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Two Acheuleans, two humankinds: From 1.5 to 0.85 Ma at Melka Kunture (Upper Awash, Ethiopian highlands)

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Summary - *The Acheulean is the longest-lasting human cultural record, spanning approximately 1.5 Ma and three continents. The most comprehensive sequences are found in East Africa, where, in large-scale syntheses, the Lower Pleistocene Acheulean (LPA) has often been considered a uniform cultural entity. Furthermore, the emergence and development of Acheulean technology are seen as linked to the emergence and evolution of* Homo ergaster/erectus. *The criterion for grouping together different lithic assemblages scattered over space and time is the presence of large cutting tools (LCTs), more than of any other component. Their degree of refinement has been used, in turn, as a parameter for evaluating Acheulean development and variability. But was the East African LPA really uniform as regards all components involved in lithic productions? The aim of this paper is to evaluate the techno-economic similarities and differences among LPA productions in a specific micro-regional and environmental context, i.e. at Melka Kunture, in the Ethiopian highlands, and in a specific period of time: between ~1.5 Ma, when some of the earliest Acheulean complexes appeared, and 1.0-0.85 Ma, when LCTs productions became intensive and widespread. Our detailed comparative analyses investigate all aspects and phases of the* chaînes opératoires. *Since hominin fossil remains were discovered at some of the analyzed sites, we also discuss differences among lithic productions in relation to the changing paleoanthropological record. Our studies show that at Melka Kunture the LPA techno-complexes cannot be grouped into a single uniform entity. The assembled evidence points instead to "two Acheuleans" well-defined by a strong discontinuity in various aspects of techno-economic behaviors. This discontinuity is related to a major step in human evolution: the transition from* Homo ergaster/erectus *to* Homo heidelbergensis.

Keywords - *Ethiopia, Melka Kunture, Lower Pleistocene, Acheulean, Lithic techno-economy, Lower Pleistocene hominins.*

Introduction

The longest Acheulean Industrial Complex sequences are found in East Africa, where it emerged between 1.76 and ~1.50 Ma. It is known from a number of well-dated sites. The oldest ones are Kokiselei 4, in West Turkana (1.76 Ma; Lepre *et al.*, 2011); KGA6-A1(1.75 Ma), and KGA4-A2 (1.6 Ma) in Konso (Beyene *et al.*, 2013); FLK West (~1.7 Ma) at Olduvai (Diez-Martín *et al.*, 2015); and BSN-12 and OGS-12 at Gona (1.6 Ma; Quade *et al.*, 2004).

Around 1.5 Ma, the number of Acheulean sites increases, notably including Olduvai, Peninj, Nyabusosi, Melka Kunture and Gadeb (Texier, 1995, 2005; de la Torre *et al.*, 2003, 2008; de la

Torre & Mora, 2005; de la Torre, 2011; Gallotti, 2013; Diez-Martín *et al.*, 2014a,b). While not all the data from the earliest Acheulean sites (~1.7-1.6 Ma) have been published, all the lithic collections from the ~1.5 Ma Acheulan sites have been investigated in systematic technological studies.

Even if multiple hominin genera and species co-existed at the time, there is a general understanding that the new techno-complex's only knapper was *Homo erectus/ergaster*, who is documented by a rich fossil record (e.g. Antón, 2003; Lepre *et al.*, 2011; Wood & Baker, 2011; Beyene *et al.*, 2013; de la Torre & Mora, 2014; Lepre, 2014; Diez-Martín *et al.*, 2015; Lepre & Kent, 2015).

Conversely, the development of the Acheulean after 1.4 Ma is still poorly understood. From then onwards and up to 0.7 Ma, the long stratigraphic sequences in East Africa are from a limited number of sites, and several are of uncertain age (e.g. Leakey, 1971; Hay, 1976; Clark & Kurashina, 1979; Isaac & Isaac, 1997; Roche *et al.,* 2003; Schick & Clark, 2003; Quade *et al.*, 2008; de la Torre, 2011; Beyene *et al.*, 2013; Pante, 2013; McHenry *et al.*, 2016). Descriptions of the corresponding late Lower Pleistocene lithic series are generally limited to the LCTs and their morphological or aesthetic patterns (e.g. Leakey, 1971; Leakey & Roe, 1994; McBrearty, 2001; Schick & Clark, 2003; Beyene *et al.*, 2013). Accordingly, no direct comparison can be made with the record of the earlier Acheulean, 1.76-1.5 Ma.

There are very few human fossils dated between 1.0 and 0.6 Ma (e.g. Manzi, 2011, 2012; Antón, 2013; Antón *et al.*, 2014; Baab, 2014; Ghinassi *et al.*, 2015; Profico *et al.*, 2016), and their association with lithic artifacts and faunal remains has usually been taken for granted, not proved.

This fragmented evidence found in the East African LPA record has frequently been underestimated in large-scale syntheses involving Acheulean technical behaviors. It is often taken for granted that the LPA is a uniform cultural entity closely related to the evolutionary history of *Homo erectus* (e.g. Leakey, 1975; Isaac, 1976; Sharon, 2007; Beyene *et al.*, 2013). The Acheulean industries are often described as "remarkably static and lacking innovation over thousands of years and across a number of varied environmental settings" (Nowell & White, 2009, p. 76).

This idea is bolstered by analyses focusing on LCTs more than on other components (e.g. Leakey, 1975; Isaac, 1977; Gowlett, 1993; Gowlett & Crompton, 1994; Sharon, 2007; Beyene *et al.*, 2013). In many cases results obtained with different methodological approaches have been simply superimposed without discussion. This rather limited level of analysis, frequently concentrating on the typological features of LCTs and their degree of refinement, made it possible to group lithic assemblages that were actually positioned apart in space and time, and use them to chart the supposed evolution of Acheulean technology. But although the outcomes of technical processes might be typologically similar, there are many ways to combine raw material selection and acquisition patterns, percussion motions and technical sequences.

Accordingly, was the LPA really uniform as regards all the components involved in lithic productions?

To answer this question and to gain a better understanding of the nature of changes in a diachronic perspective, our study made a comparative investigation of all the aspects and phases of the LPA *chaînes opératoires* between ~1.5-0.85 Ma in one micro-regional context, i.e. Melka Kunture, in the Ethiopian highlands. This site preserves one of the longest and most complete sequences that document the Acheulean Industrial Complex in East Africa, from its emergence to its transition into the Middle Stone Age (Chavaillon *et al.*, 1979; Chavaillon & Piperno, 2004). Hominin fossils have been discovered in well-dated archeological levels. The aims of this paper can be summarized as three main questions: 1) Is there any diachronic variation in raw material management and procurement, and if so what is its nature? 2) Are there any identifiable diachronic variations in the technological processes? 3) If there are, do they provide information on the behaviors of hominins associated with those processes?

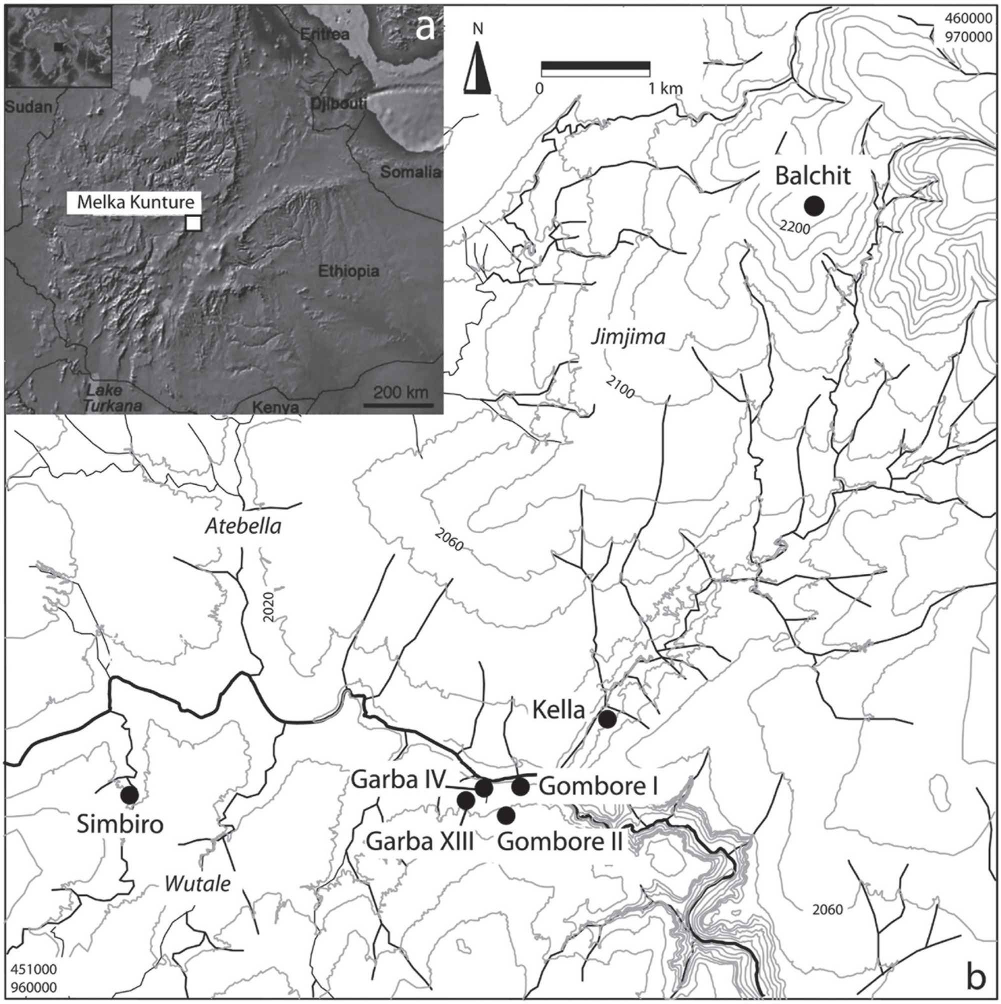

Fig. 1 - (a) Location of Melka Kunture on the shoulder of the Main Ethiopian Rift; (b) Map of the Melka Kunture area showing the location of archeological sites, of old alluvial deposits, and of raw material primary sources (vector restitution of the 1:50,000 topographic map). The primary sources of aphyric lavas and microdoleritic basalts are outside the area: aphyric lavas are among the pre-rift lava flows of Addis Ababa and Guraghe-Anchar basalts, respectively 26 km N-E and 45 km S-W of Melka Kunture (Abebe* et al.*, 2005), whereas microdoleritic basalts outcrop closer, 15-20 km north and south of Melka Kunture.

Melka Kunture and its context

The geographic, geological and archeological setting

Melka Kunture (8°42'N; 38°35'E), 50 km south of Addis Ababa, is located on the western edge of the Main Ethiopian Rift, in a half graben depression of the Ethiopian Plateau, between 2000 and 2200 m asl (Fig. 1a). The basin is drained by the Upper Awash River and its tributaries, and is delimited by Pliocene volcanoes: the Wachacha and Furi to the north, the Boti and Agoiabi to the south (Mohr, 1999). The Pleistocene reactivation of border faults led to several episodes of subsidence in the half graben.

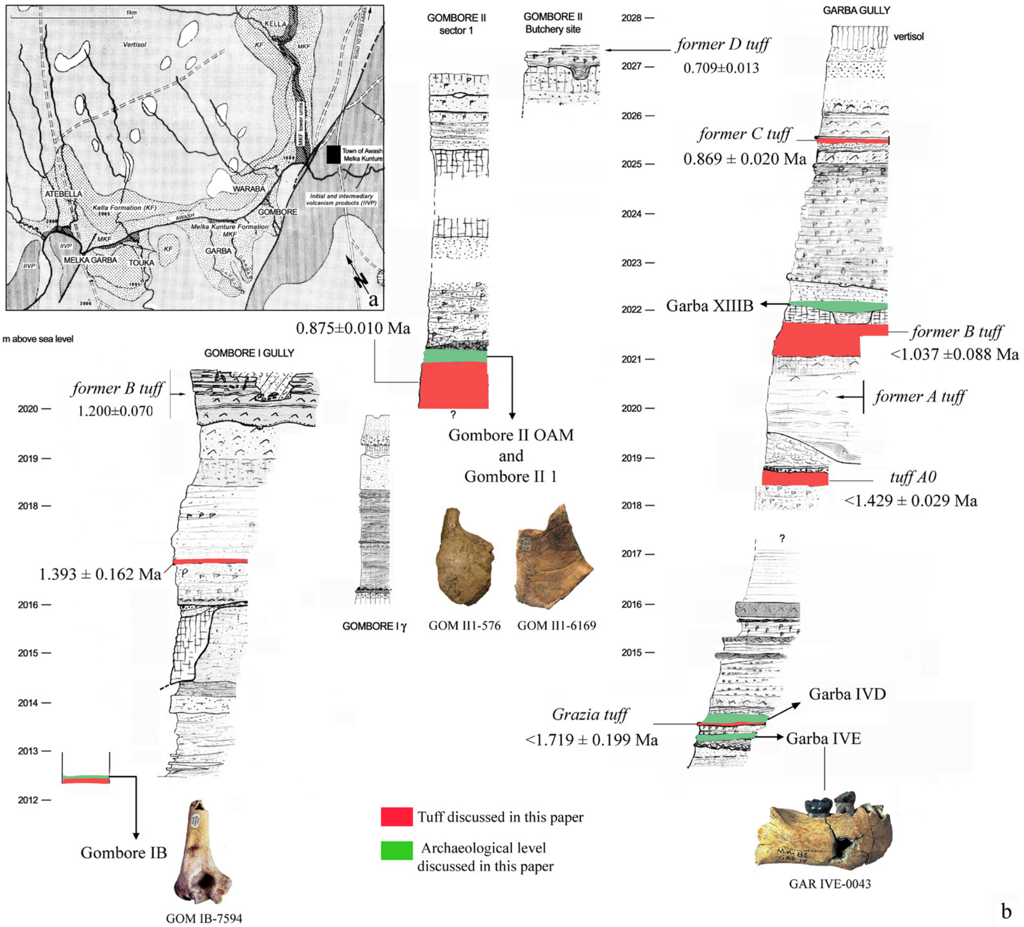

Fig. 2 - (a) Geological sketch map of the Melka Kunture area (after Taieb, 1974, revised); (b) the Melka Kunture Formation, showing the location of the archeological levels and human fossils discussed in this paper (after Raynal* et al.*, 2004, revised; radiometric dates after Morgan* et al.*, 2012). The colour version of this figure is available at the JASs website.

This in turn increased the sedimentation rate, while during eruptions pyroclastic material was added to the load transported by the river system (Bardin *et al.*, 2004; Kieffer *et al.*, 2002, 2004; Raynal & Kieffer, 2004).

Volcanism was characterized here by multiple and often violent eruptions related to the Late Cenozoic evolution of the Ethiopian Rift. The major volcanic events started 5 to 4 Ma ago, but later eruptions further modified the environment when hominin groups were already present. The Awash was able to re-establish its course after each volcanic episode. The water flow in the main river and its tributaries reworked and transported loads of sediments, including volcanic material that buried and preserved archeological sites.

The accumulations of alluviums, volcano-derived sediments and direct tephric inputs built up the Melka Kunture Formation (Figs. 2a,b; Raynal *et al.*, 2004). Recent dating documents repeated human occupation of this part of the Upper Awash Valley from the top of the Olduvai

Polarity Subzone to after the Brunhes Matuyama Reversal (Schmitt *et al.*, 1977; Cressier, 1980; Morgan *et al.*, 2012; Tamrat *et al.*, 2014).

Most of the archeological sites were discovered in the core part of the graben (Fig. 1b), clustered over some 100 km². In the last 50 years, around 20 km² were intensely researched and excavated. They are located along gullies and valleys which eroded alluvial sediments from the Lower and Middle Pleistocene. Upper Pleistocene deposits are less extensively preserved. To date, around 30 of the over 70 archeological layers located on both banks of the river have been tested or extensively excavated (Chavaillon & Piperno, 2004). Each one is named after the gully where they are located (Simbiro, Garba, Gombore, etc.), followed by a Roman numeral (e.g. Atebella II). If a site is multi-layered, a capital letter is added to each layer, referring to the archeological level (e.g. Garba IVE). The Stone Age sequence starts with the Oldowan at Karre I, Garba IVE-G, followed by the Developed Oldowan at Gombore Iγ; it continues with the early Acheulean at Garba IVD and Gombore IB; the middle Acheulean at Gombore II, Garba XII, Garba XIII, Atebella II, and Simbiro III; and the late Acheulean at Garba I, Garba IIIC and Gombore III. Garba IIIB is the most important Middle Stone Age site. The Late Stone Age is found eroding from surface deposits at Wofi II, Wofi III, Kella I (Chavaillon & Berthelet, 2004; Piperno *et al.*, 2009; Gallotti *et al.*, 2010, 2014; Gallotti, 2013; Mussi *et al.*, 2014, 2016; Gallotti & Mussi, 2015; Gallotti, unpublished data).

Human fossils were discovered in archeological contexts at Garba IVE, Gombore IB, Gombore II-1 and Garba III, i.e. with Oldowan, Acheulean and Middle Stone Age industries (Chavaillon *et al.*, 1974; Chavaillon *et al.*, 1977, 1987; Chavaillon & Coppens, 1986; Condemi, 2004; Zilberman *et al.*, 2004a,b; Mussi *et al.*, 2014; Di Vincenzo *et al.*, 2015; Profico *et al.*, 2016).

The Lower Pleistocene Acheulean sites

Garba IVD, Garba XIIIB and Gombore II OAM are dated to the Lower Pleistocene (Fig. 1b).

The Garba IV deposits belong to the lowest parts of the Melka Kunture Formation (hereinafter MKF) along the Garba gully (Fig. 2b; Raynal *et al.*, 2004). Five archeological horizons have been identified in a sedimentary fluvial series underlying tuff "A0", of reverse polarity (Cressier, 1980), which was recently dated to <1.429 ± 0.029 Ma (Morgan *et al.*, 2012). The main archeological horizon is level D, which lies on the Grazia tuff, dated to <1.719 ± 0.199 Ma. Below the Grazia tuff, levels E-F, included by Tamrat *et al.* (2014) in the normal polarity interval (N1) interpreted as the end of the Olduvai subchron, are attributed to the Oldowan (Piperno *et al.*, 2009; Gallotti & Mussi, 2015).

Garba IVD contains a high-density distribution of artifacts and faunal remains excavated over 100 m². 6986 lithic artifacts were recorded and analysed (Tab. 1), together with 2042 unworked items (Tab. 2). Lithic objects (knapped or unworked) display different levels of abrasion. Abraded areas and fresh surfaces and edges coexist on the same item (Gallotti, 2013). Raynal *et al.* (2004) suggest two alternative hypotheses for the deposition processes of this unit. According to the first hypothesis, there was no anthropic intervention and the layer was completely reworked when a flood transported both archeological and unworked materials simultaneously. The second hypothesis maintains that hominins did settle on the lag deposit, and used the raw material available on the spot to manufacture lithic tools. All the elements were partly reworked when the sands of the upper sub-unit (level C) were deposited. In level D, most lithic activities focused on producing small-to-medium flakes; only a small part aimed to manufacture LCTs. Prepared *débitage* methods together with LCT manufacturing document the emergence of the Acheulean technology not later than 1.5 Ma (Gallotti, 2013).

Garba XIII is likewise located along the Garba creek, at short distance from Garba IV and some meters higher up in the stratigraphic sequence (Fig. 1b). The main archeological feature is level B, of which ~15 m² have been excavated. This level lies stratigraphically below a tuff unit dated 0.869 ± 0.020 Ma (former C tuff) and immediately above a tuff unit dated to <1.037±0.088 Ma (former B

Tab. 1. Components of the artifact assemblages from Garba IVD, Garba XIIIB, and Gombore II OAM.

COMPONENTS		**GARBA IVD (Gallotti, 2013)**		**GARBA XIIIB (Gallotti *et al.*, 2014)**		**GOMBORE II OAM**			
		N	%	N	%	N (Gallotti *et al.* 2010)	N (this study)	N total	%
Cores		1816	26.0	32	18.2	0	35	35	14.5
Core fragments		107	1.5	0	0	0	0	0	0
Small flakes (<2 cm)		188	2.7	12	6.8	0	0	0	0
Broken flakes		874	12.5	0	0	0	0	0	0
Flakes		2508	35.9	79	44.9	0	109	109	45.0
Retouched flakes		193	2.8	1	0.6	0	5	5	2.1
Large flakes (>10 cm)		41	0.6	0	0	0	2	2	0.8
LCTs	Bifaces	0	0	18	10.2	18	40	58	24.0
	Cleavers	2	0.03	8	4.5	7	0	7	2.9
	Massive scrapers	21	0.27	0	0	0	0	0	0.0
Twisted bifaces		0	0	0	0	24	0	24	9.9
Indeterminable fragments		1151	16.5	26	14.8	0	0	0	0
Percussion elements		85	1.2	0	0	0	2	2	0.8
Total of the analyzed worked material		**6986**	**100**	**176**	**100**	**49**	**193**	**242**	**100**

tuff, Fig. 2b; Morgan *et al.*, 2012). The lithic assemblage (176 artifacts and 295 unworked objects) was analyzed in its entirety (Tabs. 1, 2). Technical activities produced bifaces and cleavers as well as small *débitage*. The artifacts are very fresh, whereas the unworked materials are highly abraded. The hominins evidently left artifacts on top of a lag deposit winnowed by fluvial processes (Gallotti *et al.*, 2014).

Gombore II OAM, in the Gombore gully, at a distance of 400 m from the sites mentioned above, is one of the excavation sectors in the lower archeo-stratigraphic unit at Gombore II (Fig. 1b). This unit lies above a tuff dated 0.875±0.010 Ma, and 4 m below another tuff unit dated 0.709±0.013 Ma (Fig. 2b; Raynal *et al.*, 2004; Morgan *et al.*, 2012). This sector was selected for a field exhibit in which 35 m² of the archeological surface were exposed, and the materials were left in situ for visitors to view (Chavaillon & Piperno, 2004; Gallotti *et al.*, 2010). The sandy-matrix deposit contains a high-density distribution of unworked and knapped lithic objects, plus faunal remains. It was strongly affected by post-depositional hydraulic processes. The assemblage, originally on a channel bank, was eventually partially displaced, concentrated and reoriented by a stream flow: the process probably occurred in multiple episodes. It can be described as an old alluvial deposit. The lithic assemblage is devoted mainly to LCT production, including the manufacture of twisted bifacial tools in obsidian. To date, 18 bifaces, 24 twisted bifaces, and seven cleavers from this collection have been studied in detail and published by Gallotti *et al.* (2010; Tab. 1).

Tab. 2. Components of the unworked assemblages from Garba IVD, Gombore IB, Garba XIIIB, and Gombore II OAM, as well as from old alluvial deposits at Kella, and Simbiro.

COMPONENTS	GARBA IVD		GOMBORE IB		KELLA		GARBA XIIIB		GOMBORE II OAM		SIMBIRO	
	N	%	N	%	N	%	N	%	N	%	N	%
Small elements	289	14.2	344	19.0	10	6.8	86	29.1	36	24.0	13	8.7
Angular elements	400	19.6	176	9.8	12	8.0	94	31.9	17	11.3	16	10.7
Small blocks	58	2.8	4	0.2	17	11.3	11	3.7	1	0.7	42	28.0
Blocks	10	0.5	8	0.4	8	5.3	0	0.0	2	1.3	7	4.7
Pebbles	82	4.0	603	33.2	24	16.0	28	9.5	24	16.0	11	7.3
Cobbles	1150	56.3	662	36.5	77	51.3	74	25.1	67	44.7	59	39.3
Large cobbles	53	2.6	17	0.9	2	1.3	2	0.7	3	2.0	2	1.3
Total of the analyzed unworked material	**2042**	**100**	**1814**	**100**	**150**	**100**	**295**	**100**	**150**	**100**	**150**	**100**

Lithic resources

Early analyses of the Melka Kunture lithic assemblages, made in the 1970s and '80s, used a straightforward classification. Raw materials were sorted into seven broad groups: basalt, trachybasalt, trachyte, rhyolite, tuff, obsidian, and "others" (Chavaillon & Chavaillon, 1973; Chavaillon, 1979, 2004; Berthelet & Chavaillon, 2004; Chavaillon N., 2004; Chavaillon *et al.*, 2004; Piperno *et al.*, 2004a,b,c,d). Raw material sources were not identified in any detail.

Geological studies undertaken during the first years of the Italian Archeological Mission at Melka Kunture, established in 1999, provided a better understanding of the volcanic events which modified the regional environment of the last few million years (Kieffer *et al.*, 2002, 2004; Bardin *et al.*, 2004; Poupeau *et al.*, 2004; Raynal & Kieffer, 2004; Raynal *et al.*, 2004). This, in turn, led to a re-appraisal of the nature and abundance of the lavas and obsidians found in the alluvial deposits of the Awash River and its tributaries. Several alluvial units and some archeological layers were sampled and petrographic counts were performed, based on macroscopic determination through a magnifying glass (x20), with some complementary microscopic determination of thin sections under the microscope. Various aphyric, porphyritic and microdoleritic rocks were identified together with Melka Fault lava, different kinds of welded and non-welded ignimbrites, and obsidian (Kieffer *et al.*, 2002, 2004).

The known primary sources for aphyric basalt are to be found among the numerous pre-rift (mainly Miocene in age) lava flows of Addis Ababa and Guraghe-Anchar basalts on the Upper Plateau, respectively 26 km N-E and 45 km S-W of Melka Kunture (Abebe *et al.*, 2005). No primary sources have been discovered closer to the sites.

The source of porphyritic rock has not yet been located. Nevertheless, in the Wutale area, some 2.5 km south-west of the Garba gully (Fig. 1b), porphyritic and vesicular lavas with large plagioclase crystals have been observed in primary position (Raynal & Kieffer, 2004). Porphyritic lava also outcrops in the Boti and Guraghe volcanic areas west and south of Melka Kunture.

Microdoleritic basalts outcrop around Melka Kunture. The flows are easy to recognize because erosion fragmented them into very large blocks, for instance 15-20 km north and south from Melka Kunture.

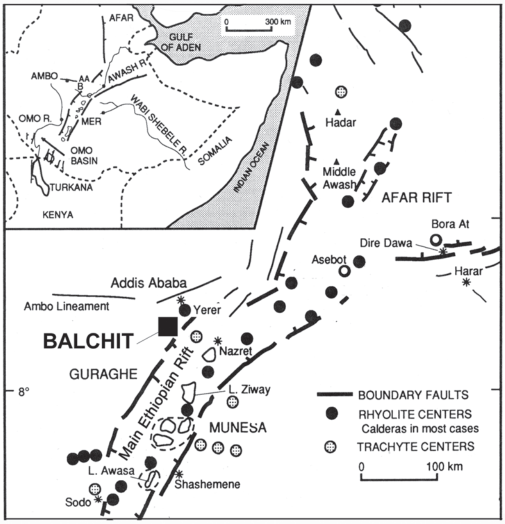

Fig. 3. Map showing the location of the Balchit and other obsidian outcrops (after WoldeGabriel* et al.*, 1992, revised).

Welded ignimbrite, which was produced during a major eruption and probably originally extended over hundreds of km^2, is easily recognizable, for it is the most notable formation of this type in the area (Kieffer *et al.*, 2002, 2004).

Melka Fault lava is related to the limit-fault (South/South East) of the Melka Kunture basin. A so-called "lava lake" structure outcrops 500 m upstream of the Atebella and Balchit creeks' confluences into the Awash (Fig. 1b). Accordingly, this lava was abundant in the paleolandscape, mainly in a vesciculated facies, less frequently in a compact facies (Kieffer *et al.*, 2002, 2004).

The nearest known primary obsidian source is named Balchit and is located 7 km north of the Awash (Fig. 1b). This outcrop belongs to the group of Pliocene Rift margin silicic centers of the Wachacha Formation, on the western border of the Main Ethiopian Rift, in the Addis Ababa Rift Embayment (Fig. 3; Poupeau *et al.*, 2004). Balchit is a flat obsidian dome flow, aged 4.37±0.07 Ma (Chernet *et al.*, 1998); it outcrops over an area of about 4 km² (Salvi *et al.*, 2011). It can be seen in situ on the Jimjima plateau and close to the nearby village, likewise named Balchit (Fig. 1b). Amygdales up to 1 m long of pure and massive obsidian are preserved among the weathered rock (Fig. 4a-c). The obsidian is mainly black. It breaks easily with a conchoidal fracture, yielding more or less translucent flakes with excellent cutting edges. The same elemental composition was recorded in the analysis of 12 obsidian samples from Balchit and two from alluvial deposits (Poupeau *et al.*, 2004; Le Bourdonnec, 2007), and in ten obsidian artifacts from Gombore I, Gombore II and Garba IV (Negash *et al.*, 2006).

Obsidian debris was widely distributed across the paleolandscape as product of erosion and redeposition from the primary source (Fig. 4e). It formed secondary sources that were available to hominins as boulders, cobbles, pebbles and gravels in the alluviums deposited by the Awash and its tributaries (Fig. 4d; Piperno *et al.*, 2009; Salvi *et al.*, 2011).

These alluviums were likewise secondary sources for some of the volcanic rocks mentioned above.

Hominins

Three human fossils discovered at Melka Kunture date from the time-span discussed in this paper (~1.5-0.85 Ma).

Specimen Gombore IB-7594, a distal portion of a left humerus of *Homo* cf. *ergaster* (Chavaillon *et al.*, 1977; Coppens, 2004; Di Vincenzo *et al.*, 2015), was discovered at Gombore IB, 400 m west of Garba IV. The Gombore I sequence belongs to the lowest parts of the Melka Kunture Formation and is older than 1.393 ± 0.162 Ma (Fig. 2b; Morgan *et al.*, 2012). Di Vincenzo *et al.* (2015) suggest that Gombore IB may correspond to the Oldowan levels (E and F) at the nearby site of Garba IV. This correlation conflicts with Raynal & Kieffer's (2004) reconstruction. Notwithstanding lateral variations in tephra facies and geochemistry, the tuff below level B at Gombore I is very close in its granulometry, geochemistry and microfacies, and identical in its polarity, to the Grazia tuff identified at Garba IV below level D (Raynal & Kieffer, 2004; Raynal *et al.*, 2004). This means that Gombore IB is penecontemporaneous to Garba IVD, which contains early Acheulean lithic products.

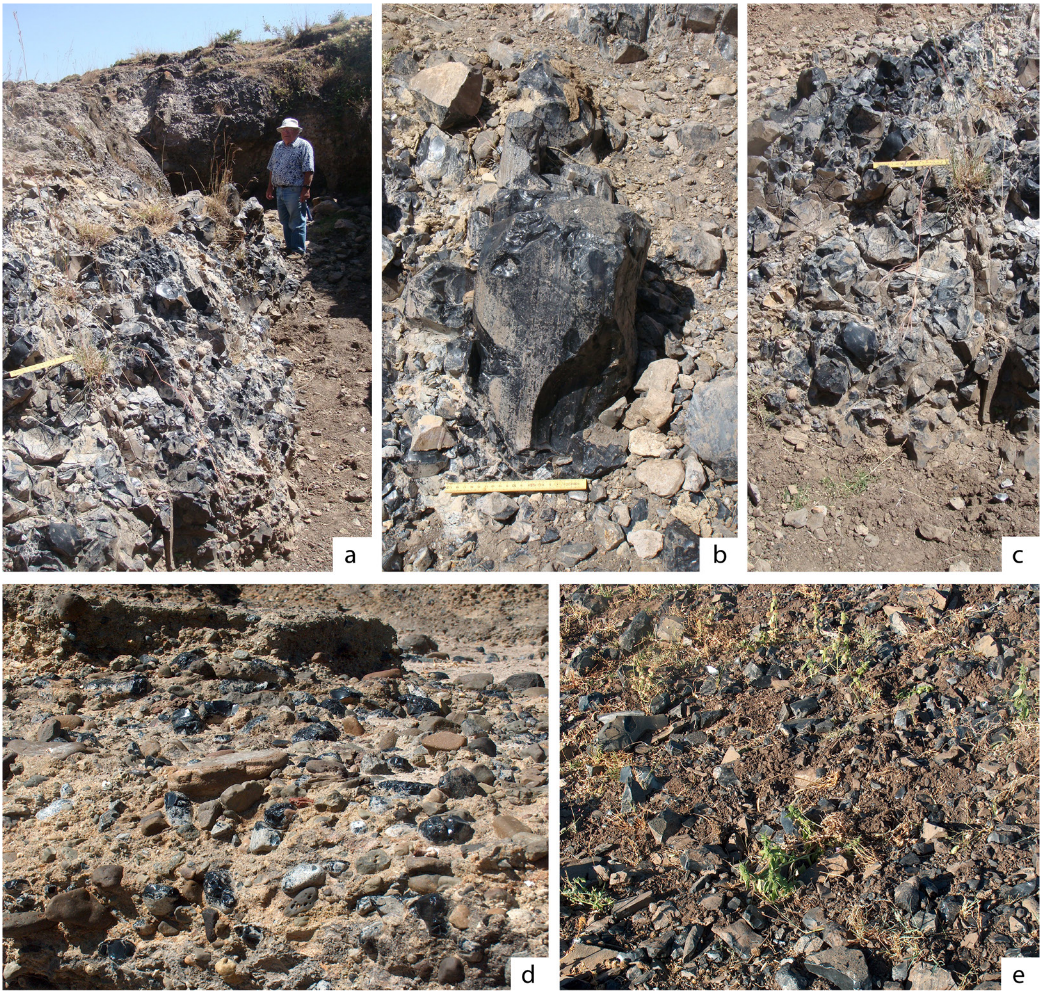

Fig. 4 - (a) Obsidian outcrop at Balchit; (b-c) obsidian blocks among weathered rocks; (d) obsidian cobbles and gravels in an ancient alluvium at Atebella; (e) obsidian angular elements on the ground at Balchit. The colour version of this figure is available at the JASs website.

The Gombore II1 exposure – which belongs to the same archeo-stratigraphic unit as Gombore II OAM (Fig. 2b; Gallotti *et al.*, 2010) – yielded two human fossils. A left parietal bone fragment (GOM II1-6169) was discovered in situ in 1973, and a frontal bone fragment (GOM II1-576) was recovered in 1975 from the section dug in a small stream that crosses the excavation area. These fossils were first attributed to *Homo erectus sensu lato* by Chavaillon & Coppens (1986). After a recent revision by Profico *et al.* (2016), these specimens are considered sound candidates for inclusion among the ancestors of *Homo heidelbergensis* in sub-Saharan Africa.

Materials and methods

Garba IVD, Garba XIIIB, and Gombore II OAM assemblages were studied with a techno-economic approach, and published in recent years (Gallotti *et al.*, 2010, 2014; Gallotti, 2013;

Fig. 5 - Sampled ancient alluvial deposits: (a) Kella; (b) detail of Kella; (c) Simbiro. The colour version of this figure is available at the JASs website.

Tab. 1). The published analysis of the Gombore II OAM assemblage focused on bifaces and cleavers (18 bifaces, 24 twisted bifaces, and 7 cleavers; Gallotti *et al.*, 2010). This paper presents new data from Gombore II OAM that are related to small *débitage* modalities and also further our understanding of the biface production (Tab. 1).

Results from previous analyses and from new data will be discussed in a comparative perspective that enables for the first time a comprehensive approach to the techno-economic changes between ~1.5 Ma and 0.85 Ma in this East African sequence.

The techno-economic analyses were performed consistently and made it possible to describe the raw-material procurement and exploitation patterns in these lithic productions (Gallotti *et al.*, 2010; Gallotti, 2013; Gallotti *et al.*, 2014). This approach, linked to the *chaîne opératoire* concept, aims to highlight the relationships between raw materials and tool production. Accordingly, lithic production is understood here as a sequence of varied technical actions and reductive phases that are comprised in a techno-economic process (Leroi-Gourhan, 1964, 1971; Pelegrin, 1985; Geneste, 1989, 1991; Perlès, 1991; Inizan *et al.*, 1999). We examine all the technical sequences, from procurement to discarding, as well as the technical skills employed in tool production.

Sampling of old alluvial deposits

The techno-economic analysis required further systematic sampling and mapping of old alluvial deposits in order to investigate the characteristics of raw materials available in the paleolandscape and appraise the extent of any geographic variation in the paleodrainage system, both synchronically and through time.

The analysis was performed in steps. First, as the most likely sources of knappable rocks were in the nearby paleochannels, we examined the unworked material (hereinafter UM; Tab. 2) recorded together with artifacts during excavations at Garba IVD (n=2042), Garba XIIIB (n=295), and Gombore II OAM (n=150). Given the spatial redistribution by hydraulic processes (Raynal *et al.*, 2004), UM actually corresponds to old alluvial deposits.

We also sampled Gombore IB (Fig. 1b), which corresponds stratigraphically to level D at Garba IV, as explained above (Fig. 2b; Raynal *et al.*, 2004; Morgan *et al.*, 2012). After a typometric and typological analysis, Jean and Nicole Chavaillon defined the lithic industry as a classic Oldowan one (Chavaillon & Chavaillon, 1969, 1976a,b; Chavaillon, 1976; Chavaillon J., 2004; Chavaillon N., 2004). Based on a recent technological review, this assemblage can be classified as early Acheulean (Gallotti, unpublished data). As was the case at Garba IVD, both worked and unworked items were affected by post-depositional disturbances. Unworked items were recorded during fieldwork and drawn on published two-dimensional maps. However, they were neither catalogued nor stored, hence they are no longer available for re-analysis. Instead, we used the results of our review of 1858 specimens (Tab. 2) originally classified by Chavaillon as battered material (Chavaillon, 1979; Chavaillon J., 2004). We found that as many as 1814 of them were actually unworked items with irregular surfaces: a suitable sample for comparative purposes.

A random sample of 150 elements was collected and analyzed (Tab. 2) from each of two spots (alluvial deposits at Kella and Simbiro) along the Awash tributaries during a systematic survey conducted in 2009.

The Kella deposit does not contain any archeological material. It is located on the right bank of a tributary of the Awash River (Fig. 1b), beneath a non-welded ignimbrite dated to 1.253 ±0.041 Ma (Fig. 5a; Morgan *et al.*, 2012). It is stratigraphically included between two tuffs, tentatively correlated to those at the base of the Kella hill (Bonnefille *et al.*, in press) and dated to 1.874±0.012 and 1.666±0.009 Ma (Morgan *et al.*, 2012). Accordingly, the age of this alluvial deposit, which is exposed over approximately 8 m² (Fig. 5b), is close to and probably earlier than Garba IVD and Gombore IB.

The other alluvial deposit was sampled at Simbiro, at the base of an exposed stratigraphic section along the gully (Fig. 1b), where the archeological levels (Oussedik, 1976; Chavaillon & Berthelet, 2004) are capped by a tuff dated to 0.878±0.014 Ma (Morgan *et al.*, 2012). About 6 m² of this old alluvial deposit are exposed. It is actually an Acheulean layer, much disrupted by water flow (Fig. 5c), and is approximately contemporaneous with Garba XIIIB and slightly older than Gombore II OAM. Only unworked specimens were recorded and analyzed for the purpose of the current study.

Raw material analysis and experimentation

Sampling of old alluviums was undertaken to refine lithological classifications and to characterize the size and geometry of cobbles, angular elements and blocks. The aims were 1) to assess the internal variability in terms of both lithology and natural shape and size; 2) to evaluate raw material availability in an environment that changed over time because of post-depositional processes and geological as well as geomorphological evolution; 3) to assess archeological site locations in relation to lithic resource locations.

We prepared a reference collection of rock samples which we characterized from thin sections viewed under a microscope. First, the rocks from the three archeological sites were observed and classified by naked eye and with a magnifying glass (x20). Then this preliminary sorting was checked against the reference collection. The knapping suitability of each rock was also determined and recorded (Appendix). The problems involved in measuring rock quality objectively have been addressed several times (e.g. Crabtree, 1967; Andrefsky, 2000; Brantingham, 2000; Goldman, 2004; Stout *et al.*, 2005; Braun *et al.*, 2009; Goldman-Neuman & Hovers, 2009, 2012). Many studies take into account the physical properties of rocks with reference to the goals of lithic production. We follow the approach adopted by Inizan *et al.* (1999). Accordingly, our evaluation does not take into account mineralogical or petrographic classifications. It is based on the knapping characteristics of different rock types, as assessed in experimental tests. Rocks are placed on a continuum, ranging from those with which "anything is possible to those from which flakes can only be removed with difficulty" (Inizan *et al.*, 1999, p. 21).

For each rock type a test was performed by an experienced knapper on about 20 elements of different shapes and dimensions. A maximum of ten flakes were detached from each specimen to test its knapping suitability to direct percussion by hard and soft hammers. We recognized five degrees of suitability:

1) Rocks that are very easy to knap;
2) Rocks that are quite easy to knap;
3) Rocks that are easy to knap;
4) Rocks that are difficult to knap;
5) Rocks that are unsuitable for knapping.

Tab.3 - Morpho-metrical types in the old alluvial deposits of the Melka Kunture region.

GROUP	CATEGORY		ROUNDNESS/ANGULARITY	LENGTH (CM)
Small-sized matrixes	Small elements		angular	≤ 6
	Pebbles		rounded	≤ 6
Medium-sized matrixes	Angular elements		angular	6.1 – 12
	Small blocks		angular	12.1 – 18
	Cobbles	spherical	rounded	6.1 – 18
		elongated	rounded	6.1 – 18
		flat	rounded	6.1 – 18
		angular	rounded/angular	6.1 – 18
Large-sized matrixes	Large cobbles		rounded	> 18 cm
	Blocks		angular	> 18 cm

This ranking corresponds to an average evaluation. For example, medium-sized obsidian cobbles are quite easy to knap by direct percussion with a hard hammer, but they can break. This is not the case with large obsidian blocks. Overall, to investigate all the criteria followed by knappers to guide their techno-economic activities, we must include 1) lithology, dimension, geometry, location, availability and frequency of the lithic resources; and 2) technical patterns and goals of the lithic production.

Therefore, we recorded the morphology, length, width and thickness of specimens > 6 cm. The technological analysis of lithic assemblages from Melka Kunture does suggest that natural matrices with a minimum length of approximately 6 cm were required for lithic exploitation. This value also differentiates cobbles from pebbles (Wentworth, 1922). Three metrical groups, including seven main morpho-metrical types, have been classified according to 1) the range of dimensions available in the alluvial deposits, and 2) the goals of the lithic productions (Tab. 3). 18 cm is the minimum length of a large cobble or block from which a large flake could be detached and turned into a LCT. Thus, we set a limit of 18 cm between mid-sized and large matrices. The maximum length of the large cobbles and blocks we collected is 24.5 cm.

The natural angles among surfaces facilitate the initial lithic production phases and play a role in the type of activity performed (Inizan *et al.*, 1999). Roundness/angularity was also recorded, because it may have been an important selection criterion.

Technological analysis

The technological analysis was made in order to reconstruct the *chaînes opératoires* involved in lithic productions.

Cores were classified according to 1) the number of flaking surfaces; 2) the direction of flaking; 3) the presence or absence of a distinct striking platform; 4) the features of the striking platform; 5) the angle between the striking platform and the flaking surface; and 6) the angle(s) among flaking surfaces. Considering these features, core analysis allows us to identify exploitation modalities and management of volumes, and to determine whether the surfaces are or are not hierarchically organized.

The flake analysis takes into account the type of butt, the number and direction of negative scars on the dorsal face, the item's shape and cross-section, the correspondence between morphological and *débitage* axis, the presence of overshot/hinged removals, the presence of retouch, the location and type of retouch, and possible correspondence among shapes, sizes and flaking methods.

Large flakes and LCTs have been defined as being longer or wider than 10 cm (e.g., Sharon, 2010; de la Torre, 2011; Beyene *et al.*, 2013). The analysis of LCTs considers the features of flake blanks, the presence, location and extent of shaping, the presence of patterns predetermined by flaking, the presence of planned bifacial and bilateral equilibrium, and the presence of standardized shapes and sizes.

The study of percussion features takes into account blank type and the aspect, position and extent of percussion marks.

Results: new data from raw material analysis and Gombore II OAM artifact study

Raw material composition in old alluvial deposits

Our analysis increases the number of lithotypes identified by Kieffer *et al.* (2002, 2004), providing more detailed information on the composition of alluvial deposits (Appendix).

We eventually omitted from our list amorphic silica and syenitic inclusions (Appendix) because they occur with negligible frequency in alluvial deposits and in Oldowan and Acheulean assemblages. We distinguished a new lithotype – obsidian lava – from Kieffer *et al.*'s (2002, 2004) welded ignimbrite no. 1, because obsidian lava formed within welded ignimbrite in only a few spots in the paleolandscape. To date no artifacts made of welded ignimbrite no. 1, or of other types of welded ignimbrite or ignimbritic tuff, have been discovered at Melka Kunture. After conducting our knapping tests (Appendix), we assume that this is because those rocks are unsuitable for knapping. The LCTs that Gallotti *et al.* (2010) described as being made of welded ignimbrite no. 1 are actually made of obsidian lava.

Welded ignimbrites and ignimbritic tuff were included in our general analysis of alluvial deposits for comparison with UM lithological composition, but omitted from the morphometric analysis. Melka Fault lava, which had a primary source at Atebella (Fig. 1b), was notably abundant in the paleolandscape. However, only the compact facies is suitable for knapping (Appendix), and was taken into account in the morphometric analysis of matrices.

<u>~ 1.5 Ma old alluvial deposits (OA1s): Garba IVD-UM, Gombore IB-UM, and Kella.</u> All three OA1 samples are quite similar to each other in their lithology and morphometrics.

1) Lithological composition. Aphyric rocks are common, mostly as aphyric basalt and Melka Fault lava. The vesiculated facies is frequent in Melka Fault lava, but examples of compact facies are also present. Welded ignimbrite no. 1 is likewise very common. Other rocks are less frequent, while trachyandesite and obsidian lava are truly unusual or altogether absent (Fig. 6).
2) Morphometric composition. Medium-sized matrices are the most common found in our lithotypes and in all three samples. However, small-sized matrices occur more often in the Gombore IB-UM sample than elsewhere, while in the Kella sample small obsidian elements and pebbles are much more frequent than cobbles. Among medium-sized matrices, cobbles – mainly angular, elongated or spherical – are far more numerous that angular elements. Small blocks are rather rare, except at Kella, where they occur mostly as Melka Fault lava or porphyritic basalt. Generally speaking, large forms are uncommon and consist mainly of Melka Fault lava or porphyritic rocks. Large specimens of aphyric basalt (Garba IVD-UM and Kella) or trachybasalt (Garba IVD-UM) also occur occasionally. The very few obsidian blocks observed were only at Gombore IB-UM. In the case of porphyritic basalt, the large matrices are large cobbles (Fig. 7).

<u>~ 1.0-0.85 Ma old alluvial deposits (OA2s): Garba XIIIB-UM, Gombore II OAM-UM and Simbiro</u>

1) Lithological composition. The OA2s are quite similar to OA1s in their lithology (Fig. 8). Aphyric rocks always are the best represented lithotypes. Melka Fault lava is less frequent in Gombore II OAM-UM than elsewhere. Overall, the compact facies is more common here than in OA1s. Welded

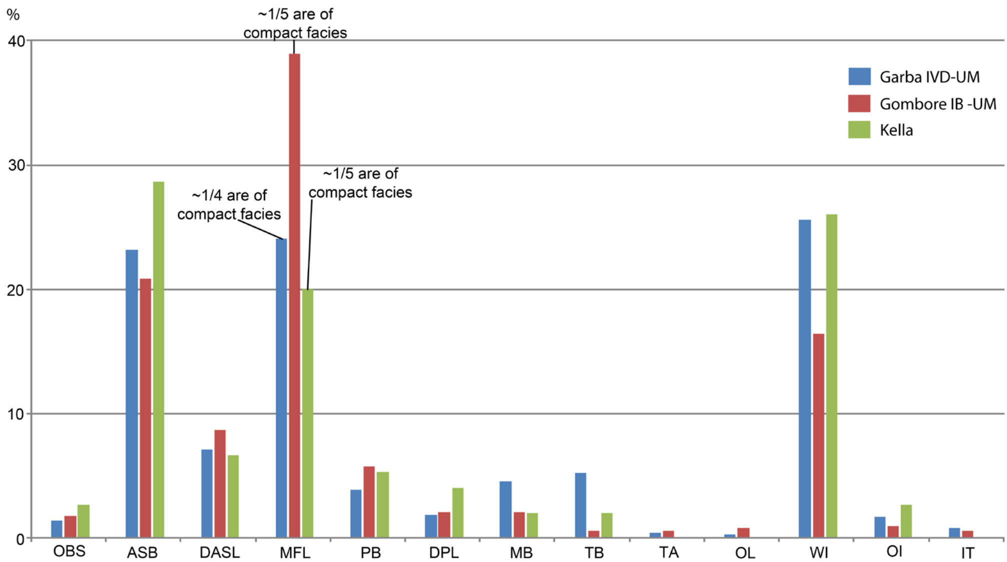

Fig. 6 - Lithological composition of the ancient alluvial deposits approximately dated to 1.5 Ma. ASB: aphyric to subaphyric basalt; DASL: differentiated aphyric to subaphyric lavas; DPL: differentiated porphyritic lavas; IT: ignimbritic tuff; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OI: other types of welded ignimbrite; OL: obsidian lava; PB: porphyritic basalt; TA: trachyandesite; TB: trachybasalt; WI: welded ignimbrite no. 1. The colour version of this figure is available at the JASs website.

ignimbrite no. 1 is less common in OA2s, while porphyritic rocks and obsidian are rather rare, especially in level Garba XIIIB. Other rocks are rare, whereas microdoleritic basalt, trachybasalt and trachyandesite are totally absent. Obsidian lava, quite rare in OA2s just as it was in OA1s, is perhaps slightly more frequent at Simbiro.

2) Morphometric composition. There are more medium-sized matrices in levels Gombore II OAM and Simbiro than in Garba XIIIB, where small-sized components are well represented. Of the medium-sized matrices, cobbles – mainly angular, elongated or spherical – are usually more frequent than angular elements and small blocks. At Simbiro, however, there are many small blocks of obsidian, Melka Fault lava and porphyritic basalt. As in OA1s, large elements are mostly of Melka Fault lava and porphyrithic basalt. Several blocks of obsidian lava also have been found at Simbiro and Gombore II OAM-UM, and a few obsidian blocks at Simbiro. Large angular forms (blocks) consist solely of Melka Fault lava, obsidian and obsidian lava. Conversely, large cobbles consist solely of porphiritic basalt (Fig. 9).

Techno-economic patterns in the Gombore II OAM lithic assemblage

Forty bifaces, 2 large flakes, 35 cores, 109 flakes, 5 retouched flakes, and 2 hammerstones were removed from the surface exposed for the field exhibition, and are analyzed in this work (Tabs. 1, 2). In this assemblage, *chaînes opératoires* devoted to biface and to small-medium flake production coexist. Large flakes and bifaces on the one hand, and small-medium flakes and flake tools on the other, correspond to two size groups in the assemblage (Fig. 10).

<u>Bifaces.</u> Biface manufacture was performed on Kombewa flakes (n=25) or on skewed flakes (n=13). In only two cases, the blank cannot be recognized because shaping removals involved all

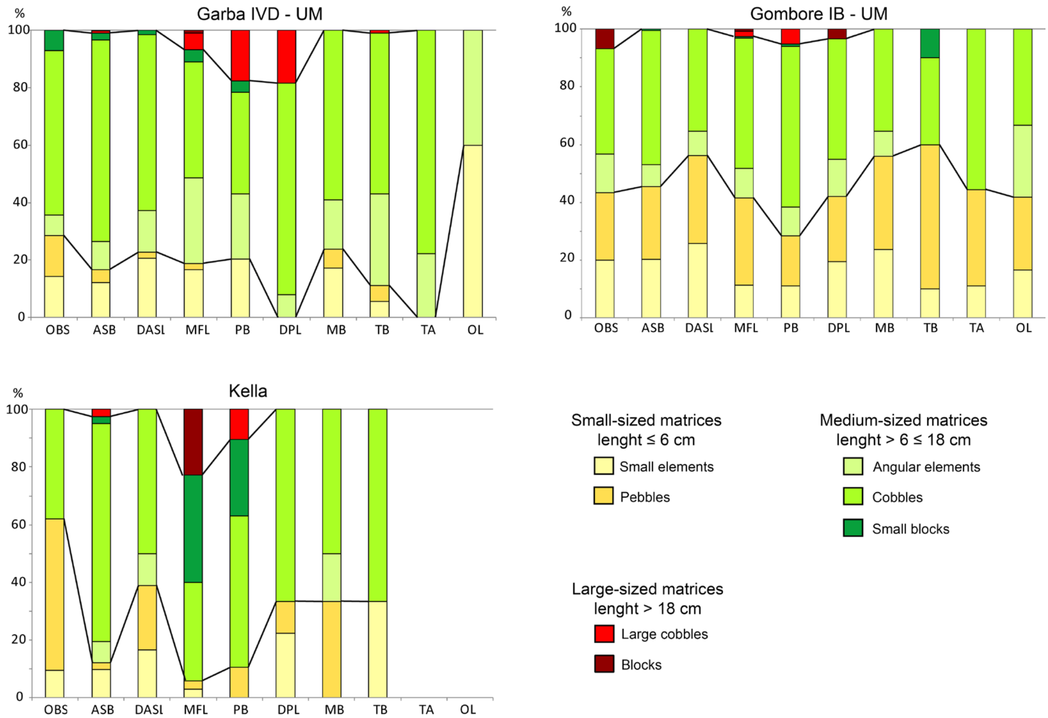

Fig. 7 - Frequencies of morphometric types in alluvial deposits approximately dated to 1.5 Ma. Welded ignimbrite no. 1, other types of welded ignimbrite and ignimbritic tuff are not shown because they were never used for knapping. ASB: aphyric to subaphyric basalt; DASL: differentiated aphyric to subaphyric lavas; DPL: differentiated porphyritic lavas; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OL: obsidian lava; PB: porphyritic basalt; TA: trachyandesite; TB: trachybasalt. The colour version of this figure is available at the JASs website.

the surfaces. Given the lack of any large cores, the skewed flakes cannot be attributed to any specific *débitage* method.

Adoption of the Kombewa method for producing biface blanks is strictly linked to the exploitation of microdoleritic basalt (n=14) and obsidian (n=9). The use of porphyritic basalt is documented in two cases. The extensive use of microdoleritic basalt for Kombewa *débitage* is confirmed by the two large unmodified Kombewa flakes found in the assemblage (Tab. 4).

The predetermination of the bifacial equilibrium which characterizes the use of a Kombewa flake blank requires limited shaping procedures. Shaping is generally performed with one or two series of invasive removals that produce the biconvex section, followed by marginal retouch that delineates portions of the edges which are rather rectilinear (Fig. 11: 2-4). The shapes produced are similar, pointed, and standardized in size, regardless of the raw material employed (Tab. 4).

The shaping of the skewed flake blanks is intense on both faces, producing ovate, more or less pointed or *limande* bifaces characterized by bifacial asymmetry and poorly delineated edges. It consists of two or three series of alternate invasive removals involving all or nearly all of both faces, and also thinning the bulb, sometimes removing the butt and determining biconvex or flat/convex sections. The finishing phase consists of removing

Tab. 4 - Gombore II OAM. Size (mm) of the bifaces analysed in this work, grouped by blank type and raw material. ASB: aphyric to subaphyric basalts; MB: microdoleritic basalts; OBS: obsidian; OL: obsidian lava; PB: porphyritic basalts.

		KOMBEWA FLAKE BLANK (N=25)			SKEWED FLAKE BLANK (N=12)					UNDETERMINED FLAKE BLANK		
		MB (N=14)	PB (N=2)	OBS (N=9)	ASB (N=1)	MB (N=6)	PB (N=3)	OL (N=1)	OBS (N=1)	ASB (N=1)	PB (N=1)	OBS (N=1)
Length	Min.	129	130	136	-	110	132	-	-	-	-	-
	Max.	155	137	161	-	210	142	-	-	-	-	-
	Mean	142.3	-	145.9	133	171.6	135.3	178	108	135	160	162
	St. dev.	7.9	-	8.1	-	75.7	5.8	-	-	-	-	-
Width	Min.	76	71	85	-	75	80	-	-	-	-	-
	Max.	110	82	100	-	150	85	-	-	-	-	-
	Mean	90.3	-	91.5	78	95.7	82.3	60	70	77	100	103
	St. dev.	8.8	-	5.1	-	36.7	2.5	-	-	-	-	-
Thickness	Min.	28	27	28	-	31	42	-	-	-	-	-
	Max.	55	28	43	-	60	59	-	-	-	-	-
	Mean	35.6	-	35.5	39	39.3	52.3	31	26	36	40	75
	St. dev.	7.4	-	4.8	-	10.7	9.1	-	-	-	-	-

a series of short unifacial, seldom bifacial retouch flakes. This limited finish, together with the alternating directions of the removals in the roughing-out process, creates a denticulate cutting edge (Fig. 11: 5). The raw-material composition of these bifaces is less homogeneous and the dimensions are not standardized as they are in the bifaces made on Kombewa flakes (Tab. 4).

Small *débitage*. Small *débitage* is represented by 35 cores, 109 flakes, and 5 retouched flakes. The number of flakes is very small compared with the number of negative scars recorded during core analysis. The core/flake ratio is 3.5, which does not match the average number of negative scars observed on the cores. Moreover, most cores have been intensively exploited, and most flakes exhibit a large number of negative scars on their dorsal face. This suggests that the count of detached pieces does not exactly reflect the number of flakes that were originally obtained from the cores. Nonetheless, the flakes represent all the flaking stages and methods identified in the core analysis. Accordingly, this large number of missing flakes can be interpreted as the result of winnowing by natural agents rather than of spatial and temporal fragmentation of the *chaînes opératoires* (Raynal *et al.*, 2004).

Discoid technology is the dominant *débitage* concept here (21 cores and 57 flakes). Multifacial multidirectional exploitation is also present (14 cores and 32 flakes). Aphiric lavas are the most exploited raw materials (57.7%), followed by obsidian (38.8%) and porphiritic basalt (3.5%).

Discoid exploitation is systematically bifacial: two fairly similar symmetrical surfaces created by removals were used as striking platforms and flaking surfaces, simultaneously or with alternate series of removals (Fig. 12: 2-3; Boëda, 1993; Jaubert & Mourre, 1996; Mourre, 2003; Terradas, 2003). The natural surfaces of the original matrix, when preserved, show that the knappers used spherical or angular cobbles and angular elements as blanks, adapting or modifying the original geometry to meet the method's requirements. Flakes also were used as core blanks (n=6), taking advantage of significant convexities for the series of removals (Defleur & Crégut-Bonnoure,1995; Moncel, 1998; Pasty, 2000; Terradas, 2003). These discoid cores display an average removal count of 22 flakes per core. This was possible

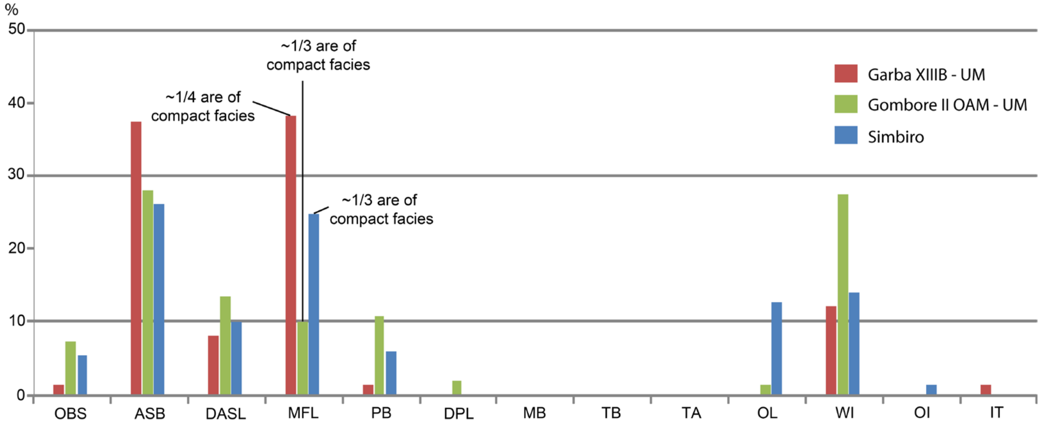

Fig. 8 - Lithological composition of ancient alluvial deposits approximately dated to 1.0-0.85 Ma. ASB: aphyric to subaphyric basalt; DASL: differentiated aphyric to subaphyric lavas; DPL: differentiated porphyritic lavas; IT: ignimbritic tuff; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OI: other types of welded ignimbrite; OL: obsidian lava; PB: porphyritic basalt; TA: trachyandesite; TB: trachybasalt; WI: welded ignimbrite no. 1. The colour version of this figure is available at the JASs website.

thanks to control in peripheral convexity maintenance. In fact, despite overexploited appearance of the cores, negative removal scars do not overshoot the prominent point of the central part of the flaking surface, which remains convex until its final state. Convexity maintenance is also validated by the presence of many flakes (n=35) that have a tangential flaking direction on the dorsal face and opposition between the cutting edge and the back. These flakes usually display deviation of the flaking axis from the morphological axis (Fig. 12: 6-9). The other flakes were usually obtained by centripetal flaking, and the morphological and flaking axes coincide (Fig. 12: 5).

Multifacial multidirectional cores were flaked through removals in multiple directions, with no clear organization of the reduction process (Fig. 12: 1). There was no platform preparation, and each negative was used as a striking platform for the next removal on a secant face. When recognizable, the blanks are mainly angular cobbles or angular elements with flat surfaces. The angles between surfaces were respected during flaking. Continuous rotation of the cores produced many edge-core flakes (Fig. 12: 4) which reflect a search for new angles rather than a rejuvenation attempt to rearrange the flaking and striking surfaces. Such flakes have various shapes and are frequently short, with a thick, asymmetrical cross-section. A large number of negative scars that varies from five to ten is visible on the flake dorsal faces (Fig. 12: 7). The high productivity of this flaking method is confirmed by the average of 39 negative scars on the cores.

Retouched flakes are very few. There are some denticulates (n=3) and notches (n=2). The retouch did not modify the shape of the blank, only the edges.

Percussion elements. Two artifacts show clear evidence of percussion. These artifacts are elongated rounded cobbles of aphyric basalt with bi-convex cross-sections. Areas with highly concentrated pitting are located in the proximal and distal protruding part of the cobble. One cobble also shows percussion marks in the central part of one face.

Discussion

Our study, based on techno-economic analyses of the lithic artifacts, on their raw material sourcing and characterization, and on experimental

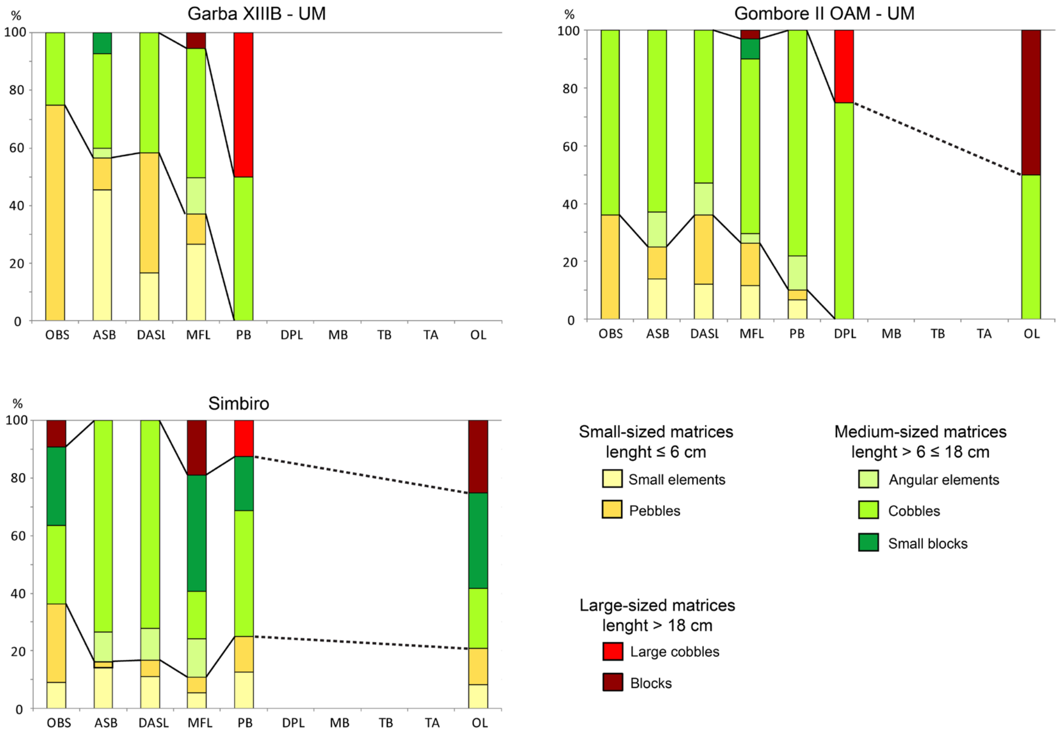

Fig. 9 - Frequencies of morphometric types in alluvial deposits approximately dated to 1.0-0.85 Ma. Welded ignimbrite no. 1, other types of welded ignimbrite and ignimbritic tuff are not shown because they were never used for knapping. ASB: aphyric to subaphyric basalt; DASL: differentiated aphyric to subaphyric lavas; DPL: differentiated porphyritic lavas; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OL: obsidian lava; PB: porphyritic basalt; TA: trachyandesite; TB: trachybasalt. The colour version of this figure is available at the JASs website.

activities, makes it possible to follow the diachronic variations in procurement and selection systems as well as in technical strategies at three LPA sites at Melka Kunture, dated between ~1.5 and 0.85 Ma. In this section, the new data introduced in this paper and the published data from Garba IVD, Garba XIIIB and Gombore II OAM (Gallotti *et al.*, 2010, 2014; Gallotti, 2013) are merged into a comprehensive comparative techno-economic analysis. The results of similar studies of other East African assemblages are also taken into account.

Raw material availability

Raw material procurement strategies are indicators of minimum ranging distances of hominin groups and of technological behaviors, hence it is relevant to assess variations at the archeological assemblage level (Jones, 1979; Merrick *et al.,* 1984, 1994; Bamforth, 1986; Potts, 1988; Roebroeks *et al.*, 1988; Dibble, 1991; Geneste, 1991; Perlès, 1991; Stiles, 1991, 1998; Morala & Turq, 1992; Wengler, 1992; Féblot-Augustins, 1993, 1997; Minichillo, 2006; Harmand, 2007, 2009a,b; Braun *et al.*, 2009; Goldman-Neuman & Hovers, 2009, 2012; Proffitt & de la Torre, 2014).

In the case of the Acheulean, much research has been done on the impact that raw-material properties, availability and procurement have on large blank production and on LCT size and morphology (e.g. Hay, 1976; Petraglia *et*

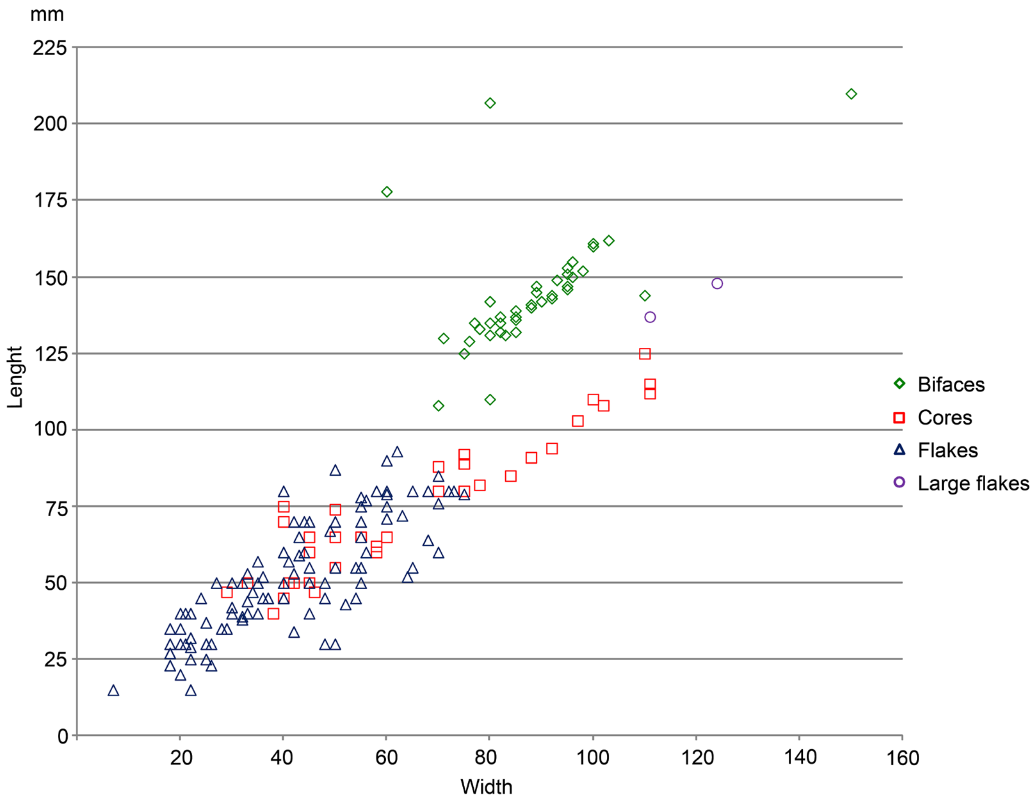

Fig. 10 - Gombore II OAM. Size distribution (mm) of the artifacts analyzed in this paper. The colour version of this figure is available at the JASs website.

al., 1999, 2005; Barkai *et al.*, 2006; Sampson, 2006; Stiles, 1991, 1998; Sharon, 2008). Only recently, however, has archeological research on the Early Stone Age in East Africa focused systematically on raw-material procurement strategies. This approach has mostly centered on lithic sourcing and on the characterization of Oldowan lithic assemblages, and has found that ever since the beginning of lithic production resource management was much more complex than expected (Harmand, 2005, 2007, 2009a,b; Stout *et al.*, 2005; Negash & Shackley, 2006; Negash *et al.*, 2006; Braun *et al.*, 2008a,b, 2009; Goldman-Neuman & Hovers, 2009, 2012). Conversely, reports on Acheulean sites in East Africa do not usually detail raw material availability and source distances, while systematic lithological identification is often omitted. Consequently, our analysis is the first systematic account of lithic resource availability, procurement and selection identified at Acheulean sites.

The analyzed lithic assemblages comprise artifacts and unworked objects, often affected by hydraulic processes altering their physical state and original spatial distribution. All the alluvial deposits of the MKF except the one at Kella contain archeological items. Matrix frequencies are very similar to each other when we compare the lithological and morphometric composition of unworked specimens from the ~1.5 Ma archeological sites to those of Kella (Fig. 6). Accordingly, unworked assemblages reflect the same original composition of alluvial deposits of the time, before any human intervention.

The lithotype compositions of OA1s and OA2s are very similar to each other, as already

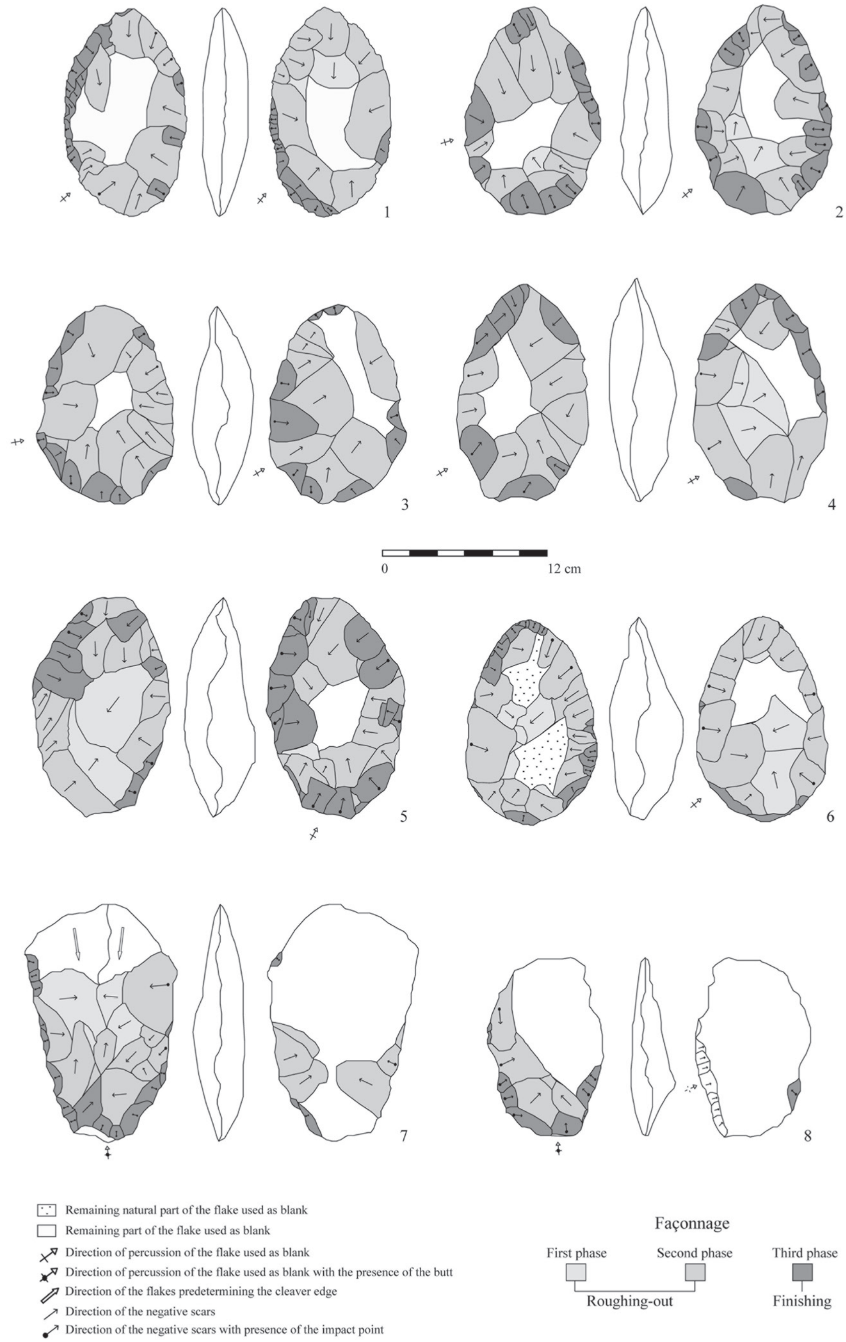

Fig. 11 - Gombore II OAM. Bifaces and cleavers. 1-4: bifaces on Kombewa flakes. 5, 6: bifaces on skewed flakes; 7: cleaver on flake with bidirectional removals; 8: cleaver on Kombewa flake. 1, 2, 4, 5, 8: microdoleritic basalt; 3: obsidian; 6: aphyric basalt; 7: obsidian lava. 1, 6-8 after Gallotti* et al.*, 2010.

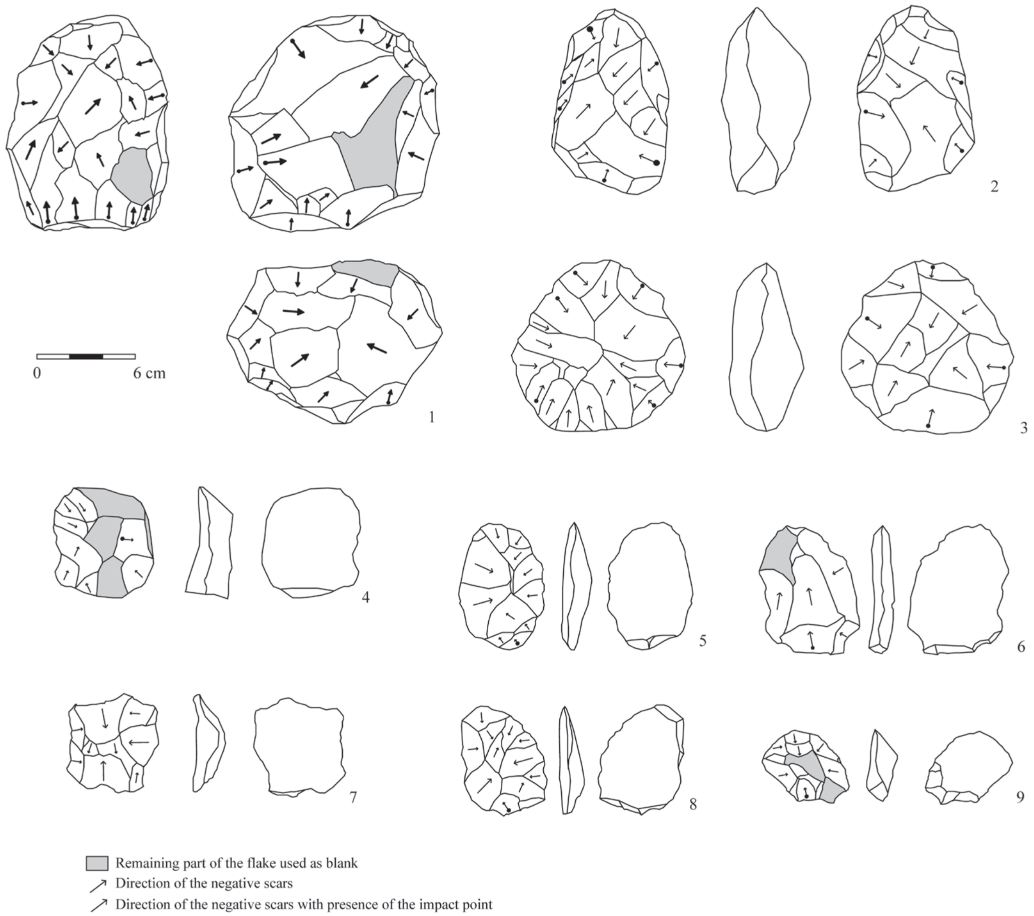

Fig. 12 - Gombore II OAM. Cores and flakes from small* débitage*. 1: multifacial multidirectional core; 2, 3: bifacial discoid cores; 4, 7: flakes from multifacial exploitation; 5, 6, 8, 9: flakes from discoid exploitation. 1, 3-6: aphyric basalt; 2, 7-9: obsidian.

noted (Figs. 6, 8). As a rule, large cobbles and blocks, which could be turned into ideal cores for large flake production, are scarce. Besides, they consist almost exclusively of porphyritic rocks or Melka Fault lava. Large blocks of obsidian lava occur only in OA2s, that is, in the later alluvial deposits, which are dated to around 1.0-0.85 Ma. Obsidian blocks are very rare in both OA1s and OA2s (Figs. 7, 9). However, whenever large sizes were required for LCT production, they were available at outcrops of suitable lava and obsidian only 2 to 7 km away.

Diachronic variation in LCT techno-economies

The emergence of LCT *chaînes opératoires* is dated to ~1.5 Ma at Garba IVD, where they were just a minor aspect of lithic production (Gallotti, 2013). The most frequently exploited raw materials were Melka Fault lava of compact facies, porphyritic rocks and obsidian. Three segments of the *chaînes opératoires* are documented for all three raw materials: large cores, large flakes and LCTs (Fig. 13). Large core blanks were extracted from large sub-spherical cobbles of porphyritic basalt and from blocks of Melka Fault lava and

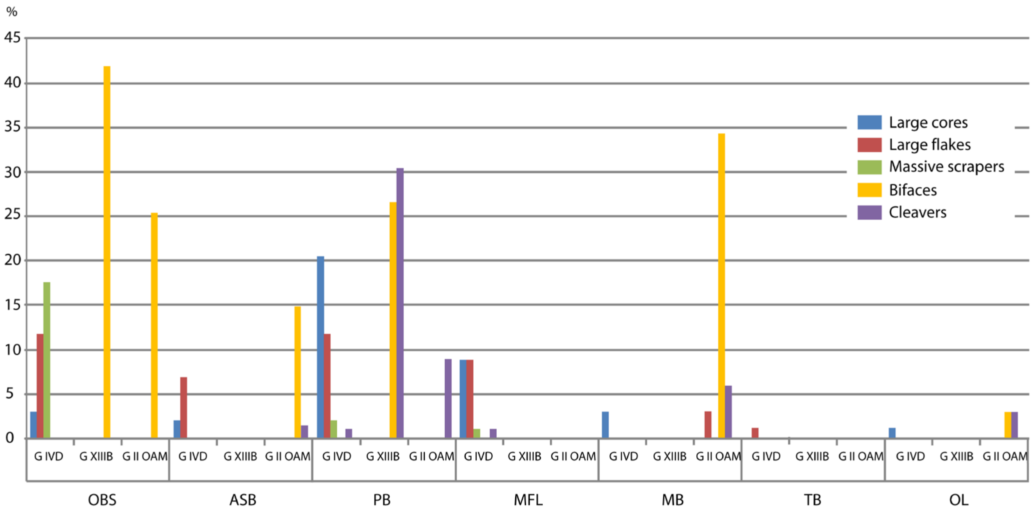

Fig. 13 - Lithological composition and technological components of the LCT productions at Garba IVD (G IVD), Garba XIIIB (G XIIIB) and Gombore II OAM (G II OAM). ASB: aphyric to subaphyric basalt; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OL: obsidian lava; PB: porphyritic basalt; TB: trachybasalt. Twisted bifaces are not included because they constitute unique discovery not only at Melka Kunture, but also in East Africa. The colour version of this figure is available at the JASs website.

obsidian. This was done by two methods: discoid for obsidian, and prepared unifacial centripetal for the other two lithotypes (Fig. 14: 1-2).

Garba IVD also offers a rare opportunity to analyze large cores used for large flake production, which are absent from other Acheulean sites of similar age (Texier & Roche, 1995; Potts *et al.*, 1999; de la Torre & Mora, 2005; de la Torre *et al.*, 2008; de la Torre, 2011; Chevrier, 2012; Beyene *et al.*, 2013). This led some scholars to infer temporal and spatial fragmentation of the LCT operational sequence, considered to be typical of the Acheulean (de la Torre and Mora, 2005; Goren-Inbar and Sharon, 2006; de la Torre *et al.*, 2008; de la Torre, 2011). In the case of Garba IVD, the scenario is different: the natural occurrence of a few large matrices in the alluvial deposits allowed the knappers to produce in situ limited quantities of large flakes to be turned into LCTs (Gallotti, 2013). The key factor for selection was the occurrence of properly sized rocks, rather than specific physical properties and better knapping suitability. Only flake blanks suitable for cleaver production possibly document *chaîne opératoire* fragmentation, but as their quantity is negligible, firm conclusions cannot be drawn (Gallotti, 2013). The absence of fragmentation of the LCT *chaînes opératoires* is also documented at FLK West in Olduvai, where LCTs have been found together with large flakes and large cores (Diez-Martín *et al.*, 2015).

The procurement of raw materials at secondary sources for LCT production is documented at several early Acheulean sites in East Africa, and coexists with procurement at primary sources. At the oldest Acheulean site, Kokiselei 4, in West Turkana, LCTs were knapped from large cobbles or tabular clasts of aphyric phonolite obtained directly at primary sources, as proven by the fact that rocks of these types and sizes are rarely found in nearby conglomerates (Harmand, 2009a; Lepre *et al.*, 2011). Conversely, in KGA6-A1 Locus C, at Konso, LCTs were made of locally available basalt (Beyene *et al.*, 2013). At the RHS-Mugulud and MHS-Bayasi sites in Peninj, LCT blanks were obtained from basalt boulders,

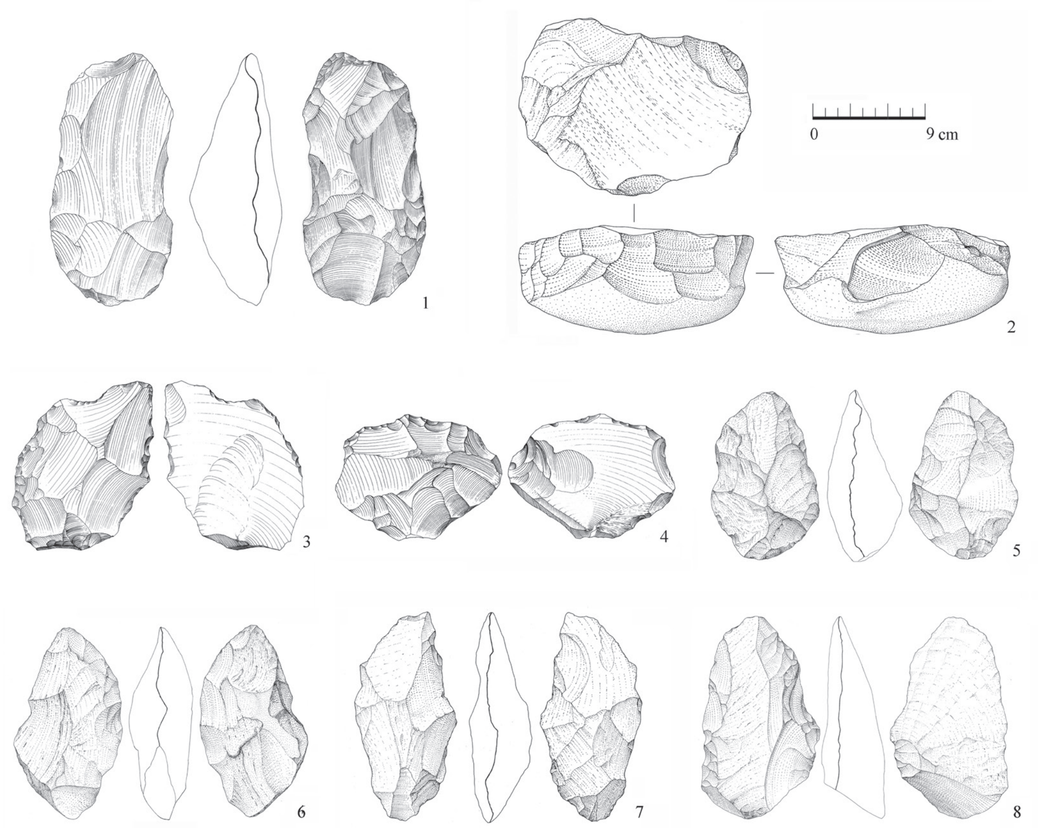

Fig. 14 - LCT production at Garba IVD. 1: discoid core; 2: unifacial centripetal prepared core; 3-6: massive scrapers; 7-8: cleavers. 1, 3, 4: obsidian; 2, 7: Melka Fault lava; 5, 6, 8: porphyritic basalt. Drawings by M. Pennacchioni; after Gallotti, 2013.

abundantly distributed in the nearby Sambu volcano piedmont, where very large and thick flakes were detached and transported to the site, fully or partially shaped (de la Torre *et al.*, 2008; Diez-Martín *et al.*, 2014a,b). At EF-HR, in Olduvai, quartz and lavas used for manufacturing LCTs came from a local stream. Conversely, at FC West Occupation Floor and at TK, tabular slabs must have been transported from the outcrops (de la Torre & Mora, 2005). At Gadeb 2E, several handaxes were made of ignimbrite, which came from outcrops 6 km to the south and west of the site (de la Torre, 2011).

At Garba IVD, LCTs were all made on large flakes (that is, flakes that were wider than they were long). When retouch was applied to turn large flakes into LCTs, it was a scraper-like retouch. Only the edges were modified; the overall shape of the blanks did not change. When removals were not limited to the edges but penetrated into the blank volume, the aim was to thin the butt-bulb portion, not to alter the volume balance (Fig. 14: 3-6). Accordingly, the lack of any search for specific morphological traits prevents the identification of shaping in LCT production. At any rate, the term "shaping" is not warranted here in its original meaning, as this specific process is not a repetitive one performed on a number of specimens, all tending towards the same morphology: the knapper's objective was not "to manufacture one single object with a definite morphology" (Roche, 2005, p. 40), but

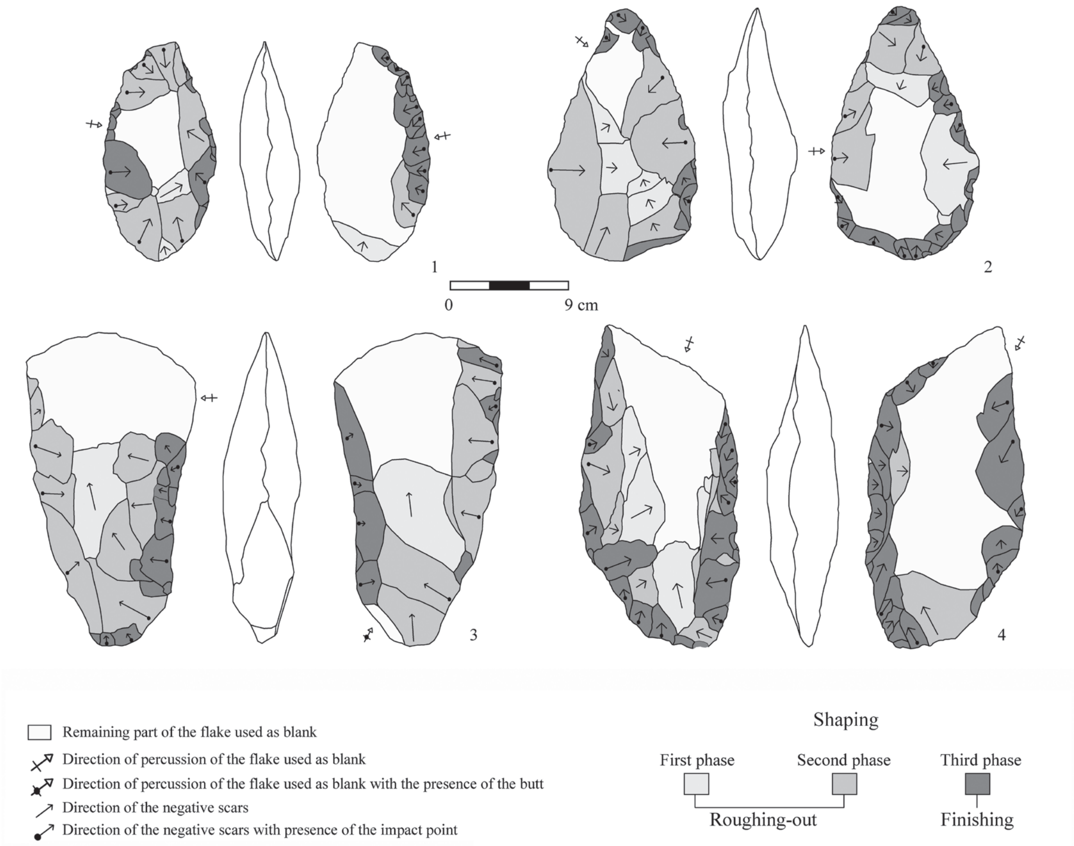

Fig. 15 - Garba XIIIB. Bifaces (1, 2) and cleavers (3, 4) on Kombewa flake blanks of porphyritic basalt.

rather to modify edges. Some of the criteria followed in turning large flakes into LCTs at Garba IVD, i.e. the use of thick, wider-than-long flakes, were adopted at all the other sites where LCTs were produced from large flakes. Nevertheless, the use of large flakes was not systematic. Large cobbles and large tabular slabs might be directly retouched or shaped, as at Kokiselei 4, Gadeb 2E and Olduvai (de la Torre & Mora, 2005; de la Torre, 2011; Chevrier, 2012; Diez-Martín *et al.*, 2015). The LCTs in Garba IVD are massive scrapers, as are most of the LCTs at EF-HR, FC West and TK in Olduvai, in Peninj and at Gadeb 2E; the retouching never aims to manage the whole volume of the object or to divide it into two different planes (contra Diez-Martín *et al.*, 2014b). In this process, the thinning of the percussion platforms and of the bulb can be seen as another repetitive pattern (de la Torre *et al.*, 2008). In some cases, as at Peninj, Kokiselei 4 and FLK West, shaping and/or retouch produced pointed forms (de la Torre *et al.*, 2008; Chevrier, 2012; Diez-Martín *et al.*, 2015). Conversely, bifacial and/or bilateral planes management occurred at the Kokiselei 4 and BK sites in Olduvai. It is hardly surprising that cleavers (sensu Tixier, 1956) are very rare and that the shaping process was generally very limited as at Garba IVD (Fig. 14: 7-8; de la Torre *et al.*, 2008; Chevrier, 2012; Gallotti, 2013).

Around 1.0 Ma, at Melka Kunture LCT productions became large-scale and systematic. New technological features document major changes in the *chaînes opératoires*. In the Garba XIIIB

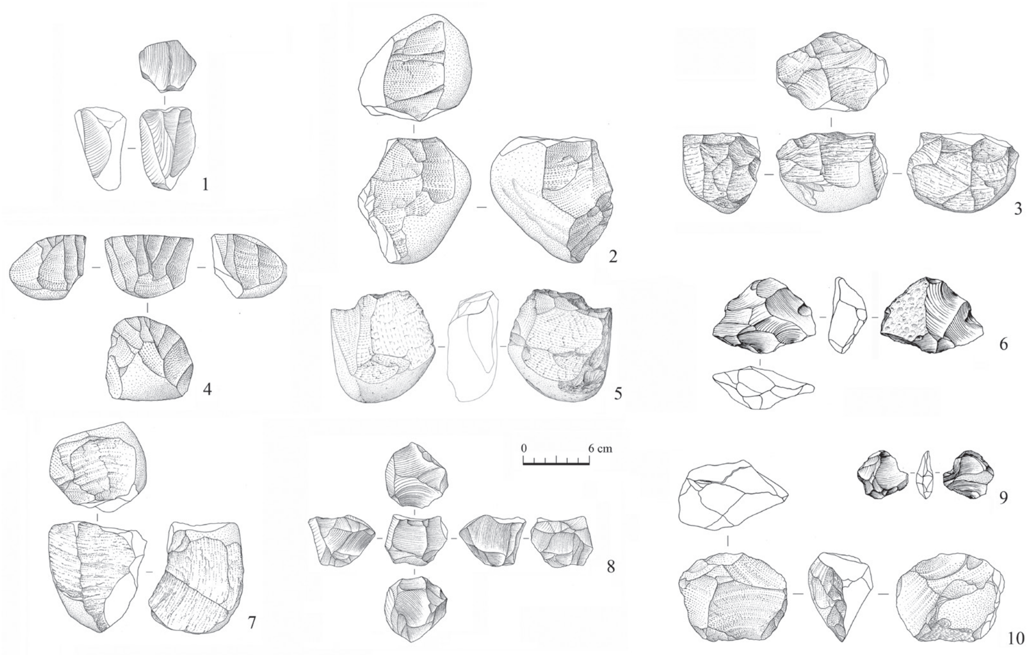

Fig. 16 - Garba IVD. Small* débitage *cores. 1, 2: unifacial unidirectional core; 3: unifacial centripetal prepared core; 4: peripheral unidirectional core; 5: bifacial partial core; 6, 9, 10: discoid cores; 7: SSDA core; 8: multifacial multidirectional core. (1, 6, 8-9, 12: obsidian; 2, 3, 7: aphyric basalt; 4: obsidian lava; 5: differentiated aphyric to subaphyric lava.) (Drawings by M. Pennacchioni; after Gallotti, 2013, revised).

and, later, the Gombore II OAM assemblages (but not in the Garba IVD ones), there are few large unmodified flakes and large cores are absent. Evidently, large flakes were detached and partially or totally shaped into LCTs before they were carried to the sites (Gallotti *et al.*, 2010, 2014). Other lines of evidence likewise point to the fragmentation of the *chaînes opératoires*. First of all, the large number of obsidian and porphyritic basalt LCTs found at both sites can no longer be correlated to the few large matrices present in alluvial deposits. Besides, at Gombore II OAM, dated to ~0.85 Ma, LCTs were mainly made of microdoleritic basalt (Fig. 13). This rock is very rare in ~1.5 Ma-old OA1s, and altogether absent in 1.0 Ma-old OA2s. However, there are outcrops of this basalt 15 to 20 km north and south of Melka Kunture. We also note that the Melka Fault lava (compact facies), exploited ~1.5 Ma in the early Acheulean of Garba IVD, was no longer used for LCT production at these later sites (Fig. 13). Secondly, at the 1.0-0.85 Ma sites, *débitage* methods for large flake extraction changed: predetermined modalities played an important role in the search for standardized flake blanks and superseded the organized prepared methods of the early Acheulean. The Kombewa method was the only *débitage* method in use at Garba XIIIB and was widely used to produce flake blanks for both bifaces and cleavers at Gombore II OAM (Figs. 11: 15). The systematic and frequent use of Kombewa flakes in both sites togheter with the presence of prepared striking platforms on some cleavers at Gombore II OAM (Fig. 11: 8; Gallotti *et al.*, 2010) allow to suppose a predetermined Kombewa strategy. A bidirectional (or peripheral) modality was also used at Gombore II OAM. These methods as

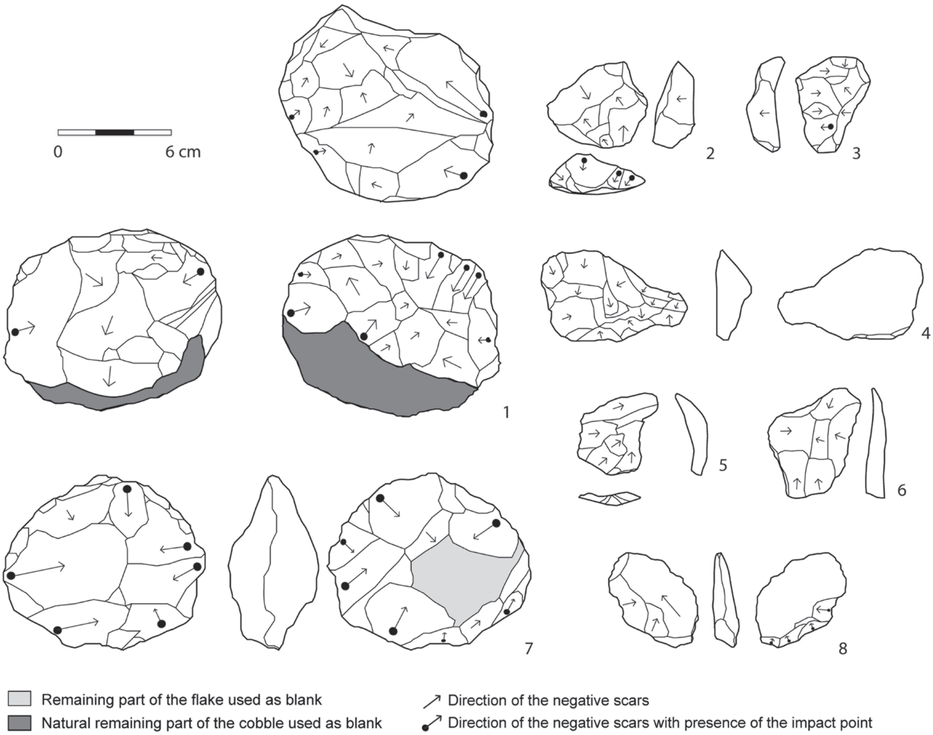

Fig. 17 - Garba XIIIB. Small* débitage *cores and flakes. 1: multifacial multidirectional irregular core; 2, 3: flakes from multifacial exploitation; 4-6, 8: flakes from discoid exploitation; 7: bifacial discoid core on flake. Aphyric basalt (after Gallotti* et al.*, 2014).

well as the large-scale and systematic production of standardized LCT blanks required giant cores (sensu Sharon, 2009). The few large cobbles of porphyritic basalt and obsidian fetched from the alluvial deposits were too small for knappers to use such methods to detach even a single flake that could serve as a LCT blank. This is further confirmed by the length of the LCTs at Garba XIIIB (18- 23 cm; Gallotti *et al.*, 2014) and of the cleavers at Gombore II OAM (18-21 cm; Gallotti *et al.*, 2010).

Accordingly, at 1.0-0.85 Ma raw material collection for LCT production was based on a procurement system operating right at the primary sources. This led automatically to fragmentation of the LCT *chaînes opératoires*. As mentioned above, site-to-source distances were less than 10 km. Comparable distances (1.0-7.5 km) are known at Olorgesailie Member 1, dating to ~0.9 Ma, where raw material procurement focused on the Mt. Olorgesailie highlands; the stones were then carried to the sites located in the basin (Noll, 2000; Noll & Petraglia, 2003). The change in procurement systems at Melka Kunture was linked not only to the dimensional constraints of OA1s and OA2s, but also to the search for high-quality raw materials: the use of microdoleritic basalts for producing bifaces and cleavers at Gombore II OAM definitely indicates that site-to-source distances were lengthening to as far as 15-20 km. This conflicts with Sharon's hypotesis (2008) that 1) coarser-grained materials were preferred in assemblages where LCT blanks were produced from large flakes; and that

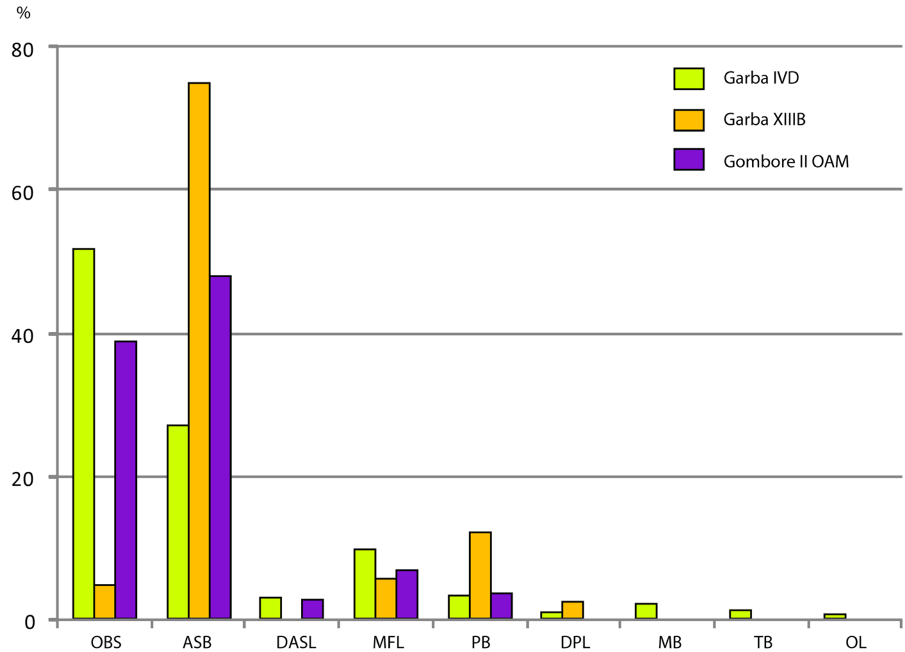

Fig. 18 - Lithological composition of the small* débitage *productions at Garba IVD, Garba XIIIB and Gombore II OAM. ASB: aphyric to subaphyric basalt; DASL: differentiated aphyric to subaphyric lavas; DPL: differentiated porphyritic lavas; MB: microdoleritic basalt; MFL: Melka Fault lava; OBS: obsidian; OL: obsidian lava; PB: porphyritic basalt; TB: trachybasalt.

2) there would be very few examples of large-flake-based Acheulean industries dominated by high-quality raw materials. In our research area, the exploitation of microdoleritic basalt, a fine-grained rock, is the earliest evidence of procurement strategies that included non-local raw materials, originating from outside the region outlined in Fig. 1b.

Management of volumes divided into two planes for LCT manufacture appeared at Melka Kunture around 1.0-0.85 Ma. Bifaces were produced by balancing the bifacial and bilateral planes and creating convergence between the two edges (Fig. 11: 1-6; Fig. 15: 1-2). The intensity of shaping was directly linked to the degree of predetermination of the bifacial and bilateral equilibrium of the flake blanks. Accordingly, *débitage* of Kombewa flake blanks played an important role in both biface and cleaver productions. The Kombewa method made it possible to produce highly predetermined flakes that resembled each other in their technical, morphological and dimensional features (Fig. 11: 7-8; Fig. 15: 3-4). Similar patterns are documented at Isenya (>0.96 Ma; Durkee and Brown, 2014). At Kariandusi (~0.97 Ma; Durkee & Brown, 2014), there are few bifaces on Kombewa blanks and it is difficult to assess the existence of a predetermined Kombewa method (Shipton, 2011).The scenario is different at Gadeb even if, admittedly, the sites are only loosely bracketed between 1.48 and 0.7 Ma. LCTs are usually minimally shaped, while bifacial volume management is found only in some handaxes and not even in all assemblages (de la Torre, 2011).

*Diachronic variation in small-*débitage *techno-economies*

As regards small *débitage*, at Melka Kunture blanks used for core exploitation correspond to the medium-sized matrices abundantly available in old alluvial deposits. At Garba IVD, the *débitage* methods imply the emergence of innovation ~1.5 Ma: a certain degree of independence from raw material geometry, preparation performed to facilitate repeated exploitation, management of the entire volume of the blanks, convexity configuration. These innovations were linked to the adoption of two methods: discoid and unifacial centripetal exploitation. They were made in the context of highly variable *débitage* methods that were closely linked to the available natural shapes (Fig. 16). This variability consistently decreased in the late Lower Pleistocene, when only two methods were eventually retained: discoid and multifacial multidirectional (Figs. 12, 17). Both aimed to extract a substantial number of flakes. Aphyric basalt and obsidian were constantly the two raw materials mainly exploited (Fig. 18).

At Garba XIIIB and Gombore II OAM, the blanks used for discoid exploitation were spherical cobbles and angular cobbles/elements. While at Garba IVD only the geometry of angular obsidian elements was configured, at the two late Lower Pleistocene sites angular lava cobbles also started to be used for discoid exploitation. At Garba IVD, angular lava cobbles with one convex surface were ideal cores for unifacial centripetal exploitation, which prepares the striking platform using angular planes and exploits the convex surface for repeated removals. The angle between the two surfaces is ~90°, as it is in the original angular cobble. This method later disappeared at Garba XIIIB and Gombore II OAM, where it was replaced by discoid exploitation of angular lava cobbles. By then, late Lower Pleistocene knappers evidently knew how to modify the natural angular planes regardless of the raw material's lithology.

Detailed data are not currently available for small-medium flake production at Kokiselei 4, where only LCTs were subjected to technological analysis (Chevrier, 2012). At Kokiselei 5, the *débitage* systems appear to be less constrained by the initial morphology of the raw materials, and they are unifacial or alternating bifacial (Texier *et al.*, 2006). At FLK West in Olduvai, cores used to produce medium-sized flakes were subjected to a variety of unifacial, bifacial and multifacial reduction strategies, including linear, orthogonal and centripetal models, as well as bipolar reduction on anvil (Diez-Martín *et al.*, 2015).

The same variability documented in Garba IVD also characterizes small *débitage* at Peninj. It is worth emphasizing that hierarchical centripetal exploitation was the most common strategy implemented there. As de la Torre *et al.* mantain (2008), the adoption of this method is relevant in cultural terms because the same technological knowledge seems to have been shared by knappers in the ST complex and those in RHS-Mugulud and MHS-Bayasi, regardless of the presence or absence of LCTs. This *débitage* concept was also adopted at Nyabusosi, where, except for a single core, centripetal exploitation of one surface from a natural or prepared striking platform was the only *débitage* method used for small flake production (Texier, 1995, 2005). At Olduvai, despite the large variability of methods, no diachronic trend seems to have been aimed at a specific type of reduction. Moreover, at the BK and TK Upper Floor, there are examples in which the centripetal hierarchical method was implemented (de la Torre & Mora, 2005). Bifacial systems account for most of the cores from Gadeb 2E, with frequent rotation of volumes and shifts from one knapping surface to another. There are also examples of well-structured exploitation sequences, such as the ones resulting from hierarchical centripetal and discoid methods (de la Torre, 2011).

To sum up: prepared methods appeared around 1.6-1.4 Ma at different sites, whether or not in association with LCT production.

As noted above, small *débitage* at late Lower/early Middle Pleistocene sites has rarely if ever been studied from a technological standpoint. The only comparable evidence is from the early Middle Pleistocene site of Nadung'a 4 in West Turkana, where small *débitage* consists of discoid, unifacial unidirectional, and multifacial multidirectional exploitations. Discoid cores display one preferential flaked surface with centripetal removals, and one natural or prepared striking surface (Delagnes *et al.*, 2006).

Diachronic variation in percussion techno-economies

The fundamental role of percussion processes during early human technological phases has been postulated by several authors (e.g. Mora & de la Torre, 2005; Haslam *et al.*, 2009; de la Torre *et al.*, 2013; de la Torre & Hirata, 2015), and recently was further demonstrated by Harmand *et al.* (2015).

In level Garba IVD, ~ 1.5 Ma, percussion material is abundant and can be grouped into two distinct sets, based on raw material lithology, shape and weight, as well as on the type of percussion marks (Gallotti, 2013). At Olduvai, even if percussion objects occur at both Oldowan and early Acheulean sites, knapping hammerstones and hammerstones with fractured angles do not fit into well-defined morphotypes, and might have been used in the same reduction sequence (Mora & de la Torre, 2005). Later, at Melka Kunture, only two knapping hammerstones have been discovered in level Gombore II OAM, ~0.85 Ma. Lavas are easily abraded, and reworking of the Melka Kunture deposits significantly altered the surfaces of lava items, hence the possibilities of recognizing impact scars are limited. Nevertheless, we suspect that their absence could well be due to technical choices. It is worth mentioning here that Chavaillon recognized 1858 battered cobbles in level Gombore IB (Chavaillon J., 2004), which (as discussed above) is approximately of the same age as Garba IVD. Our own review showed that only 34 actually display fracture angles, and only 10 display pitted areas. However, Chavaillon recognized only 24 battered cobbles in Simbiro IIIA-B – that is, in levels located below a tuff dated to 0.878 ±0.014 Ma (Morgan *et al.*, 2012) and therefore penecontemporaneous to Garba XIIIB – and only 16 at Gombore II1 (Chavaillon & Berthelet, 2004), where he excavated part of the same level that is exposed at Gombore II OAM (Chavaillon & Berthelet, 2004). Even if the percussion material from the other Acheulean sites still needs the kind of review already performed at Garba IVD, this substantial difference in raw numbers may indicate that percussion activities, as documented by hammerstones with fracture angles, were no longer performed to any substantial extent around 1.0-0.85 Ma.

The limited evidence available in the Gadeb sequence supports this hypothesis. At Gadeb 2E, the most abundant percussion artifacts are hammerstones with fracture angles (n=56); the numbers of these items decrease over time. Only one percussive object sensu lato was discovered at Gadeb 2C and Gadeb 2B; there are none at Gadeb 8D and few at Gadeb 8F, which is probably the most recent Gadeb site (de la Torre, 2011).

Reconciliation of the techno-economic and paleoanthropological records

The emergence of the Acheulean and the initial evolution of *Homo ergaster/erectus* are often thought to be linked to each other. This is because they share a similar geographic origin and overall chronology. However, several hominin genera and species co-existed at the time in East Africa (c.f. Wood, 1993; Antón, 2003; Lepre *et al.*, 2011; Wood & Baker, 2011; Beyene *et al.*, 2013; de la Torre & Mora, 2014; Lepre, 2014; Diez-Martín *et al.*, 2015; Lepre & Kent, 2015; de la Torre, 2016). *Homo* species other than *erectus* (*H. habilis, H. rudolfensis*) are better represented between ~2.0 Ma and 1.44 Ma (Feibel *et al.*, 1989; Spoor *et al.*, 2007; Antón, 2012). One cannot rule out the possibility that more than one tool-making hominin species existed at the time when the Acheulean emerged, 1.8-1.5 Ma ago. Afterward, later than 1.5 Ma, while Acheulean industries developed and evolved, *Homo ergaster/erectus* persisted while other taxa went extinct (Spoor *et al.*, 2007).

At Melka Kunture, the Acheulean emerged when *Homo ergaster/erectus* was populating the region, as borne out by specimen Gombore IB-759 (Di Vincenzo *et al.*, 2015). No Australopithecine and no *Homo habilis sensu lato* have been discovered. At Garba IVE, specimen Garba IVE-0043, ~1.7 Ma, associated with an Oldowan industry and the earliest fossil so far discovered at Melka Kunture, was likewise a *Homo ergaster/erectus* (Condemi, 2004; Zilberman *et al.*, 2004a,b; Gallotti & Mussi, 2015). Given

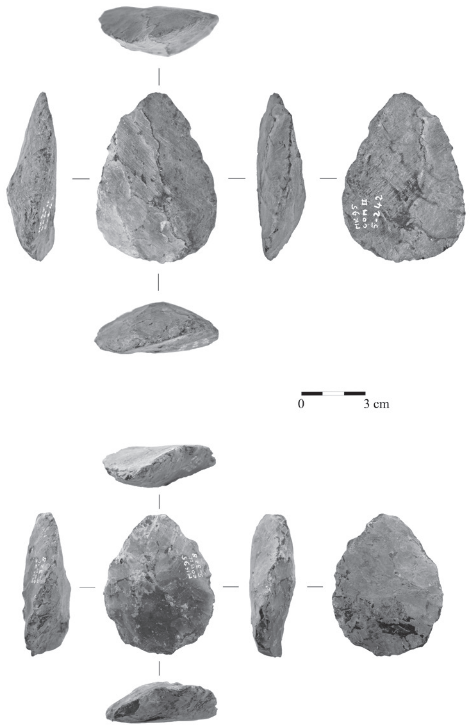

Fig. 19 - Twisted bifaces from Gombore II5.

the location of Melka Kunture on the Ethiopian highlands at 2000-2200 m asl, this may suggest that *Homo ergaster/erectus* was the first and only species able at that time to adapt to high altitudes and mountain environments. This capacity would fit with the large body size of specimen Gombore IB-759 and with the robustness of specimen Garba IVE-0043. Furthermore, it supports the hypothesis that in early *Homo*, changes related to larger body size were exaptations (Will & Stock, 2015) that allowed hominins to face climate conditions that were very different from those of lowland tropical regions (Di Vincenzo *et al.*, 2015). It also means that the "two-phyla" theory – that is, the traditional binomial equations whereby Oldowan = *Homo habilis* and Acheulean = *Homo erectus* (Leakey 1971, 1975, 1978; de la Torre & Mora, 2014) – is belied at Melka Kunture, where the technical innovations leading to the origin of the Acheulean were introduced by the same hominin species which 0.2 Ma earlier had produced Oldowan techno-complexes (Gallotti & Mussi, 2015).

In the later record at Melka Kunture, we identify techno-economic innovations that occurred in a period crucial for human evolution: the late Lower Pleistocene, albeit the evolution of *Homo ergaster/erectus*, and the time, place and mode of origin of *Homo heidelbergensis*, are still matters of debate (Antón, 2003, 2012; Manzi, 2004, 2012; Wood & Baker, 2011; Stringer, 2012; Rightmire, 2013; Ghinassi *et al.*, 2015; Profico *et al.*, 2016).

The African hominin fossil record dating to 1.0-0.70 Ma is quite limited. Furthermore, some remains come from uncertain chronostratigraphies, while direct association with lithic industries is often taken for granted rather than proven. This is the case of the human fossil skull BOU-VP-2/66 (~1 Ma), which was discovered in situ in the silty sands of the Daka Member (Ethiopia): no artifacts were associated with it (Asfaw *et al.*, 2002). At Olorgesailie (Kenya), the partial hominin cranium KNM-OL-45500 (0.97-0.9 Ma) was found in the same stratigraphic level as archeological sites 1.5 km away that have yielded dense in situ accumulations of Acheulean bifaces (Potts *et al.*, 2004). The UA 31 cranium from Buia (Eritrea) (~1.0 Ma; Abbate *et al.*, 1998) is only indirectly associated with Acheulean artifacts, which were collected on the surface. At Olduvai, specimens OH 12, OH 22 and OH 28 (1.25-0.78 Ma) were found respectively on the west side of the VEK gully where the Masek Beds and Beds III and IV outcrop, on the surface of the lower part of Bed IV near the junction with Bed III, and on the surface of an Acheulean site in the upper part of Bed IV (Hay, 1976; Walter *et al.*, 1991, 1992; Tamrat *et al.*, 1995; Wolpoff, 1999, p.428; Delson & Van Couvering, 2000; McBrearty & Brooks, 2000; Antón, 2004). Specimen OH 23 (0.37 - 0.99 Ma) was discovered in the FLK Masek Beds, but about 0.5 m above a level that yielded extensive Acheulan industry (Walter *et al.*, 1991, 1992; Leakey & Roe, 1994, p. 116; Tamrat *et al.*, 1995; Delson & Van Couvering, 2000). Overall, the late Lower/early Middle Pleistocene record

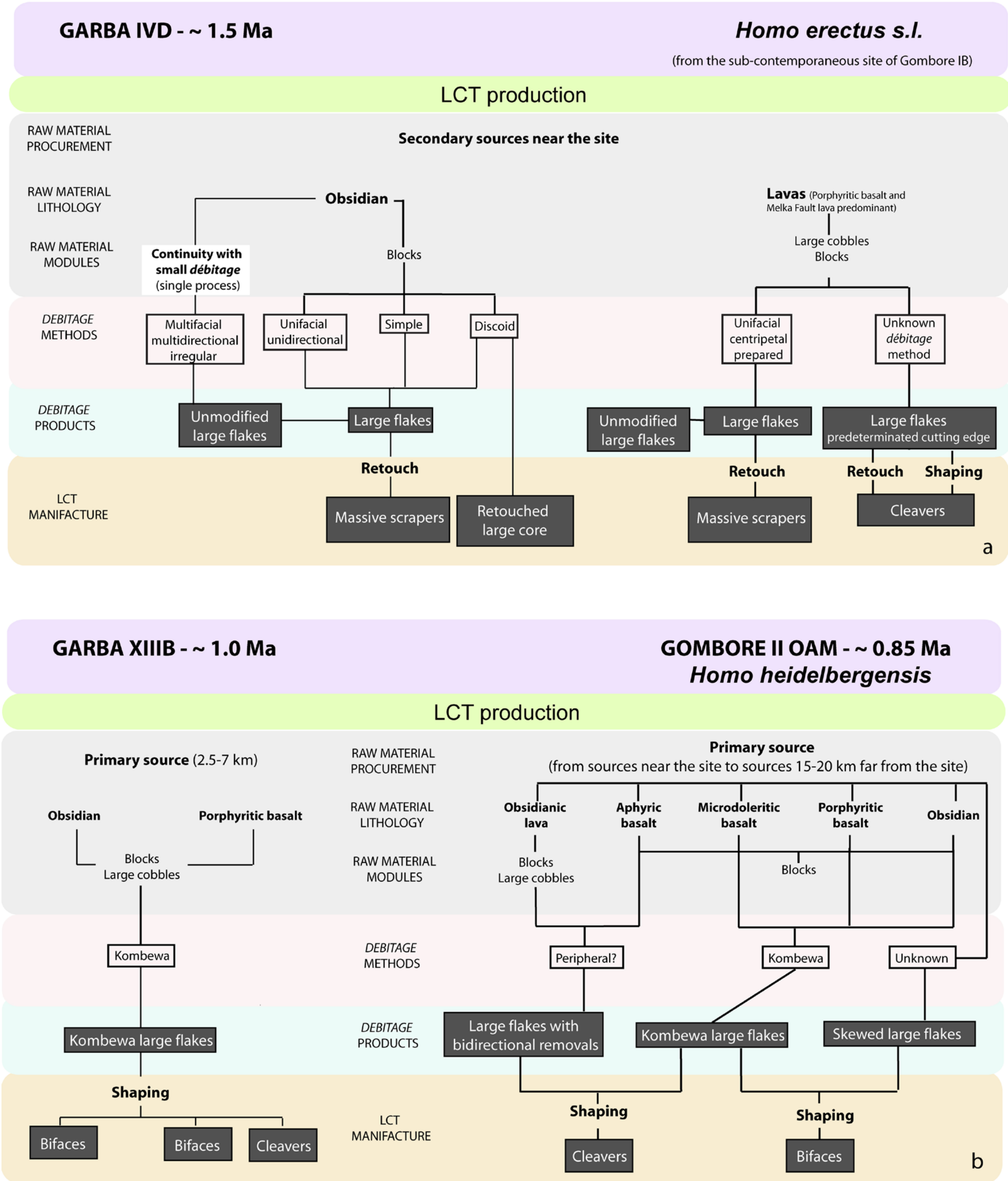

***Fig. 20** - Schematic reconstruction of LCT productions and associated hominins at Garba IVD (a), Garba XIIIB, and Gombore II OAM (b). The colour version of this figure is available at the JASs website.*

displays significant morphodimensional variation in African *Homo erectus sensu lato* (Antón, 2013; Antón *et al.*, 2014; Baab, 2014; Ghinassi *et al.*, 2015). While there is no general agreement over which specimens/assemblages best represent the African paleo-population ancestral to the Middle Pleistocene *Homo heidelbergensis* lineage, they all share phenetic affinities closer to *Homo*

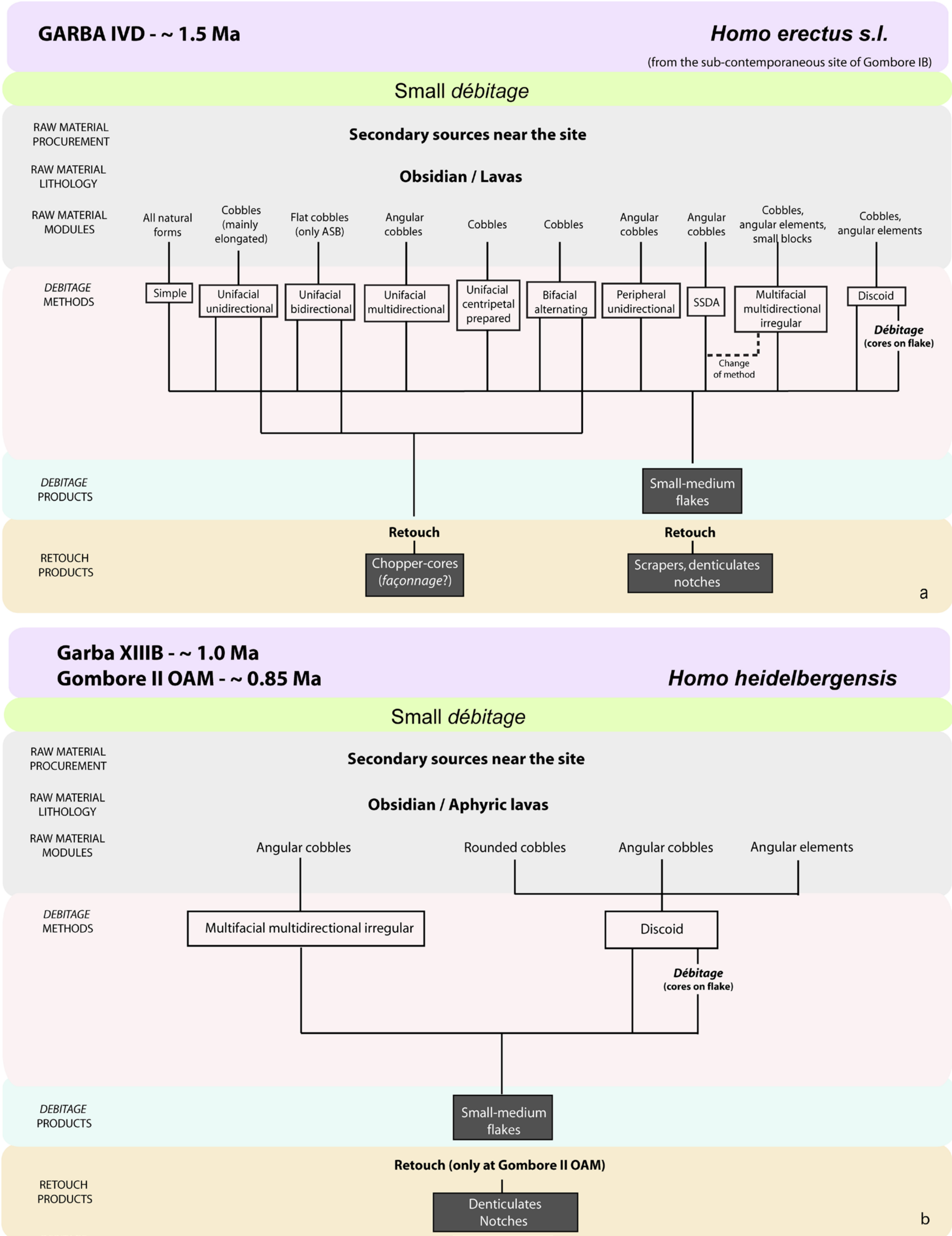

Fig. 21 - Schematic reconstruction of small-medium flake productions and associated hominins at Garba IVD (a), Garba XIIIB, and Gombore II OAM (b). The colour version of this figure is available at the JASs website.

ergaster/erectus than to the Middle Pleistocene hominins – Bodo and Kabwe specimens – which themselves are considered to be *Homo heidelbergensis* or *Homo rhodensiensis*.

At Melka Kunture, the Gombore II1 skull fragments are now attributed to an ancestor of *Homo heidelbergensis*, thereby starting to fill the gap (Profico *et al.*, 2016). Furthermore, they were found in situ with lithics and fauna, and provided what is to date a uniquely firm insight into the knapping skills developing at this stage of human evolution. From an archeological standpoint, we underline the emergence of new concepts and behaviors at this time, as exemplified by the record discussed above. The main ones are morphometric predetermination, shaping, systematic procurement at primary sources, systematic fragmentation of the LCT *chaînes opératoires*, and greater knowledge of the paleolandscape as related to resource exploitation. This was also the time when the innovative twisted bifaces were part of the assemblages (Fig. 19). Given the recent attribution of the Gombore II1 fossils, we mantain that the major innovations highlighted here in lithic productions were linked to the major step also seen in the paleoanthopological record: the emergence of a new and more encephalized type of hominin.

Conclusions

At Melka Kunture, a cluster of archeological sites with well-established chrono-stratigraphies document Acheulean techno-complexes and co-occurring hominin evolution during the Lower Pleistocene (Figs. 20, 21). The study of their industries made it possible to track the techno-economic trends in the origin and development of the Acheulean and the related behavioral and paleoanthropological implications.

LCT manufacture appears at Melka Kunture at ~1.5 Ma. LCT production is limited when compared with small *débitage*. This is probably due to the scarcity of large forms in the alluvial deposits, the only sources of raw material that knappers used at the time. The raw material provisioning system was the same as during the Oldowan. Procurement at primary sources and the consequent *chaîne opératoire* fragmentation – technological and economic traits of LCTs that are considered typical of Acheulean techno-complexes – appear later, not at the time of the earliest Acheulean in this region.

Furthermore, large flake extraction occured before the emergence of the ability (or maybe need) to manage the volume of objects, creating bifacial and bilateral equilibrium and two convergent edges. Accordingly, at ~1.5 Ma, LCT manufacture was limited to edge retouch and did not produce specific tool-types, as was the case for small tools. However, while the blanks that were to be turned into small tools were undifferentiated flakes, the flake blanks for LCTs usually pertain to specific *débitage* methods.

At Melka Kunture, the main innovations that distinguish the early Acheulean from the Oldowan technology are just some of the technical criteria that were introduced into *débitage*: namely the systematic preparation of the striking platform, the recurrence of exploitation that made it possible to obtain flakes with longer suitable edges or large flakes that were wider than long, volume/convexities management and maintenance, and hierarchy among surfaces. The knappers systematically selected geometrically suitable large blanks to facilitate the adoption of these technical criteria.

In the current state of research, both Oldowan and early Acheulean techno-complexes at Melka Kunture are thought to be the cultural outcome of *Homo ergaster/erectus* technical behaviors. Accordingly, the technological changes that led to the emergence of the Acheulean on the Ethiopian highlands were not related to the emergence of new hominin species.

At the end of the Lower Pleistocene, there was a surge in the production of LCTs: bifaces and cleavers were made in great numbers. New large flake *débitage* methods and systematic shaping processes emerged to produce, respectively, highly standardized flake blanks and large tools. Volume management allowed predetermination of the geometrical, dimensional and technical aspects of the large flakes. The division of flake volume into two planes, and cleaver edge production were systematically predetermined. The intensity of the shaping process mostly depends on the degree of flake blank predetermination. It is aimed at refining the bilateral/bifacial equilibrium, at creating convergent edges for bifaces manufacture, and at producing specific tool-types. One consequence of systematic procurement right at primary sources was the fragmentation of the LCT *chaînes opératoires*. At 0.85 Ma, the search for very fine rocks drove hominins to range afar, widening their knowledge of the landscape at distances as far as 15-20 km and possibly more.

At 1.0-0.85 Ma we also clearly detect an increase of recurrence and productivity in small *débitage*, thanks to highly efficient volume control and maintenance. The early Acheulean was characterized by the great variety of small *débitage* methods. This variability was the outcome of geometrical constraints imposed by raw materials. Although incipient independence from raw material shape is documented, it is related to the knapping suitability of obsidian. These constraints were superseded at 1.0-0.85 Ma, when the variability of the methods decreased sharply and the discoid concept was adopted regardless of the geometrical and physical properties of raw materials. However, no predetermination of morpho-technical features emerges in the small-medium flakes. It will appear much later with the Levallois concept. Levallois technology appears at 0.5 Ma in East Africa, as giant Levallois cores for the production of cleaver blanks. Small Levallois is only known from ~0.3 Ma onwards (Tryon *et al.*, 2005).

At Melka Kunture there is a gap of about 0.5 Ma between the early Acheulean and the late Lower Pleistocene techno-complexes. To date, no archeological evidence belonging to this time span has been discovered here. Further investigations at Melka Kunture will focus on this chrono-stratigraphic and/or archeological discontinuity. This might be the human response to a major volcanic event and to subsequent landscape changes and instability, for extensive deposition of an ignimbrite documented at ~1.2 Ma. In any case, even if this volcanic event could raise a number of questions regarding hominin resilience, our findings prove that it did not affect the raw material composition of alluvial deposits. Lithic resource availability and accessibility remained unchanged in the paleolandscape. Consequently, changes occurred in raw material procurement systems while the *chaînes opératoires* were reorganized in both space and sequencing. They are clearly linked to cultural choices, objectives, and knowledge.

The techno-economic discontinuity highlighted in this paper was so sharp that it justifies our introducing a distinction within the Acheulean, defining two discrete, well-defined Acheuleans in the Lower Pleistocene of Melka Kunture. The innovations that occurred at the end of the Lower Pleistocene were not a small qualitative step, but a gigantic leap taken in parallel with the gradual emergence of a new and more encephalized type of hominin: *Homo heidelbergensis*.

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Appendix. Lithotypes identified in old alluvial deposits of the Melka Kunture region.

LITHOTYPE	GRAIN SIZE AND HOMOGENEITY	KNAPPING SUITABILITY		DESCRIPTION
		Hard hammer	Soft hammer	
Obsidian	Very fine grained, compact and homogeneous	****	*****	The obsidian color is dominantly black, but blue, green, red and beige colors have been observed. The unweathered lava is massive, black, very finely banded and breaks easily with conchoidal fracture, giving more or less translucent flakes with excellent cutting edges. Obsidian outcrops at Balchit, 7 km north from Melka Kunture sites.
Aphyric to subaphyric basalts	Fine grained, compact and homogeneous	****	**	Aphiric basalts do not exhibit visible crystals. They are characterized by a compact texture formed by very fine minerals (microlites), plagioclase, augite and olivine, and by glass giving them a dark grey-blue colour. They seldom have more than 50% of SiO2, and accordingly are fairly fluid at eruption temperature.
Differentiated aphyric to subaphyric lavas	Fine grained, rather compact and homogeneous with few small crystals	***	**	Aphyric and subaphiric differentiated lavas are trachytes or rhyolites (60/70% of SiO2) with a compact gray, green or yellow fine grained texture, more or less bright, and variable porosity sometimes including a few small crystals. At the time of eruption they were fairly viscous.
Melka Fault lava	Compact facies: fine grained, rather compact and homogeneous	***	**	Aphyric fluidal lava, related to the limit-fault (South/South East) of Melka Kunture basin, is particularly abundant. This gray to blue facies resembles the benmoreite (similar to alkaline trachytes, with 62/65% of SiO2). Notwithstanding the peculiar fluidal texture, it can be very compact, but it often displays vesicles oriented following the sense of fluidality.
	Vesciculated facies: inhomogeneous and even compact	*	*	
Porphyritic basalts	Fine grained, rather compact and homogeneous with large crystals	***	**	Porphyritic basalts have large crystals of up to 1 cm (phenocrystals), within a microlithic or vitreous groundmass. Poorly porphyritic to semiporphyritic basalts have some visible (1 to 3 mm) crystals (olivine and augite) within a microlithic or vitreous groundmass.
Differentiated porphyritic lavas	Fine grained, rather compact and homogeneous with large crystals	***	**	Porphyritic differentiated lavas are generally brighter and less compact. They usually have either some phenocrystals of alkaline feldspars (sanidine), or of augite and hornblende or quartz. They are usually related to trachytes or to rhyolites, and rarely to phonolites. Very viscous.
Microdoleritic basalts	Very fine grained, very compact and homogeneous with microcrystals	****	****	Microdoleritic basalts display a fine grained and grey texture rich in plagioclase, including augite and olivine microlites. Some basalts with a larger doleritic texture, and interstitial wides, outcrop around Melka Kunture. Their flows are easily recognizable because of the erosion which shaped them into large blocks (e.g. some kilometres North-East from Awash village).

Appendix. Continued

LITHOTYPE	GRAIN SIZE AND HOMOGENEITY	KNAPPING SUITABILITY		DESCRIPTION
		Hard hammer	Soft hammer	
Trachybasalt	Fine grained, compact and rather homogeneous with crystals	***	**	Trachybasalts have rare olivine crystals and they include feldspars phenocrystals (plagioclase or alkaline feldspar as anorthose) within a texture of basaltic composition, whose compactness determines the rock hardness.
Trachyandesite	Fine grained, tender with large crystals	**	*	Mesocratic lava, lighter than the basalts, usually with numerous large phenocrystals of alkaline feldspaths.
Welded ignimbrite n.1	Coarse grained, inhomogeneous and even compact	*	*	Welded ignimbrite, which probably originally extended over hundreds of km2, is the more remarkable formation of this type in the area of Melka Kunture. It was produced during a major peralkaline rhyolitic eruption, and moved like an aerosol before releasing lava elements which were welded when gas energy diminished.
Other types of ignimbrites and ignimbritic tuff	Coarse/fine grained, inhomogeneous and even compact	*	*	Thirteen types of welded ignimbrites with various facies and lithological characters have been identified in the ancient alluviums of Simbiro along with some ignimbritic tuff. They all refer to welded or non-welded pyroclatic flows emitted during peralkaline rhyolitic (pantelleritic) syn-rift eruptions
Obsidian lava	Fine grained, homogeneous and more or less compact	***	***	Distinct from real obsidian, as Balchit obsidian. They were produced by quick cooling, as at the base of some welded ignimbrites. Vitrification is more or less developed, and accordingly the rock is more or less compact, following local features, notably the thickness of cooling and the presence/absence of water.
Syenitic inclusions	Very fine grained, compact and homogeneous	*****	*****	They were produced in a magma chamber where crystallized minerals had accumulated before being brought up, dislocated and thrown out of the volcano during a major eruption which also expelled the magma. They are mainly constituted by alkaline feldspars and they document the trachytic, phonolithic or rhyolitic composition of the magma.
Amorphic silica	Very fine grained, compact and homogeneous	*****	*****	Amorphic silica material (flint and opale), usually classified as sedimentary rocks, in the Melka Kunture Basin is the outcome of hydrothermal circulations and of amorphic silica precipitation (silcrete).