Chapter 4
Before, During, and After the Early Acheulean at Melka Kunture (Upper Awash, Ethiopia): A Techno-economic Comparative Analysis

Rosalia Gallotti and Margherita Mussi

Abstract The emergence of the Acheulean is a major topic, currently debated by archaeologists researching all over East Africa. Despite the ongoing discussion and the increasing amount of available data, the mode(s) of the technological changes leading to this emergence remain(s) largely unexplained. Overall, there is a dearth of continuous stratigraphic sequences recording both the late Oldowan and the early Acheulean at the same site. Accordingly, the technological changes cannot be evaluated taking into account the variability of each microregional context. Besides, the early Acheulean must be defined not only with respect to the Oldowan, but also in comparison with the following middle Acheulean.

At Melka Kunture, on the Ethiopian highlands, the rather continuous record allows a diachronic analysis from ~ 1.7 to ~ 0.85 Ma in a single microregion. In this paper we address the emergence and later developments of the Acheulean in the perspective of technical responses to the qualities/limits of raw materials (lithology, dimensions, geometry). A comparative techno-economic perspective makes it possible to investigate the nature of technological change(s) taking into account the role played by lithic resource availability and constraints in the same paleolandscape.

Our results demonstrate that in this area the main novelties leading to the early Acheulean were new concepts in small and large débitage, in addition to the manufacture of large tools. These innovations emerged at Melka Kunture over two hundred thousand years, during a continuous cultural process leading from the late Oldowan to the early Acheulean. On the opposite side, at the end of the Early Pleistocene, the innovations are not a small qualitative step, but rather a gaint leap. We underline the strong techno-economic discontinuity between the early Acheulean and the middle Acheulean.

There is also evidence that *Homo ergaster/erectus* produced both the Oldowan and the early Acheulean at Melka Kunture. Accordingly, the technological changes leading to the emergence of the Acheulean on the Ethiopian highlands are not explained by a newly developing hominin species. Conversely, the middle Acheulean develops while *Homo heidelbergensis*, a new and more encephalized type of hominin, appears on the scene.

Keywords Ethiopian plateau • Melka Kunture • Early Pleistocene • Oldowan • Raw materials • Techno-economic behaviors

4.1 Introduction

Melka Kunture is located 50 km south of Addis Ababa, on the western edge of the Main Ethiopian Rift, in a half-graben depression of the Ethiopian plateau (Fig. 4.1). This cluster of sites preserves one of the longest and most complete prehistoric sequences in East Africa, from the late Oldowan (~ 1.7 Ma) to the Late Stone Age.

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R. Gallotti and M. Mussi (eds.), *The Emergence of the Acheulean in East Africa and Beyond: Contributions in Honor of Jean Chavaillon*, Vertebrate Paleobiology and Paleoanthropology,
https://doi.org/10.1007/978-3-319-75985-2_4

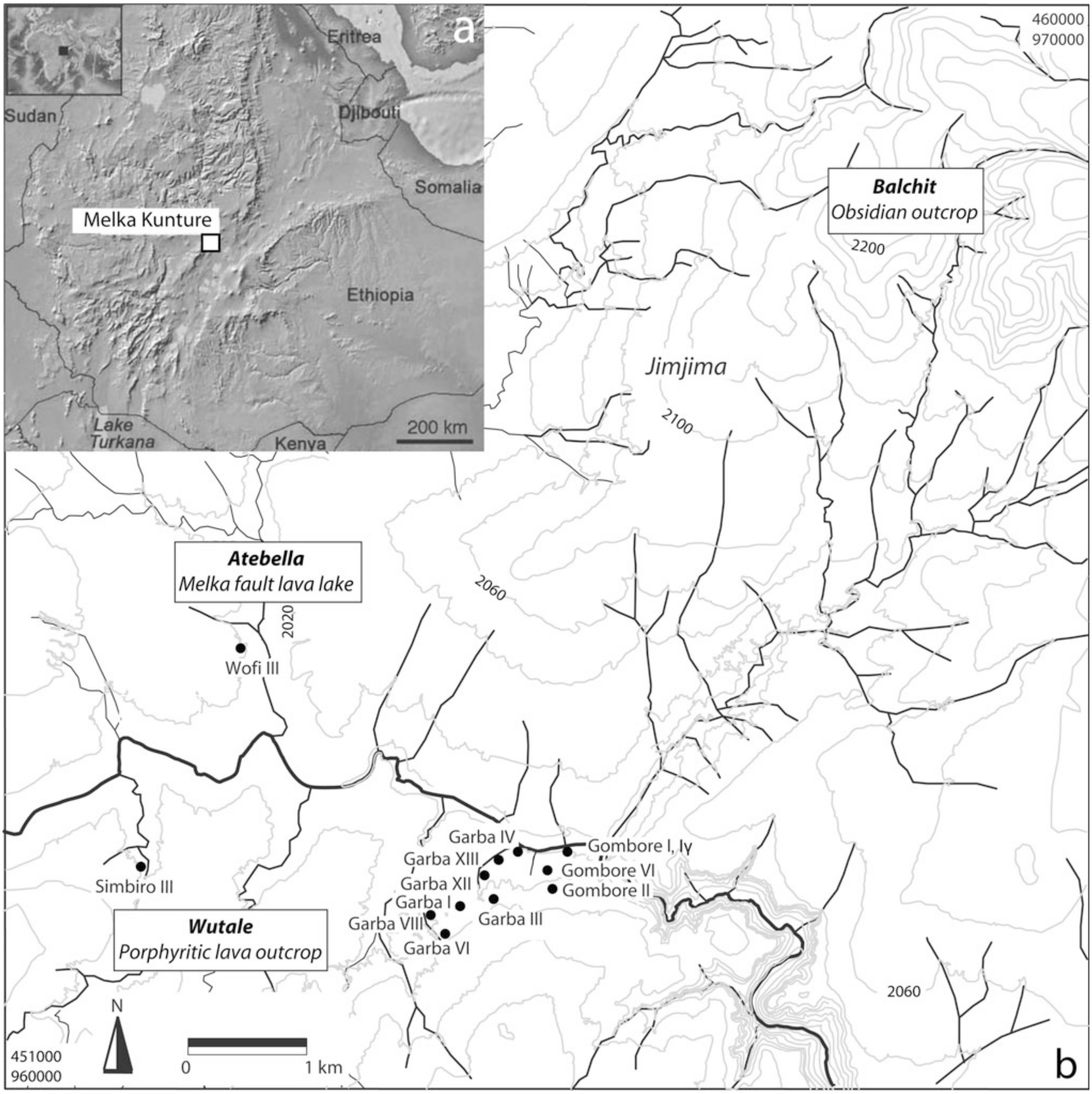

Fig. 4.1 **a** Map showing the location of Melka Kunture on the shoulder of the Main Ethiopian Rift. **b** Location of archaeological sites and primary sources of raw materials in the Melka Kunture area (vector restitution of the 1:50,000 topographic map)

In 1979, Chavaillon et al. recognized locally the first emergence of the Acheulean in level J of Garba XII, a site dated to ∼1.0 Ma (Fig. 4.1b; Schmitt et al. 1977; Cressier 1980). They distinguished this "ancient" Acheulean from the Oldowan (Gombore IB; ∼1.6 Ma; Fig. 4.1b) and Developed Oldowan (Garba IVD, ∼1.6 Ma, and Gombore Iγ, ∼1.3 Ma; Fig. 4.1b) on the basis of innovations in lithic productions: the first appearance and consistent manufacture of handaxes, cleavers, and standardized scrapers, and changes in chopper types. In a word, the Acheulean emerged later at Melka Kunture than elsewhere in East Africa (Leakey 1971, 1975). Later, it was also underlined that Melka Kunture Acheulean levels were never discovered above the Oldowan or Developed Oldowan ones in the same stratigraphic sequence (Piperno et al. 2004c). This was contrary to the dichotomy of Developed Oldowan/early Acheulean proposed by M. Leakey (1971, 1975) at Olduvai. On the Ethiopian plateau, there was no evidence of two parallel cultures developing side by side over more than one million years (Chavaillon et al. 1979).

The Acheulean sequence at Melka Kunture was in turn divided into four stages (Chavaillon 1980; Chavaillon and Chavaillon 1980): ancient (Garba XIIJ; ~1.0 Ma), middle (Garba XIIH-D, Simbiro III, Gombore II, Gombore VI, Gotu II, Garba IIIE; 0.8–0.5 Ma), upper (Garba I, Garba VI, Garba VIII; 0.4–0.3 Ma), and final Acheulean (Garba XIIIB, Garba IIIB, Wofi III; 0.25–0.15 Ma; Fig. 4.1b).[1] Chavaillon and Chavaillon (1980) interpreted the cultural change as a gradual local evolution of technology in a unilinear sequence from Oldowan to Acheulean. This scenario was put forward at a time when quantitative and typological features were the basis for any interpretation. The first appearance of certain tools and the variability in the presence of different types of tools were the main factors that made it possible to identify the Oldowan and the Acheulean, while the degree of biface and cleaver refinement was the main parameter defining the evolution of the Acheulean. At the time, this approach was the rule at East African sites (e.g., Kleindienst 1962; Leakey 1971, 1975).

In the last fifteen years, new systematic research at Melka Kunture cast doubt on this technological and stratigraphic characterization of the Oldowan/Developed Oldowan and Acheulean. New excavations and analyses of the Garba IV basal sequence (levels F-E), the review of the Garba IVD lithic assemblage in a techno-economic perspective, the excavations and analysis of new late Early Pleistocene sites (Garba XIIIB and Gombore II OAM), as well as new dates and the stratigraphic construction of the Melka Kunture Formation all pointed to a different scenario (Raynal et al. 2004; Piperno et al. 2009; Gallotti et al. 2010, 2014; Morgan et al. 2012; Gallotti 2013; Gallotti and Mussi 2015, 2017; Mussi et al. 2016; Bonnefille et al. 2018). The emergence of the Acheulean at Melka Kunture is now recognized at ~1.6 Ma (Garba IVD). The attribution to the early Acheulean was made after a detailed comparative analysis with the other early Acheulean sites in East Africa (Gallotti 2013). At the time, technological data from the Oldowan assemblages (Garba IVF-E) were not yet available. They have been published only recently (Gallotti and Mussi 2015).

In this paper, we analyze in a comparative perspective Early Pleistocene techno-economic behaviors at three archaeological sites of Melka Kunture with well-established chronostratigraphies: Garba IVF-D (~1.7–1.6 Ma), Garba XIIIB (~1.0 Ma), and Gombore II OAM (~0.85 Ma). We assess the range of variation and characterize the modes of lithic productions through a descriptive rather than a quantitative approach. Following the chaîne opératoire approach, lithic production, as examined here, is a sequence of technical actions and reductive phases ending in a techno-economic process; that is, we include the technical sequences as well as the technical and cognitive skills involved in tool production (Leroi-Gourhan 1964, 1971; Pelegrin 1985; Geneste 1989, 1991; Perlés 1991; Inizan et al. 1999; Harmand 2009). Additionally, we analyze the location, availability, composition, shape, and dimension of raw materials in order to understand how the knappers responded to lithic resources during the phases of the production process. We discuss the results in a comparative diachronical perspective. Our aim is (1) to identify more precisely the emergence and development of the local Acheulean during the Early Pleistocene, (2) to define the early Acheulean with respect both to the late Oldowan and to the middle Acheulean, and (3) to evaluate the role played by raw material availability and constraints on techno-economic change.

4.2 Melka Kunture: The Geological and Archaeological Setting

The Upper Awash River and its tributaries drain the area of Melka Kunture, and Pliocene volcanoes surround it (Mohr 1999). The major volcanic events started 5–4 million years ago, but later eruptions also modified the environment when hominin groups were already present in the area. The Awash re-established its course after each volcanic event. As described in the literature, the currents in the main river and its tributaries reworked and transported loads of sediments, including volcanic material, that buried and preserved archaeological sites (Kieffer et al. 2002, 2004; Bardin et al. 2004; Raynal and Kieffer 2004).

The archaeological sites are clustered over some 100 km^2 (Fig. 4.1b). During the last 50 years they have been intensely researched and excavated over some 20 km^2. They are located on the edges of gullies and valleys which cut through alluvial sediments from the Early and Middle Pleistocene ages. Upper Pleistocene deposits are less extensively preserved. To date around 30 of the over 70 archaeological levels located on both banks of the river have been tested or extensively excavated (Chavaillon and Piperno 2004). The levels are named after the gully where they are located (e.g., Simbiro, Garba, Gombore), followed by a Roman numeral (e.g., Atebella II). If a level contains multiple sub-levels, a capital letter is added for each one (e.g., Garba IVE).

[1] No systematic excavations were carried out at Gombore VI, Gotu II, Garba VI and Garba VIII. The lithic artifacts were collected along exposed sections. The location of Gotu II is unknown, hence it is not shown in Fig. 4.1b. The Garba IIIB industry, heretofore attributed to the final Acheulean, was recently reanalyzed and assigned to the early Middle Stone Age (Mussi et al. 2014).

4.3 The Analyzed Early Pleistocene Sites

Hominins settled again and again in this part of the Upper Awash valley from the end of the Olduvai Polarity Subzone to later than the Brunhes/Matuyama Reversal, as evidenced by dated chrono-stratigraphic successions (Schmitt et al. 1977; Cressier 1980; Morgan et al. 2012; Tamrat et al. 2014).

All the Early Pleistocene sites discovered along the Garba (Garba IV, Garba XII and Garba XIII) and Gombore gullies (Gombore I, Gombore Iγ, and Gombore II) are included in the Melka Kunture Formation (hereinafter MKF; Fig. 4.2a, b; Raynal et al. 2004). However, while the overall chronostratigraphy is well understood, a detailed reassessment is under way for each site. Accordingly, in this paper we shall discuss Garba IVD-F, Garba XIIIB, and Gombore II OAM, which have already been reviewed.

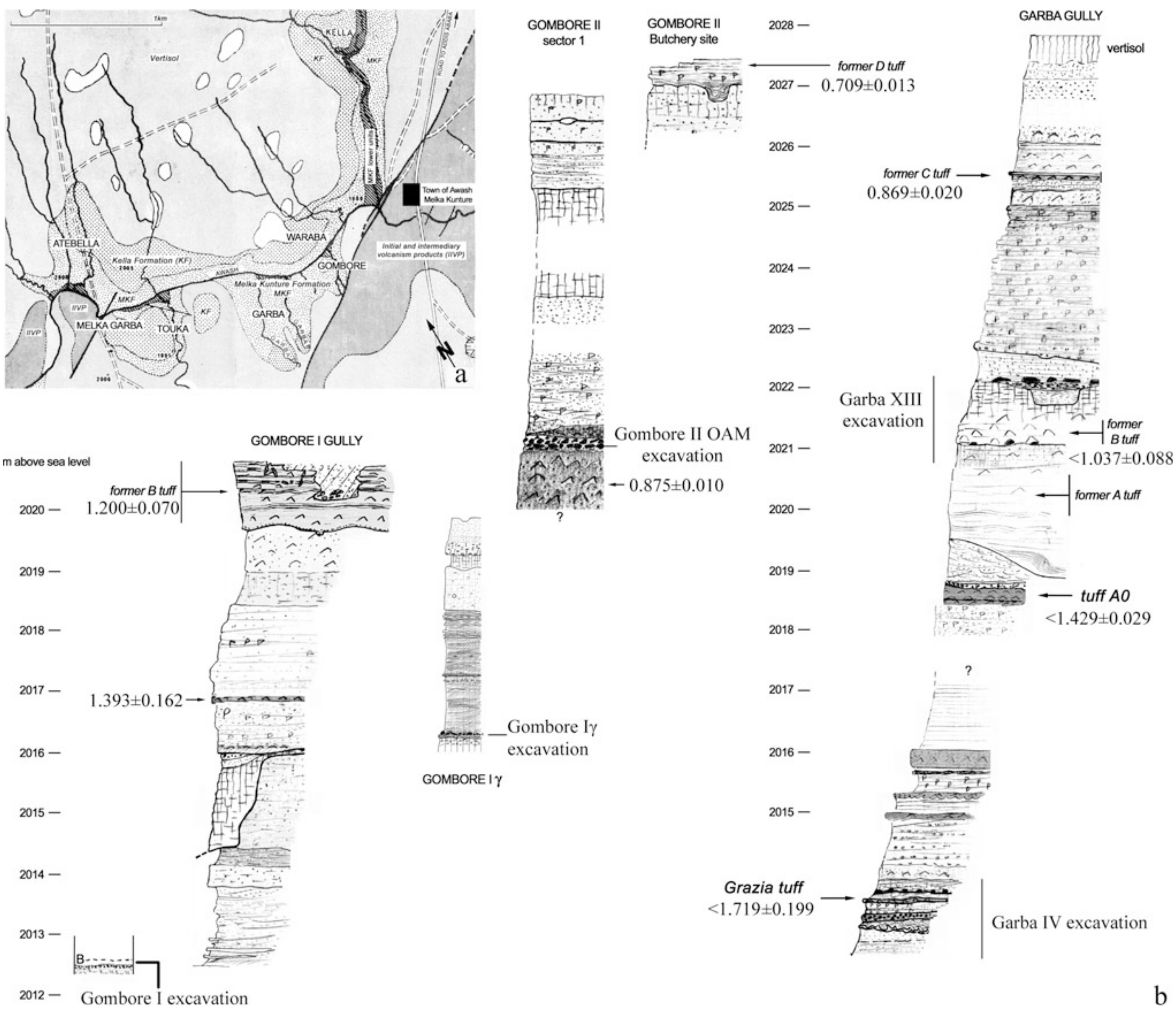

Fig. 4.2 **a** Geological sketch map of the Melka Kunture area (after Taieb 1974, revised). **b** The Melka Kunture Formation (after Raynal et al. 2004, revised; radiometric dates as in Morgan et al. 2012)

4.3.1 Garba IV (~1.7–1.6 Ma)

Garba IV is located on the right bank of the Awash at the confluence of the Garba creek (Fig. 4.1b). It was discovered in 1972 by Jean Chavaillon, who excavated it from 1973 to 1982 (Chavaillon and Piperno 1975; Piperno and Bulgarelli-Piperno 1975; Piperno and Bulgarelli 2004). The deposit, which belongs to the lowest parts of the MKF, consists of a stratigraphy that is approximately 3 m high. Three stratigraphic units were recognized in fluvial sedimentary series, and several archaeological horizons were discovered (Raynal et al. 2004). The sequence lies below tuff A0, dated to <1.429 ± 0.029 Ma (Morgan et al. 2012), which caps levels C and D. The lithic assemblage found in level D documents the emergence of the Acheulean at Melka Kunture at approximately 1.6 Ma (Gallotti 2013). The Grazia tuff sandwiched between level D and the underlying level E is dated to <1.719 ± 0.199 Ma (Morgan et al. 2012) (Figs. 4.2b, 4.3a–c). Levels E and F, below the Grazia Tuff, are included by Tamrat et al. (2014) in the normal polarity interval (N1), which they assign to the end of the Olduvai subchron. The Garba IVE-F lithic assemblages have been attributed to the late Oldowan (Gallotti and Mussi 2015).

4.3.1.1 Levels E-F

In 1982, level E was tested over 4 m^2 (Piperno et al. 2004d, 2009). The fragmented mandible of a two- or three-year-old *Homo erectus s.l.* child was discovered here (Condemi 2004; Zilberman et al. 2004a, b) together with lithics and faunal remains. In 2005, 2008 and 2009, level E and the underlying level F were expanded over approximately 34 m^2 and 12 m^2, respectively (Fig. 4.4). Every single item was recovered, including unworked lithic items. Level E yielded 504 unworked lithic objects, 718 artifacts, and 774 faunal remains; level F yielded 80 unworked lithic objects, 113 artifacts and 110 faunal remains. The spatial data of each object >1 cm were recorded in three dimensions. Hundreds of small flakes and unidentifiable fragments less than one cm long were also collected by systematically sieving the sediment from each level in half-square-meter sections (Gallotti and Mussi 2015). According to Raynal et al. (2004), the assemblages from levels E and F (Table 4.1) had deposited within a relatively short period of time.

4.3.1.2 Level D

The Garba IVD site displays a high-density distribution of artifacts and faunal remains. More than 100 m^2 were excavated here between 1972 and 1982. The Awash destroyed an unknown portion of the northern part of the site, and the Garba creek washed away the central part of this level (Gallotti and Piperno 2004; Piperno and Bulgarelli 2004; Fig. 4.5a).

A total of 19,055 finds (9,821 lithic artifacts, 6,654 unworked lithic objects, and 2,580 faunal remains) were systematically recorded (Gallotti and Piperno 2003, 2004; Piperno et al. 2004a, b; Gallotti 2013). The unworked lithic objects found during the excavations are no longer available for study. They had been neither catalogued nor stored, but only drawn on two-dimensional maps (D'Andrea et al. 2000, 2002; D'Andrea and Gallotti 2004). When we re-examined 9,028 of the 9,821 items originally described as "artifacts", we found that 6,986 had indeed been knapped, while 2,042 were unworked objects (Gallotti 2013; Table 4.1). The 793 items we did not re-examine included 499 obsidian pieces that were completely broken and 294 items that were missing.

Unit D is made of tightly packed lithic artifacts and faunal remains embedded in sands and gravels (Fig. 4.3d). The gravels are fine, but also include numerous unworked pebbles, cobbles, and blocks. The lithic objects (both knapped and unworked) display different degrees of abrasion. Fresh surfaces and edges sometimes coexist on the same object with abraded areas (Gallotti 2013). Raynal et al. (2004) suggest two alternative hypotheses regarding the deposition processes that formed this unit. According to the first hypothesis, a flood simultaneously transported and redeposited archaeological remains and unworked materials, and hominins had no impact on this deposit thereafter. According to the second hypothesis, when the water receded hominins did settle on the lag deposit. They knapped lithic tools using raw materials available on the spot. Later on, this new horizon was buried and partially reworked when a low-energy flow deposited sands on top of it.

4.3.2 Garba XIIIB (~1.0 Ma)

Garba XIII is likewise located along the Garba creek, not far from Garba IV and some meters higher up in the stratigraphic sequence (Fig. 4.1b). A stratigraphic section of ~2 m has been fully documented (Raynal et al. 2004; Gallotti et al. 2014). The main archaeological feature is level B, which has been excavated over ~15 m^2. It lies stratigraphically below a tuff unit dated to 0.869 ± 0.020 Ma (former C tuff) and immediately above a tuff unit dated to <1.037 ± 0.088 Ma (former B tuff, Figs. 4.2b, 4.6a; Morgan et al. 2012). Both tuffs are of reverse polarity (Westphal et al. 1979; Cressier 1980).

The lithic assemblage from level B (176 artifacts and 295 unworked objects) was analyzed in its entirety (Table 4.1). The artifacts are very fresh, whereas the unworked materials are very abraded. Accordingly, the hominins left artifacts on a lag deposit winnowed by fluvial agents (Gallotti et al. 2014; Fig. 4.6b–d).

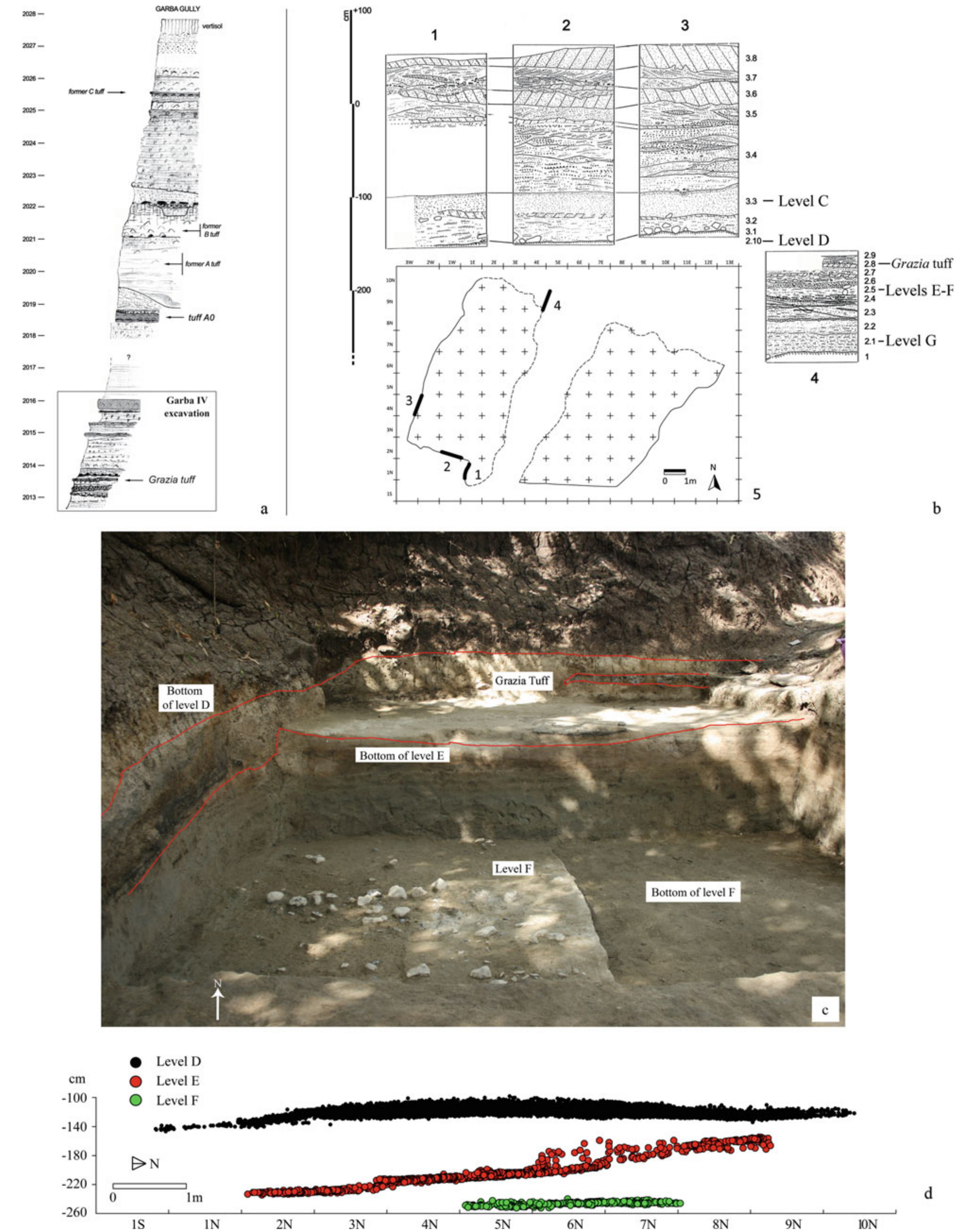

Fig. 4.3 **a** Stratigraphic position of Garba IV at the bottom of the Garba gully. **b** Lithostratigraphy of the Garba IV site. **c** Garba IV during the 2009 excavations. **d** S-N projections of lithic artifacts and faunal remains

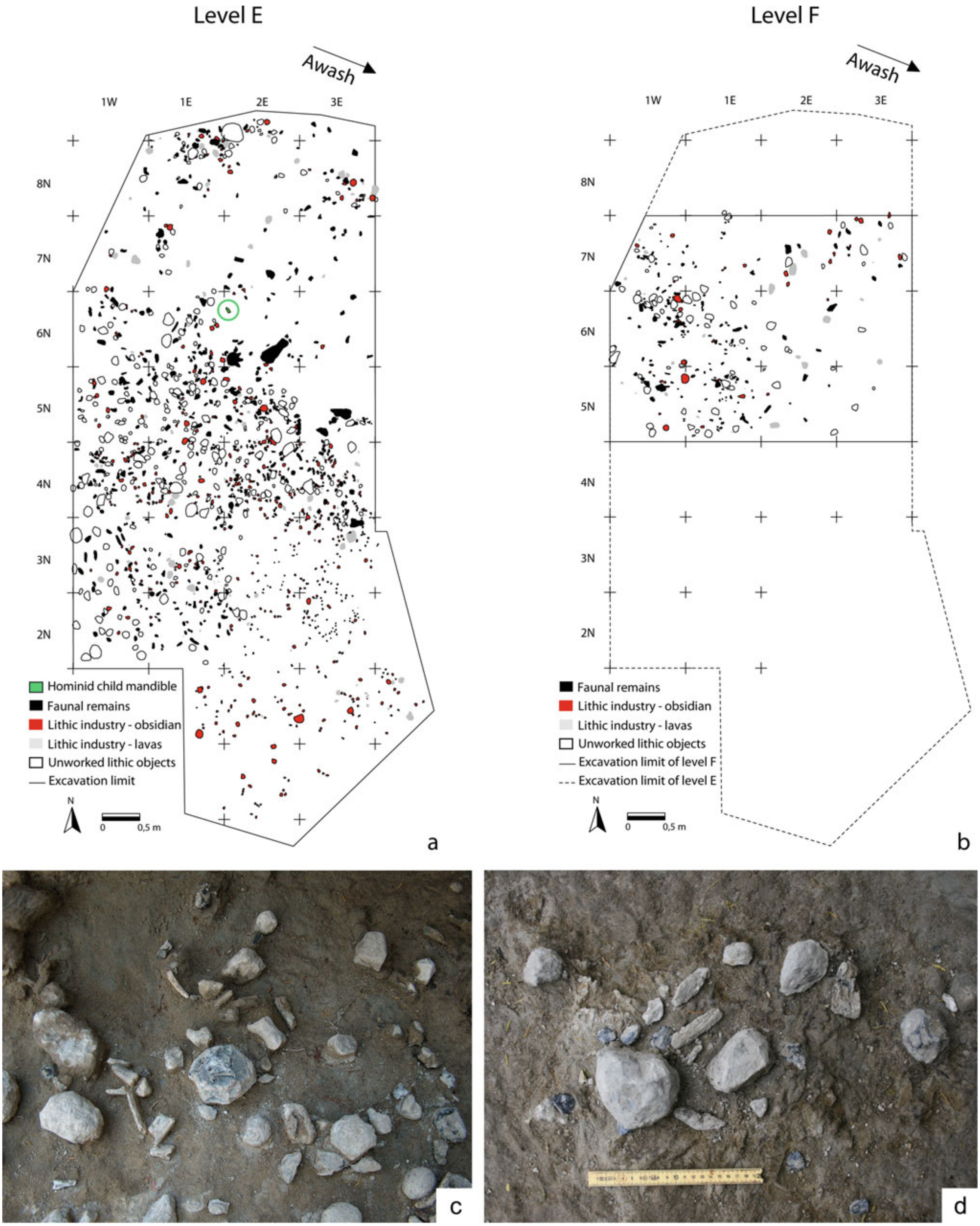

Fig. 4.4 Garba IVE-F. Horizontal maps and details of the excavation of layers E (**a**, **c**) and F (**b**, **d**)

Table 4.1 Components of the worked and unworked assemblages from Garba IVE-D, Garba XIIIB, and Gombore II OAM

Components		Garba IVE-F		Garba IVD		Garba XIIIB		Gombore II OAM	
		N	%	N	%	N	%	N	%
Cores		92	*8.2*	1816	*26.0*	32	*18.2*	35	*14.5*
Core fragments		9	*0.8*	107	*1.5*	0	*0*	0	*0*
Small flakes (<1 cm for Garba IVE-F, <2 cm for the others)		294	*26.1*	188	*2.7*	12	*6.8*	0	*0*
Broken flakes		158	*14*	874	*12.5*	0	*0*	0	*0*
Flakes		295	*26.3*	2508	*35.9*	79	*44.9*	109	*45.0*
Retouched flakes		74	*6.6*	193	*2.8*	1	*0.6*	5	*2.1*
Large flakes (>10 cm)		0	*0*	41	*0.6*	0	*0*	2	*0.8*
LCTs	*Bifaces*	0	*0*	0	*0*	18	*10.2*	58	*24.0*
	Cleavers	0	*0*	2	*0.03*	8	*4.5*	7	*2.9*
	Massive scrapers	0	*0*	21	*0.27*	0	*0*	0	*0.0*
Twisted bifaces		0	*0*	0	*0*	0	*0*	24	*9.9*
Indeterminable fragments		203	*18*	1151	*16.5*	26	*14.8*	0	*0*
Percussion elements		0	*0*	85	*1.2*	0	*0*	2	*0.8*
Total of the worked material		**1125**	***100***	**6986**	***100***	**176**	***100***	**242**	***100***
Angular items	*Small elements*	133	*22.8*	289	*14.2*	86	*29.2*	36	*24.0*
	Angular elements	71	*12.2*	400	*19.6*	94	*31.9*	17	*11.3*
	Small blocks	5	*0.8*	58	*2.8*	11	*3.7*	1	*0.7*
	Blocks	7	*1.2*	10	*0.5*	0	*0.0*	2	*1.3*
Rounded items	*Pebbles*	74	*12.7*	82	*4.0*	28	*9.5*	24	*16.0*
	Cobbles	279	*47.7*	1150	*56.3*	74	*25.1*	67	*44.7*
	Large cobbles	15	*2.6*	53	*2.6*	2	*0.6*	3	*2.0*
Total of the unworked material		**584**	***100***	**2042**	***100***	**295**	***100***	**150**	***100***

4.3.3 Gombore II OAM (~0.85 Ma)

Gombore II OAM, located in the Gombore gully at a distance of 400 m from the sites discussed above, is one of several sectors that were excavated in the same archaeostratigraphic unit (Figs. 4.1b, 4.7a). It lies above a tuff dated to 0.875 ± 0.010 Ma, 5 m below another tuff unit dated to 0.709 ± 0.013 Ma (Figs. 4.2b, 4.7c; Raynal et al. 2004; Morgan et al. 2012; Mussi et al. 2016) and belongs to the upper part of the Matuyama chron (Tamrat et al. 2014). This sector was chosen to become an open-air exhibit where visitors can see 35 exposed square meters of the archaeological surface, with its various materials still in place (Chavaillon and Piperno 2004; Gallotti et al. 2010).

A 2-m-high section located at the northwest end of the Gombore II OAM excavation has been described in detail (Raynal et al. 2004; Gallotti et al. 2010). The archaeological level is a thin clast-supported pebble bed, 0.10 m thick, which was once part of a paleochannel. In the section it looks like a row of stones containing many artifacts and bones. Where the surface of this unit is exposed, we see that the components are imbricated and graded by kinetic sieving (e.g., smaller items such as obsidian bifaces stand upright in gaps between larger items). In mid-channel, items from the archaeological level float in bedded sands, thereby demonstrating the mixed history of the archaeological surface. Large flat artifacts and long bones are clearly oriented, indicating that the current mainly flowed ENE.

The archaeological level contains unworked and knapped lithic objects as well as faunal remains, all present in high densities (Fig. 4.7b, d, e).

The assemblage, originally on a channel bank, was eventually partly displaced, concentrated and reoriented by the stream flow, a process that was probably repeated several times. This layer can be described as an ancient alluvial deposit. The lithic assemblage extracted from the exposed surface consists of 242 artifacts and 150 unworked pieces (Table 4.1; Gallotti et al. 2010; Gallotti and Mussi 2017).

The nearby Gombore II1 exposure, which belongs to the same archaeostratigraphic unit (Fig. 4.7a; 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 flows through the excavation area. Profico et al. (2016) conclude that the hominins from whom these specimens came are likely to be recognized as ancestors of *Homo heidelbergensis* in sub-Saharan Africa.

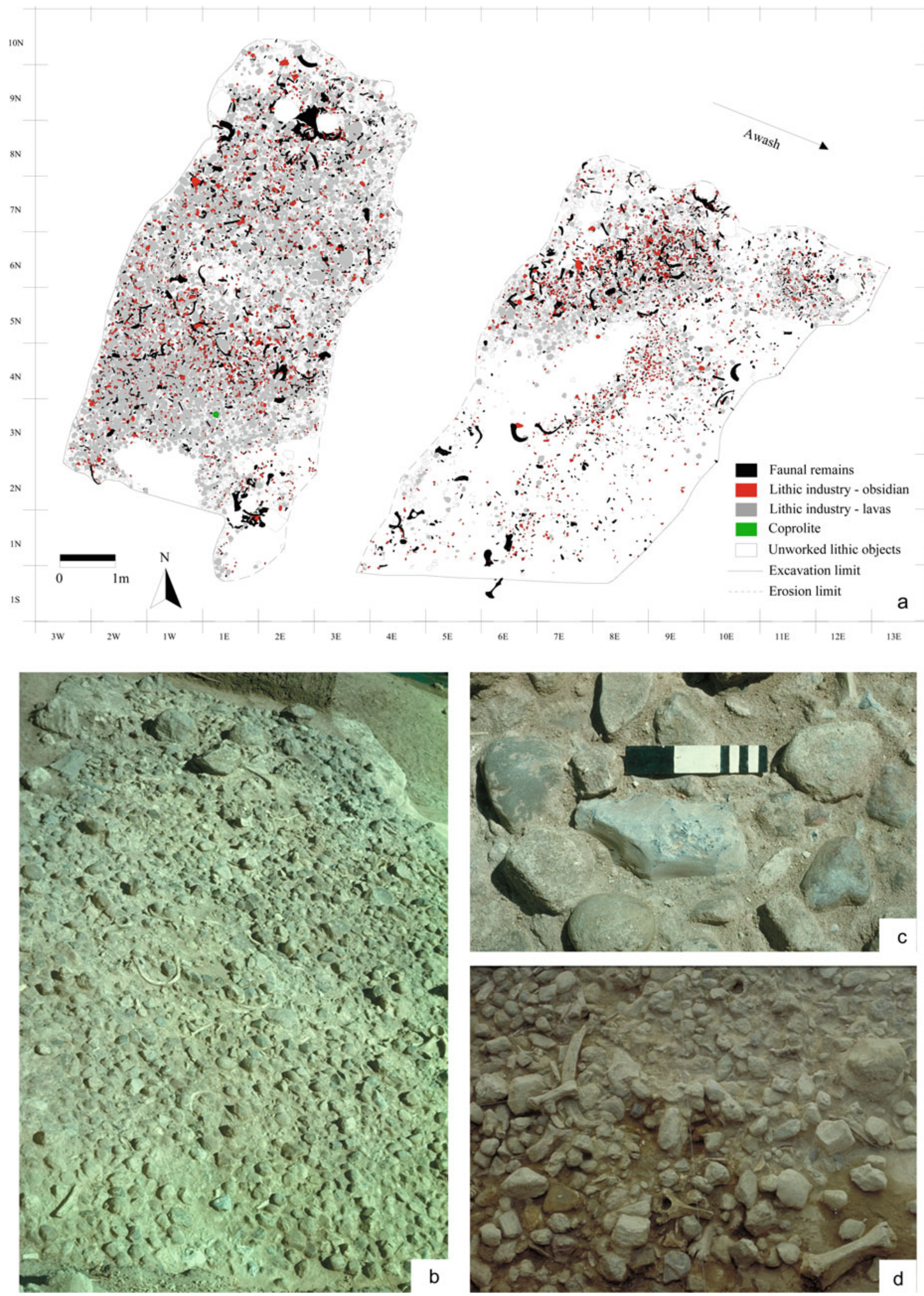

Fig. 4.5 Garba IVD. Horizontal map (**a**) and details of the excavation (**b**–**d**) of layer D. The middle part of the deposit is eroded

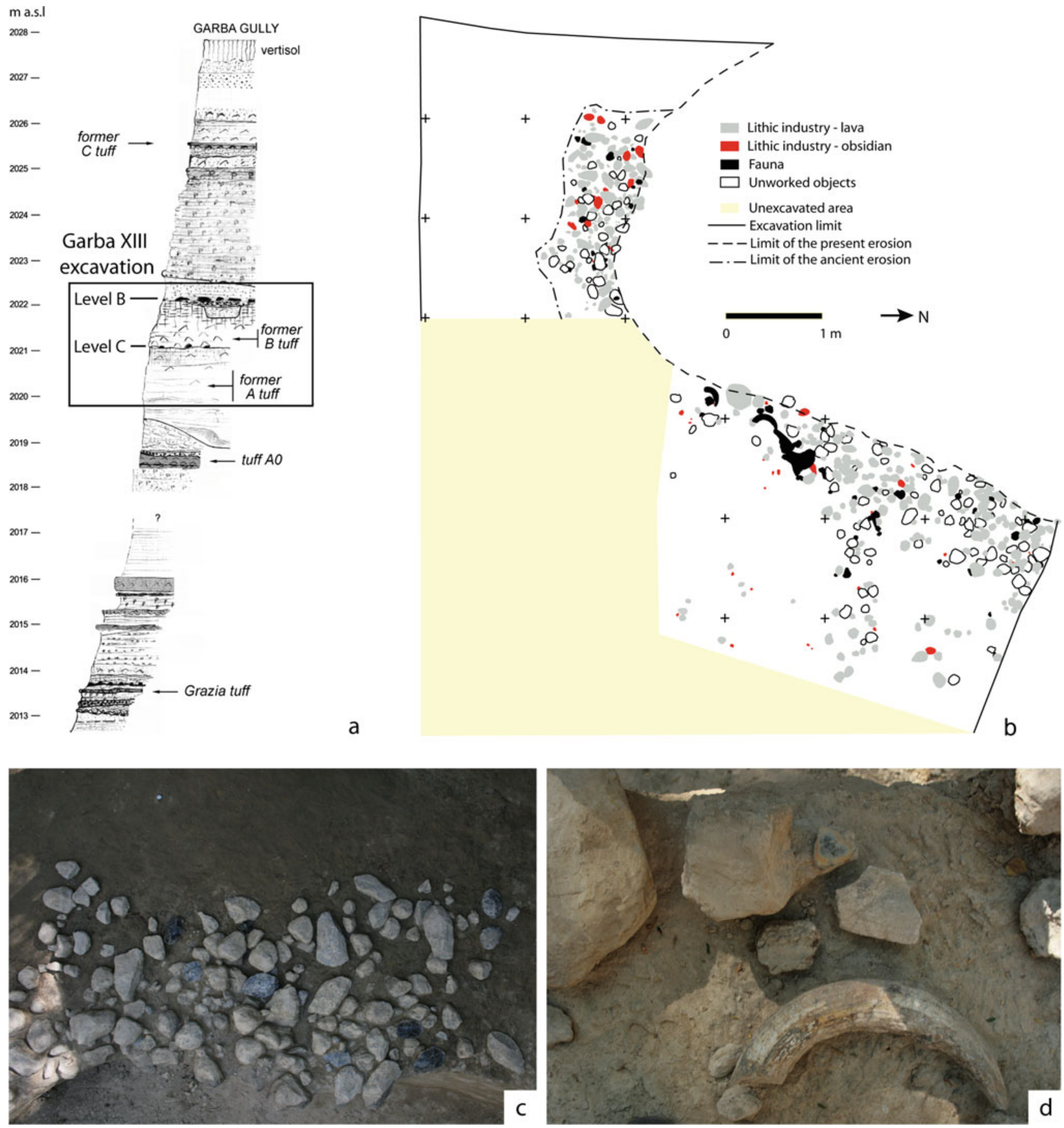

Fig. 4.6 Garba XIIIB. **a** Stratigraphic position of Garba XIII along the Garba gully. **b** Horizontal map of layer B. **c**–**e** Details of the excavation of layer B

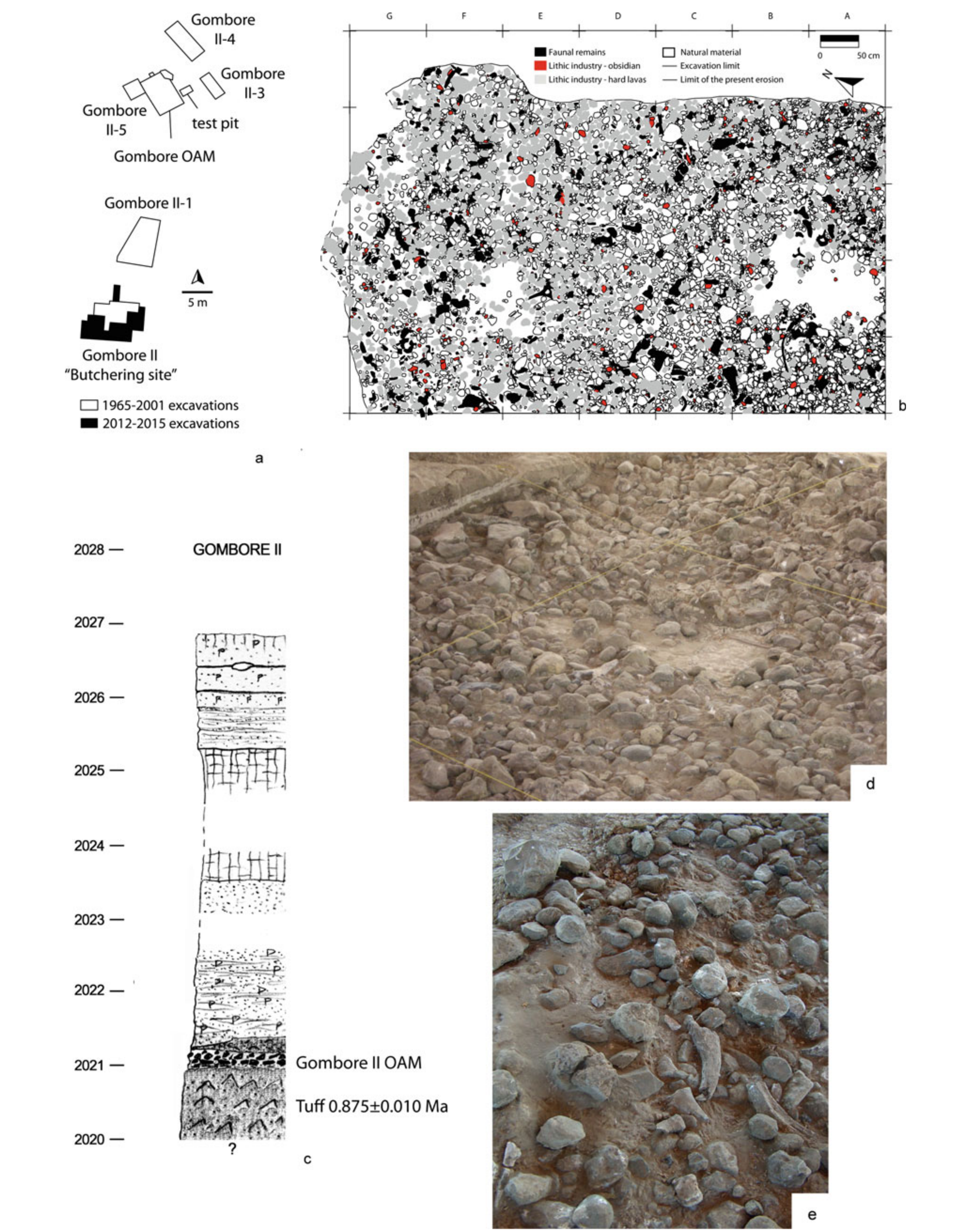

Fig. 4.7 Gombore II. **a** Excavation sectors. **b** Horizontal map of Gombore II OAM. **c** Stratigraphic position of Gombore II OAM along the Gombore II gully. **d**–**e** Details of the excavation of Gombore II OAM

4.4 Availability of Raw Materials

The raw materials available in the Melka Kunture region are of volcanic origin. Some aphyric, porphyritic, and micro-doleritic rocks were identified in the alluvial deposits of the Awash River and its tributaries, together with Melka Fault lava, different kinds of welded and non-welded ignimbrites and obsidian (Table 4.2; Kieffer et al. 2002, 2004; Gallotti and Mussi 2017). The lithological and morphometric composition of the Early Pleistocene alluvial deposits is very similar to that of the archaeological sites (Gallotti and Mussi 2017).

Table 4.2 Lithotypes identified in old alluvial deposits of the Melka Kunture region

Lithotype	Grain size and homogeneity	Knapping suitability		Primary sources	Secondary sources	Description
		Hard hammer	Soft hammer			
Obsidian	Very fine-grained, compact, and homogeneous	****	*****	Melka Kunture region Angular elements and fragments widely distributed across the paleolandscapes as products of erosion and redeposition from the primary source	Pebbles and cobbles in low frequencies	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	****	**	Known source at 26 km NE and 45 km SW of Melka Kunture	Pebbles, small elements, angular elements and cobbles in high frequencies Large cobbles and blocks are exceptional	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 gray-blue color. They seldom have more than 50% of SiO_2, and accordingly are fairly fluid at eruption temperature
Differentiated aphyric to subaphyric lavas	Fine-grained, rather compact and homogeneous with few small crystals	***	**	Known source at 26 km N-E and 45 km S-W of Melka Kunture	Pebbles, small elements, angular elements and cobbles in medium frequencies	Aphyric and subaphiric differentiated lavas are trachytes or rhyolites (60/70% of SiO_2) 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	***	**	Melka Kunture region	Angular elements and cobbles in high frequencies Large cobbles and blocks are not frequent	Aphyric fluidal lava, related to the limit-fault (south/southeast) of Melka Kunture Basin, is particularly abundant. This gray to blue facies resembles the benmoreite (similar to alkaline trachytes, with 62/65% of SiO_2). 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	*	*			

(continued)

Table 4.2 (continued)

Lithotype	Grain size and homogeneity	Knapping suitability		Primary sources	Secondary sources	Description
		Hard hammer	Soft hammer			
Porphyritic basalts	Fine-grained, rather compact and homogeneous with large crystals	***	**	Melka Kunture region	Angular elements, cobbles and large cobbles in low frequencies	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	***	**	Melka Kunture region	Angular elements and cobbles in low frequencies Large cobbles and blocks exceptional	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	****	****	Known sources 15–20 km north and south from Melka Kunture	Pebbles, small elements, angular elements and cobbles in low frequencies	Microdoleritic basalts display a fine-grained and gray 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 kilometers northeast from Awash village)
Trachybasalt	Fine-grained, compact, and rather homogeneous with crystals	***	**	Unknown	Pebbles, small elements, angular elements and cobbles in low frequencies or absent	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	**	*	Unknown	Pebbles, small elements, angular elements and cobbles in very low frequencies or absent	Mesocratic lava, lighter than the basalts, usually with numerous large phenocrystals of alkaline feldspaths
Welded ignimbrite n.1	Coarse-grained, inhomogeneous, and even compact	*	*	Melka Kunture region	Pebbles, small elements, angular elements and cobbles in high frequencies Few large cobbles and blocks	Welded ignimbrite, which probably originally extended over hundreds of km^2, 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

(continued)

Table 4.2 (continued)

Lithotype	Grain size and homogeneity	Knapping suitability		Primary sources	Secondary sources	Description
		Hard hammer	Soft hammer			
Other types of ignimbrites and ignimbritic tuff	Coarse-/fine-grained, inhomogeneous and even compact	*	*	Melka Kunture region	Pebbles, small elements, angular elements and cobbles in very low frequencies or absent	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 pyroclastic flows emitted during peralkaline rhyolitic (pantelleritic) syn-rift eruptions
Obsidian lavas	Fine-grained, homogeneous and more or less compact	***	***	Melka Kunture region	Pebbles, small elements, angular elements and cobbles in low frequencies or absent Very few blocks	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	*****	*****	Unknown	Exceptional small elements and pebbles	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	*****	*****	Unknown	Exceptional small elements and pebbles	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)

The closest known primary source of obsidian is Balchit, 7 km north of the Awash (Fig. 4.1b). Balchit—the name means "obsidian" in Amharic—is a flat dome flow aged 4.37 ± 0.07 Ma (Chernet et al. 1998), that outcrops today over an area of about 4 km^2 (Salvi et al. 2011). This obsidian flow can be seen in situ on the Jimjima plateau, and near a village that is likewise named Balchit (Fig. 4.8a). Pure and massive obsidian amygdales up to 1 m long are scattered among the weathered rocks (Fig. 4.8b, c). This obsidian is mainly black. It breaks easily (the fracture is conchoidal), producing more or less translucent flakes with excellent cutting edges. The analysis of 12 obsidian samples from Balchit, two obsidian samples from alluvial deposits (Poupeau et al. 2004; Le Bourdonnec 2007) and 10 obsidian artifacts from Gombore I, Gombore II and Garba IV (Negash et al. 2006) showed that they all had the same chemical composition. Angular pieces of obsidian eroded from the primary source lie on the ground near the outcrop (Fig. 4.9a, b). Rounded pieces, i.e., pebbles and cobbles, have been found in small percentages in paleochannels (Fig. 4.9c); blocks are rare (Fig. 4.9d; Piperno et al. 2009; Salvi et al. 2011).

Obsidian lava, which differs from true obsidian, was produced by quick cooling, as at the base of some welded ignimbrites. Vitrification is more or less developed, and accordingly the rock is fine-grained and more or less compact. Obsidian lava is sparsely represented in ancient alluviums; the most frequent forms are small to large cobbles (Gallotti and Mussi 2017).

Welded ignimbrite cobbles, angular pieces, and blocks are widely distributed in the ancient alluvial deposits. This type of rock is easily recognizable all over the area. It was produced during a major eruption and probably originally extended over hundreds of km^2 (Fig. 4.8d–e; Kieffer et al. 2002, 2004). It is not suitable for knapping and was never used by hominins in lithic percussion (Gallotti and Mussi 2017).

Aphyric rocks—fine-grained, homogeneous, and compact, with few or no small crystals—are abundantly available. They can be found in alluvial deposits, mainly in the form of medium-sized angular, elongated and spherical cobbles; large forms are rare. Though they are abundant in secondary sources, no primary sources have yet been discovered close to the archaeological sites (Kieffer et al. 2002, 2004; Gallotti and Mussi 2017). The closest primary sources are in the many pre-rift flows of the Addis Ababa and Guraghe–Anchar basalts, respectively, 26 km NE and 45 km SW of Melka Kunture (Abebe et al. 2005).

Conversely, Melka Fault lava is related to the limit-fault (SSE) of the Melka Kunture Basin. A so-called lava lake structure outcrops 500 m upstream from the places where the Atebella and Balchit creeks flow into the Awash (Figs. 4.1b, 4.8f). Accordingly, it was abundant in the paleolandscape, mainly in a vesciculated facies, less frequently in a compact facies (Kieffer et al. 2002, 2004). Despite its typical fluidic texture, this lava is very compact, but it often contains oriented vesicles (vesciculated facies). In the paleochannels, the compact facies is less frequent than the vesciculated one, but it is the only one that was used by knappers. It is available mainly as angular cobbles; large forms (mainly blocks) are more abundant than is the case with other aphyric rocks (Gallotti and Mussi 2017).

Porphyritic rocks—fine-grained, rather compact and homogeneous, but containing large crystals—are found in low percentages in the alluvial deposits, mainly in the form of medium-sized and large cobbles. In the Wutale area, some 2.5 km southwest of the Garba gully (Fig. 4.1b), porphyritic and vesicular lavas with large plagioclase crystals have been observed in primary position (Raynal and Kieffer 2004). Porphyritic lava also outcrops in the Boti and Guraghe volcanic areas west and south of Melka Kunture.

Microdoleritic basalts are very fine-grained, very compact and homogeneous rocks containing microcrystals. The outcrops are 15–20 km north and south of Melka Kunture, where they are fragmented by erosion into very large blocks and are easily recognizable (Fig. 4.8g). Microdoleritic basalts are found in very low numbers in secondary sources, mainly in small or medium-sized rounded forms (Kieffer et al. 2002, 2004; Gallotti et al. 2010; Gallotti and Mussi 2017). The other rocks listed in Table 4.2 are only rarely discovered.

4.5 Techno-economic Behaviors

4.5.1 Production of Small- and Medium-Sized Flakes at Garba IVE-F, ~1.7 Ma

Knapping activities documented in levels E-F at Garba IV focused solely on the production of small or medium-sized flakes (Table 4.1). All stages of the chaînes opératoires are present in both levels. Our comparative analysis of the Garba IVE and Garba IVF series showed very similar technical patterns. Accordingly, the two series are analyzed jointly with no stratigraphic subdivision (Gallotti and Mussi 2015).

Obsidian, present in low percentages in unworked material, accounts for 79.4% of the artifacts in level E and 86.7% in level F (Fig. 4.10a); this indicates that knappers selected it intentionally. Lavas suitable for knapping are abundant in the unworked assemblage (Fig. 4.11), but obsidian pebbles and cobbles are the most frequently exploited lithic resources in both levels E and F.

The cores exploited for small- to medium-sized flake production can be grouped in two technologically significant sets. The first set corresponds to a type of débitage described by Delagnes and Roche (2005) as "simple"; it consists of items that have few unorganized flake scars. The second set, which is quantitatively and qualitatively more significant, comprises cores that show organized and structured exploitation patterns (Delagnes and Roche 2005). Omitting core fragments, the flake-to-core ratio[2] is 5.7:1, which is not consistent with the average number of removal scars observed on the cores. Moreover, most of these cores were intensively exploited, and most of the flakes have a large number of removal scars on their dorsal face, which suggests that the count of detached pieces does not reflect the number of flakes that were originally obtained from the cores.

Five organized débitage methods have been identified in this level (Gallotti and Mussi 2015; Fig. 4.10b):

[2]Flakes include whole, broken, and retouched flakes of small-medium dimensions, i.e., with length or width <10 cm.

Fig. 4.8 **a** Obsidian outcrop at Balchit. **b–c** Obsidian blocks among weathered rocks. **d** Welded ignimbrite at Atebella. **e** Non-welded ignimbrite overlying welded ignimbrite with large columnar jointing. **f** Lava lake structure 500 m downstream from the confluence of the Atebella and Balchit creeks. **g** Large blocks of microdoleritic basalt scattered on the ground 15 km north of the Melka Kunture area

- Unifacial unidirectional. The flaked surface is the convex face of the cobble and is located either on the transversal or longitudinal plane of elongated and spherical cobbles, or on the sagittal plane of flat cobbles. A flaked surface on the sagittal/longitudinal plane (i.e., on the blank's longest natural convex face) strongly suggests an intention to produce elongated products. The striking platform is a flat natural surface or a platform rectified by removals to create a suitable angle (Fig. 4.12: A–E). The corresponding flakes show a unidirectional removal-scar pattern. These flakes are more elongated than the other whole flakes and show a different

Fig. 4.9 **a–b** Angular pieces of obsidian lying on the ground near the outcrop. **c** Obsidian pebbles and cobbles in an ancient alluvial deposit. **d** Obsidian block in an ancient alluvial deposit

flake-scar pattern on the dorsal face. Although several flakes show a backed lateral and/or distal edge, long portions of the edges are sharp and suitable for cutting (Fig. 4.12: F–J).

- Peripheral unidirectional. A peripheral flaking surface exploits the whole or nearly whole thickness of the cobbles by detaching several generations of flakes, resulting in short and wide/thick cores. The natural striking platform corresponds to the flat surface of plano-convex cobbles or to a surface rectified by few removals (Fig. 4.12: K). The angle of interaction between the striking and flaking surfaces is abrupt. Flakes produced from these cores show technical patterns similar to those of flakes produced from unifacial unidirectional cores.
- Partial bifacial. This method exploits the core by unidirectional removals on two adjacent surfaces. Each removal scar is used alternatively as a striking platform to flake the adjacent plane. The resulting flakes are short and wide and have plain or dihedral butts (Fig. 4.12: L).
- Centripetal. Centripetal/tangential exploitation is usually performed on one flaking surface from a cortical peripheral platform (Fig. 4.12: O) or from a striking platform rectified by a few removals (Fig. 4.12: M). There is no management of volume or convexity configurations, no recurrence or preparation, and no hierarchy. This method seeks to achieve the best solution for exploiting (sub)spherical cobbles. Only one core shows bifacial centripetal exploitation of a blank consisting of a thick flake (Fig. 4.12: N). The flakes produced by this method are circular, triangular or sub-quadrangular with centripetal or tangential removals on the dorsal face. The butts are natural, plain, dihedral or rarely facetted, wide and thick, and the flaking angle is generally obtuse (Fig. 4.12: P–Q).

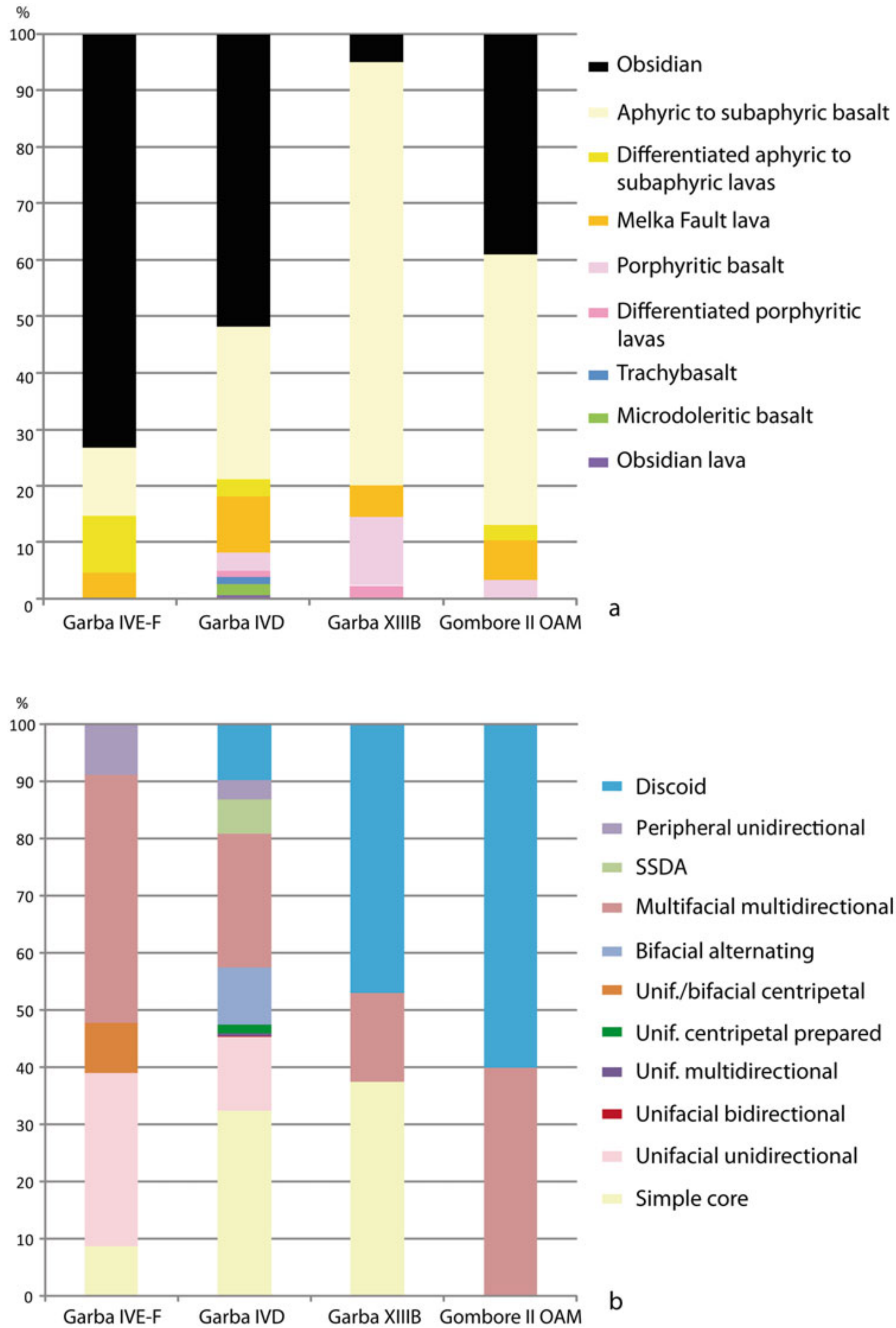

Fig. 4.10 **a** Lithological composition of the small- and medium-sized flake tools. **b** Frequency of the small débitage methods identified in the assemblages studied

- Multifacial multidirectional irregular. This method was used on most of the cores. The core surfaces were alternately flaked with multidirectional removals with no clear organization of the reduction process (Fig. 4.12: R–S). Nevertheless, some cores attest to the knapper's attempt to maintain an orthogonal organization during flaking (Fig. 4.12: U). Moreover, a few cores have long unidirectional flake scars on their major flaked surfaces, which were exploited at the beginning of the reduction process, and multidirectional removals on their other faces, which correspond to the final core reduction phase, when the main flaking surfaces were probably no longer functional (Fig. 4.12: T). No specific platform preparation was carried out, because each removal scar served as

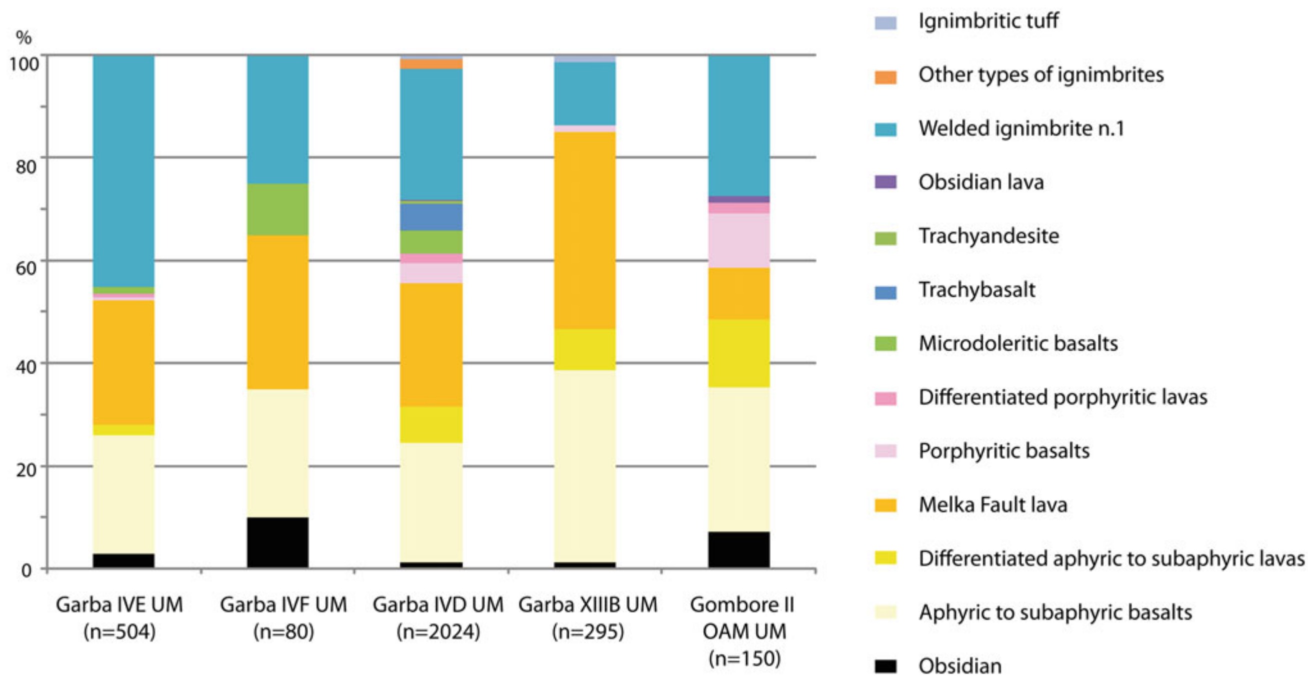

Fig. 4.11 Lithological composition of the unworked materials (UM) found at the analyzed sites

a striking platform for the next removal on a secant face. The flakes thus produced have various shapes. They are frequently short, with thick, asymmetrical cross-sections. The multiple removal scars on the dorsal face have irregular or perpendicular directions (Fig. 4.12: V–X, b–d). A few flakes present one or two series of unidirectional flake scars together with multidirectional removal scars, which are correlated with the multifacial multidirectional cores with one preferred unidirectional flaking surface (Fig. 4.12: e, Y). The percentage of core-edge flakes is high, which implies continuous rotation of the flaking surfaces (Fig. 4.12: Z–a, f).

A relatively large percentage of the whole obsidian flakes are retouched (31%). They can be grouped in two sets. The first one, identified only in level E, consists of flakes (n = 32) whose edges were modified by continuous retouch, ranging from marginal to invasive, that modified one or two edges. The resulting tools display considerable dimensional and morphological variability (Gallotti and Mussi 2015). Most blanks are first flakes (opening flakes), or flakes with natural residual parts on the dorsal face (Fig. 4.13: L, N), or core-edge flakes (Fig. 4.13: M).

The second set (41 tools) displays a retouch process aimed specifically at producing a small point by modifying the distal part of the blank. The percussion axis may or may not correspond to the morphological axis. The point is produced in different ways: (a) by two or more notches on two convergent edges (Fig. 4.13: B, C, F, I, J); (b) by one or more notches opposite a retouched edge (Fig. 4.13: A, K); (c) by one or more notches opposite a (natural) back (Fig. 4.13: G, H); (d) by a retouched edge opposite a back (Fig. 4.13: E); or (e) by a convergent side-scraper (Fig. 4.13: D).

Accordingly, what we are seeing here is some degree of standardization. By the term “standard product” we mean a product that conforms to specifications resulting from the same technical requirements (Daniel and Lapedes 1978; Gallotti and Mussi 2015). In the small pointed tools found at Garba IVE-F, standardization is expressed by (a) the repetitive aim to shape the distal portion of the flake into a tip; (b) the repetitive aim to create a convergence, either by modifying both edges or by modifying one edge and using the technical properties of the other edge; and (c) recurrent efforts on the knappers’ part to achieve a small and homogeneous size.

Intentional behavior is further proved by (a) hundreds of whole small flakes (<1 cm) found in the same levels but clearly distinct from natural or knapped fragments of the same size; (b) the lack of any bipolar technique on anvil, which is often responsible for pseudo-retouching (de la Torre and Mora 2005; Zaidner 2013); (c) the similar technical marks left by retouch on both lava and obsidian flakes in more recent Melka Kunture assemblages (Gallotti 2013); (d) the lack of any evidence of bioturbation or trampling in the deposit (Raynal et al. 2004).

In brief, the unusually high number of retouched and often pointed tools found at Garba IVE-F is not the outcome of any natural process that altered their edges (Gallotti and Mussi 2015).

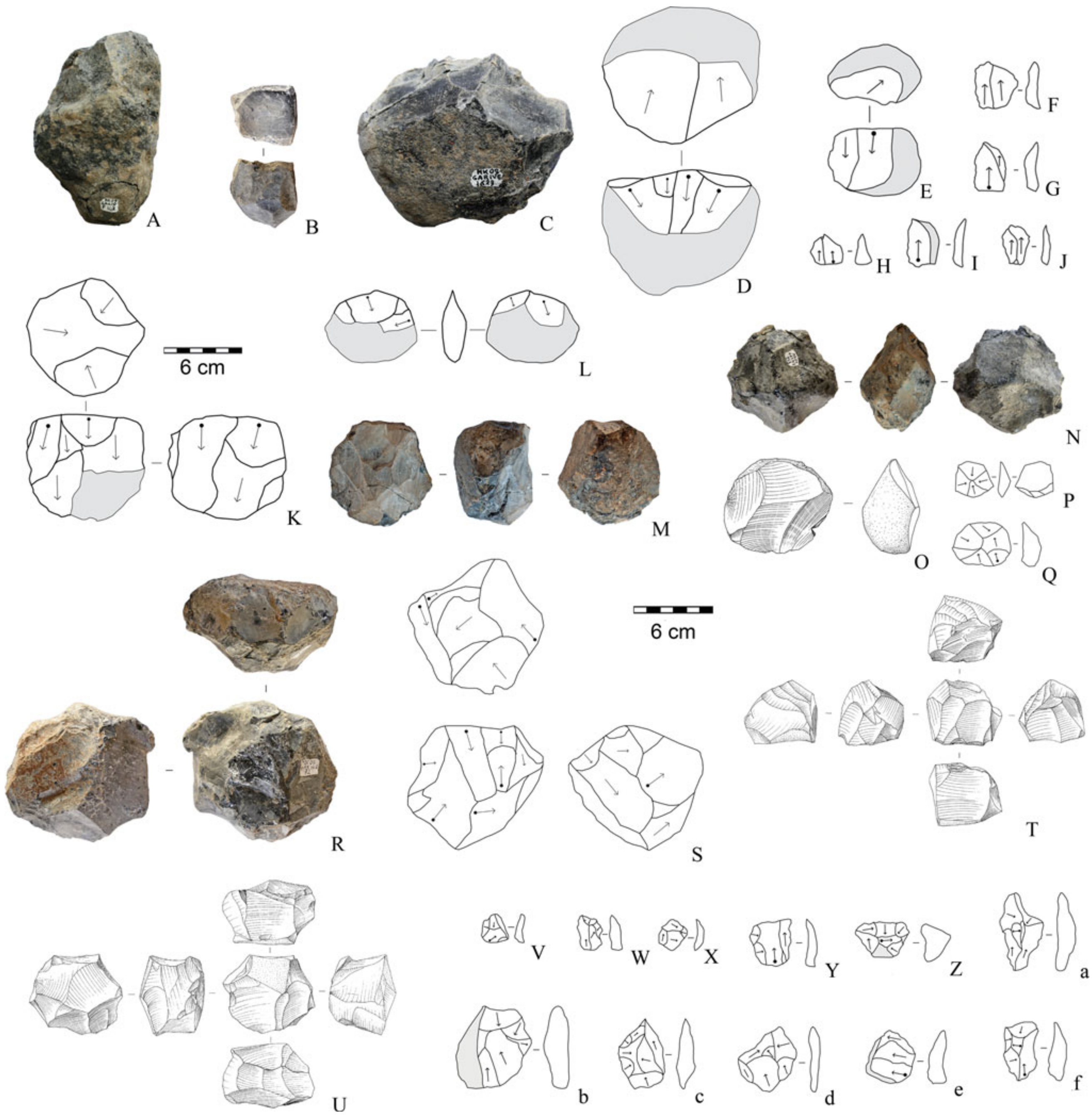

Fig. 4.12 Garba IVE-F. **A**–**E**: unifacial unidirectional cores (**A**–**C**, **E**: OBS; **D**: MFL). **F**–**J**: flakes with unidirectional removal scars on the dorsal face (OBS). **K**: peripheral unidirectional core (OBS). **L**: partial bifacial core (MFL). **M**–**O**: centripetal/tangential cores (OBS). **P**, **Q**: flakes with centripetal/tangential removal scars on the dorsal face (OBS). **R**–**S**: irregular multifacial multidirectional cores (OBS). **T**: multifacial multidirectional cores with major unidirectional flaking surfaces (OBS). **U**: orthogonal multifacial multidirectional core (OBS). **V**, **W**, **b**, **c**: flakes with irregular multidirectional removal scars on the dorsal face (**b**: ASB; **V**, **W**, **c**: OBS). **X**–**Y**, **d**–**e**: flakes with orthogonal removal scars on the dorsal face (OBS). **Z**–**a**, **f**: core-edge flakes with multidirectional removals (OBS). ASB: aphyric to subaphyric basalt. MFL: Melka Fault lava. OBS: obsidian. **O**, **T**–**U**: drawings by M. Pennacchioni

4.5.2 Production of Small- and Medium-Sized Flakes at Garba IVD, ~1.6 Ma

All the steps in the small débitage chaînes opératoires, representing the main knapping activities, are documented at Garba IVD. With a flake-to-core ratio of 2:1, the number of flakes is very low compared to the number of negative scars on both cores and flakes. As in the case of Garba IVE-F, the flakes correspond to all the flaking stages and methods identified in core analysis. Accordingly, the flake deficit is the outcome of post-depositional processes (Figs. 4.14, 4.15; Raynal et al. 2004; Gallotti 2013).

The most exploited raw materials are obsidian and aphyric rocks (Fig. 4.10a). Aphyric rocks are also abundant in the unworked assemblage, while obsidian, as noted above, is very scarce (Fig. 4.11). Medium-sized angular forms are the most frequently exploited blanks. This is clearly shown by a certain number of first flakes whose thick triangular cross-section is produced by two flat faces of the natural blank (Fig. 4.15: A). Medium-sized elongated and spherical obsidian cobbles were also used frequently. Conversely, in the available unworked assemblage from the site, obsidian cobbles are present only in low percentages, which shows that the available obsidian was exploited intensely. Knappers probably also collected this raw material in the nearby alluvial deposits. They also flaked angular pieces of obsidian, which are not found in the alluvial deposits but are abundantly scattered on the ground near the Balchit outcrop (Gallotti and Mussi 2015; Fig. 4.1b). Therefore, the knappers must have collected angular obsidian rocks at a distance of 5–7 km from the site, or maybe from closer by if the primary source was more extended ~1.6 Ma than it is today, and/or was less covered by the subsequent accumulation of fluviolacustrine and volcanic deposits (Gallotti 2013).

Small débitage is the outcome of several exploitation methods. The ones identified at Garba IVD are the following: simple, unifacial uni/bi/multidirectional, peripheral unidirectional, alternating bifacial, multifacial multidirectional, alternating débitage surface system, or SSDA (Système par Surface de Débitage Alternée; Forestier 1992, 1993), prepared unifacial centripetal and discoid[3] (Figures 4.10b, 4.14; Gallotti 2013).

The choice of a specific method was influenced by the geometry of the raw materials and by the knappers' technical purposes. The peripheral unidirectional, SSDA, and multifacial multidirectional irregular exploitation methods all suggest that the knappers found solutions adapted to the cobbles' natural morphology, in order to maximize the production of flakes without pursuing any preferred exploitation pattern.

A peripheral flaking surface makes it possible to exploit nearly the whole thickness of plano-convex cobbles by means of unidirectional removals, thereby producing short and wide/thick cores. A flat surface on the cobble is used as striking platform (Fig. 4.14: J). The angle of interaction between the striking and flaking surfaces is abrupt. The number of detached flakes is high (average: 17), because knappers exploited the same surface again and again.

The SSDA cores found here, all of which are of lava rocks, have three to four flaked surfaces. They are produced by unidirectional removals from angular cobbles that have both flat and convex surfaces. During flaking, the cobble is rotated continuously, in order to follow the orthogonal angles from one face to the next. The first striking platform is a natural face; thereafter, each flaked surface becomes the striking platform of the adjacent face (Fig. 4.14: M). The flakes display unidirectional removals on adjacent orthogonal faces that are, respectively, the dorsal face and the distal face (Fig. 4.15: K), or lateral edges.

In several cases, edge-core flakes indicate that the knapper was seeking new angles so as be able to continue to exploit exhausted irregular multifacial multidirectional SSDA cores (Fig. 4.15: I, L).

Most cores are irregular, multifacial and multidirectional. The flakes produced from them vary in shape; they are frequently short with thick, asymmetrical cross-sections (Fig. 4.14: N, P; Fig. 4.15: D, F–G). Many are core-edge flakes produced with continuous rotation of the core. The removals sometimes follow orthogonal directions (Fig. 4.15: J). The cores are typically small and overexploited. The largest ones (n = 14) have a major flaked surface, displaying long unidirectional flake scars, that was exploited at the beginning of the reduction process. The other core faces bear evidence of the multidirectional removals made in the final reduction phase (Fig. 4.14: O). On the dorsal face of the resulting flakes there are one or two series of unidirectional flake scars and multidirectional removal scars (Fig. 4.15: E, H).

Cores that show evidence of unifacial unidirectional exploitation are mainly on elongated cobbles. In a few cases, the removals are bi- and multidirectional (Fig. 4.14: H). The knappers chose the longest available convex face to produce elongated flakes (Fig. 4.14: A–F; Fig. 4.15: B–C). In elongated cobbles, the striking platform had to be rectified in order to create a suitable angle and begin the débitage. With angular cobbles, the flaked surface is the convex face of the cobble, and a flat natural surface is used as striking platform, with no rectification. Sometimes such cores were also retouched, and in these rare cases a continuous uni- or bifacial retouch is located on the transversal edge of a plano-convex cobble at an angle close to 75°. This

[3]The term discoid corresponds to the discoid concept, as defined by Boëda 1993.

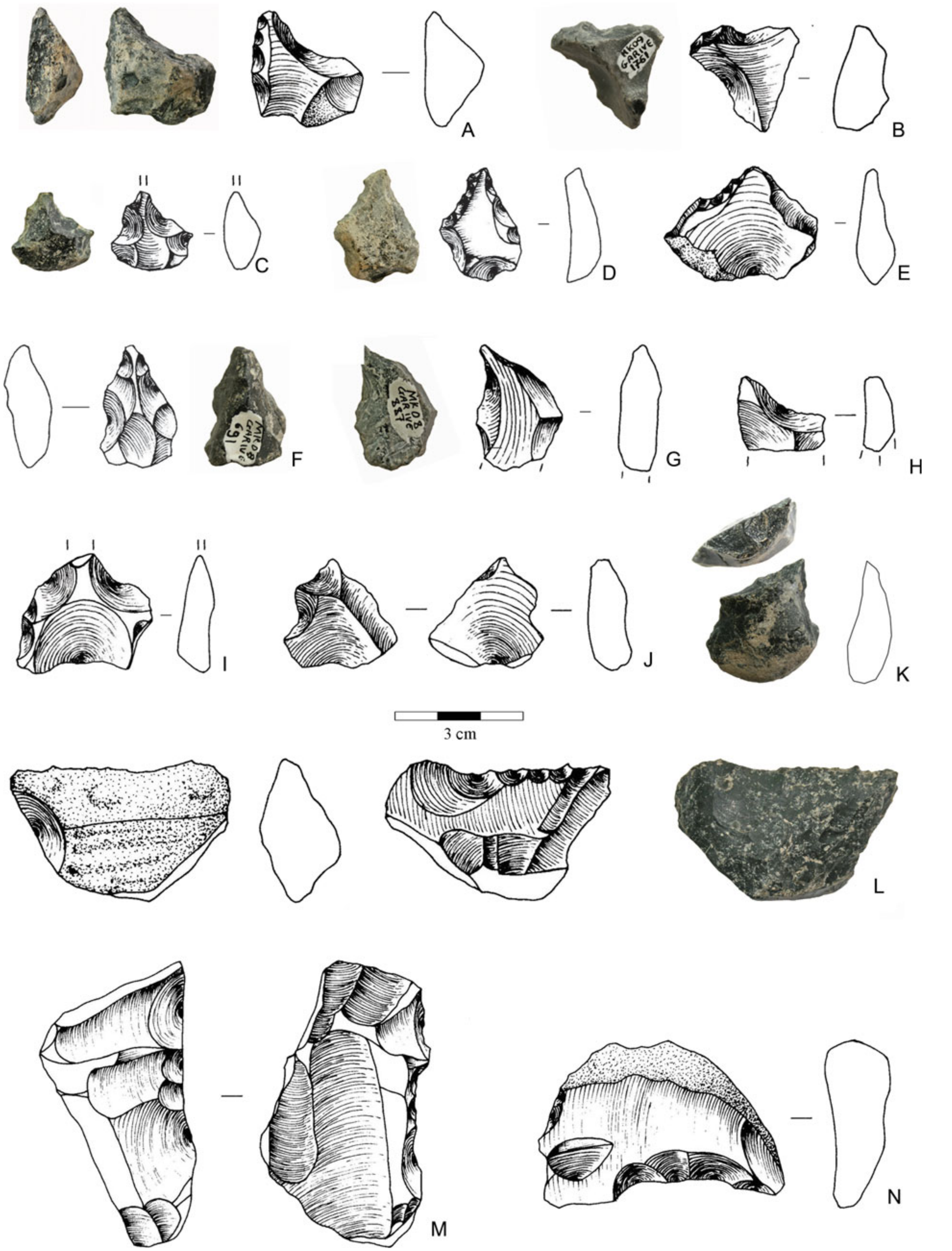

Fig. 4.13 Garba IVE-F. Small pointed obsidian tools (**A**–**K**) and undifferentiated retouched obsidian flakes (**L**–**N**). **A**, **K**: notch opposite a retouched edge. **B**, **C**, **F**, **I**, **J**: two or more notches on two convergent edges. **D**: convergent side-scraper. **E**: retouched edge opposite a back. **G**, **H**: notch opposite a back. **L**: transverse side-scraper. **M**: lateral side-scraper on core-edge flake. **N**: retouched proximal notch. Drawings by N. Tomei

corresponds to the last phase of reduction, as evidenced by scars that are altogether different from the ones produced in the débitage process (Fig. 4.14: G).

Biconvex and flat cobbles were used for partial bifacial exploitation, and exhibit unidirectional removals on two adjacent surfaces. Each removal scar was used as a striking platform to flake the adjacent plane (Fig. 4.14: I).

Unifacial prepared centripetal method required the selection of round cobbles or of angular cobbles that have one convex surface (Fig. 4.14: K, L). This débitage method was used only to exploit lava cores. The volume of these cores is divided into two asymmetrical hierarchical surfaces. One is the flaking surface, which was exploited by repeated centripetal or tangential removals. The other one is a peripheral or semi-peripheral striking platform perpendicular to the flaking surface; it was prepared by unidirectional removals. Angular flat surfaces were chosen as striking platforms, as appears clearly when parts of the cobbles' natural surfaces are preserved. The flaking surface is generally secant to the plane of intersection of both surfaces. Conversely, the flaking surface is parallel and flat when the centripetal exploitation continues, detaching second-generation flakes. The role of the surfaces is maintained throughout the reduction sequence.

Discoid cores too are mainly produced on round cobbles, which are ideal blanks for meeting the technical requirements of the discoid concept. Discoid cores have two convex surfaces that are usually asymmetrical, i.e., the flaking surface and the striking platform, whether hierarchized or not. Flakes are detached according to a plane that is secant to the plane of intersection of the two surfaces, or sub-parallel when the core becomes overexploited. The striking platform may be a natural surface, or the convex dorsal face of a flake, or a prepared peripheral surface, or two fairly similar symmetrical surfaces. The latter are created by removals and can be used either simultaneously or, during alternating series of removals, one as a striking platform and the other as a flaking surface (Boëda 1993; Jaubert and Mourre 1996; Mourre 2003; Terradas 2003). For the most part, peripheral convexity is created by centripetal flaking and tangential removals (Fig. 4.14: Q–V). The flakes are mostly short and wide with centripetal/tangential removals on the dorsal face, with wide and thick plain, dihedral, or facetted butts, with at least one cutting edge and frequently with a pointed distal-lateral end (Fig. 4.15: M–R).

However, if the geometry of the raw material was not suitable for discoid exploitation, as in angular obsidian elements, the knappers prepared an initial configuration that modified the original geometry of the natural blanks (Gallotti 2013).

Five percent of the flakes were retouched as side-scrapers, denticulates, and notches. No specific correlation is observed between flake blank types and retouch systems on the one hand, and the choice of a specific flaking method on the other. Retouch was usually applied to only one edge, either lateral (Fig. 4.16: A–C) or transversal (Fig. 4.16: D–H), and only rarely on two edges (Fig. 4.16: I–M). It is sometimes convergent (Fig. 4.16: N–Q) or skewed (Fig. 4.16: R–U), so as to produce pointed shapes. Retouch scars are marginal, abrupt, denticulate or invasive, producing a linear, convex or concave cutting edge. Notches are frequent; sometimes they are retouched (Fig. 4.16: X) and sometimes they are not (Fig. 4.16: B, V–W, Y–Z). They are often associated with a retouched edge (Fig. 4.16: B, W, Y). However, the retouch never modifies the shape of the blank. No standardization develops.

4.5.3 Production of Small- and Medium-Sized Flakes at Garba XIIIB, ~1.0 Ma

Small and medium-sized flakes were produced at Garba XIIIB mainly on cobbles of aphyric basalt which is found in high percentages in the unworked assemblage (Figs. 4.10a, 4.11).

The core-to-flake ratio is 1.8 flakes per core, which does not match the average number of removal scars on the cores (average: 22). Furthermore, the flakes do not represent all the flaking stages identified by core analysis. Notably, the first flaking stage is represented by only two first flakes, and a few more that preserve small portions of the natural surfaces.

Twelve cores are characterized by a low count of removal scars (distributed at random on distinct faces), which indicates simple débitage. The other cores were exploited through two débitage methods: discoid and multifacial multidirectional irregular (Fig. 4.10b).

Discoid technology is the prevailing débitage method (Fig. 4.10b). The exploitation is bifacial (Fig. 4.17: G): two fairly similar symmetrical surfaces created by removals were used as striking platforms and flaking surfaces, either simultaneously or by alternate series of removals. Both cobbles and flakes were used as blanks. The natural surfaces of the original blank, when preserved, show that the knappers either took advantage of any significant convexity to perform removals (Defleur and Crégut-Bonnoure 1995; Moncel 1998; Pasty 2000; Terradas 2003), or that they configured the core's initial geometry by removing its natural angles. The flakes produced by this method are either (a) circular, triangular or sub-quadrangular, with centripetal removals (Fig. 4.17: F), or (b) triangular or irregular with tangential removals (Fig. 4.17: D–E, H), i.e., flakes with a pointed distal-lateral end and pseudo-Levallois points. The butts are mostly plain, dihedral or facetted, wide and thick. The flaking angle is generally obtuse. Few flakes have a cutting edge opposed to a prepared or natural back.

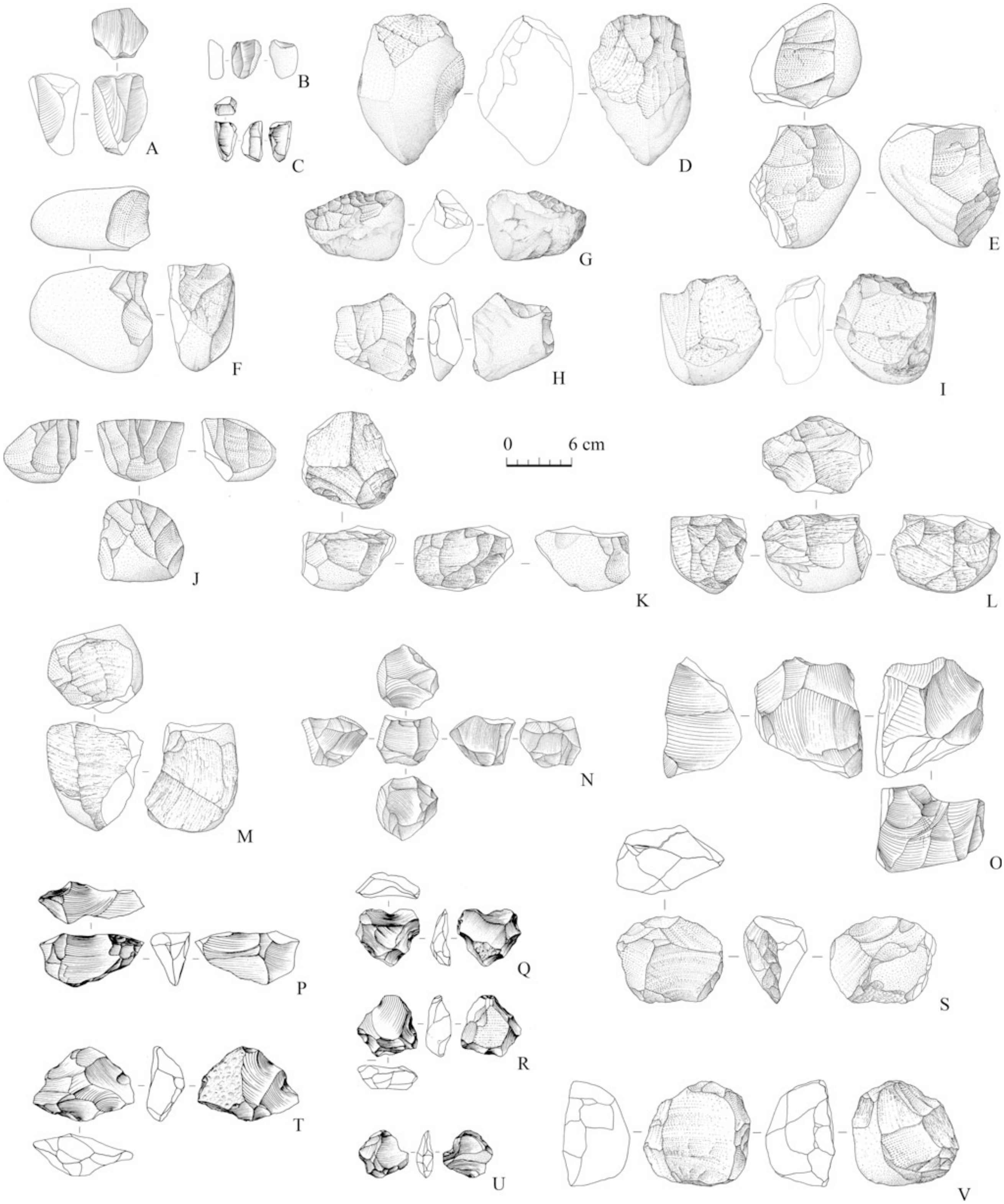

Fig. 4.14 Garba IVD. **A**–**F**: unifacial unidirectional cores. Core **E** is one of the few specimens that was exploited by bipolar technique (**A**–**C**: OBS; **D**: DPL; **E**–**F**: ASB). **G**: retouched unifacial unidirectional core (ASB). **H**: retouched unifacial bidirectional core (ASB). **I**: bifacial partial core (DASL). **J**: peripheral unidirectional core (OL). **K**, **L**: prepared unifacial centripetal cores (ASB). **M**: SSDA core (ASB). **N**: irregular multifacial multidirectional core (OBS). **O**, **P**: irregular multifacial multidirectional cores that have a major flaked surface showing unidirectional removals (OBS). **Q**–**V**: discoid cores (**Q**–**R**, **T**–**U**: OBS; **S**, **V**: ASB). ASB: aphyric to subaphyric basalts. DASL: differentiated aphyric to subaphyric lavas. DPL: differentiated porphyritic lavas. OBS: obsidian. OL: obsidian lava (after Gallotti 2013, modified). Drawings by M. Pennacchioni

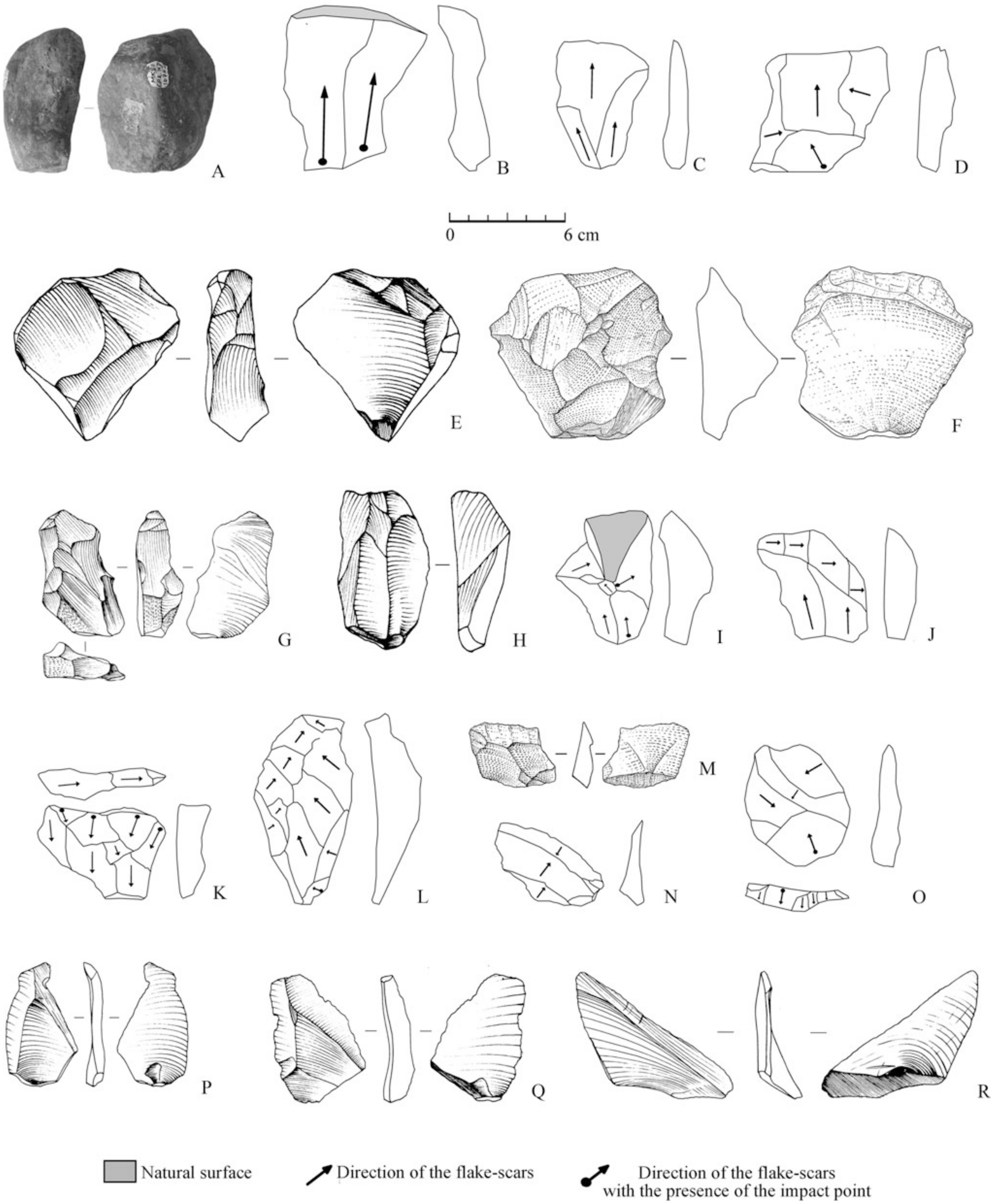

Fig. 4.15 Garba IVD. **A**: first flake (MFL). **B**, **C**: flakes with unidirectional flake scars on the dorsal face (**B**: PB; **C**: DASL). **D**–**H**: flakes with multidirectional removal scars on the dorsal face (**D**, **F**: ASB; **E**, **G**–**H**: OBS). **I**, **K**, **L**: flakes with unidirectional removals on orthogonal surfaces (**I**: ASB; **K**: MFL; **L**: PB). **J**: flake with orthogonal removal scars on the dorsal face (PB). **M**–**R**: flakes with centripetal or tangential flake scars on the dorsal face (**M**, **O**: MFL; **N**, **P**–**R**: OBS). ASB: aphyric to subaphyric basalts. DASL: differentiated aphyric to subaphyric lavas. MFL: Melka Fault Lava. OBS: obsidian. PB: porphyritic basalt (after Gallotti 2013). **E**–**H**, **M**, **P**–**R**: drawings by M. Pennacchioni

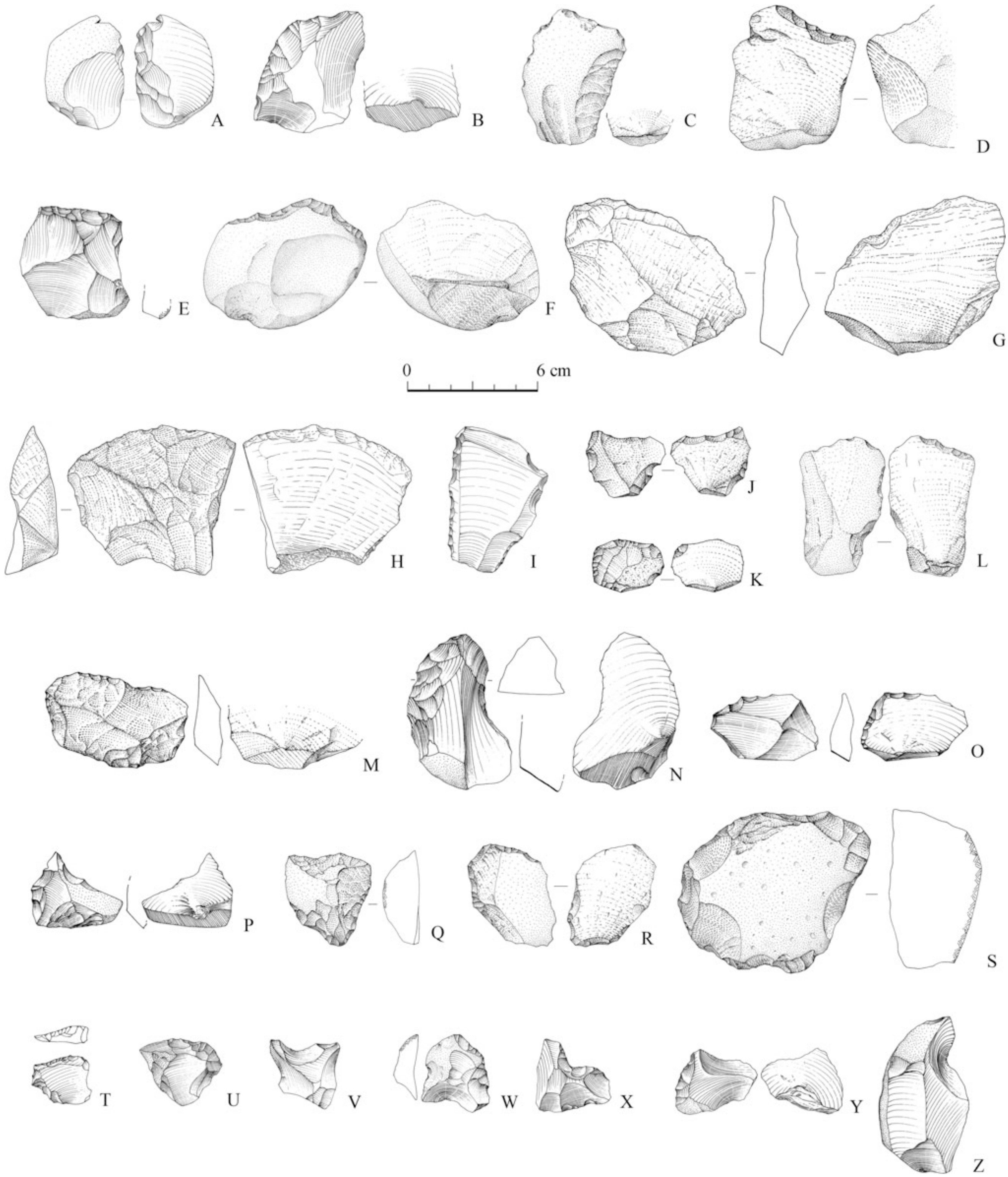

Fig. 4.16 Garba IVD. Retouched flakes. **A**, **C**: lateral side-scrapers (**A**: OBS; **C**: DASL). **B**, **W**, **Y**: lateral side-scrapers and notches (OBS). **D**–**H** transverse side-scraper (**D**: MFL; **E**: OBS; **F**: PB; **G**–**H**: ASB). **I**: bilateral side-scraper (OBS). **J**–**M**: lateral-transverse side-scrapers (**J**, **L**: DASL; **K**, **M**: ASB). **N**–**Q**: convergent side-scrapers (**N**–**P**: OBS; **Q**: ASB). **R**–**U**: skewed side-scrapers (**R**: DASL; **S**: ASB; **T**–**U**: OBS). **V**, **Z**: notches (OBS). **Y**: retouched notch (OBS) (after Piperno et al. 2004b, modified). ASB: aphyric to subaphyric basalts. DASL: differentiated aphyric to subaphyric lavas. MFL: Melka Fault Lava. OBS: obsidian. PB: porphyritic basalt (after Gallotti 2013)

Multifacial multidirectional irregular cores were alternately flaked through multidirectional removals without any recognizable organization of the reduction process and without any specific platform preparation (Fig. 4.17: A). The flakes thereby produced display three to seven negative scars, thus confirming that the multifacial multidirectional cores were overexploited. Flake shapes vary; they are often sub-quadrangular with a thick and asymmetrical cross-section. Core-edge flakes (Fig. 4.17: B–C) indicate continuous rotation of flaking surfaces. Nonetheless, these flakes are apparently the outcome of the search for new angles, rather than of a rejuvenation phase aimed at rearranging the flaking and striking surfaces (Gallotti et al. 2014).

4.5.4 Production of Small- and Medium-Sized Flakes at Gombore II OAM, ~0.85 Ma

As is the case at Garba XIIIB, discoid technology is the dominant débitage concept at Gombore II OAM. The second most prevalent technology is multifacial multidirectional exploitation. Aphyric lavas are the most frequently exploited raw materials, followed by obsidian and porphyric basalt (Fig. 4.10a, b), which are also well documented in the unworked assemblage (Fig. 4.11). Because of winnowing by natural agents, most of the flakes are missing (flake-to-core ratio 3.2:1) (Raynal et al. 2004; Gallotti and Mussi 2017).

Discoid exploitation is systematically bifacial (Fig. 4.17: J, K). The natural surfaces of the original blank, when preserved, show that the knappers used round or angular cobbles and stones as blanks, adapting or modifying their natural geometry in order to meet the method's requirements. Flakes too were used as core blanks. The average removal count of these discoid cores is 22 flakes per core. This result was made possible by maintaining peripheral convexity. In fact, despite the overexploited appearance of the cores, negative removal scars do not overlap the prominent central part of the flaking surface, which remains convex until its final state. The many flakes that show a tangential flaking direction on their dorsal face, and a cutting edge opposite a back, also suggest that convexity was maintained intentionally. These flakes usually display a deviation of the flaking axis from the morphological axis (Fig. 4.17: N, P–Q). The other flakes were usually obtained by centripetal flaking, in which case the morphological and flaking axes coincide (Fig. 4.17: M).

Multifacial multidirectional exploitation is irregular. Angular cobbles were intensely exploited (with an average of 39 removal scars per core); the cores were rotated and removals were made in multiple directions, as documented by many edge-core flakes (Fig. 4.17: I, L, O).

There are very few retouched flakes. There are some denticulates (n = 3) and notches (n = 2). Retouch did not modify the shape of the blank, only the edges (Gallotti and Mussi 2017).

4.5.5 LCT[4] Production at Garba IVD, ~1.6 Ma

The LCT chaînes opératoires appear for the first time in the Melka Kunture region in level D of Garba IV, ~1.6 Ma, where they constitute a minor aspect of the technical activities (1.5% of the artifacts). A specific knapping process was adopted to produce large flakes that were to be turned into LCTs. There is also a notable difference in flake dimensions (Gallotti 2013).

All the LCTs are on large flakes except one obsidian discoid core that was eventually turned into a massive scraper. The raw materials most exploited are porphyritic rocks, Melka Fault lava and obsidian (Fig. 4.18). This circumstance is noteworthy because the percentages of these three materials in the unworked assemblage are low in comparison with aphyric basalts. Overall, in the unworked assemblage, as in the other ancient alluvial deposits, large cobbles and blocks—i.e., blanks large enough to allow at least one large flake to be detached from them—are usually either porphyritic rocks or Melka Fault lava (Gallotti and Mussi 2017).

Lavas and obsidian were exploited in different ways for the production of LCT blanks. Three obsidian cores were treated by simple débitage; i.e., they are small blocks displaying just one or two removals, either longitudinal or transversal. The corresponding flakes were turned into massive transverse side-scrapers by a unifacial, non-invasive continuous retouch on the dorsal face (Fig. 4.19: E).

[4]LCTs are intended here as shaped or retouched tools with a length or width > 10 cm. They include massive scrapers, bifaces, and cleavers. Massive scrapers are large flake blanks with retouched edge(s). Bifaces are LCTs whose morphology «résulte de l'aménagement simultané de deux convexités, de manière à ce que l'une soit à l'image de l'autre en fonction d'un *plan d'équilibre bifacial* … De l'intersection de ces deux convexités naît une silhouette « lissée » par retouche, qui se distribue par rapport à un *plan d'équilibre bilatéral* » (Roche and Texier 1991: 102). Cleavers (sensu Tixier 1956) are intended here as LCTs obtained either by débitage only, or by débitage followed by shaping. The cutting edge must be left unretouched, i.e. it is the outcome of the débitage of the blank. Bifacial pieces with a bit achieved by shaping or by lateral tranchet blow technique are not cleavers but handaxes with a transverse (or terminal) cutting edge (Inizan et al. 1999).

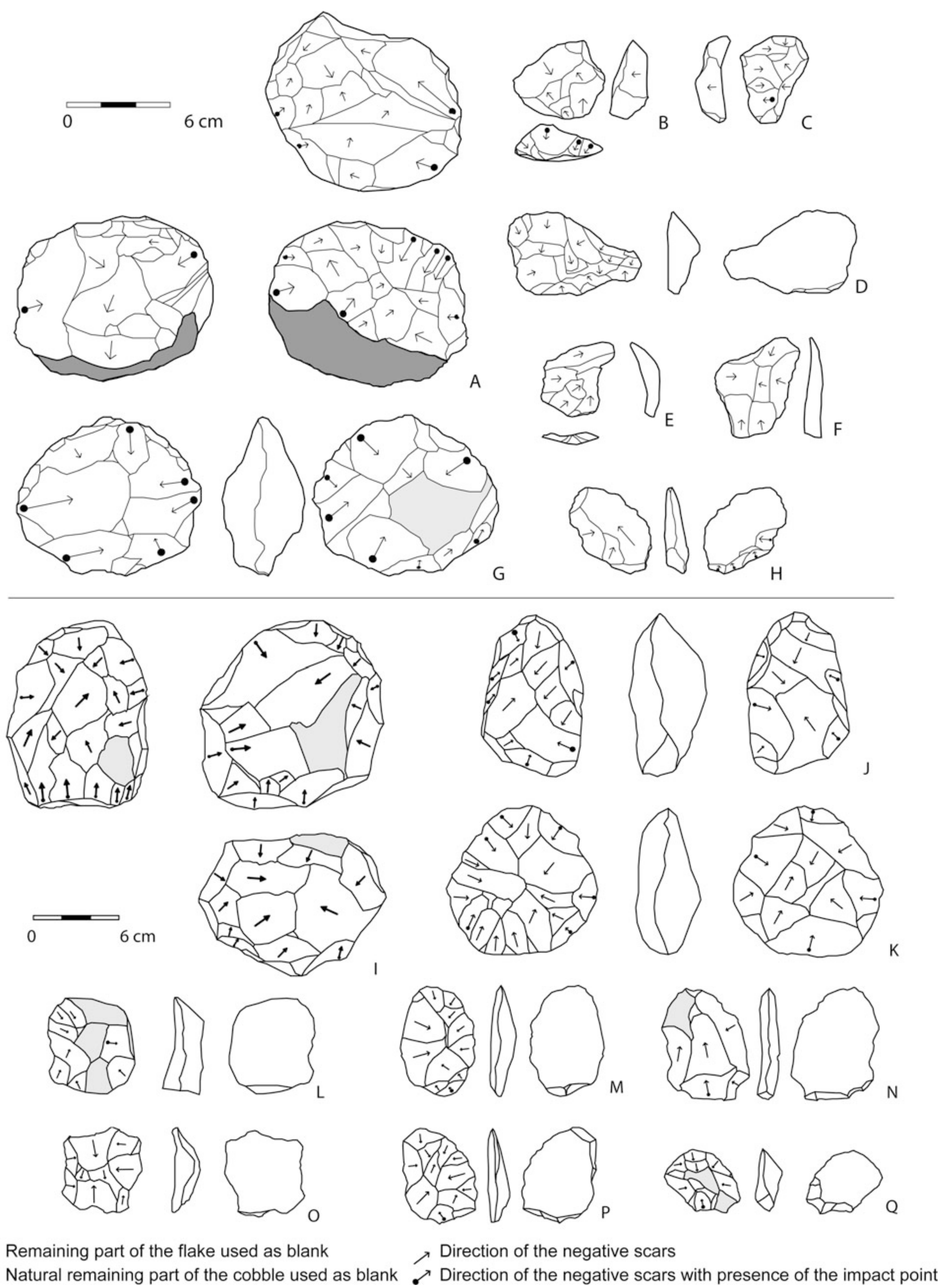

Fig. 4.17 Small débitage cores and flakes from Garba XIIIB (**A**–**H**) and Gombore II OAM (**I**–**Q**), **A**: irregular multifacial multidirectional core (ABS). **B**, **C**: flakes obtained by multifacial exploitation (ASB). **D**–**F**, **H**: flakes obtained by discoid exploitation (ABS). **G**: bifacial discoid core on flake (ASB). **I**: multifacial multidirectional core (ASB). **J**, **K**: bifacial discoid cores (**J**: OBS; **K**: ASB). **L**, **O**: flakes obtained by multifacial exploitation (**L**: ASB; **O**: OBS). **M**, **N**, **P**, **Q**: flakes obtained by discoid exploitation (**M**, **N**: ASB; **P**, **Q**: OBS). ASB: aphyric to subaphyric basalts. OBS: obsidian (after Gallotti et al. 2010, 2014, modified)

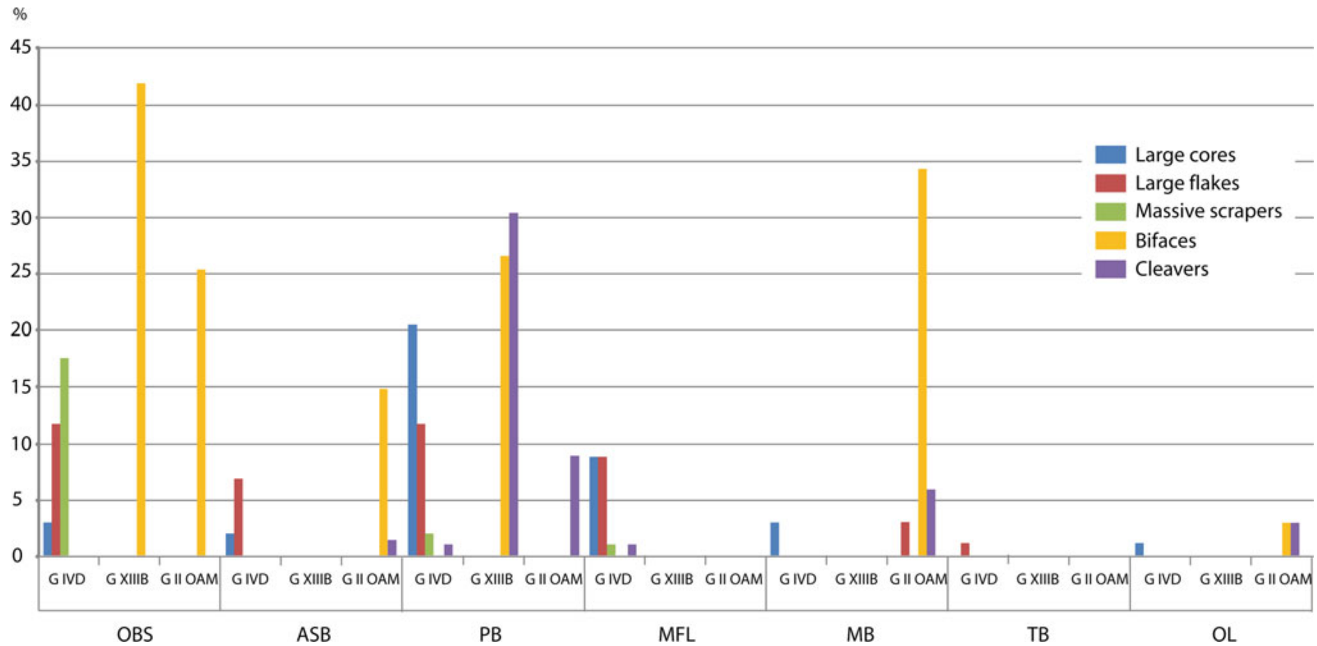

Fig. 4.18 Lithological composition and technological components of the LCT productions at Garba IVD (G IVD), Garba XIIIB (G XIIIB) and Gombore II OAM (G II OAM). ASB: aphyric to subaphyric basalts. MB: microdoleritic basalt. MFL: Melka Fault Lava. OBS: obsidian. OL: obsidian lava. PB: porphyritic basalt. TB: trachybasalt. Twisted bifaces are not included in this figure because they have not been found anywhere else at Melka Kunture nor in East Africa

Most of the LCTs (n = 10) were produced from flakes resulting from discoid exploitation. The obsidian discoid core mentioned above is long and narrow. It has a thick pyramidal cross-section created by two flaking surfaces created by means of centripetal/tangential exploitation. One flaking surface is marked by the large removal scar of a short and wide flake that could have been used as LCT blank. After this large flake was detached, the core was likewise turned into an LCT by marginal non-continuous retouch (Fig. 4.19: A). In all other cases, wide and thick flakes obtained by discoid exploitation were turned into massive scrapers through unifacial or bifacial retouch on the transverse or lateral edges (Fig. 4.19: F, H). Three massive scrapers present marginal, denticulate and non-continuous retouch along two convergent and skewed edges. On some of them, an invasive retouch on the dorsal face, or on both faces, thinned the butt-bulb part (Fig. 4.19: G–H). There is only one massive transverse scraper; it was produced by retouching a wide and thick flake with unidirectional removals on the dorsal face (Gallotti 2013; Fig. 4.19: D).

One débitage method is documented by the lava-core analysis, which points to a prepared unifacial centripetal method similar to that used for small and medium-sized flake production (Fig. 4.19: B–C). The flaking surface is a horizontal plane on a large cobble or block, whereas a peripheral or semi-peripheral plane makes it possible to prepare the striking platform by unidirectional removals. On most cores, evidence of large flake production is limited to that provided by a single scar. On a few cores, a few centripetal scars precede this final large scar, suggesting the preparation of peripheral convexity, and predetermination. After the flake was detached by direct freehand percussion, the core was discarded.

The resulting large flakes display remains of the natural surface in the middle of the dorsal face, peripheral centripetal removals and wide, thick, facetted butts. The latter are often adjacent to one of the backed side edges. Some flakes look like large éclats débordants. However, three flakes have on their dorsal face invasive negative centripetal and chordal scars, thereby documenting lengthy preparation of the convexity of the flaking surface. Oddly, only three such flakes were retouched: one by large notches on the dorsal face, one by a bifacial, rather invasive and non-intensive retouch that created a convex cutting edge (Fig. 4.19: J), and the third by a fairly invasive and continuous retouch on one edge of the ventral face, which thinned and removed the butt-bulb part. Small isolated and non-continuous removals were made on thin portions of the edges (Fig. 4.19: I).

The edge morphology of the two cleavers (sensu Tixier 1956) was determined prior to the blank's detachment. The flaking axis is either perpendicular (Fig. 4.19: L) or oblique (Fig. 4.19: K) to the cleaver's axis. However, we have not found any large core related to the production of flake blanks that have a predetermined cutting edge. Accordingly, the débitage method remains unknown. One of the

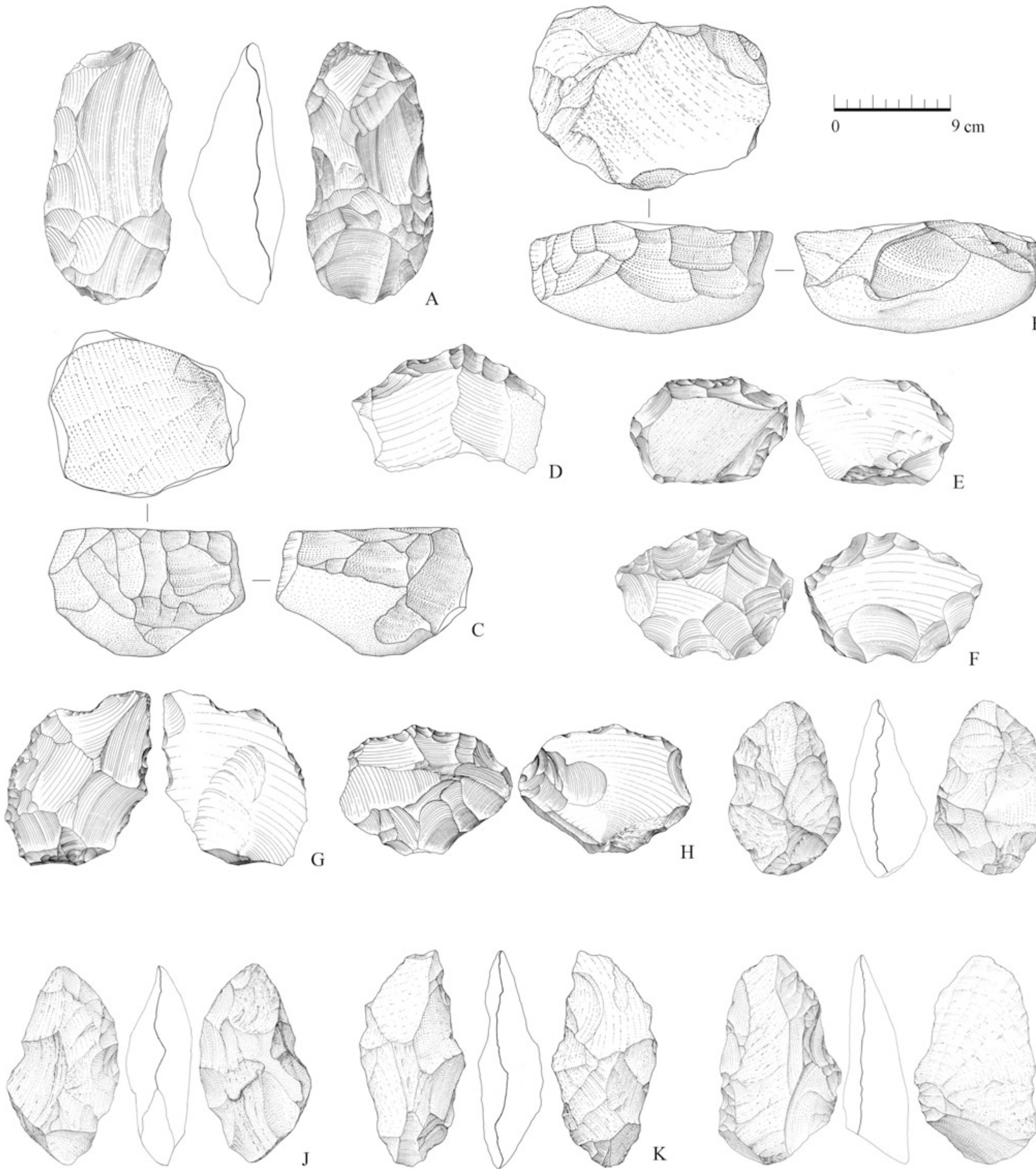

Fig. 4.19 Garba IVD. **A**: large retouched core (OBS). **B–C**: large cores (MFL). **D–J**: massive scrapers (**D–H**: OBS; **I–J**: PB). **K–L**: cleavers (**K**: MFL; **L**: PB). MFL: Melka Fault Lava. OBS: obsidian. PB: porphyritic basalt (after Gallotti 2013, modified). Drawings by M. Pennacchioni

cleavers was shaped by reducing the irregular convexity of the dorsal face and thinning the butt-bulb part (Fig. 4.19: K). The retouch did not regularize the edges; they retain a rather denticulate and irregular outline. The second cleaver was not shaped, just retouched on its dorsal face (Gallotti 2013; Fig. 4.19: L).

4.5.6 LCT Production at Garba XIIIB, ~1.0 Ma

At Garba XIIIB, the LCT chaînes opératoires are represented by bifaces and cleavers. Neither large cores nor unmodified large flakes were discovered (Table 4.1). Bifaces are in obsidian (n = 11) or porphyritic rocks (n = 7). All the cleavers are made of porphyritic basalt (Fig. 4.18). The Kombewa method was the only débitage mode used on large flake blanks. It made it possible to produce flakes whose technical, morphological and dimensional features were extremely homogeneous. In other words, the Kombewa flakes point to a high degree of predetermination (Texier and Roche 1995; Inizan et al. 1999).

As to bifaces, the shaping of Kombewa flakes is either intense on both faces (Fig. 4.20: B), or intense on the upper face and limited on the lower one (Fig. 4.20: A, C). The shapes thus produced are rather pointed, standardized in size, and bifacially symmetrical. The flakes were shaped in two phases: first, alternate invasive removals involving all or part of both faces; second, thinning the bulb, removing the butt and producing a biconvex section.

The bits of the cleavers are either convex (Fig. 4.20: E) or oblique (Fig. 4.20: D, F) and are predetermined by the morphology of the Kombewa flake blanks. The cleavers' size was predetermined by the unmodified edge and butt; their bifacial symmetry was partly predetermined by the Kombewa flake blank and partly achieved through the shaping process.

The cleavers have standardized intra-shape dimensions and the bifaces have standardized intra-type dimensions, which were obtained partly by means of strict predetermination of the blank type and partly by means of standardized shaping procedures (Gallotti et al. 2014).

4.5.7 LCT Production at Gombore II OAM, ~0.85 Ma

As was the case at Garba XIIIB, only the final stage of LCT production is documented at Gombore II OAM, i.e., bifaces and cleavers. A specific aspect of the technical activities is the manufacture of obsidian twisted bifaces, which have not been found anywhere else in the Melka Kunture archaeological sequence, nor at any other prehistoric African site documented in stratigraphic context (Fig. 4.21; Gallotti et al. 2010). Their length (between 6 and 10 cm) is smaller than is generally recognized as diagnostic for LCTs, i.e., length or width >10 cm (cf. Sharon 2010; de la Torre 2011; Beyene et al. 2013; Gallotti 2013). Accordingly, they are omitted from the lithotype counts discussed here.

Bifaces are mainly made of microdoleritic basalt, porphyritic basalt or obsidian. Most of the cleavers are made of microdoleritic basalt (Fig. 4.18). Biface blanks, if recognizable, are Kombewa flakes or large skewed flakes. Given the absence of large cores and the near absence of residual natural surfaces, the débitage method cannot be determined. The shaping of skewed flake blanks is intense on both faces, thereby producing more or less pointed ovoid or limande bifaces characterized by intra-shape standard sizes, bifacial asymmetry and poorly delineated edges (Fig. 4.22: E, F). Kombewa flakes are solely made of obsidian or microdoleritic basalt. Predetermined bifacial symmetry leads to more limited shaping procedures, which generally require one or two series of invasive removals and marginal retouch. Symmetry is fully achieved, the sections are biconvex and the edges are well delineated and continuous (Gallotti et al. 2010; Gallotti and Mussi 2017; Fig. 4.22: A–D).

Cleaver flake blanks were detached by means of the Kombewa method and a method involving bidirectional removals from opposite core platforms. Due to the lack of cores, we cannot determine whether only bidirectional débitage with opposed striking platforms was performed, or if a more complex predetermined flaking system involving the whole periphery of the core was also applied. The systematic and frequent use of Kombewa flakes and of prepared striking platforms on some cleavers (Fig. 4.22: H) both suggest a predetermined Kombewa strategy. In general, both débitage methods produce flakes that have similar technical aspects, morphology and dimensions, i.e., highly predetermined flakes. The intensity of shaping depended on the degree of predetermined bifacial symmetry of the flake blank. Finishing consisted of edge delineation (Gallotti et al. 2010; Gallotti and Mussi 2017; Fig. 4.22: G, H).

4.6 Discussion: The Origin of the Acheulean at Melka Kunture

The Early Pleistocene sequence at Melka Kunture offers a rare opportunity to analyze technological changes related to the emergence and development of the Acheulean in a microregion.

This sequence starts with the basal levels (E–F) of Garba IV, dated to ~1.7 Ma (Raynal et al. 2004; Morgan et al. 2012; Gallotti and Mussi 2015). The artifact assemblage is made up of all the components that belong to small débitage, and no others. The unworked assemblage consists mainly of aphyric lavas that are quite suitable for knapping but were not exploited to any great degree. Conversely, obsidian was very clearly chosen as the preferred raw material. Procurement was evidently local, i.e., the necessary raw materials

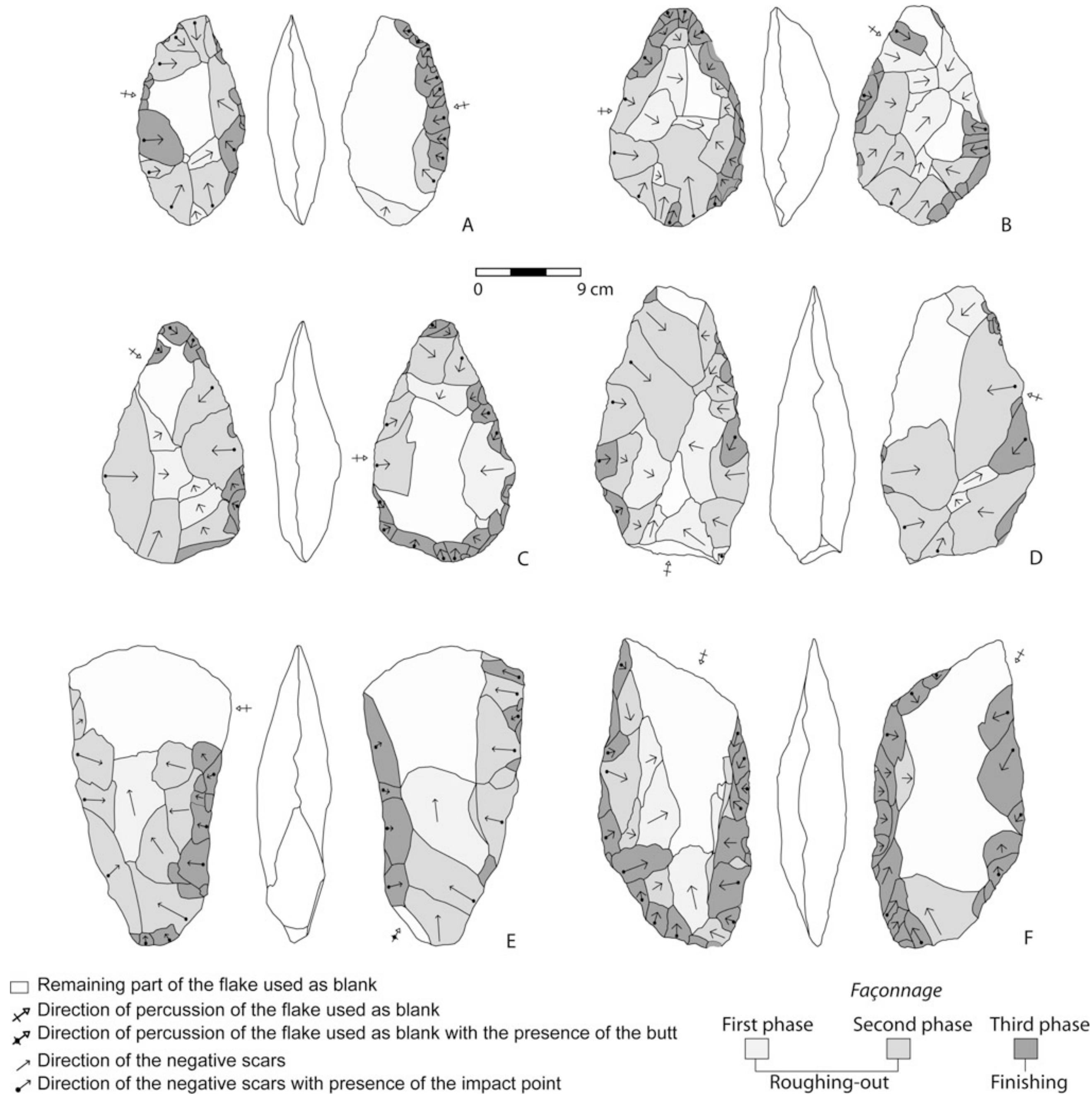

Fig. 4.20 Garba XIIIB. **A**–**C**: bifaces (**A**, **C**: PB; **B**: OBS); **D**–**F** cleavers (PB). OBS: obsidian. PB: porphyritic basalt (after Gallotti et al. 2014)

were collected in alluvial deposits near the sites. This conclusion is supported by the systematic use of pebbles and cobbles as blanks, i.e., rounded stones available in the paleochannels, where there were no angular natural blanks. Conversely, the latter are widely distributed in the vicinity of the primary source, within a radius of one or two km from Balchit (Gallotti and Mussi 2015; Fig. 4.1b).

Small and medium-sized flakes were produced by several different débitage methods that developed as the best ways to exploit cobble geometries. Technical patterns document the efficient use of any available angle through continuous core rotation, while the surfaces were rectified in order to create suitable striking platforms and angles that made it possible to detach flakes. However, there was no systematic preparation of striking platforms, no recurrence, no volume/convexity management or hierarchy among surfaces and no modification of the natural blank geometry that would have made it possible to use a particular flaking method. The débitage

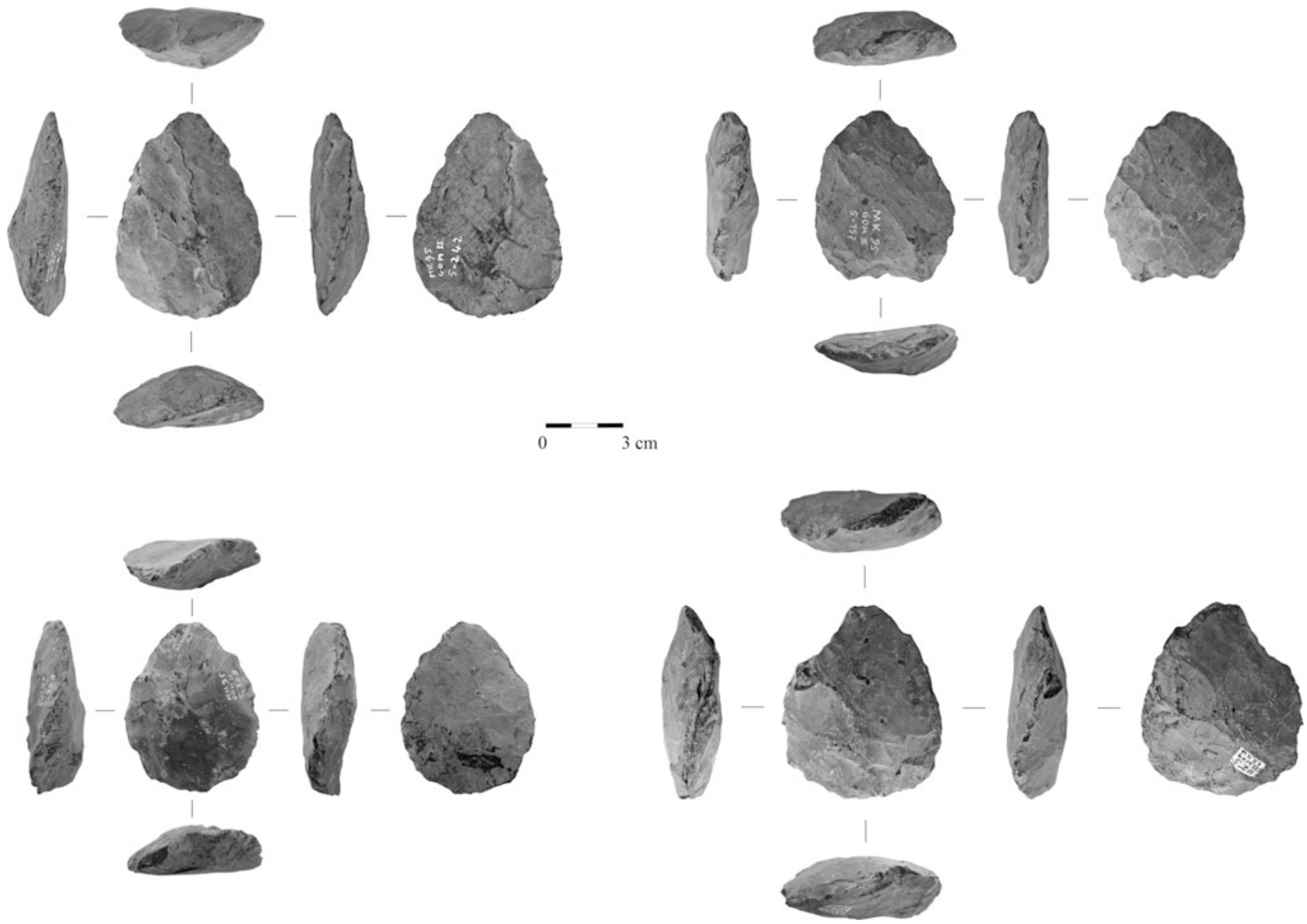

Fig. 4.21 Gombore II5. Twisted obsidian bifaces

methods were the outcome of technical structures, skills and cognitive abilities similar to those identified at the other Oldowan sites in East Africa (e.g., de la Torre 2004; Delagnes and Roche 2005; de la Torre and Mora 2005; Semaw 2006; Braun et al. 2009; Gallotti 2018). The intra-site variability of débitage modalities is also observed in late Oldowan complexes (Gallotti 2018). This was happening at a time when the early Acheulean had already appeared elsewhere in East Africa (Quade et al. 2004, 2008; Lepre et al. 2011; Beyene et al. 2013; Díez-Martin et al. 2015; Semaw et al. 2018; Texier 2018).

At Melka Kunture there is also evidence of a specific technical process that has never been recorded elsewhere in the Oldowan, i.e., a systematic search for small pointed forms. This process is closely linked to obsidian exploitation, and most probably aimed to serve a specific techno-functional purpose (Gallotti and Mussi 2015; Gallotti 2018).

The variability of small débitage methods increases at Garba IVD, ~1.6 Ma. The knappers used as core blanks all the clasts available in the alluvial deposits, which were mainly obsidian and aphyric cobbles (Gallotti 2013; Gallotti and Mussi 2017). However, the knappers also used angular pieces of obsidian, produced by fracturing of the primary source due to weathering. Ongoing site formation analysis further confirms that angular pieces are not natural components of alluvial deposits. They are exogenous and were brought to the site as manuports by the knappers. Besides, they are not found in other penecontemporaneous alluvial deposits (Gallotti and Mussi 2017). This may also confirm that hominins did use a lag deposit (Raynal et al. 2004). They used local raw materials and angular pieces of obsidian that they found scattered near the obsidian outcrop; today such stones can be collected at distances ranging from 5 to 7 km. This means that during the procurement phase, the chaînes opératoires correlated with the exploitation of these specific forms were fragmented. However, we do not know how extensive the primary obsidian source was ~1.6 million years ago. If at that time some obsidian outcropped closer to the site, or if the pattern of the dispersion of angular stones was different from what it is today, the chaînes opératoires would not have been fragmented.

In any case, the use of such stones for discoid exploitation reflects a new technical skill: the ability to produce an initial

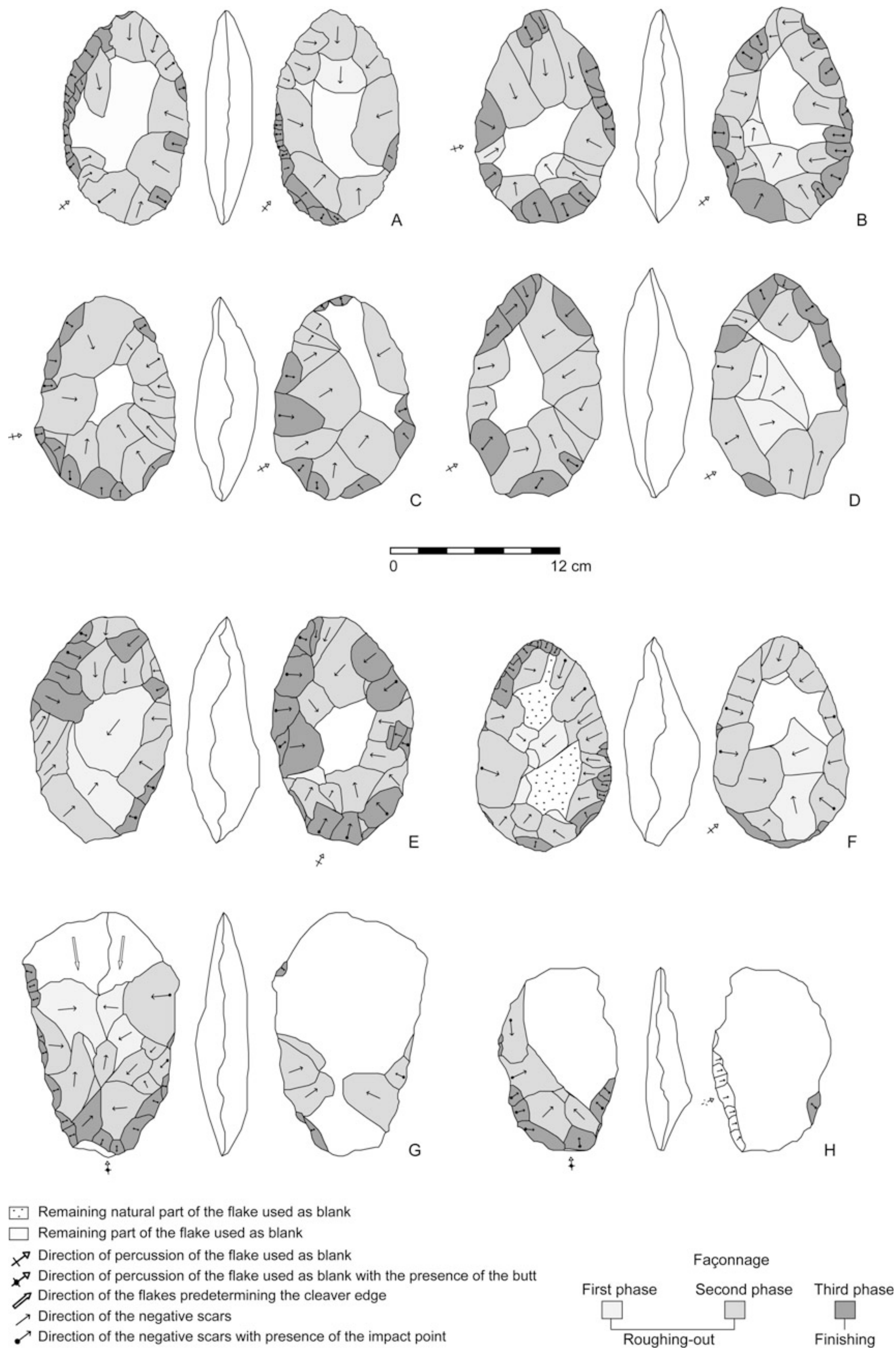

Fig. 4.22 Gombore II OAM. **A**–**D**: bifaces on Kombewa flakes (**A**, **B**, **D**: MB; **C**: OBS). **E**–**F**: bifaces on skewed flakes (**E**: MB; **F**: ASB). **G**: cleaver on flake with bidirectional removals (OL). **H**: cleaver on Kombewa flake (MB). ASB: aphyric to subaphyric basalts. MB: microdoleritic basalt. OBS: obsidian. OL: obsidian lava (after Gallotti and Mussi 2017)

configuration of the core that modified the blank's natural geometry. Discoid and unifacial centripetal exploitations reflect other technical innovations as well: preparation of the striking platform, recurrence, volume/convexity management and hierarchy among surfaces. The variability of the operational scheme of the discoid concept (Peresani 2003) is fully observed at Garba IVD. The other débitage methods are the outcome of geometrical constraints imposed by raw materials (Gallotti 2013). The technical parameters are the same as those identified in the older Oldowan levels (E–F).

In later Acheulean sites the variability of the small débitage processes unquestionably decreases. At Garba XIIIB and Gombore II OAM ($\sim$1.0–0.85 Ma), the only débitage methods are the discoid and the multifacial multidirectional ones. The knappers' very effective volume control and maintenance allowed greater recurrence and higher productivity. For the first time, both spherical cobbles and angular lava cobbles/elements were used for discoid exploitation. The knappers succeeded in overcoming the lithological and geometric constraints. Conversely, in the early Acheulean at Garba IVD, it was precisely the suitability of obsidian for knapping that allowed a limited degree of independence from the original shape of the raw material. Angular lava cobbles with one convex surface were chosen because they were easy to turn into cores for unifacial centripetal exploitation. The convex surface was exploited by using the existing angular planes as striking platforms. The angle between the two surfaces remained the original one, i.e., $\sim$90°. At Garba XIIIB and Gombore II OAM, discoid exploitation of angular lava cobbles replaced this method.

At Garba IVD, just as at Garba XIIIB and Gombore II OAM, small débitage was used to produce small- and medium-sized flakes that were rarely modified by retouch. The fairly standardized small tools at Garba IVE-F are no longer found in later periods. This suggests that it was only an occasional technological development, possibly driven by practical needs and facilitated by obsidian's high suitability for knapping. The absence of such tools at later sites is at odds with hypotheses such as those advanced by Barsky et al. (2014), which suggests that the growing numbers of retouched flakes and the emergence of standardization in toolkits are related to improvements in technical skills, hence they reflect a major step in cultural evolution. However, the question of why small-tool production was not actually part of the emerging Acheulean is still open.

The other major technical innovation first seen at Garba IVD was the production of large flakes to be turned into LCTs. LCT production is linked to the exploitation of raw materials—namely obsidian, porphyritic basalt and Melka Fault lava—found as large blanks in alluvial deposits. However, these large forms are scarce in secondary sources, which may explain why LCT production was very limited. In this region, only later on there is any evidence of procurement at primary sources and of the fragmentation of the related chaîne opératoire, both of which are considered typical of Acheulean techno-complexes (e.g., de la Torre and Mora 2005; Goren-Inbar and Sharon 2006; de la Torre et al. 2008; de la Torre 2011). Systematic procurement at a primary source—i.e., at the porphyritic lava and obsidian outcrops located 2.5 to 7 km away—enabled large-scale manufacturing of LCTs at Garba XIIIB and Gombore II OAM. At the latter site, there is evidence that hominins ranged far afield in their search for microdoleritic basalt, a very fine-grained rock. This reflects broadening of landscape cognition over a radius of at least 15–20 km. As a consequence of procurement right at the primary sources, the LCT chaînes opératoires were fragmented (Gallotti and Mussi 2017).

At Garba IVD, the LCTs were always made on large flakes. The two débitage methods used to produce such flakes were the discoid and the prepared unifacial centripetal. Both are related to innovations in small débitage: systematic preparation of the striking platform; recurrence in exploitation, which made it possible to obtain flakes with longer suitable edges or large flakes that were wider than they were long; management and maintenance of volume and convexities; and hierarchy among surfaces. To achieve their purposes, the knappers systematically selected geometrically suitable large blanks. At the end of the Early Pleistocene, new large flake débitage methods emerged for the production of highly standardized flake blanks. Volume management eventually made it possible to produce highly predetermined flakes that resembled each other in their technical and morphological features and in their dimensions.

Accordingly, the ability to extract large flakes emerged well before the ability (or maybe the need) to manage the volume of objects by means of bifacial and bilateral equilibrium and two convergent edges. At $\sim$1.6 Ma, LCT manufacturing was limited to edge retouch and produced generic tool types, better described as massive scrapers. One of the criteria followed was to use thick, wider-than-long flakes. Another repetitive pattern was the thinning of percussion platforms and bulbs (Gallotti 2013).

At $\sim$1.0–0.85 Ma, there was a surge in the production of bifaces and cleavers. Bifaces were produced by balancing the bifacial and bilateral planes and creating systematic convergence of the two edges. The intensity of shaping was directly linked to the degree of predetermination of bifacial and bilateral equilibrium in the flake blanks. The shaping process was aimed at refining this equilibrium, at creating convergent edges in order to manufacture bifaces, and at producing specific tool types. The Kombewa method made it possible to produce highly predetermined flakes that resembled each other in their technical and morphological features and in their dimensions (Gallotti et al. 2010, 2014; Gallotti and Mussi 2017). It was the only débitage method in use at Garba XIIIB and it was widely used at Gombore II OAM.

4.7 Conclusions

Melka Kunture preserves one of the longest and most complete sequences that document the transition from the late Oldowan to the early Acheulean in East Africa, as well as the development of the Acheulean Industrial Complex up to the transition to the Middle Stone Age (Chavaillon et al. 1979; Chavaillon and Piperno 2004; Mussi et al. 2014; Gallotti and Mussi 2015, 2017). Furthermore, East African sites where both the late Oldowan and the early Acheulean have been recovered are very few (Gallotti 2018). Despite the great importance of the Oldowan–Acheulean transition for understanding human evolution, the biological and cultural mechanisms underlying this process are still poorly understood (e.g., de la Torre et al. 2011; Gallotti 2013; de la Torre 2016).

Until now, the early Acheulean at Melka Kunture has been characterized through techno-economic comparison with other East African sites (Gallotti 2013). We are now able to add a detailed comparative analysis of Early Pleistocene lithic assemblages dated between ~1.7 Ma and ~0.85 Ma, highlighting the changes which are specific to this region.

If we consider the diachronic variations in a techno-economic perspective, the early Acheulean, as identified at Garba IVD at ~1.6 Ma, has the following ontological characteristics:

- it includes two main lithic activities, i.e., production of small and medium-sized flakes and LCTs. The production of LCTs and of large flakes do not appear in the late Oldowan at Garba IVE–F;
- both productions are based on a local procurement system that exploits nearby alluvial deposits;
- the selection of lithologies and natural morphometrical types for small débitage is very similar in both the late Oldowan and the early Acheulean assemblages. Aphyric lavas and obsidian are the most exploited lithotypes in both assemblages. Nevertheless, the late Oldowan small débitage is more focused on the selection of the rock type easiest to knap, i.e., on obsidian. The early Acheulean small débitage is apparently less constrained by raw material lithology;
- small débitage chaînes opératoires were not fragmented in the early Acheulean, just as they were not in the late Oldowan. The incipient fragmentation that may have emerged in the early Acheulean between the procurement and production phases would have been connected to the exploitation of a specific lithotype, i.e., obsidian;
- the small débitage methods used in the late Oldowan also persist in the early Acheulean, as they were the best ways to exploit the natural geometries of rocks available in alluvial deposits. However, these technical solutions were more variable in the early Acheulean, when knappers started to exploit a wider variety of natural blanks;
- although there were strong similarities with the late Oldowan, new technical criteria emerge in small débitage, notably preparation of the striking platform, recurrence, volume/convexity management, hierarchy among surfaces and modification of the natural geometry of the blanks. The adoption of these technical criteria is closely linked to new débitage methods and concepts—i.e., discoid and prepared unifacial centripetal exploitations—which made it possible to produce flakes with long serviceable edges. However, the incipient ability to configure for discoid exploitation natural clasts that were not ideal as blanks for cores depended strongly on raw material lithology. This constraint was systematically overcome only at the end of the Early Pleistocene at Garba XIII and Gombore II;
- the same innovative criteria adopted in small débitage are also seen in large flake débitage. Discoid and prepared unifacial centripetal exploitation were used to produce large flakes and blanks to be turned into LCTs. The knappers' main purpose was to detach fairly thick flakes that would be wider than they were long. Predetermination of the shapes, sizes and technical features of large blanks did not appear at Melka Kunture until later on, i.e., at ~1.0 Ma;
- LCT production is not fragmented and is quantitatively limited by the scarcity of suitable large forms in the paleochannels. This may mean that (a) the knappers did not organize systematic production of large flakes because they were unable to conceive of a wider-ranging provisioning system in which raw materials would be obtained directly at their primary sources, and the production phase as well as the procurement phase would be fragmented; or that (b) the actual functional needs for which the LCTs were meant were not yet strong enough to drive the knappers to change their landscape perception and temporal sequencing;
- after ~1.0 Ma, provisioning at primary sources, wider knowledge of the landscape and chaîne opératoire fragmentation co-occurred systematically. This happened in parallel with the frequent manufacturing of bifaces and cleavers: specific tool types that were technologically (and most probably functionally) different from small tools. With the exception of two cleavers, at this site

large tool types are not found in the early Acheulean, and LCT retouching was limited to edge retouching that did not modify the shape of the blank, just as was the case with small tools.

Summing up, the transition from the late Oldowan to the early Acheulean at Melka Kunture was a cultural continuum, during which new concepts and behaviors gradually emerged. The production of large tools is a diagnostic aspect of the early Acheulean. Nevertheless, these large tools are the outcome of retouch modifying only edges, not the shape of the blank, and shaping is absent. Bifaces are missing and there are only two cleavers. Actually, the main conceptual innovations are just the introduction of some technical criteria into débitage for the extraction of small, medium and large-sized flakes. For the knappers, these innovations were a first step in gaining independence from constraints imposed by nature, i.e., by lithic resources. This local evolution was accomplished by *Homo erectus* sensu lato, whose remains have been recorded both in Oldowan levels (Garba IVE) and in early Acheulean ones (Gombore IB; Di Vincenzo et al. 2015).[5]

Based on a techno-economic approach, the transition from the late Oldowan to the early Acheulean at Melka Kunture was completed within 200 kyr- not, as Chavaillon et al. (1979) had suggested, in 500 kyr. At Melka Kunture, biface and cleaver production does not characterize the emergence of the Acheulean; it pertains to the Acheulean of the late Early Pleistocene, which is distinguished from the early Acheulean by a sharp temporal, techno-economic and human paleontological discontinuity.

Acknowledgements We thank the Authority for Research & Conservation of the Cultural Heritage of Ethiopia's Ministry of Culture & Tourism, the National Museum of Addis Ababa, and the Oromia Culture and Tourism Bureau for fieldwork permits and access to the lithic collections. The research was supported by grants from "La Sapienza" University of Rome ("Grandi scavi archeologici") and from the Italian Foreign Ministry, awarded to MM. The study of the Garba IVD lithic artifacts was made possible by a Post-Ph.D research grant from the Wenner-Gren Foundation (number 7715 "Technical Behaviors During the Oldowan at Garba IVD, Melka Kunture, Ethiopia") awarded to RG. We also wish to thank Guy Kieffer and Jean-Paul Raynal for lithological analysis of raw materials, Massimo Pennacchioni and Noemi Tomei for their drawings of artifacts, and Jean-Paul Raynal for the photos in Fig. 4.8e, f. We express deep thanks to the anonymous reviewers as well as to the VERT Series editors, who all helped us to improve this paper.

RG studied the lithic collections. MM, director of the Italian Archeological Mission at Melka Kunture and Balchit, coordinates research and designed and organized this project. RG wrote the paper and MM contributed to the draft.

[5]Cf. Gallotti and Mussi (2017) for a redefinition of the cultural attribution of level Gombore IB, previously thought to be related to the Oldowan.

References

Abebe, T., Manetti, P., Bonini, M., Corti, G., Innocenti, F., & Mazzarini, F. (2005). *Geological Map of the Northern Main Ethiopian Rift*. Map and chart series MCH094, The Geological Society of America. USA: Inc. Boulder.

Bardin, G., Raynal, J.-P., & Kieffer, G. (2004). Drainage patterns and regional morphostructure at Melka Kunture (Upper Awash, Ethiopia). In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic Site of Melka Kunture, Ethiopia* (pp. 83–92). Florence: Origines.

Barsky, D., Garcia, J., Martínez, K., Sala, R., Zaidner, Y., Carbonell, E., et al. (2014). Flake modification in European Early and Early-Middle Pleistocene stone tool assemblages. *Quaternary International, 316,* 140–154.

Beyene, Y., Katoh, S., WoldeGabriel, G., Hart, W. K., Uto, K., Sudo, M., et al. (2013). The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. *Proceedings of the National Academy of Sciences, 110,* 1584–1591.

Boëda, E. (1993). Le débitage discoïde et le débitage Levallois récurrent centripète. *Bulletin de la Société Préhistorique Française, 90–96,* 392–404.

Bonnefille, R., Melis, R. T., & Mussi, M. (2018). Variability in the Mountain Environment at Melka Kunture Archaeological Site, Ethiopia, During the Early Pleistocene ($\sim$1.7 Ma) and the Mid-Pleistocene Transition (0.9–0.6 Ma). In R. Gallotti & M. Mussi (Eds.), *The Emergence of the Acheulean in East Africa and Beyond. Contributions in Honor of Jean Chavaillon.* Cham: Springer.

Braun, D. R., Plummer, T., Ferraro, J. V., Ditchfield, P., & Bishop, L. C. (2009). Raw material quality and Oldowan hominin toolstone preferences: Evidence from Kanjera South, Kenya. *Journal of Archeological Science, 36,* 1605–1614.

Chernet, T., Hart, W. K., Aronson, J. L., & Walter, R. C. (1998). New age constraints on the timing of volcanism and tectonism in the northern Main Ethiopian Rift and the southern Afar transition zone (Ethiopia). *Journal of Volcanology and Geothermal Research, 80,* 267–280.

Chavaillon, J. (1980). Chronologie archéologique de Melka-Kunturé (Ethiopie). In R. E. F. Leakey & B. A. Ogot (Eds.), *Proceedings VIII Panafrican Congress of Prehistory and Quaternary Studies, Nairobi 1977* (pp. 200–201). Nairobi: The International Louis Leakey Memorial Institute for African Prehistory.

Chavaillon, J., & Chavaillon, N. (1980). Évolution de l'Acheuléen à Melka-Kunturé (Éthiopie). *Anthropologie, XVIII*(2/3), 153–159.

Chavaillon, J., Chavaillon, N., Hours, F., & Piperno, M. (1979). From the Oldowan to the Middle Stone Age at Melka-Kunture (Ethiopia). Understanding cultural changes. *Quaternaria, XXI*, 1–26.

Chavaillon, J., & Piperno, M. (1975). Garba IV, site paléolithique ancien de Melka-Kunturé (Éthiopie). *Bulletin de la Société Préhistorique Française, 72,* 134–138.

Chavaillon, J., & Piperno, M. (2004). *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia*. Florence: Origines.

Condemi, S. (2004). The Garba IVE mandible. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 687–701). Florence: Origines.

Cressier, P. (1980). Magnétostratigraphie du gisement pléistocène de Melka-Kunturé (Éthiopie). Datation des niveaux oldowayens et acheuléens. Ph.D. Dissertation, Université Louis Pasteur.

D'Andrea, A., & Gallotti, R. (2004). GIS and intra-site spatial analysis. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 589–597). Florence: Origines.

D'Andrea, A., Gallotti, R., & Piperno, M. (2000). Applicazione di un GIS intra-site al giacimento paleolitico di Garba IV (Melka Kunture, Etiopia). *Archeologia e Calcolatori, 11,* 319–338.

D'Andrea, A., Gallotti, R., & Piperno, M. (2002). Taphonomic interpretation of the Developed Oldowan site of Garba IV (Melka Kunture, Ethiopia) through a GIS application. *Antiquity, 76,* 991–1001.

Daniel, N., & Lapedes, D. N. (1978). *McGraw-Hill Dictionary of Scientific and Technical Terms* (2nd ed.). New York: McGraw-Hill Inc.

de la Torre, I. (2004). Omo Revisited: Evaluating the Technological Skills of Pliocene Hominids. *Current Anthropology, 45,* 439–465.

de la Torre, I. (2011). The Early Stone Age lithic assemblages of Gadeb (Ethiopia) and the developed Oldowan/early Acheulean in East Africa. *Journal of Human Evolution, 60,* 768–812.

de la Torre, I. (2016). The origins of the Acheulean: Past and present perspectives on a major transition in human evolution. *Philosophical Transactions of the Royal Society of London. Series B, 37,* 20150245.

de la Torre, I., & Mora, R. (2005). *Technological Strategies in the Lower Pleistocene at Olduvai Beds I & II*. Liege: ERAUL.

de la Torre, I., Mora, R., & Martínez-Moreno, J. (2008). The early Acheulean in Peninj (Lake Natron, Tanzania). *Journal of Anthropological Archeology, 27,* 244–264.

Defleur, A., & Crégut-Bonnoure, E. (1995). Le gisement paléolithique moyen de la grotte des Cèdres (Le Plan-d'Aups, Var). Paris: *Documents d'Archéologie Française, 49*, CNRS.

Delagnes, A., & Roche, H. (2005). Late Pliocene knapping skills: The case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution, 48,* 435–472.

Diez-Martín, F., Sánchez-Yustos, P., Uribelarrea, D., Baquedano, E., Mark, D. F., Mabulla, A., et al. (2015). The Origin of the Acheulean: The 1.7 Million-Year-Old Site of FLK West, Olduvai Gorge (Tanzania). *Scientific Reports, 5*, 17839.

Di Vincenzo, F., Rodriguez, L., Carretero, J. M., Collina, C., Geraads, D., Piperno, M., et al. (2015). The massive fossil humerus from the Oldowan horizon of Gombore I, Melka Kunture (Ethiopia, >1.39 Ma). *Quaternary Science Review, 122,* 207–221.

Forestier, H. (1992). Approche technologique de quelques séries dites clactoniennes du nord-ouest de la France et du sud-est de l'Angleterre. Mémoire de Maîtrise, Université Paris X Nanterre.

Forestier, H. (1993). Le Clactonien : mise en application d'une nouvelle méthode de débitage s'inscrivant dans la variabilité des systèmes de production lithique du paléolithique ancien. *Paléo, 5,* 53–82.

Gallotti, R. (2013). An older origin for the Acheulean at Melka Kunture (Upper Awash, Ethiopia). Techno-economic behaviors at Garba IVD. *Journal of Human Evolution, 65,* 594–620.

Gallotti, R. (2018). Before the Acheulean in East Africa: An Overview of the Oldowan Lithic Assemblages. In R. Gallotti & M. Mussi (Eds.), *The Emergence of the Acheulean in East Africa and Beyond. Contributions in Honor of Jean Chavaillon*. Cham: Springer.

Gallotti, R., & Mussi, M. (2015). The Unknown Oldowan: ~1.7-Million-Year-Old Standardized Obsidian Small Tools from Garba IV, Melka Kunture, Ethiopia. *PLoS ONE, 10,* e0145101.

Gallotti, R., & Mussi, M. (2017). Two Acheuleans, two humankinds: From 1.5 to 0.85 Ma at Melka Kunture (Upper Awash, Ethiopian highlands). *Journal of Anthropological Sciences, 95,* 1–46.

Gallotti, R., & Piperno, M. (2003). Recent activities of the Italian Archeological Mission at Melka Kunture: The Open Air Museum Project and the GIS application to the study of the Oldowan sites. In J. M. Moreno, R. M. Torcal, & I. de la Torre Sainz (Eds.), *Oldowan: Rather more than smashing tools, First Hominid Technology Workshop* (pp. 37–75). Bellaterra: Treballs d'Arqueologia, 9.

Gallotti, R., & Piperno, M. (2004). The site of Garba IV. Spatial analysis of the lithic material from Level D. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 599–635). Florence: Origines.

Gallotti, R., Collina, C., Raynal, J.-P., Kieffer, G., Geraads, D., & Piperno, M. (2010). The Early Middle Pleistocene Site of Gombore II (Melka Kunture, Upper Awash, Ethiopia) and the Issue of Acheulean Bifacial Shaping Strategies. *African Archeological Review, 27,* 291–322.

Gallotti, R., Raynal, J.-P., Geraads, D., & Mussi, M. (2014). Garba XIII (Melka Kunture, Upper Awash, Ethiopia): A new Acheulean site of the late Lower Pleistocene. *Quaternary International, 343,* 17–27.

Geneste, J. M. (1989). Économie des ressources lithiques dans le Moustérien du sud ouest de la France. In M. Otte (Ed.), *L'Homme de Néanderthal, La Subsistance vol. 6* (pp. 75–97). Liege: ERAUL.

Geneste, J. M. (1991). Systèmes techniques de production lithique : variations technoéconomiques dans les processus de réalisation des outillages paléolithiques. *Technique et Culture, 17*(18), 1–35.

Goren-Inbar, N., & Sharon, G. (2006). Invisible handaxes and visible Acheulan biface technology at Gesher Benot Ya'aqov, Israel. In N. Goren-Inbar & G. Sharon (Eds.). *Axe Age. Acheulean Toolmaking from Quarry to Discard* (pp. 111–135). London: Equinox.

Harmand, S. (2009). Raw material and techno-economic behaviours at Oldowan and Acheulean sites in the West Turkana region, Kenya. In B. Adams & B. Blades (Eds.), *Lithic Materials and Paleolithic Societies* (pp. 3–14). Oxford: Blackwell.

Inizan, M. L., Reduron-Ballinger, M., Roche, H., & Tixier, J. (1999). *Technology and Terminology of Knapped Stone (Préhistoire de la Pierre taillée 5).* Nanterre: CREP.

Jaubert, J., & Mourre, V. (1996). Coudoulous, le Rescundudou, Mauran : diversité des matières premières et variabilité des schemas de production d'éclats. In A. Bietti & S. Grimaldi (Eds.), *Reduction Processes* (chaînes opératoires) *in the European Mousterian* (pp. 313–341). Rome: Quaternaria Nova 6, Istituto Italiano di Paleontologia Humana.

Kieffer, G., Raynal J.-P., & Bardin, G. (2002). Cadre structural et volcanologiques des sites du Paléolithique ancien de Melka Kunture (Awash, Ethiopie) : premiers résultats. In J.-P. Raynal, C. Albore-Livadie, & M. Piperno (Eds.), *Hommes et Volcans. De l'éruption à l'objet* (pp. 77–92). Les Dossiers de l'Archéo-Logis 2, Proceedings XIV UISPP Congress, Symposium 15.2, Liege, 2001.

Kieffer, G., Raynal, J.-P., & Bardin, G. (2004). Volcanic markers in coarse alluvium at Melka Kunture (Upper Awash, Ethiopia). In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 93–101). Florence: Origines.

Kleindienst, M. R. (1962). Components of the East African Acheulian assemblages: An analytic approach. In G. Mortelmans & J. Nenquin (Eds.), *Actes du IV° Congrès Panafricain de Préhistoire et d'Études du Quaternaire, Leopoldville, 1959* (pp. 81–108). Tervuren: Belgie Annalen, Musée Royal de l'Afrique Centrale.

Leakey, M. D. (1971). *Olduvai Gorge. Excavations in Bed I and II, 1960–1963* (Vol. 3). Cambridge: Cambridge University Press.

Leakey, M. D. (1975). Cultural patterns in the Olduvai sequence. In K. W. Butzer & G. L. Isaac (Eds.), *After the Australopithecines. Stratigraphy, Ecology, and Cultural Change in the Middle Pleistocene* (pp. 477–493). Chicago: Mouton.

Le Bourdonnec, F.-X. (2007). Aspects archéométriques de la circulation de l'obsidienne préhistorique. Développements analytiques et applications en Corse, Sardegne, Éthiopie. Ph.D. Dissertation, Université Michel de Montaigne Bordeaux 3, Pessac.

Leroi-Gourhan, A. (1964). *Le geste et la parole. Technique et langage*. Paris: Albin Michel.

Leroi-Gourhan, A. (1971). *Évolution et Technique. L'Homme et la Matière*. Paris: Albin Michel.

Lepre, C. J., Roche, H., Kent, D. V., Harmand, S., Quinn, R. L., Brugal, J.-P., et al. (2011). An earlier origin for the Acheulian. *Nature, 477,* 82–85.

Mohr, P. (1999). Le système des rifts Africains. Environnement géologique et géographique. In A. Gallay (Ed.), *Comment* *l'Homme ? A la découverte des premiers hominidés d'Afrique de l'Est* (pp. 231–288). Paris: Editions Errance.

Moncel, M. H. (1998). Les niveaux moustériens de la grotte de Saint-Marcel (Ardèche). Fouilles René Gilles. Reconnaissance de niveaux à débitage discoïde dans la vallée du Rhône. *Bulletin de la Société Préhistorique Française, 95,* 141–170.

Morgan, L. E., Renne, P. R., Kieffer, G., Piperno, M., Gallotti, R., & Raynal, J.-P. (2012). A chronological framework for a long and persistent archeological record: Melka Kunture, Ethiopia. *Journal of Human Evolution, 62,* 104–115.

Mourre, V. (2003). Discoïde ou pas Discoïde ? Réflexions sur la pertinence des critères techniques définissant le débitage Discoïde. In M. Peresani (Ed.), *Discoid Lithic Technology—Advances and implications* (pp. 1–18). Oxford: BAR International Series 1120.

Mussi, M., Altamura, F., Bonnefille, R., De Rita, D., & Melis, R. T. (2016). The environment of the Ethiopian highlands at the Mid Pleistocene Transition: Fauna, flora and hominins in the 850–700 ka sequence of Gombore II (Melka Kunture). *Quaternary Science Review, 149,* 259–268.

Mussi, M., Altamura, F., Macchiarelli, R., Melis, R. T., & Spinapolice, E. E. (2014). Garba III (Melka Kunture, Ethiopia): A MSA site with archaic *Homo sapiens* remains revisited. *Quaternary International, 343,* 28–39.

Negash, A., Shackley, M. S., & Alene, M. (2006). Source provenance of obsidian artifacts from the Early Stone Age (ESA) site of Melka Kunture, Ethiopia. *Journal of Archeological Science, 33,* 1647–1650.

Pasty, J.-F. (2000). Le gisement paléolithique moyen des Meillers (Allier) : un exemple de la variabilité du débitage discoïde. *Bulletin de la Société Préhistorique Française, 97,* 165–190.

Pelegrin, J. (1985). Réflexions sur le comportement technique. In M. Otte (Ed.), *La signification culturelle des industries lithiques* (pp. 72–91). Liege: Studia Praehistorica Belgica 4, BAR International Series 239.

Peresani, M. (Ed.). (2003). *Discoid Lithic Technology—Advances and implications*. Oxford: BAR International Series 1120.

Perlès, C. (1991). Économie des matières premières et économie du débitage : deux conceptions opposées ? In S. Beyries, L. Meignen, & P. J. Texier (Eds.), *25 ans d'études technologiques en Préhistoire : bilan et perspectives. Proceedings XIème rencontres internationales d'Archéologie et d'Histoire d'Antibes* (pp. 35–46). Juan-les-Pins: APDCA.

Piperno, M., & Bulgarelli, G. M. (2004). The site of Garba IV. Excavation 1973–1982. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 449–458). Florence: Origines.

Piperno, M., & Bulgarelli-Piperno, G. M. (1975). First approach to the ecological and cultural significance of the early Palaeolithic occupation site of Garba IV at Melka-Kunture (Ethiopia). *Quaternaria, XVIII*, 347–382.

Piperno, M., Bulgarelli, G. M., & Gallotti, R. (2004a). The site of Garba IV. The lithic industry of Level C. Typological and technological study. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 459–468). Florence: Origines.

Piperno, M., Bulgarelli, G. M., & Gallotti, R. (2004b). The site of Garba IV. The lithic industry of Level D. Débitage and tools on flake. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 469–544). Florence: Origines.

Piperno, M., Bulgarelli, G. M., & Gallotti, R. (2004c). The site of Garba IV. The lithic industry of Level D. Tools on pebble and percussion material. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 545–580). Florence: Origines.

Piperno, M., Bulgarelli, G. M., & Gallotti, R. (2004d). The site of Garba IV. The test trenches A and B and the sounding in Level E. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 581–587). Florence: Origines.

Piperno, M., Collina, C., Gallotti, R., Raynal, J.-P., Kieffer, G., Le Bourdonnec, F.-X., et al. (2009). Obsidian exploitation and utilization during the Oldowan at Melka Kunture (Ethiopia). In E. Hovers & D. R. Braun (Eds.), *Interdisciplinary Approaches to the Oldowan* (pp. 111–128). Dordrecht: Springer.

Poupeau, G., Kieffer, G., Raynal, J. P., Milton, A., & Delerue, S. (2004). Trace element geochemistry in Balchit obsidian (Upper Awash, Ethiopia). In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 103–110). Florence: Origines.

Profico, A., Di Vincenzo, F., Gagliardi, L., Piperno, M., & Manzi, G. (2016). Filling the gap. Human cranial remains from Gombore II (Melka Kunture, Ethiopia; ca. 850 ka) and the origin of *Homo heidelbergensis*. *Journal of Anthropological Sciences, 94,* 1–24.

Quade, J., Levin, N., Semaw, S., Stout, D., Renne, P., Rogers, M. J., et al. (2004). Paleoenvironments of the earliest stone toolmakers, Gona, Ethiopia. *Geological Society of America Bulletin, 116,* 1529–1544.

Quade, J., Levin, N., Simpson, S., Butler, R., McIntosh, W., Semaw, S., et al. (2008). The Geology of Gona, Afar, Ethiopia. *Geological Society of America Bulletin, Special Paper, 446,* 1–31.

Raynal, J.-P., & Kieffer, G. (2004). Lithology, dynamism and volcanic successions at Melka Kunture (Upper Awash, Ethiopia). In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 111–135). Florence: Origines.

Raynal, J.-P., Kieffer, G., & Bardin, G. (2004). Garba IV and the Melka Kunture Formation. A preliminary lithostratigraphic approach. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 136–166). Florence: Origines.

Roche, H., & Texier, P.-J. (1991). La notion de complexité dans un ensemble lithique. Application aux séries acheuléennes d'Isenya (Kenya). In S. Beyries, L. Meignen, & P.-J. Texier (Eds.), *25 ans d'études technologiques en Préhistoire : bilan et perspectives. Proceedings XIème rencontres internationales d'Archéologie et d'Histoire d'Antibes* (pp. 99–108). Juan-les-Pins: APDCA.

Salvi, M. C., Salvini, R., Cartocci, A., Kozciak, S., Gallotti, R., & Piperno, M. (2011). Multitemporal analysis for preservation of obsidian sources from Melka Kunture (Ethiopia): Integration of fieldwork activities, digital aerial photogrammetry and multispectral stereo-IKONOS II analysis. *Journal of Archeological Science, 38,* 2017–2023.

Schmitt, J.-J., Wempler, J.-M., Chavaillon, J., & Andrews, M. C. (1977). Initial K/Ar and paleomagnetic results of the Melka-Kunturé early-man sites, Ethiopia. In *Proceedings VIII Panafrican Congress of Prehistory and Quaternary Studies, Nairobi*.

Semaw, S. (2006). The Oldest Stone Artifacts from Gona (2.6–2.5 Ma), Afar, Ethiopia: Implications for understanding the earliest stages of stone knapping. In N. Toth & K. Schick (Eds.), *The Oldowan: Case Studies into the Earliest Stone Age* (pp. 43–75). Gosport, Indiana: Stone Age Institute Press.

Semaw, S., Rogers, M. J., Cáceres, I., Stout D., & Leiss, A. C. (2018). The Early Acheulean ~1.6–1.2 Ma from Gona, Ethiopia: Issues on the Emergence of the Acheulean in Africa. In R. Gallotti & M. Mussi (Eds.), *The Emergence of the Acheulean in East Africa and Beyond. Contributions in Honor of Jean Chavaillon*. Cham: Springer.

Sharon, G. (2010). Large flake Acheulan. *Quaternary International, 223–224,* 226–233.

Tamrat, E., Thouveny, N., Taieb, M., & Brugal, J. P. (2014). Magnetostratigraphic study of the Melka Kunture archeological site (Ethiopia) and its chronological implications. *Quaternary International, 343,* 5–16.

Taieb, M. (1974). Evolution quaternaire du bassin de l'Awash. Ph.D. Dissertation, University of Paris VI.

Terradas, X. (2003). Discoid flaking method: Conception and technological variability. In M. Peresani (Ed.), *Discoid Lithic Technology—Advances and implications* (pp. 19–32). Oxford: BAR International Series 1120.

Texier, P.-J. (2018). Technological Assets for the Emergence of the Acheulean? Reflections on the Kokiselei 4 Lithic Assemblage and Its Place in the Archaeological Context of West Turkana, Kenya. In M. Mussi & R. Gallotti (Eds.), *The Emergence of the Acheulean in East Africa and Beyond. Contributions in Honor of Jean Chavaillon*. Cham: Springer.

Texier, P.-J., & Roche, H. (1995). The impact of predetermination on the development of some Acheulan chaînes opératoires. In J. M. Bermudez, J. L. Arsuaga, & E. Carbonell (Eds.), *Human Evolution in Europe and the Atapuerca Evidence* (pp. 403–420). Valladolid: Regional Junta de Castilla y León.

Tixier, J. (1956). Le hachereau dans l'Acheuléen nord-africain. Notes typologiques. In *Proceedings of the XV Session of the Congrès préhistorique de France, July 15–22, 1956, Poitiers-Angoulême* (pp. 914–923).

Westphal, M., Chavaillon, J., & Jaeger, J. J. (1979). Magnétostratigraphie des dépôts Pléistocènes de Melka-Kunturé (Éthiopie) : premières données. *Bulletin de la Société Géologique Française, 7,* 237–241.

Zaidner, Y. (2013). Adaptive flexibility of Oldowan hominins: Secondary use of flakes at Bizat Ruhama, Israel. *PlosOne, 8,* e66851.

Zilberman, U., Smith, P., & Condemi, S. (2004a). Evidence for a genetic disorder affecting tooth formation in the Garba IV child. In J. Chavaillon & M. Piperno (Eds.), *Studies on the Early Paleolithic site of Melka Kunture, Ethiopia* (pp. 703–713). Florence: Origines.

Zilberman, U., Smith, P., Piperno, N., & Condemi, S. (2004b). Evidence of amelogenesis imperfecta in an early African *Homo erectus*. *Journal of Human Evolution, 46,* 647–653.