka	U-series; travertine deposits associated with Acheulean limestone artefacts, the earlier date is considered more reliable (Szabo et al. 1990:319)
Sabarmati and Mahi Rivers, Gujarat	131 ka (Mh/V/1) 120 ka (R/V3/Rh) 104 ka (M/C/0) 82 ± 24 ka (TL-6)	ESR (131–104 ka): basal vertisols at Mahudi (Sabarmati) and Rayka (Mahi) in Acheulean-bearing sediments BGSL (82 ka): Gravel 2 at Rayka, Mahi, minimum age for underlying Acheulean artefacts
Patpara, Middle Son Valley, Madhya Pradesh	140 ± 11 ka (PAT-3/2) 137 ± 10 ka (PAT-4/1)	OSL; Patpara Formation in strata containing and immediately underlying Late Acheulean artefacts
Bamburi 1, Middle Son Valley, Madhya Pradesh	131 ± 10 ka (BAM-1/1) 125 ± 13 ka (BAM-2/1) 131 ± 9 ka (BAM-3/2)	OSL; Sihawal Formation upper and lower members, directly associated with Late Acheulean quartzite and limestone artefacts
Nakjhar Khurd, Middle Son Valley, Madhya Pradesh	103.8 ± 19.8 ka (Alpha-899)	TL; Sihawal Formation upper member, minimum age for underlying Late Acheulean in Sihawal lower member
Nakjhar Khurd, Middle Son Valley, Madhya Pradesh	~100 ka (N1)	IRSL; Sihawal Formation upper member, minimum age for underlying Late Acheulean in Sihawal lower member
Adi Chadi Wao, Hiran Valley, Gujarat	69 ± 4 ka (49-1) 69 ± 4 ka (49-5)	U-series; miliolite (Quaternary carbonate) deposits, minimum age for Acheulean handaxes in underlying gravels (maximum age ca. 190 ka)
Bhimbetka III-F23, Madhya Pradesh	>41 ± 12 ka (BH-2)	OSL; minimum age for underlying Late Acheulean layers, preliminary age as sediment mixing is possible
Bhimbetka III-F23, Madhya Pradesh	>47 ± 4 ka (BH-1)	OSL; Associated with Late Acheulean artefacts near base of site, preliminary age as sediment mixing is possible

Data compiled from Sharma and Clark (1983); Baskaran et al. (1986); Szabo et al. (1990); Khadkikar et al. (1999); Juyal et al. (2000); Bednarik et al. (2005).
[a] U-series = ^{230}Th-^{234}U radiometric dating; ESR = electron spin resonance; BGSL = blue-green light stimulated luminescence; OSL = optically stimulated luminescence; TL = thermoluminescence; IRSL = infrared stimulated luminescence.

1991) and Middle Pleistocene *Homo* (Athreya, 2007). Gamma spectrometric uranium-series dating of a bovid scapula, reportedly from the same 'Boulder Conglomerate' as the Hathnora cranium, gave a preliminary minimum age of 236 ka (Cameron et al., 2004), placing it well into the Middle Pleistocene. However, recent re-evaluation of the sedimentary context for this important fossil, accompanied by chronometric dating, suggests that Middle Pleistocene age estimates may be erroneous (Patnaik et al., 2009). The Surajkund Formation, in which the Hathnora fossil was discovered, is now suggested to have been laid down during a warm, humid period interspersed with arid phases, and electron spin resonance ages of ungulate teeth stratigraphically associated with the fossil span the interval from approximately 160 to 85 ka (assuming a linear rate of uranium uptake by the dental tissues) (Patnaik et al., 2009). Artefacts from the same stratigraphic setting as the Hathnora fossil include handaxes alongside flake-based core reduction, falling within our Late Acheulean designation. The Narmada deposits have very likely been reworked, but on present data it appears plausible that the archaic *Homo* taxon represented by the Hathnora individual was the same as that producing Late Acheulean technology in the Middle Son Valley during late MIS 6 and early MIS 5.

Following this line of reasoning, technological data from Bamburi, Sihawal, Nakjhar Khurd and Patpara suggest that archaic *Homo* occupied the Middle Son Valley until at least MIS 5e, and potentially later. Having survived the drier glacial conditions of MIS 6 and shown evidence of an ability to adopt widespread technological change, there is presently little reason to assume that the region's residents would have then disappeared during the more clement interglacial conditions. However, if another large bodied and large brained hominin – *H. sapiens* – began to encroach on the geographic range of the Middle Son groups, then competition and subsequent extinction would be a possible outcome. We stress that no definitive evidence for direct encounters between archaic and modern human groups has been found in South Asia, but given the problems with demonstrating such contact in parts of the world with many more sites and fossils in dated contexts (e.g., Europe; Hoffecker, 2009), absence of evidence means little at present.

Primary difficulties in assessing South Asian Late Pleistocene hominin replacement include (i) the lack of Indian fossil remains (all known South Asian *H. sapiens* remains post-date 40 ka), and (ii) the fact that initial *H. sapiens* populations expanding out of Africa during the Late Pleistocene possessed a Middle Palaeolithic toolkit with some similarities to that already in use in both Europe (by the Neanderthals) and South Asia (James and Petraglia, 2005; Petraglia et al., 2010). Evidence for technological similarity across the continents during this period comes from the Levant between ~120 and 80 ka (Shea, 2008), from Arabia during MIS 5 (Marks, 2009), and also from assemblages in the southern Indian Jurreru Valley, buried by tephra from the 74 ka Toba super-eruption (Petraglia et al., 2007, 2009b; Haslam et al., 2010a,b; Haslam and Petraglia 2010). The MIS 5 Jurreru lithic assemblages lack cleavers or refined bifaces of the type associated with the Indian Late Acheulean, and discriminant analysis of lithic core morphology and reduction strategies from the Jurreru sites places them closest to sub-Saharan African Middle Stone Age technologies (Haslam et al., 2010a). On these bases, *H. sapiens* cannot be ruled out as the occupant of the Jurreru sites more than 74 ka ago, and the Indian Middle Palaeolithic has yet to be disproved as a modern human introduction.

If modern human arrival was partly responsible for the demise of archaic South Asian hominin populations (during either MIS 5 or 4), then comparisons for the nature of such an encounter may be tentatively drawn from the European record of Neanderthal extinction during MIS 3. For example, we may anticipate some transfer of cultural knowledge between the indigenous and incoming species, either through direct contact or stimulus diffusion (Tostevin, 2007), and potentially also genetic intermixing (Trinkhaus, 2007). Recent reports of the draft Neanderthal genome suggest that Neanderthals and *H. sapiens* likely did interbreed successfully soon after the latter had left Africa (Green et al., 2010), with the probable location of such contact to the west of India, in the Middle East. The southern limit of the Neanderthal range is unknown (Dennell and Roebroeks, 2005), but we emphasise that the continuity seen in the Middle Pleistocene South Asian technological record suggests that taxa derived from earlier hominin dispersals, and not Neanderthals, were the creators of the Indian Late Acheulean. Greater biological separation between dispersing humans and resident Indian hominins may have precluded viable genetic mixing (although see Liu et al., 2010 for an alternate view from East Asia), while similarities in certain technological strategies may have rendered cultural exchange a somewhat more likely occurrence. In any case, the process of South Asian hominin replacement will undoubtedly yield important differences to the European record, and wholesale adoption of models based on Neanderthals is inadvisable.

In advancing our understanding of archaic *Homo* replacement in South Asia, the immediate challenge is to identify and track those technological characteristics that were not shared between earlier hominins and *H. sapiens*, despite convergence in their technological strategies. In this regard, the co-occurrence in South Asian Late Acheulean sites of cleavers, refined bifaces and initial flake-based technologies is hypothesised here to mark non-*sapiens* populations, leaving both the Bamburi and Patpara toolmakers designated archaic. Along with lithic core comparison data (Haslam et al., 2010a), the same assessment would consider the 78–74 ka Jurreru hominins, for example, as more likely to be modern humans.

While acknowledging both the size of the Indian subcontinent and the multiple routes by which colonisation may occur (Field et al., 2007), we suggest that geographic, geological and hydrological factors may have channelled such movements towards favourable areas already occupied by Late Acheulean hominins (Korisettar, 2007), setting up potential encounters soon after initial *H. sapiens* entry into the region. In this respect, the restricted northwest entrance to the region, in and around the Thar Desert (Singhvi et al., 2010), will provide one important testing ground for identifying early modern human incursion into India. Other key areas potentially preserving evidence for Late Pleistocene hominin contact will be those regions that acted as refugia during MIS 6, where archaic populations are likely to have been most dense.

In terms of timing, previous (Petraglia et al., 2010) and current work suggests that the interval between 130 and 75 ka (i.e. MIS 5) is most parsimonious for targeted studies of initial hominin replacement in South Asia. This date range fits with new fossil data of a potential modern human mandible fragment from southern China dated older than 100 ka (Liu et al., 2010; Dennell, 2010), and suggests that the genetic lineages of the earliest dispersing modern humans have been lost from modern populations. Technologically, we posit that this dispersal was accompanied, at least as far as South Asia, by Middle Palaeolithic flake-based technologies without cleavers and handaxes. A demographically-driven shift to microlithic technology occurs in late MIS 3 in India, well after *H. sapiens* had dispersed through the region to southeast Asia and Sahul (Petraglia et al., 2009a); microliths do not therefore signal initial human arrival in the subcontinent.

Conclusions

OSL ages from the Bamburi 1 and Patpara sites in the Middle Son Valley provide the first securely dated stratified Late Acheulean assemblages in north-central India. This region has produced the only pre-*sapiens* hominin remains in South Asia, and we anticipate that continued concentration of research effort on localities such as Bamburi and Patpara will provide significant insights into hominin technology and adaptative strategies in this under-researched area. Ages of ~120–130 ka for the Sihawal Formation upper member and ~130–140 ka for the Patpara Formation refine and improve upon existing data for modelling the geomorphological evolution of the Middle Son Valley system in response to fluctuating climates, and give an upper age boundary to one of the world's latest-surviving Acheulean populations. Future research in this area is likely to shed light on the potential interactions of dispersing modern human and resident hominin populations in the Indian subcontinent.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.yqres.2011.02.001.

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