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Contents

Excavations at Attirampakkam

The site of Attirampakkam (ATM) was discovered in 1863[32] and subsequently visited by various investigators[33]. Nineteenth and early 20th century collections of bifaces from this site are displayed in museums worldwide, but their precise origin has been doubtful because artefacts came from surface exposures eroding out of different layers at ATM, and from other streams and unspecified localities in the region[18,33]. Given that early work generated a variety of interpretations of the cultural sequence and its stratigraphy, a reinvestigation of this site and of neighbouring archaeological landscapes in northern Tamil Nadu was taken up by S. Pappu and K. Akhilesh. Systematic excavations at ATM resulted in a substantive reinterpretation of previous work, with key updates presented here. New findings regarding the technology, its chronology, and palaeoenvironmental conditions were reported. Gully erosion at ATM exposed artefacts across the surface over an area of ~50,000 m^2. A contour map of the site and its surface deposits was prepared at 1 m intervals and used with satellite imagery at nested ground resolutions to investigate local landscapes. Test-pits, geological step-trenches and horizontal trenches were excavated across the site and a meticulous record of all artefacts and features was maintained. In addition, video footage and 3-D visualizations of the trenches based on photomosaics were produced. Samples from sediment layers were dry- or wet-sieved to recover artefacts < 2 cm and lithic microdebitage. Sediment samples were collected for sedimentological, palaeobotanical, and micropalaeontological analysis, for rock magnetism studies, and for age determination. Extensive surveys of prehistoric sites were conducted over a region covering an area of ~8000 km^2 in the watersheds of the Arani, Kortallaiyar and Palar rivers. This resulted in a comprehensive database of prehistoric sites and stratigraphic sections, which has been used to further our understanding of the prehistoric environments, chronology, and raw material sources (Figs 1, 2; Extended Data Figs 1–8, Supplementary Table 1)[24-26,33-39].

Geomorphological and stratigraphic evidence

The archaeological site is situated on the concave bank of an entrenched meandering creek (Strahler order 3) confined by bedrock riverbanks of cohesive Lower Cretaceous shale. Consequently, the stream lacks a broad and continuous floodplain. Instead, a succession of 'pocket' floodplains is distributed at discrete locations along the bedrock stream of this shale-dominated catchment. In a semi-arid tropical environment prone to flash floods, the hominins adopted one of these small floodplains as an attractive waterside habitat. The stratigraphic beds containing the Middle Palaeolithic artefacts are predominantly fine-grained and subhorizontal, indicating that the sediment was deposited on the floodplain in a low-energy environment, quite different from the more powerful (Strahler order 6) Arani and Kortallaiyar rivers nearby (Fig. 1).

The archaeological sequence at ATM displays eight stratigraphic units comprising sediments of fluvial origin. The base of the sequence consists of silt-rich claystone (layers 6 and 8) interlayered with a gravel bed (layer 7). These layers record the earliest Acheulian occupation at ATM[24]. They are overlain by the sequence of interest to this study, which comprises a ferruginous gravel bed (layer 5) capped by clay-rich silt (layers 3 and 4), followed by fine-grained ferruginous gravel (layer 2), itself capped by a final layer of clay-rich silt (layer 1). Layers 5 to 1 contain a suite of progressively younger Middle Palaeolithic (henceforth MP) cultural assemblages (Fig. 2, Extended Data Fig. 2).

The artefact-rich silt units in the stratigraphy (layers 3 and 4) are overbank deposits, whereas the ferruginous gravels of layer 5, Unit 5a and layer 2 indicate higher-energy epochs or events. Mineral magnetic studies suggested greater aridity at the time of gravel layers 5 and 2, and more humid conditions at the time of layers 3 and 4[25]. Transport of ferruginous gravel thus probably occurred at times when the laterite outcrops capping the drainage divide in the northern headwaters of the Attirampakkam watershed (Extended Data Fig. 1) underwent headward erosion, plausibly under a combination of sparser vegetation and greater surface runoff.

Palaeovegetation data from phytoliths collected from the site[39] have revealed an increase in C4 Chloridoid phytoliths in layers 5 to 3, followed by a decrease in C4 Panicoid taxa in layers 2 and 1. Such assemblages suggest a shift towards drier climates at the time of layers 2 and 1, with highest aridity at the time of layer 1. Fluctuations in C3 Pooid phytoliths and a decrease in phytoliths from woody taxa in the younger stratigraphic levels support this conclusion. Palaeobotanical evidence suggests the presence in layers 5 and 1 of phytoliths belonging to wetland species[39]. This is consistent with the edaphic conditions expected on a riverbank or in the floodplain environment of ephemeral rivers.

Stratigraphically consistent pIR-IRSL ages indicate that sediment aggradation, on average, prevailed over channel and floodplain erosion. Unconformable boundaries between the gravel-rich and silt-rich beds and the absence of palaeosols suggest occasional erosive episodes. The sedimentation at ATM was followed by regional drainage incision, which took place after ~74 ka.

ATM was periodically visited by hominins, perhaps seasonally to achieve specific tasks. At the time of deposition of layers 5, 2 and Unit 5a, raw materials were available in situ (layer 5) or brought to the site for toolmaking (Extended Data Figs 3–8). Accordingly, in these archaeological horizons extensive and pristine evidence of manufacturing is observed in the form of cores in varied stages of reduction, waste products (including flakes < 2 cm), and finished tools. Given that even the trunk streams in the region are seasonally dry, frequent occupation of ATM would have been possible for extended periods.

Such a protracted frequentation of ATM by hominins, from perhaps ~1.7 Ma[24] to 0.074 Ma (this study), suggests that these groups possessed a distinctive sense of place based on an understanding of landforms and habitat mosaics — in this case a low-order stream, narrow enough for riparian vegetation to provide shade and habitats not available along the higher-order and much wider sand- and gravel-bed rivers flowing just a few kilometres to the south (Kortallaiyar) and north (Arani). This evidence of ‘placemaking’ was itself enshrined within broader strategies of regional mobility and spatial knowledge (Extended Data Fig. 1).

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Supplementary Table 1. Frequency distribution of artefact categories in Trench T7A, Attirampakkam

	Phase I		Phase II								Phase III		
	Layer 5		Layer 4		Layer 3		Unit 5a		Layer 2		Layer 1		
	N_5	%	N_4	%	N_3	%	N_{5a}	%	N_2	%	N_1	%	Total
Artefact Categories													
Cores													
Blade cores	12	0.24	1	0.21	2	0.77	1	0.69	5	0.35	–	–	**21**
Flake cores	205	4.15	6	1.25	10	3.83	2	1.39	7	0.49	1	14.29	**231**
Levallois cores	54	1.09	–	–	2	0.77	–	–	1	0.02	–	–	**57**
Levallois point cores	1	0.02	–	–	–	–	–	–	–	–	–	–	**1**
Subtotal	***272***		***7***		***14***		***3***		***13***		***1***		***310***
Cores on handaxes with one preferential flake removal													
Subtotal	***6***	***0.12***	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**	***6***
Tools		0.00											
Scrapers	612	12.38	28	5.83	15	5.75	6	4.17	51	3.58	2	28.57	**714**
Scraper and borers	3	0.06	–	–	1	0.38	–	–	–	–	–	–	**4**
Scraper and notches	1	0.02	–	–	–	–	–	–	–	–	–	–	**1**
Knives	1	0.02	–	–	–	–	–	–	–	–	–	–	**1**
Notches	32	0.65	2	0.42	4	1.53	–	–	2	0.14	–	–	**40**
Denticulates	11	0.22	–	–	2	0.77	–	–	–	–	–	–	**13**
Borers	31	0.63	2	0.42	2	0.77	–	–	4	0.28	–	–	**39**
Burins	1	0.02	–	–	–	–	–	–	4	0.28	–		**5**
Blades	–		–	–	6	2.3	–	–	9	0.63	–		**15**
Retouched points	9	0.18	1	0.21	2	0.77	–	–	1	0.07	–		**13**
Retouched flakes	325	6.57	24	5	6	2.3	6	4.17	22	1.54	–	–	**383**
Retouched blades	1	0.02	–	–	1	0.38	–	–	3	0.21	–	–	**5**
Silicifed wood (retouched)	–		–	–	1	0.38	–	–	–	–	–	–	**1**
Levallois flakes	3	0.06	–	–	2	0.77	–	–	9	0.63	–	–	**14**
Levallois points	2	0.04	–	–	–	–	1	0.69	1	0.07	–	–	**4**
Levallois points (retouched)	4	0.08	1	0.21	–	–	–	–	–	–	–	–	**5**
Scrapers on Levallois flake	10	0.20	–	–	3	1.15	–	–	8	0.56	–	–	**21**
Notches on Levallois flake	–		–	–	–	–	–	–	1	0.07	–	–	**1**
Bifacially flaked tools	10	0.20	–	–	–	–	–	–	–	–	–	–	**10**
Handaxes	12	0.24	–	–	–	–	1	0.69	–	–	–	–	**13**
Cleavers	7	0.14	–	–	–	–	–	–	–	–	–	–	**7**
Chopper	–		–	–	–	–	–	–	1	0.07	–	–	**1**
Chopping tool	8	0.16	–	–	–	–	–	–	3	0.21	–	–	**11**
Retouched pebbles/cobbles	82	1.66	8	1.67	1	0.38	–	–	2	0.14	–	–	**93**
Modified pebbles/cobbles	356	7.20	13	2.71	4	1.53	1	0.69	13	0.91	–	–	**387**
Subtotal	***1521***		***79***		***50***		***15***		***134***		***2***		***1801***
Anvils and hammerstones													
Anvil	4	0.08	–	–	–	–	–	–	1	0.07	–	–	**5**
Hammerstone	73	1.48	1	0.21	3	1.15	–	–	7	0.49	1	14.29	**85**
Subtotal	***77***		***1***		***3***		**–**		***8***		***1***	**–**	***90***
Broken parts of tools		0.00											
Broken parts of handaxes	3	0.06	–	–	–	–	–	–	–	–	–	–	**3**
Broken part of tools	10	0.20	2	0.42	1	0.38	–	–	20	1.4	–	–	**33**
Subtotal	13		*2*		*1*		–	–	*20*		–	–	***36***
Waste products													
Subtotal	***3056***	***61.80***	***391***	***81.46***	***193***	***73.95***	***126***	***87.5***	***1249***	***87.71***	***3***	***42.86***	***5018***
Total	**4945**	100.00	**480**	**100**	**261**	**100**	**144**	**100**	**1424**	**100**	**7**	**100**	**7261**

Chronology

Sample collection was undertaken using steel tubes[40], and analysis followed standard OSL dating procedures[41]. In the laboratory, sample preparation and handling was performed under subdued LED lights emitting at ~650 nm. The samples were pretreated with 1N hydrochloric acid followed by 30% hydrogen peroxide to remove carbonates and organic materials, respectively. Grains 150–210 μm in diameter were then sieved, and a separation of quartz and feldspar grains was obtained using a Frantz® magnetic separator[42,43]. Selected feldspar grains were subsequently etched with 10% hydrofluoric (HF) acid for 10 minutes to remove the alpha-irradiated skin. A few minutes of treatment by 37% HCl followed HF etching immediately to dissolve residual fluorides. The grains were then sieved through a 90 μm sieve to remove the smaller grains.

Measurements were carried out on feldspar grains mounted over an area of 3 mm in diameter on a 9.65 mm diameter stainless-steel disc using Silkospray™. This implied that typically 50 to 70 grains were being measured. Expecting the light sum to be generated by ~10% of the grains, the analysis was expected to provide the maximum dispersion in the palaeodoses. Infrared stimulation was generated using IR-LEDs in a Risø TL/OSL DA-20 reader[44]. The detection optics comprised Schott BG-39 and Corning 7-59 filters, allowing transmission in the blue-violet band (370–440 nm) with a peak at ~410 nm[45]. The beta irradiation strength applied to the aliquot was 0.113 Gy/s using a 1.48 GBq ^{90}Sr / ^{90}Y source.

The pIR-IRSL Single Aliquot Regeneration (SAR) protocol was used for the estimation of palaeodoses (D_e)[46,47] (Supplementary Table 2). A preheat of 320 °C for 30 s was used and pIR-IRSL was measured at 290 °C for 200 s. The initial 6 s luminescence signal was used as the age signal, and a final 60 s signal was used as background. A test dose of 100 Gy (except for samples 11L1 and 12L1, where a 25 Gy test dose was applied) was used to normalize the natural and regenerated signals. For all samples, the acceptance criteria were as follows; recuperation ratio: 5%; recycling ratio: 10%; test-dose (D_T) error: 10%; measurement error: 5%. The laboratory-generated dose response curve was fitted to a single saturating exponential. For the preheat test, a beta dose of 60 Gy was administered after 8 hours of bleaching of a fresh natural sample under a filtered sunlamp followed by a preheat. The data points are the arithmetic mean of 3 aliquots for each preheat. The recovered dose for 260 °C, 290 °C and 320 °C fell within 5% of the expected dose. The dose-recovery–preheat-plateau test for sample ATSP#2013/12L1 is shown in Extended Data Fig. 9. The *g*-values (fading rates) of the pIR-IRSL signal were estimated by irradiating the samples to 200 Gy in the laboratory[48]. The decrease of the pIR-IRSL signal over time at room temperature was measured using the standard procedure for long-term anomalous fading evaluation[49]. The time delays ranged from prompt measurements to up to 2 days. Typical *g*-values ranged from 1% to 3%/decade, and a mean of 4 to 8 aliquots was considered for the final g_{2days}.

Typical pIR-IRSL shine-down curves, growth curves, and radial plots are shown for each sample in Extended Data Fig. 10, along with a representative *g*-value plot for the corresponding sample. The dose rate was measured using a High Purity Germanium detector (HPGe) and is given in Supplementary Table 3. Given that the activity ratios were close to unity, equilibrium in the decay chain was assumed. The summary of equivalent dose values (D_e), fading rates and corrected feldspar age data is shown in Supplementary Table 4.

Given the scientific importance of the archaeological site, we also examined possible luminescence signals other than pIR-IRSL. These were the blue-green stimulated luminescence (BGSL) of quartz, and the infrared stimulated luminescence (IRSL) of feldspars. As expected, the quartz signal showed saturation for older ages (> 100 ka), thereby limiting the dating potential.

Despite corrections for athermal fading, the IRSL ages underestimated the true ages. Nonetheless, for two of the younger samples, 11L1 and 12L1, we observed a good concordance between BGSL, IRSL and pIR-IRSL ages, suggesting that the samples were well bleached at the time of their burial and that pIR-IRSL could be used with confidence in the older deposits of the stratigraphy. It is also known that for older samples the issue of incomplete bleaching gets diluted because the residual dose becomes increasingly a small fraction of the total dose. Lastly, in archaeological strata, the incremental disturbance of surface particles caused by the physical presence of hominins throughout the history of episodic floodplain aggradation results in a churning motion of the particles. This entails an exposure to daylight of the mineral grains before their burial becomes definitive[50].

Given the nature of the pIR-IRSL protocol and the age range of the samples, irradiation times implied several weeks of measurement time for each sample. For this reason, the palaeodose measurements were limited to a maximum of 8 aliquots. Given the inference of complete predepositional bleaching and the fact that the residual pIR-IRSL signal — a few Grays — was very small compared to the total palaeodose of the sample, this was considered as a reasonable tradeoff between analytical precision and time. We used mean ages in accordance with the approach described in the relevant references[51,52], and subtracted a residual dose of 8 Gy, which is the value of the dose remaining in the sample after extended solar lamp bleaching.

Supplementary Table 2 Parameters of the pIR-IRSL SAR protocol

Step	Treatment	Observed measurement
1	Give dose, D_i[1]	
2	Preheat, 30 s at 320 °C	Remove thermally unstable signal
3	IR stimulation, 100 s at 50 °C	
4	IR stimulation, 200 s at 290 °C	L_X (measured luminescence)
5	Give test dose, D_T	
6	Preheat, 30 s at 320 °C	Remove thermally unstable e^-, signal
7	IR stimulation, 100 s at 50 °C	
8	IR stimulation, 200 s at 290 °C	T_X (measured temperature)
9	IR stimulation, 300 s at 325 °C	Bleach
10	Return to step 1	

[1] For natural luminescence measurement, $D_i = 0$.

Supplementary Table 3 High Purity Germanium (HPGe) detector data

Sample Name	K (^{40}K) 1460.7 keV (Bq/kg±1σ)	Th (^{208}Tl) 583.1 keV (Bq/kg±1σ)	U (^{214}Bi) 609 keV (Bq/kg±1σ)	U (^{214}Pb) 352 keV (Bq/kg±1σ)	U (^{226}Ra) 186.0 keV (Bq/kg±1σ)
ATSP#2013/12(L1)	37.2±3.1	14.5±0.9	16.3±0.7	16.2±0.8	16.4±0.8
ATSP#2013/11(L1)	71.2±3.6	15.2±1.2	29.1±1.5	29.3±1.5	29.1±1.4
ATSP#2013/9(L2)	37.2±1.9	11.0±0.9	14.8±0.7	14.7±0.7	14.9±0.7
ATSP#2013/7(L3)	27.9±1.4	10.6±0.8	12.5±0.6	12.4±0.7	12.6±0.6
ATSP#2013/5(Unit 5a)	83.6±4.2	21.7±1.7	18.9±0.9	19.0±0.9	18.8±0.9
ATSP#2013/3(L4)	46.5±2.3	19.5±1.6	18.3±0.9	18.4±0.9	18.3±0.9
ATSP#2013/1(L5)	78.0±3.9	28.9±2.3	49.4±2.5	49.1±2.5	49.5±2.4

Supplementary Table 4 Equivalent dose (D_e) and dose rate (D_R) (Trench T7A, west wall, ATM)

Sample Number	Sedimentary layer	Depth below datum (cm)	D_R[1] (Gy/ka±1σ)	pIR-IRSL SAR D_e[2] (Gy±1σ))	pIR-IRSL SAR g-values (%/decade)	Corrected pIR-IRSL age[3] (ka±1σ)	Over-dispersion (%)
ATSP#2013/12(L1)	Layer 1	88	1.64±0.12	95±5	2.4±1.1	73±11	1
ATSP#2013/11(L1)	Layer 1	107	1.99±0.11	120±6	2.1±1.0	74±10	3
ATSP#2013/9(L2)	Layer 2	139	1.53±0.35	224±12	1.7±0.5	172±41	18
ATSP#2013/7(L3)	Layer 3	178	1.41±0.39	237±23	2.2±0.9	210±64	14
ATSP#2013/5	Unit 5a	217	1.90±0.3	296±20	1.1±0.5	174±31	20
ATSP#2013/3(L4)	Layer 4	245	1.70±0.4	399±24	1.4±0.7	268±68	14
ATSP#2013/1(L5)	Layer 5	287	2.54±0.3	786±68	2.2±0.7	385±64	33

[1] 12.5±0.5% Potassium (K) and 400±100 ppm Rubidium (^{87}Rb) concentrations were used to estimate the internal dose rate
[2] after subtraction of a residual dose of 8 Gy
[3] Based on the method applied for fading correction described in Ref. 49

Additional information on the assemblages in layers 5 to 2 at Attirampakkam (ATM)

Here we present additional information on the nature of the assemblage of layers 5 to 2 at ATM. Middle Palaeolithic (MP) horizons were observed in trenches, test-pits and geological step-trenches excavated across the site (Extended Data Fig. 2). This study was based on data from a large sample of 7261 artefacts from Trench T7A (30 m^2, ~105 m^3 of excavated sediment volume from layers 1 to 5), and additional observations of artefacts from the adjacent Trenches T7B and T7C (layers 1 to 4) (Extended Data Figs 3–8, Supplementary Table 1).

The earliest Phase I represents assemblages indicative of transitional processes leading to the establishment of the MP culture. These are observed in layer 5 (385 ± 64 ka), a ferruginous gravel bed partly sourced by the laterites capping the Kortallaiyar / Arani drainage divide[26] (Fig. 1, Extended Data Fig. 1). This deposit supplied hominins with raw materials in the form of pebble and cobble-sized quartzite clasts. On-site manufacture of tools was thus facilitated. This is evidenced by a legacy of all the manufacturing stages relevant to a variety of lithic reduction sequences reflected in cores, shaped tools, waste, hammerstones, and anvils. Site integrity is exceptional, as testified by the occurrence of waste flakes < 2 mm in size. Phase I marks the first appearance at the site of preferential and recurrent Levallois technologies for small-flake detachment (Fig. 3, Extended Data Fig. 3) and the first appearance of diagnostic Levallois points (Fig. 3). Incipient blade cores and associated debitage also appear for the first time, with a predominantly unidirectional removal of blades and elongated blade-like flakes (Fig. 3). Blade cores document the creation of platforms by slicing cobbles, by flaking, or by utilisation of existing cortical surfaces. Blade scars often terminate in step fractures, indicative of knapping errors. Other cores include discoidal cores, and bifacially flaked and multi-platform flake cores (primarily for small flake detachment). In addition to Levallois points, the small-flake tool assemblage comprises a range of points and a few bifacially flaked points, with scrapers predominant among other tool types (Supplementary Table 1). A tanged point appeared for the first time in the stratigraphy during Phase I (Fig. 3j, Extended Data Fig. 5a). Bifaces, and other large cutting tools (LCTs) characteristic of the Indian Acheulian, are rare occurrences in layer 5 (Fig. 3, Extended Data Fig. 3). The dimensions of handaxes and cleavers (Extended Data Fig. 7a) indicate that size ranges vary from diminutive to large. An important feature for examining the roots of the Levallois technology is the presence of bifacially flaked tools from which one preferential flake was detached[17] (Extended Data Fig. 3i).

During the later Phase II (layers 4 and 3, 268 ± 68 ka to 210 ± 64 ka), changes in fluvial transport capacity occurred and promoted the deposition of silt rather than gravel (Fig. 2). This interruption in the direct supply of raw-material sources implies that access to raw material was no longer possible in the immediate vicinity of ATM. Transport by hominins of raw material and hammerstones to the site, where further reduction occurred, was therefore a necessity. Accordingly, for the first time in the stratigraphy we observe the occasional use of exotic raw materials, including one flake on silicified wood of unknown provenance. From that time onwards, we also observe a greater preference for finer-grained quartzite. Preferential and recurrent Levallois cores continued to prevail. One handaxe and two small cleavers were also present in layers 4 and 3 in Trench T7B. Blade technology continues through these horizons, with evidence of blades and associated debitage, and presence of Levallois points (Fig. 4, Extended Data Fig. 4, Supplementary Table 1).

In layer 2 (172±41 ka), the Phase II MP levels display continuity in assemblage structure, with complete disappearance of the occasional bifaces previously encountered deeper in the stratigraphy (Fig. 4, Extended Data Fig. 4). Levallois reduction sequences for flakes and points continued unchanged, as did likewise blade reduction sequences. This pattern is also observed in adjacent trench T7B, including the presence of tanged points.

The density of artefacts in layer 1 (Phase III) is very low, with a few tools occurring from depths > 0.4–0.6 m and forming a technological continuum with layer 2. The upper levels of layer 1 are disturbed by historically recent human activity.

Summary of key features of the ATM MP assemblage

1. Overall preference for a shift from large flake technology towards small tool production. The principal characteristic of the ATM MP is the general avoidance of technological strategies typical of the preceding Acheulian culture, namely the flaking of large to giant cores for the production of large flakes subsequently shaped into bifaces and other large cutting tools (LCT > 10 cm)[33,38]. Indications of this technological revolution include the following:

a. **Scarcity of large cutting tools**. LCTs (excluding bifaces) are negligible (Trench T7A, layer 5: *n* = 7, i.e. 0.14 %), which is a drastic shift from the preceding Indian Acheulian culture at ATM[24,33].
b. **Scarcity of bifaces.** The assemblage comprises only a few bifaces [Trench T7A: 0.38% of the assemblage in layer 5; 0.69% of Unit 5a (*n* = 1)]. Bifaces > 100 mm are only 0.16% of the total assemblage in layer 5, or a vanishingly low proportion.
c. **Small size of bifaces.** In Trench T7A, 11 bifaces (> 50% of the total sample of 19) are all < 10 cm in length (Extended Data Fig. 7a).
d. **Predominance of small flake debitage sequences.** In Trench T7A, the MP sequence is dominated by small flake detachment strategies. Thus, if we consider the small tool component (LCT's being negligible as demonstrated in point (a) above), we note that 88.98% are ≤ ~68 mm (Extended Data Fig. 7b). This is also the case of Levallois cores (Extended Data Fig. 7c) while blade cores have mean dimensions of 77.23 x 56.23 x 44.10 mm.

2. Sustained presence of Levallois reduction sequences. Distinct Levallois strategies for the detachment of small flakes appear for the first time (Extended Data Figs 7c, 8a-d). A co-occurrence of preferential and recurrent strategies was observed.

3. Other features. Levallois points, tanged points, other retouched and bifacially flaked points, and an evolving blade component are other characteristic features of this assemblage.

A brief note on the Levallois cores at ATM

The Levallois concept followed here is based on definitions in the established literature[53-57]**.** The distinctive feature at ATM, is that, in Phase I, this technology appears well developed rather than at an incipient stage.

A total of 58 Levallois cores were studied in layers 2 to 5 (Extended Data Figs 7c, 8a-d). Like all the Palaeolithic artefacts at ATM and the wider region, they are made from quartzite (see above), either using cobbles that were intrinsic to layer 5, or cobble manuports in other layers (24.1%) as well as on flakes (20.7%). Blank types are less clear for the remainder of the sample owing to extensive core reduction (55.2%). The cortex percentage is predominantly < 25% and retained on the lower preparatory surface (striking platform surface). The Levallois strategy comprised both preferential and recurrent Levallois cores. In the preferential Levallois strategy (n = 25, 43.1%), one preferential flake was detached along the prepared debitage surface, from predominantly faceted striking platforms. The mean dimensions of the last visible preferential flake scar were 38.68 mm x 42.21 mm. The striking platform edge angle along the core was, on average, 69.84°. The recurrent Levallois core strategies refer to specific core preparation techniques that were intended to enable the removal of a series of intended flakes. These include recurrent centripetal (n = 15, 25.9%), recurrent unidirectional (n = 11, 19.0%) and recurrent bidirectional (n = 2, 3.4%) cores. The sample studied also displayed specimens representing manufacturing stages expected from a Levallois reduction sequence, with some examples of unstruck cores (n = 4, 6.9%) suggestive of a complex sequence of reduction strategies employed at the site. The same strategies continued within a narrow band of variability through the sequence.

The Levallois has deep roots in the bifacial knapping strategies, as noted elsewhere in the world including India[17,58]. We see this in the small sample at ATM as well (Extended Data Fig. 3i).

Conclusion

We suggest that the characterisation of an assemblage as either Late Acheulian or early MP should not be solely based on the use of 'index fossils' (e.g. presence/absence of bifaces, or Levallois concept) because this is likely to be a inappropriate dichotomy given that these are time-transgressive. Much is gained from adopting a more holistic view of the entire gamut of core reduction sequences observed in an assemblage. We argue that a gradual or rapid discontinuance of typical Acheulian large flake technologies in favour of small flake production, including recurrent Levallois, signals major cognitive and behavioural changes, as also reported elsewhere[8,10,11,59]. The duality of these two repertoires, i.e. sporadic bifaces and Levallois, is thus precisely what typifies the early Indian MP. In this respect the sequence described at ATM, differs significantly from the Terminal/Late Acheulian site of Bhimbetka[58]. The process of transition from the Acheulian is poorly known[8]: it was possibly a gradual and regionally diverse process, with contemporaneity and overlaps in the occurrence of Late Acheulian and MP industries across South Asia[19].

Overall, the structure of the MP assemblage at ATM reflects a shift towards greater geographic mobility, hominins no longer being tied to the raw-material sources containing the large cobble to boulder-sized cores that the Acheulian populations in this region depended upon[24,26,38]. The adoption of reduction sequences predominantly aimed at small flake production, including the Levallois repertoire, also marked a change in hunting strategies — a process that has been widely recognized worldwide[10,11,16,59,60].

Ascribing the technological changes recorded at ATM to a particular hominin species is currently beyond resolution. Middle Pleistocene hominin fossils uncovered in India comprise little more than a partial cranium at Hathnora in the Narmada Valley, around 1100 km from ATM. Unfortunately, the context, chronology, and species identification for this skull are debatable because the fossil has been variously tied to *H. erectus*, to an “archaic” grade of *H. sapiens*, or advocated as a possible specimen of *Homo heidelbergensis*[61-64]. It was retrieved from fluvial gravels on the banks of the river Narmada, in association with reworked fossils and tools of different ages. Its age could lie anywhere between ~48 ka and > 236 ka, with a strong possibility of transport and redeposition[65]. In the absence of conclusively dated hominin fossil remains from India, links at ATM between the excavated tools and the taxonomic identity of their makers thus remain speculative. It is also essential to allow for complications arising from the dispersal times and potential interactions between a diversity of hominin species during the time period discussed in this paper, be they modern humans or other archaic species[60,66-69].

Additional information concerning bifaces in Indian Palaeolithic cultures

Debates on the relationship between the Late or Terminal Acheulian and the origins of the MP/ MSA are central to the practice of classifying sites into cultural phases, to understanding transitions between those phases, and to addressing questions relating to the dispersals of modern humans. They are also influenced by regionally ingrained historical conventions[2-8,10,11,13,15,19]. The presence/absence of specific tool types such as bifaces or points, or the Levallois concept are often used as an index for determining cultural boundaries[10]. This approach, however, is ambiguous given the time-transgressive nature of cultural change, functional needs, and the incidence of regional variations in artefact ratios and abundances. These difficulties are particularly acute in India owing to the paucity of dated or excavated MP sites[8], and they apply equally to the Indian Acheulian[60,70]. As a result, producing robust constraints on the origins of the MP culture in South Asia has so far been an exceedingly difficult task.

In India, the classification of industries into either Late or Terminal Acheulian, early MP, or transitional has been approached from two major conceptual perspectives. One widely held view is that bifaces in India are an integral component of early MP assemblages, albeit sporadic and often smaller than those noted in the Acheulian. Assemblages also contain Levallois and blade components, small tools, and occasional LCTs. Together, these characteristics signify continuity with the preceding Acheulian phases, within which the Indian MP is therefore believed to be directly rooted[8,18,71-86]. The second, alternative view is that bifaces are the cultural markers of a distinct Acheulian presence, irrespective of other assemblage components[19,87]. This view has led to the reclassification of MP sites as being Late Acheulian[79]. Taking into consideration bifaces and key features of the Indian Late Acheulian and Indian MP we emphasize the following.

Late Acheulian bifaces. The Indian Acheulian can be classified as a Large Flake Acheulian, where the principal reduction strategy was the flaking of giant and large cores using a variety of techniques (Kombewa, Levallois, bifacial flaking, slicing, Chirki cleaver technique, etc.) in order to detach large flakes (> 10 cm)[9,24,88,89]. Bifaces and other LCTs, e.g. large scrapers, knives, etc. were fashioned primarily on these large flakes. Despite conceptual differences in classifying the Late Acheulian in India[73,90,91] it is generally agreed that this phase was marked (i) by more refined, thinner, smaller, and more intensively flaked and symmetrical bifaces than in the Early Acheulian; and (ii) by the presence of Levallois and other prepared core and blade technologies[60,72,91-93]. Of course, widely-held beliefs about the decline in biface size during the Late Acheulian are debatable when data reported from outside South Asia, such as very large bifaces at Isimila (Tanzania) and very small ones at Tabun Cave (Israel)[9], are considered. Despite regional variability in biface quantities and morphologies, most Late Acheulian sites nonetheless display distinct evidence of large/giant core reduction strategies. Few sites, however, have been dated[70], and the youngest have been estimated to be as young as 140–120 ka[19], or as young as 100 ka[58,94]. Ambiguities, however, have been noted at some sites in the middle Son Valley, where early MP horizons[79] were later thought to be Late Acheulian largely on the basis of biface presence[19,87].

Early MP bifaces. Continuance of bifaces from the Acheulian into the early MP is a feature at many sites. The principal features that distinguish such sites from the preceding Acheulian include the gradual/abrupt discontinuance of LCTs, a drastic reduction in biface frequency, a preference for smaller bifaces, and a coexistence of bifaces with Levallois reduction strategies aiming for small flake production. A distinction has been made between MP sites with high and with low biface frequencies, and also on the basis of the proportion of Levallois artefacts[72].

Bifaces occur at sites in the Kaladgi Basin (northern Karnataka), a landscape rich in quartzite outcrops[83]. At the MP site of Lakhampur East, bifaces are present, including a large cleaver measuring 15 x 11 x 4 cm in addition to smaller ones[82]. Handaxes at this site ranged from 8 to 13 cm in length (mean: 10 cm) and were ~7 cm in width[82]. Continuity with the preceding Late Acheulian was advocated based on this kind of evidence, with indications of gradual technological transitions from an evolved biface industry to one where prepared cores were well established and with continuing use of quartzite as raw material[82].

Assemblages spanning the transition to the MP were identified in the Hunsgi–Baichbal Basin, Karnataka. Some sites displayed bifaces, often on limestone varieties preferred by Acheulian hominins. These continued into the MP. Other Late Acheulian sites displayed a use of chert, which was preferred by MP populations[81]. Similar patterns are also noted at Renigunta (Andhra Pradesh), with MP sites displaying handaxes and cleavers[86]; and at other MP sites in SE, S and E India[8,18, 84,95].

At the rock shelter site of Bhimbetka, in central India, bifaces continue into the MP horizon overlying the Late Acheulian horizons[96]. There is a significant drop in biface counts in the MP (handaxes: n = 8), along with a decrease in tool size ranges, a decrease in core and flake dimensions[92,96], and an increase in Levallois components. The excavators argued in favour of continuity of Acheulian elements into the MP[92].

At Patpara, in the middle Son Valley, North India, some ambiguity prevails. One study[79] classified the assemblages as MP on the basis of various assemblage characteristics including low biface counts (~10% of the assemblage, whether > 10 cm or not). Another group interpreted it as Late Acheulian or transitional because of the presence of bifaces[19,87]. Cleavers occur at MP sites in the Belan Valley (Uttar Pradesh)[80].

In western and NW India, small bifaces, including cleavers, occur with MP artefacts in the Luni basin[74], with the unique mention of bifaces in 'Middle'[60] or 'Upper Palaeolithic'[97] horizons in the 16R dune section at Didwana. At the MP site of Katoati, in the Thar Desert[98], 7 large bifaces, including a single ovate biface, were ascribed an age of ~95 ka. In the Orsang valley, Gujarat, 'transitional/early' MP assemblages[75] are marked by decreasing handaxe sizes, diminutive handaxes, few cleavers, and prepared core flakes. In the Sukhi Valley (Gujarat), diminutive handaxes and cleavers are present[76].

In conclusion, bifaces are an intrinsic component of MP sites in India and may occur along with Levallois and blade elements. Despite some disagreement, most authors suggest that, in the Indian context, there is a continuation of Acheulian technological strategies.

Beyond India: bifaces and Levallois during the early MP/MSA

In Africa, processes of transition to the MP/MSA are complex and variable both geographically and through time[2-4,10,11,99], and sites have been often variously classified as Terminal Acheulian or early MSA or transitional[100]. For example, assemblages of the Middle Awash (Ethiopia), Upper Herto Member (~160–154 ka), report 28 bifaces (< 5% of the total assemblage), are throught to be indicators of transitional phases from the Acheulian to the MSA. These include ovates, elongate ovates, triangulars, cleavers, a pick, a biface scraper, and a biface nucleus in association with *H. sapiens* fossils[14].

Biface continuity was noted in the MSA at Garba III, Melka Kunture (Ethiopia)[100], where 10 bifaces were found (average length: 70.6 mm; mean width: 55.3 mm, mean thickness: 29.4 mm). These co-existed with evidence of Levallois technology, but with low densities of points and blades. In the Omo–Kibish valley[101], rare bifaces likewise occurred in MSA contexts in association with Levallois components.

At older sites, such as in the Kapthurin Formation (Kenya), complex and often overlapping sequences of Late Acheulian, transitional, and MSA assemblages have been reported[3,4,10,11]. Here, distinct differences are observed in the Late Acheulian Levallois compared to the MSA Levallois[16], with the latter exhibiting a diversification of Levallois technology, a range of preferential and recurrent methods, with some reduction in flake size and the use of different raw materials[16]. The overall transition from the Acheulian to the MSA is attributed to the discontinuation of Acheulian LCTs and a shift to small flake tools, all related to behavioural changes[16].

In the Arabian Peninsula, small bifaces are reported from Jebel Faya[12] (Assemblage C; ~127 ka), and coexist with blade and Levallois strategies. Broken handaxes were found at the MP site of Jebel Barakah[102]. In Europe, the presence of MP handaxes is well documented that co-occurs with Levallois components, and with complex links with Acheulian evolutionary trajectories[7,15,103-107]. Cleavers in Europe were still in use during the MP[105].

This summary clearly indicates that bifaces of varying morphologies did continue into the processes leading to and during the MP/MSA, with distinct regional, spatial and temporal variability regarding their presence and disappearance.

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