Chapter 2
Before the Acheulean in East Africa: An Overview of the Oldowan Lithic Assemblages

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Abstract In 2009, Hovers and Braun published in Springer's Vertebrate Paleobiology and Paleoanthropology Series the volume "Interdisciplinary Approaches to the Oldowan," stemming from the symposium of the 2006 SAA meeting in Puerto Rico. Many contributors focused on the description of the Oldowan as a lithic production system, showing the high technical variability of the techno-complexes. As pointed out by Braun and Hovers (2009: 4), even if most or all scholars agree that the study of Oldowan behaviors is fundamental to understand early hominin evolution, "not all would agree on a definition of the Oldowan." Forty years after it was first defined (Leakey 1971, 1975), many sites scattered over approximately one million years are labelled as "Oldowan" in large-scale syntheses. While the available data are highly fragmented both in time and space, and the study of lithic assemblages follows different theoretical and methodological approaches, major overviews simply take for granted that a correlation among the East African assemblages is inescapable. However, the term Oldowan is still a vague concept, lacking a comprehensive definition of what an Oldowan technology is. Additionally, who were the authors of the Oldowan stone tools remains an open question.

Nine years after the publication of Hovers and Braun's volume, this is a short overview and update of the current state of our knowledge of the Oldowan technical behaviors recorded in East Africa, to put in the proper perspective specific sites with "emerging" Acheulean.

Keywords Oldowan • Lithic techno-economy • Technological stasis/development • Early Pleistocene hominins

2.1 Introduction

In Leakey's original definition, the Oldowan is a cultural entity within East Africa dating between ca. 1.8 and 1.5 Ma. This definition pertains exclusively to the material culture and is grounded in the chrono-stratigraphic and cultural framework of the Olduvai sequence as described in Leakey's report (1971).

Following the methodological approach developed in Europe by Bordes (1961), Leakey (1971) established the fundamental characters of the Oldowan industries of Olduvai. She proposed the terminology and associated descriptive criteria allowing to define them. She further defined in 1975 the guidelines of the typological evolution of the Olduvai industries suggesting a homogeneous nomenclature and producing a unilinear evolutionary cultural synthesis. Leakey's seminal definition has been the reference ever since, over more than forty years, for the Early Pleistocene prehistory of East Africa. Nevertheless, some later analyses, albeit based on Leakey's typological list, focused on the characterization of specific types of artifacts in a diachronic perspective, often extracting them out of their relations with the other elements of the same complex. In the end, the perception of the intra-site synchronism was missed (Bower 1977; Dies and Dies 1980; Wynn 1981; Willoughbly 1987; Sahnouni 1991).

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A few years after Leakey, Isaac proposed an alternative system for the study of the Oldowan industries. Isaac's model linked each lithic component to a specific production stage and suppressed the functional connotations of each morpho-type found in M. Leakey's perspective (Isaac 1977, 1984, 1986). Isaac also insisted on the need of relating stone artifacts to economic and ecological patterns, in order to evaluate if some degree of variability was the outcome (Isaac 1977). The differences highlighted between the KBS and Karari industries of Koobi Fora on the one hand, and the Oldowan of Olduvai Gorge on the other, made clear that with two different methodological approaches it was truly a challenge to evaluate inter-site Oldowan technical variability (Isaac and Isaac 1997).

At the end of the 1970s, Chavaillon (1979) introduced a detailed typology of the percussion material, which is abundant at Melka Kunture as well as at Olduvai, but only rarely found at Koobi Fora. Chavaillon (1979) underlined for the first time that percussion activities, overlooked in Leakey's and Isaac's models, rather were a structural element of early technologies.

In the 1980s, several primatologists and some archaeologists suggested that Oldowan industries were sets of tools that did not require skills beyond those observed in apes (Wynn and McGrew 1989; Foley 1991). The Oldowan was seen as an expedient toolkit. In the same years, Toth's (1982, 1985) reinterpretation of the Oldowan led to a somewhat different picture: the Oldowan was reassessed as the result of a more complex technological behavior than documented among non-human primates. However, even if more elaborate, this technology was seen as definitely simpler and more expedient than in later Acheulean industries (Martínez-Moreno et al. 2003). Toth's (1982, 1985) experimental studies furthermore demonstrated that the flakes, considered by M. Leakey as waste, actually were end products, as already argued by Isaac (1977).

As it had been in the case of Leakey's studies, Isaac and Toth's contributions opened the path to new research, mainly by American scholars. Unfortunately, as de la Torre and Mora pointed out (2009: 17), this next generation of analyses lacked "the theoretical and methodological approaches that had guided these authors", i.e., respectively, the ecological perspective and the experimental analysis (e.g., Potts 1988, 1991; Semaw 1997, 2000; Kimura 1999, 2002; Ludwigh 1999; Noll 2000; de la Torre et al. 2003).

The discovery of sites older than 2 Ma elsewhere in East Africa, notably Gona/Hadar and Omo in Ethiopia, and West Turkana in Kenya, promoted the idea of an even simpler and less developed technology (Chavaillon 1976; Roche and Tiercelin 1980; Roche 1989; Kibunjia 1994; de Lumley and Beyene 2004). Initially, this earlier evidence was assigned to the Oldowan, giving further weight to an assumed one-million-year-long stasis in technological development (Semaw 2000; Semaw et al. 2003). Between the end of the 1980s and the beginning of the 1990s, the hypothesis started to emerge that more archaic artifacts, predating 2 Ma, should be classified separately. A new terminology was introduced, including "pre-Oldowan," "Shungura facies," or "Nachukui industry" (Howell et al. 1987; Piperno 1987; Roche 1989, 1996; Kibunjia 1994, 1998; Roche et al. 1999, 2003).

The detailed analysis of artifacts available at the 2.34 Ma site of Lokalalei 2C (West Turkana, Kenya) suggests that early hominids displayed distinct technical competencies and techno-economic behaviors more sophisticated than expected. Accordingly, it was argued that intra-site complexity and inter-site variability were not accounted for by the existing chrono-cultural classifications (Delagnes et al. 2005). This recognized that higher degree of variability and complexity is not just the outcome of the analysis of Lokalalei 2C. It is also the effect of a new theoretical and methodological approach to the study of stone artifacts, i.e., of the chaîne opératoire approach. The chaîne opératoire concept allows to place each object in a precise technical context, identifying all the technical processes performed for its production, from raw material procurement modalities to the manufacture and use phases, ending with final abandonment (Leroi-Gourhan 1964, 1971; Lemonnier 1976; Pelegrin 1985; Geneste 1989, 1991; Boëda 1991; Perlès 1991; Inizan et al. 1999). While a typological approach considers exclusively the final state of the technical operations, making comparisons and recognizing likeness or differences, the technological approach takes into account the whole history of a lithic object and the various modalities of manufacturing. This allows for a broad range of variability, well beyond the finished object.

Right now, the chaîne opératoire approach is widely used in lithic studies of early technologies and many assemblages have been recently reviewed following this concept. Even if the level and the details of analyses vary from one site to another, they generated a common methodological background allowing comparisons.

The next sections will explore the techno-economic behaviors of any Oldowan assemblage analyzed through this methodology (Table 2.1) in order to micro-analyze (to the degree possible) the lithic productions in order to comment on the issues of complexity, diversity, and flexibility of behaviors. Based on Isaac and Isaac's typological analysis (1997), the Early Pleistocene[1] assemblages from the KBS and Okote members at Koobi Fora (1.9–1.6 Ma) are considered here as a local variant of the Oldowan from Olduvai. The Koobi Fora assemblages, however, are not discussed here, because of the lack of a systematic and comprehensive

[1]I use in this paper the revised timescale approved by IUGS, in which the base of the Pleistocene is defined by the GSSP of the Gelasian Stage at 2.588 (2.6) Ma (Gibbard et al. 2010).

Table 2.1 East African Oldowan sites discussed in this paper

Site	Sub-site	Age (Ma)	m^2	Hominins	Fauna	Lithic assemblage	Percussion elements	Small débitage				Technique	References
								Raw material provisioning	Raw material morphology	Flaking exploitation	Retouched flakes (% of all the flakes)		
Gona	EG10	2.6–2.5	13	Absent	Absent	2236	Absent	Local	Medium-sized rounded cobbles	• Unifacial (mainly) simple/unidirectional/centripetal • Bifacial partial • Multidirectional irregular	2.5	Free hand	Semaw et al. (2003), Stout et al. (2005, 2010), Semaw (2006)
	EG12		8	Absent	Absent	754					4		
	OGS-7		2.6	Absent	Present	~700		Local/non-local		• Unifacial simple/unidirectional/centripetal • Bifacial partial and multidirectional irregular (mainly)	Absent		
Hadar	AL849	2.4–2.3	20	*Homo* aff. *habilis*	Present	4828	Absent	Local	Medium-sized angular cobbles	Mainly unifacial	Absent	Free hand	Hovers (2003, 2009), Goldman-Neuman and Hovers (2009, 2012)
	AL666		2?		Present	224		Local/non-local (?)		Mainly unifacial		Free hand Bipolar	
West Turkana	LA1	2.34	60	*Homo* aff. *habilis*	Present	445	?	Local	Large-sized angular and globular cobbles	• Unifacial (mainly)/bifacial/multifacial multidirectional • Bifacial • Multifacial	?	Free hand	Roche et al. (2003), Delagnes and Roche (2005), Harmand (2009)
	LA2C		17	*Paranthropus aethiopicus*	Present	2614	Present		Large-medium-sized blocks and cobbles	• Simple • Unifacial (mainly) multidirectional • Bifacial • Multifacial	2.5		
	KS5	1.87	65	–	Present	1727	Present	Local	Large-sized angular, flat and globular cobbles	• Unifacial • Bifacial partial • Multifacial multidirectional/orthogonal • Centripetal	1.2	Free hand	Texier et al. (2006), Texier (2018)
Omo	Omo 57	2.34	?	*Homo sp.*	Absent	498	Absent	Local	Small-sized angular cobbles	Unifacial unidirectional	0.8	Free hand	de la Torre (2004)
	Omo 123		?	*Paranthropus aethiopicus*		1314					Absent	Bipolar (only two cores)	
Kanjera South	Ex. 1, 2, 5, 6	>2.0	4–169	Absent	Present	4474	?	Local/non-local	Small-medium-sized rounded cobbles	• Unifacial unidirectional • Bifacial centripetal • Multifacial multidirectional	?	Free hand Bipolar	Braun et al. (2008a, b, 2009a, b, c), Lemorini et al. (2014)
Fejej	FJ-1a	~1.9	85	*Homo* aff. *habilis* *Paranthropus boisei*	Present	2610	Present	Local	Medium-sized rounded and angular cobbles	• Unifacial unipolar/bipolar/multipolar/centripetal • Bifacial unipolar/bipolar/centripetal • Multifacial multidirectional	0.8	Free hand Bipolar (very few)	de Lumley et al. (2004b), Barsky et al. (2011)

(continued)

Table 2.1 (continued)

Site	Sub-site	Age (Ma)	m²	Hominins	Fauna	Lithic assemblage	Percussion elements	Small débitage: Raw material provisioning	Small débitage: Raw material morphology	Small débitage: Flaking exploitation	Small débitage: Retouched flakes (% of all the flakes)	Technique	References
Olduvai	DK	>1.8	380[a]	*Homo habilis*	Present	1180	Present	Local	Medium-sized cobbles Tabular blocks	• Unifacial unidirectional/peripheral • Bifacial partial/peripheral • Multifacial multidirectional	1.6	Free hand	Leakey (1971), de la Torre and Mora (2005), Mora and de la Torre (2005) Only for Levels 1–2 see also Diez-Martín et al. (2010)
	FLK Zinj	>1.8	~300	*Paranthropus boisei*		2663				• Unifacial unidirectional/peripheral • Bifacial partial/peripheral	1.5		
	FLK North Level 6	>1.8	? (6–8[b] for Levels 6 to 2–1)	Absent		130				Unifacial/bifacial partial	Absent		
	FLK North Level 5	>1.8	?	*Homo habilis?*		132 (168[c] for Levels 5 to 2–1)				Unifacial/bifacial partial/peripheral	2		
	FLK North Level 4	>1.8	264	Absent		83				• Unifacial/bifacial partial • Multifacial multidirectional	Absent		
	FLK North Level 3	>1.8	100?			214				• Unifacial/bifacial partial/peripheral • Multifacial multidirectional	1.3		
	FLK North Levels 2–1	>1.8	100?			1456				• Unifacial unidirectional/centripetal • Bifacial unidirectional/ multidirectional/ • centripetal • Trifacial	5	Free hand Bipolar	
	FLK North *D.* Level	>1.66	?			36		Only 3 cores					
	FLK North SC	~1.6	?			248		Local	Medium-sized cobbles Tabular blocks	Unifacial/bifacial partial/peripheral	5		
Melka Kunture	Garba IVE	>1.7	34	*Homo erectus s.l.*	Present	1222	Absent	Local	Small-medium-sized rounded and angular cobbles	• Multifacial multidirectional • Multifacial multidirectional with one preferential flaking surface • Unifacial unidirectional • Unifacial centripetal/radial • Unifacial/bifacial partial	15	Free hand	Gallotti and Mussi (2015)
	Garba IVF		12	Absent		193					10		

[a]DK was excavated in 4 sectors: DK IA (27 m²), DK I Strips 1-111 (218.7 m²), DK IB (45 m²), and DK IC (89.1 m²)
[b]Two test trenches excavations were performed in 2007–2008 by The Olduvai Palaeoanthropology and Palaeoecology Project (TOPPP)
[c]Diez-Martín et al. (2010) studied 168 items from Levels 1 to 5. There is not a count per level. Flaking methods identified by Diez-Martín et al. (2010) mainly concern Levels 1–2, but include also specimens from Levels 3–5

reassessment in a technological perspective, except for some studies focused on specific aspects of the lithic production (e.g., Braun et al. 2008b, c, 2009a). The current overview aims at producing a detailed dataset for a broader evaluation of the continuity/discontinuity technological patterns from the Oldowan to the early Acheulean, also including an intra- and inter-site perspective.

2.2 "Older Than the Oldowan": The Lomekwian and the Origin of Stone Technology

After the discovery of the most ancient Oldowan assemblages at Gona (∼2.6 Ma; Semaw et al. 1997, 2003; Semaw 2000), several authors speculated about an earlier phase of stone knapping. Gona artifacts appeared to be too well made to have been the first experiments in producing sharp-edged stone flakes. It was also argued that percussive activities other than knapping, well documented in extant taxa of non-human primates, could have been structural components of hominin stone tool use (e.g., Roche et al. 1999; Semaw 2000; Panger et al. 2002; Semaw et al. 2003; Davidson and McGrew 2005; Marchant and McGrew 2005; Mora and de la Torre 2005; Carvalho et al. 2008; Rogers and Semaw 2009; de la Torre 2011; Carvalho and McGrew 2012).

The cut-marked bones from Dikika (Ethiopia; McPherron et al. 2010, 2011; Thompson et al. 2015), dated to >3.39 Ma, indirectly added fuel to speculations on pre-2.6 Ma stone tool use. Other researchers questioned the find, attributing the marks to natural wear and tear such as trampling (Domínguez-Rodrigo et al. 2010b, 2011, 2012).

The recent discovery of stone artifacts dated to ∼3.3 Ma at Lomekwi 3 (LOM 3) in West Turkana validated the hypotheses of an older origin for stone tool technology. The lithic assemblage consists of 149 surfaces and in situ artifacts, used for flaking and percussion activities (Harmand et al. 2015). Cores, significantly larger than those discovered in the Oldowan sites, are made mainly from very large-sized cobbles of basalts and phonolite, selected among cobbles and blocks of all sizes available in paleochannels at less than 100 m from the site. Cores are mainly unifacial with unidirectional superposed and contiguous removals. The knappers were also able to laterally rotate the cores, flaking one surface through multidirectional removals, and to flip them over for bifacial exploitation. However, the poorly controlled percussive motion combined with a tough raw material availability resulted in repetitive failed blows, hinged removals, and step fractures (Harmand et al. 2015).

Few cores display very short small scars along an edge, which could be the outcome of using them as tools, as well as of the technique. Replication experiments suggest that flaking activities were performed using passive hammers and/or bipolar techniques (Harmand et al. 2015), rarely identified in the Oldowan (e.g., Mora and de la Torre 2005; Diez-Martín et al. 2009, 2010; de la Torre and Mora 2010). This hypothesis is possibly confirmed by pieces weighing up to 15 kg bearing similar wear and fractures, which can be interpreted as anvils or passive elements. These techniques allow understanding how the knappers were able to flake huge blanks, hardly knapped by direct freehand percussion. On medium-sized cobbles battering marks and fractured surfaces document the coexistence of hand-held or active hammerstones. A combination of flaking and percussion is further documented by some flakes with natural dorsal faces showing battered areas. As pointed out by Harmand et al. (2015: 313): "The use of individual objects for several distinctive tasks reflects a degree of technological diversity both much older than previously acknowledged and different from the generally unipurpose stone tools used by primates." Nevertheless, Hovers (2015: 295) suggests that it is also possible that "at the beginning of each discrete episode of its use, each artifact was perceived merely as available raw material."

According to Harmand et al. (2015), at Lomekwi 3 the techniques seem closer to those involved in nut-cracking by non-human primates, than to the direct freehand percussion recorded in Oldowan assemblages. This further underlines the central role played by percussion activities at the dawn of technology, as it had already been suggested (e.g., Matsuzawa 1996; Mora and de la Torre 2005; Diez-Martín et al. 2009, 2010; Haslam et al. 2009; de la Torre and Mora 2010; Visalberghi et al. 2013; Bril et al. 2015; Hayashi 2015). Although direct comparisons between Lomewiki 3 and Oldowan assemblages are difficult, given the different levels of analysis, "the technological and morphological differences between the LOM 3 and early Oldowan assemblages are significant enough that amalgamating them would mask important behavioral and cognitive changes occurring among hominins over a nearly 2-million-year timespan" (Harmand et al. 2015: 314). For this reason, and because of the long time gap separating LOM 3 from the Oldowan sites, Harmand et al. (2015) introduced the name "Lomekwian".

2.3 The Oldowan Assemblages

2.3.1 Gona (Ethiopia)

At ∼2.6 Ma, i.e., 700,000 years later, stone artifacts are documented at Gona (Ethiopia). Stone artifacts of great antiquity were known at Gona ever since the early 1970s

(Johanson et al. 1978, 1982). Low-density scatters of surface artifacts had been discovered east of the Kada Gona River (Corvinus 1976; Corvinus and Roche 1976, 1980; Roche and Tiercelin 1977, 1980). Subsequent excavations at West Gona allowed discovering low density in situ artifacts (Harris 1983; Harris and Semaw 1989). Systematic excavations and geochronological analyses started in 1992–1994. More localities along the Kada and Ounda Gona rivers yielded surface and in situ artifacts, mostly recovered from EG10, EG12, and OGS-7. EG10 and EG12 are stratigraphically located below the AST-2.75 Tuff providing a minimum age of 2.52 Ma, and just above the 2.6 Ma Gauss-Matuyama polarity transition (McDougall et al. 1992; Semaw et al. 1997). The same polarity transition occurs below the archaeological level at OGS-7, sealed by the Gonash-14 Tuff, dated in turn to 2.53 ± 0.15 Ma (Semaw et al. 2003). Two archaeological levels at EG10 and one level at EG12 yielded high densities of stone artifacts with no associated bones (Semaw 2006). OGS-7 is the only —and oldest—site where artifacts were discovered with fossil bones, a few of them possibly showing human modification (Semaw et al. 2003). Modified bones of a similar age showing cutmarks and percussion marks made by stone tools were discovered at Bouri in the Middle Awash, but without any associated artifacts (de Heinzelin et al. 1999).

The three lithic assemblages are minimally disturbed. They are exclusively focused on small-medium flake production from local raw materials available in paleochannels. Comparing the geological and archaeological samples points to a high degree of raw material selectivity, based on rock type, phenocrysts, and groundmass (Stout et al. 2005). Additionally, lithotype frequencies significantly differ between East Gona sites and OGS-7. While at EG10-12 the assemblages are dominated by trachyte and rhyolite, which are largely available in local conglomerates, the OGS-7 series are mainly composed of high-quality aphanitic and vitreous volcanic materials. Such lithotypes are scarcely found in local conglomerates, and accordingly they had to be transported into the site (Stout et al. 2010).

Knapping technique is direct hard hammer percussion, with no evidence of bipolar, anvil, or throwing techniques. Five flaking methods were observed: simple unifacial, centripetal unifacial, unidirectional, partial bifacial, and irregular multifacial. Nevertheless, the EG10-12 débitage is dominated by unifacial cores. At OGS-7 the cores instead are bifacial or multifacial, with a higher number of flake scars indicating a relatively intense reduction. According to Stout et al. (2010), although the existence of distinct techno-cultural traditions cannot be ruled out, this variability has been interpreted as possibly originated by environmental diversity. OGS-7 formed on a channel bank or channel margin, while both EG-10 and EG-12 were located on a proximal floodplain (Stout et al. 2010).

2.3.2 Hadar (Ethiopia)

Early Pleistocene archaeological occurrences were also discovered in the upper Kada Hadar Member of the Hadar Formation in the Makaamitalu Basin, where the A.L. 666 and A.L. 894 sites are overlain by the 2.33 ± 0.07 Ma BKT-3 Tuff (Kimbel et al. 1996; Campisano 2012).

A.L. 666 yielded a very restricted lithic assemblage of flakes and angular fragments, and it represents the oldest spatiotemporal co-occurrence of tools, fauna, and hominids, i.e., a maxilla of *Homo* aff. *habilis* (Kimbel et al. 1996, 1997).

At A.L. 894 a few hundred bone fragments and several thousand lithic artifacts were discovered in the silty-clay deposits of the floodplain of a low-energy stream. The rodent fauna provides important evidence for a faunal shift in the small-mammal community—coincident with a similar faunal shift in the large-mammal community (Reed 2008)—between 3.2 Ma and 2.4 Ma. This shift documents increasing aridity, but not a dramatic change in the local paleoenvironment. This shift coincides also with the local extinction of *Australopithecus afarensis* and the emergence of the genus *Homo* at Hadar (Reed and Geraads 2012). The lithic assemblage possibly represents the palimpsest of several occupations. Taphonomic interpretation of the well-preserved bone assemblage shows lack of functional association between artifacts and bones, underscoring the complexity of site formation processes (Domínguez-Rodrigo and Martínez-Navarro 2012). Nevertheless, the numerous refits among lithic items suggest that burial happened relatively fast and with minimal geological disturbance (Hovers 2009). Most of the artifacts are complete or broken flakes (83%), with cores in small numbers (1%). Angular fragments make the remaining part of the assemblage. Rather than linked to anthropic flaking, they might well have been the result of post-depositional mechanisms (Hovers 2003).

The artifacts mainly are on cobbles of volcanic rocks, primarily rhyolite, basalt, and trachyte. Cobble size suggests transport from a source located at least several meters away. They were accurately selected in the nearby conglomerate, especially in the case of rhyolites. However, at A.L. 666 the rocks are more homogeneous and more fine-grained than at A.L. 894. Quartz and chert were also exploited. These rock types are found, even if scarcely, in the conglomerate, but transport from an unknown source cannot be ruled out. These patterns suggest not only selectivity, but possibly also the search for the best quality raw materials out of the available lithic resources. Besides, some cobbles were imported to the site partly decorticated, after the knappers had tested them at source (Goldman-Neuman and Hovers 2009, 2012).

Flaking at A.L. 894 was mainly unipolar, while at A.L. 666 bipolar flaking is documented for quartz and chert exploitation. Step and hinge scars are frequent, taking place when the knappers were unable to maintain appropriate knapping angles. When flawed flake terminations occurred, the error could not be removed by further flaking from the same direction. However, cores with large surfaces were rotated in an attempt of rectifying the error and continuing to flake before the knapper made a decision to remove a "cleaning flake" bearing hinge and step scars (Hovers 2009; Goldman-Neuman and Hovers 2012).

2.3.3 West Turkana (Kenya)

Lithic artifacts comparable in age to the Hadar assemblages were discovered in the Nachukui Formation (West Turkana, Kenya) at Lokalalei 1 (LA1) and Lokalalei 2C (LA2C). The archaeological levels are capped by a mollusk-packed sandstone, a marker bed dated to 2.35 Ma which is the local boundary between the Lokalalei and Kalochoro members (Harris et al. 1988). The Kokiselei and Ekalalei tuffs (2.40 $\pm$ 0.05 and 2.34 $\pm$ 0.04 Ma, respectively) lying below the Lokalalei 1 and Lokalalei 2C are correlated with tuffs E and F-1 of the Shungura Formation (Harris et al. 1988; Feibel et al. 1989). Accordingly, the Lokalalei sites have an estimated age of 2.34 $\pm$ 0.05 Ma (Roche et al. 1999). However, after the revision of the local lithostratigraphy, LA2C could be marginally younger than LA1 (Brown and Gathogo 2002).

The archaeological levels also yielded faunal remains, which are poorly preserved and devoid of any recognizable trace of human action, except from a single cutmark on a bone fragment from the surface (Roche et al. 1999; Brugal et al. 2003). A tooth attributed to an early *Homo* was found at Lokalalei 1a, in the same lithostratigraphic unit as LA1 (Prat et al. 2005). Accordingly, early *Homo* is a candidate as a knapper of the lithic assemblages, even if *Paranthropus aethiopicus* was also present at 2.5 Ma in West Turkana (Walker et al. 1986).

Lithic items were knapped from lavas (phonolite, trachyte, basalt, and rhyolite) available in paleochannels at a maximum distance of 50 m from the site (Harmand 2009).

At LA1, flaking is produced mainly on large cobbles, which are rounded and therefore lacking any flat surfaces or suitable natural striking platforms. The resulting knapping sequences are opportunistic and heterogeneous. The cores bear evidence of frequent knapping accidents and of repeated impact damage from failed percussions (Delagnes and Roche 2005). On the opposite, LA2C technical strategies are based on the implementation of constant technical rules, documenting advanced manual dexterity. Although remains are distributed in a thickness of 50 cm, the feeble impact of post-depositional disturbance on this assemblage is demonstrated by the high number of refits scattered horizontally and vertically throughout the entire sand deposit, by the high ratio of elements <1 cm, as well as by the fresh physical state (Delagnes and Roche 2005). A set of cores shows one-to-three unorganized flake scars (simple flaking), as if they had been tested and discarded. Another set displays evidence of organized flaking on fine-grained phonolite clasts. Whole cobbles and angular blocks were knapped without any preparation, even if the deliberate breakage off-site of the largest specimens into large fragments can occur. In two cases, refitting groups testify that a preliminary phase of flaking was also conducted off-site. The cores displaying organized flaking were mainly flaked on a single surface which is the largest available one. Several series of flakes were extracted from natural or rectified platforms. The numerous changes of flaking direction ensured that the surface remained reasonably flat and regular. In some cases, few removals on another face can occur at a final reduction stage. Alternate flaking is also documented: in order to produce several series of flakes, some cores display two or three surfaces used in succession as flaking surfaces and as striking platforms. As the knappers used and maintained angles among surfaces which were already available, the outcome are cores with a final shape similar to that of the natural blank. Additionally, cores do not show any impact damage from failed or repetitive percussions. A few cores bear evidence of retouch on edges with an angle close to 90° for further use as tools after flaking. Retouch also occurs on a very few flakes, along either one or, more rarely, two edges. Several cobbles show thickly pitted areas due to percussion. They are of the same medium-grained phonolite as unworked specimens, but they are heavier. Therefore it is likely that during raw material procurement, the knappers selected specimens better suited for percussion or broke them to obtain fragments suitable for recurrent flaking (Delagnes and Roche 2005).

After a hiatus of ~0.5 Ma, Oldowan artifacts reappear at Kokiselei 5, where an archaeological level is slightly younger than the KBS Tuff (1.87 Ma; Texier 2018). Cobbles of local rocks were collected in alluvial deposits near the site and selected on the base of their knapping suitability and morphology. Although the initial geometry of the blank conditioned the exploitation modalities, cores show the ability to reconfigure the core and to rearrange the striking platform (Texier et al. 2006; Texier 2018). A large split cobble of phonolite/trachyte displays a point partially shaped by unifacial removals (Texier et al. 2006).

2.3.4 Omo (Ethiopia)

Sites of ~2.3 Ma were discovered four decades ago in the Omo Valley of southern Ethiopia, in members E and F of the Shungura Formation (Chavaillon 1970, 1975, 1976; Merrick et al. 1973; Merrick and Harry 1976; Chavaillon and Boisaubert 1977). Member E is dated between 2.40 ± 0.05 and 2.324 ± 0.020 Ma (Feibel et al. 1989; McDougall and Brown 2008), and Member F between 2.324 ± 0.020 Ma and 2.271 ± 0.041 Ma (McDougall and Brown 2008; McDougall et al. 2012). According to Chavaillon's typological description (1976), the Omo collection was composed of small-sized quartz items, i.e., fragments, flakes, and cores, and of abundant wastes. The latter were considered either as natural residues, detached during flaking, or as hammerstone fragments produced by intense percussion. After this description, the constraints imposed by small-sized quartz cobbles allowed simple smashing only, and no proper knapping and flake production. Accordingly, the Omo industries were evidence of expedient technology. Because of the lack of lithic types as defined at Olduvai, and because of the predominant tiny fragments and irregular quartz pieces, Chavaillon (1976) introduced the term "Shungura facies" for the Omo industries.

Howell et al. (1987) discussed the context and stratigraphic position of Omo 71 and Omo 84, the two sites belonging to Member E. Later, de la Torre (2004) questioned the very evidence of intentionality in stone artifacts, assessing that lithics from the two sites (24 objects from Omo 71 and 200 from Omo 84) must rather be interpreted as natural assemblages. This was confirmed during recent research in the Shungura Formation (Delagnes et al. 2011). Thus there is no consensual evidence of stone knapping in Member E.

In Member F, five archaeological sites were discovered, notably FtJi 1, 2, 5, Omo 57, and Omo 123. Merrick and Merrick (1976) divided them into sites in primary position (FtJi 2 and Omo 123), and sites in secondary contexts from the fluvial channel (FtJi 1, 5, and Omo 57). According to the brief, non-exhaustive description, the quartz industries from FtJi 1, 2, and 5 include few whole and broken flakes and high numbers of angular fragments (Merrick and Merrick 1976). According to Chavaillon (1976), in addition to flakes and angular fragments, the Omo 57 and 123 assemblages also contained cores. This was confirmed by de la Torre (2004), who pointed out, however, that many so-called artifacts actually are unworked objects. He recognized the systematic unifacial unidirectional exploitation of the cores, and occasionally even a rotation aimed at making the most of the knapping surfaces. Given that the flakes show previous removals of the dorsal face, more than one series of flakes was detached from cores. However, the small size of the angular quartz pebbles that are used as core blanks did not allow a high flake productivity. The natural angles and available surfaces are used until exhaustion, without any attempt of rejuvenation. Notwithstanding the small size of the blanks, direct knapping with a hammerstone was widely used and the bipolar technique adopted in two cases only. Very few knapping accidents, such as split fracture, are recorded, suggesting some control of the strength used in impacting the cores (de la Torre 2004).

New investigations in the Shungura Formation (Boisserie et al. 2008, 2010; Delagnes et al. 2011) allowed discovering several new localities in Member F, ranging from small concentrations with few pieces to sites with abundant material. The artifacts are almost exclusively quartz flakes and fragments. Systematic surveys demonstrated that the quartz pebbles available in paleochannels near the archaeological sites do not outnumber any other rock types, as lavas, granites, and cryptocrystalline rocks. Vice versa, quartz dominates in archaeological collections. This means that quartz was deliberately selected for knapping purposes, most probably for angular morphologies which facilitated the initial flaking phases (Delagnes et al. 2011).

2.3.5 Kanjera South (Kenya)

Oldowan occurrences were found at Kanjera South, on the northern margins of the Homa Mountain Carbonatite Complex (Homa Peninsula, southwestern Kenya). They belong to Beds KS-1 to KS-3 of the Southern Member of the Kanjera Formation, which predate the base of the Olduvai subchron at 1.95 Ma (Behrensmeyer et al. 1995; Plummer et al. 1999; Bishop et al. 2006).

Paleoenvironmental data provide the early documentation of hominin activities in an open habitat within a grassland-dominated ecosystem at Kanjera South (Plummer et al. 2009b). Multiple lines of evidence suggest that Kanjera "was a lightly-wooded to open grassland habitat, with a lake to the North and presumably bushes and woods lining nearby hills and perhaps some drainages. Wash from the foothills of the Homa Mountain drained toward the lake, burying faunal and lithic materials on a generally low-energy alluvial plain during KS-1 through KS-3 deposition" (Plummer et al. 2009a: 158).

A detailed analysis of raw material provisioning is available. Knapped rocks derived from a wide variety of geographically distinct primary and secondary sources. Lithologies incorporated in the assemblages include igneous rocks, sedimentary rocks, metamorphic rocks, and metasomatized rocks. Approximately 28% of the artifacts were made with non-local raw materials, i.e., rocks available outside outcrops and drainage systems of the Homa Peninsula (Braun et al. 2008a, b, 2009b, c).

Several flaking methods were in use. Centripetal flaking on two surfaces is the best solution when rounded cobbles are available. Two opposed convex flaking surfaces are exploited without any hierarchy, and the maintenance of convexities happens rarely. Many of them are bipyramidal. Centripetal débitage can also occur on the ventral face of large flakes, reused as core blanks. In the case of multifacial multidirectional cores, continuous core rotation allows maintaining acute angles and the production of several generations of flakes. Some such cores are of Homa limestone, otherwise rarely used. The reduction process changes progressively the original volume structure of the blank. A unifacial unidirectional method is applied on coarse-grained rhyolite/dacites. Bipolar technique also occurs, sometimes mixed to hand-held percussion.

The lack of long series of removals might simply reflect the small size of the original cobbles. Core reduction seems to covary with the availability and quality of available raw materials. Raw materials from farther away were actually reduced more extensively than those available nearby (Braun et al. 2008a, b, 2009b, c; Lemorini et al. 2014).

2.3.6 Fejej (Ethiopia)

The Fejej region is located in the Ethiopian sector of the African Rift system, in southwestern Ethiopia, and at the northernmost extremity of the Koobi Fora Formation, which was identified on the east side of Lake Turkana (Asfaw et al. 1991; de Lumley and Beyene 2004). Archaeological sites were discovered in the FJ-1 locality, where sector FJ-1a was selected for an excavation. The age of the archaeological layer is constrained between 1.95 ± 0.03 Ma, the onset of the Olduvai subchron, and 1.869 ± 0.021 Ma, the ^{39}Ar–^{40}Ar age of KBS Tuff (Cande and Kent 1995; de Lumley et al. 2004a; McDougall and Brown 2006). Three hominin teeth from FJ-1a were ascribed to a young adult *Homo* aff. *habilis.* A distal humerus fragment with affinities to *Australopithecus boisei* was discovered in an older unit (de Lumley and Marchal 2004).

The stone assemblage from Fejej FJ-1a was knapped from local raw materials collected nearby in the alluvial deposits of a small river. Quartz cobbles, mainly of small size, are dominant (91%) over basalt cobbles (7%), while just a few more artifacts were knapped from other rock types. Sampling in the FJ-1 conglomerate highlighted that quartz and basalt cobbles and pebbles are only ca. 35% of rock types, showing that quartz was purposefully selected. Thick and oval cobbles were often used as knapping hammerstones, but percussion marks also occur on cores, suggesting that they happened to be used as multipurpose tools. Flake production was often carried out on angular cobbles taking advantage of the available angles. The industry is predominantly composed of flakes and angular fragments, cores are few, and retouched flakes scarce. Artifacts are small, given the size of the available blanks.

Reduction sequences are short. Flaking is mostly unifacial unidirectional, multidirectional, bipolar, or centripetal. When centripetal exploitation occurs, it is to adapting to the original cobble morphology. Multifacial and bifacial reduction strategies are rarely observed. Striking platforms are usually natural. Flake negative scars were occasionally used as platforms, producing multifacial orthogonal cores. Direct, hard hammer percussion is most frequently observed, although some of the cores were flaked using controlled bipolar percussion on an anvil (de Lumley et al. 2004b; Barsky et al. 2011).

2.3.7 Olduvai (Tanzania)

The Oldowan sites of Olduvai are located in Bed I, Lower Bed II, and Middle Bed II up to Tuff IIB (Leakey 1971). De la Torre and Mora (2005) completely reassessed some of the lithic assemblages from Beds I and II, which had been excavated in the 1960s, from a technological perspective. In their analysis, the lithic collections from three sites were assigned to the Oldowan, i.e., those from DK, FLK Zinj, and FLK North.

The DK site is the oldest one at Olduvai. It lies just below Tuff IB, dated to 1.848 ± 0.003 Ma (Habermann et al. 2016). FLK Zinj is 6 m below Tuff IF, dated to 1.803 ± 0.002 Ma (Habermann et al. 2016). FLK North has a more complex stratigraphic development, with eight archaeological levels. Levels 6–1 belong to Upper Bed I below Tuff IF. The *Deinotherium* level lies below Tuff IIA (1.66 Ma) at the base of Lower Bed II. Sandy Conglomerate (SC) level is located in the lower part of the Middle Bed II, below Tuff IIB dated to ~1.6 Ma (Manega et al. 1993).

At all sites, lavas and quartz were mainly used. The provisioning area is no more than 4 km from any given site and, in most cases, probably at as little as 2 km from the Gorge. As a rule, lavas derive from stream cobbles, whereas the majority of quartz originates from tabular blocks transported from the source at Naibor Soit. Knappers of FLK North focused more on exploiting high-quality raw materials, mainly phonolites from a nearby stream that had not existed earlier. At FLK North SC, chert, which is available at specific time spans in the Olduvai sequence, was also collected in the vicinity (Stiles et al. 1974; Hay 1976; Blumenschine and Peters 1998; Stiles 1998; Kyara 1999; Kimura 2002; de la Torre and Mora 2005).

Percussion activities play an important role in the Oldowan assemblages of Olduvai. Active hammerstones for knapping are rounded river cobbles mainly of lavas, rather uniform in size and with ergonomic shapes that enable their use for hand-held percussion. Some were also used as cores. They show areas with thick pitting and, when a fracture occurs, the cobble is rotated or discarded. The selection of lavas was most probably linked to their weigh as well as to the need of rounded shapes, given that quartz is usually available as tabular clasts. A different type of active hammerstones are cobbles or blocks used in heavy percussion activities other than knapping, generating fracture angles in a large area of the blank. Passive percussion elements, i.e., anvils with two opposite battered surfaces, are mainly of quartz, probably because of the convenient tabular morphology, granting stability during the process (de la Torre and Mora 2005, 2010; Mora and de la Torre 2005; Diez-Martín et al. 2009).

Although percussion occurs in all Oldowan sites, it is the main technical activity at FLK North Levels 6–1 and the only one in the *Deinotherium* level. De la Torre and Mora (2005) argue that in the two instances knapping activities were residual. They draw a scenario in which hominins were mainly involved in the intense percussion of a variety of organic materials, particularly long bone shafts. However, no evidence of hammerstone-broken bones has been found in most of the FLK North levels (Domínguez-Rodrigo et al. 2007).

Small-medium flake production was the only knapping activity as for the other Oldowan assemblages. Many flakes show remains of natural surfaces, suggesting limited intensity of exploitation and little recurrence in core flaking. Inter-site metrical similarities suggest a rather homogeneous metric module. Very few flakes were retouched, modifying one or two edges, without creating specific morphologies.

Flaking is unifacial, bifacial, and multifacial. Unifacial exploitation is usually unidirectional from natural striking platforms. The resulting flakes are elongated and were produced from a flaking surface usually restricted to a portion of the blank and just occasionally involving its periphery. In a few instances, after the flaking surface is exhausted, the core is rotated to pursuit the same method on a new surface. Bifacial cores are also abundant. They can be bifacial abrupt, when there is an interchange between striking and flaking surfaces; bifacial peripheral with the intersection of two asymmetrical flaking surfaces; and bifacial simple partial, when removals involve only a portion of two flaking surfaces and are used alternatively as platform for flaking. Few cores from DK are evidence of multifacial exploitation: the core surfaces were alternatively flaked through multidirectional removals without a clear organization of the reduction process and without any specific platform preparation. These cores were abandoned when exhausted (de la Torre and Mora 2005).

Recent investigations at FLK North Levels 6–1 unearthed a new archaeological assemblage. Levels 1–2 yielded the majority of lithic objects (Domínguez-Rodrigo et al. 2010a). Battering is the main activity inferred again at the site, just as in the previous assessment (de la Torre and Mora 2005). Flaking, however, displays more complex patterns than in the assemblage excavated by Leakey and revised by de la Torre and Mora (2005). Freehand direct percussion is largely used; bipolar technique is also present, but restricted to the knapping of quartz slabs. Flaking modalities are (Diez-Martín et al. 2010):

(1)
- unifacial unipolar, when only one striking direction or platform is visible;
- unifacial bipolar, when two opposed and parallel striking platforms show negative scars in two directions.

(2)
- bifacial unipolar, when two surfaces have been exploited from a single striking platform;
- bifacial bipolar opposed, when the exploitation occurs on two opposed parallel striking surfaces on two different planes;
- bifacial multipolar orthogonal, when negative scars occur on two surfaces and the negative scar sequences are arranged orthogonally. Bifacial cores show more intense exploitation and volume reduction, although no such core has been exploited to exhaustion.

(3)
- trifacial, when the exploitation is carried out on three different surfaces and from multiple striking platforms.

(4)
- centripetal, both unifacial and bifacial, ending with intense reduction.

2.3.8 Melka Kunture (Ethiopia)

Two Oldowan assemblages were recovered at Garba IV levels E and F in the basal part of the Melka Kunture Formation, stratigraphically located just below the Grazia Tuff, dated to <1.719 ± 0.199 (Piperno et al. 2004, 2009; Raynal et al. 2004; Morgan et al. 2012; Gallotti and Mussi 2015). Tamrat et al. (2014) include both levels in a normal polarity interval (N1), which they interpret as the end of the Olduvai subchron.

The assemblages share similar technical patterns and include all the phases of small débitage chaînes opératoires. Approximately 80% of the artifacts are of obsidian, followed by aphyric lavas and by few items of porphyritic and microdoleritic basalts. All these rocks were abundantly available nearby in paleochannels, but obsidian cobbles and pebbles are found there in small proportion when compared to aphyric lavas (Kieffer et al. 2002, 2004). The large proportion of high-quality raw material artifacts is clearly the outcome of strict selection by the knappers.

In addition to a few simple cores, several structured flaking methods were recognized, closely dependent on blank geometry. The most frequent flaking method is irregular multifacial multidirectional exploitation. Cobbles with several flat surfaces were flaked irregularly using any available flaking angle, without preparing a striking platform, to produce the largest feasible number of flakes. Besides, a few cores show major flaked surface(s) with unidirectional long flake scars exploited at the beginning of the reduction process. Multifacial multidirectional cores were usually abandoned when their size had been considerably reduced.

Unifacial unidirectional exploitation of the longest available surface of elongated cobbles produced flakes with a length exceeding the width. The natural convex surface of cobbles was chosen for detaching flakes by the peripheral unidirectional method over the maximal available extension. The striking platform was a naturally flat surface.

Centripetal/tangential exploitation was mostly performed on a flaking surface from a natural peripheral platform, or from a striking platform rectified by only a few removals. Volume and convexity configurations were not managed, recurrence and preparation are absent, and there is no evidence of hierarchy. When the lack of convexities (as on flat cobbles) made it possible to detach only short flakes, the resulting cores are unifacial or bifacial partial ones.

Retouch frequently occurs exclusively on obsidian flakes. Side-scrapers and notches, as well as small points, were manufactured at Garba IVE-F. They can be grouped in two sets. The first one, identified only in layer E, consists of flakes whose edges were modified by a retouch that did not transform the original blank into any standard form. The retouch is continuous but highly variable, ranging from marginal to invasive. The resulting tools display large dimensional and morphological variability. In contrast, the second set (41 tools) displays a retouch process aimed specifically at producing a small point, modifying the distal part of the blank though standardized procedures expressed by the simultaneous occurrence of: (1) a repetitive intention to shape the distal portion of the flake into a tip; (2) a repetitive intention to create a convergence; and (3) a recurrent search for a small and homogeneous size (Gallotti and Mussi 2015).

2.4 Discussion

The evidence for Oldowan stone knapping falls into two chronological sets divided by a gap of approximately 0.3 Myr.[2] The first set, the early Oldowan, includes archaeological sites dated between 2.6 and 2.3 Ma, located in the northern part of the Rift Valley with two main clusters: the Middle Awash River (Gona and Hadar) and the Lake Turkana Basin (Omo and West Turkana). Except West Turkana, these long sequences did not yield later Oldowan assemblages and a relevant chronological gap further separates the Oldowan from the early Acheulean appearing in the area at approximately 1.8–1.6 Ma (Quade et al. 2004, 2008; Lepre 2011; Beyene et al. 2013). The second set dates between 2.0 and 1.6 Ma and includes the later Oldowan sites of Olduvai Gorge, of Melka Kunture in the Ethiopian highlands, of Kanjera South in the Lake Victoria Basin, and of Fejej in the Omo-Turkana Basin at the northern limit of the Koobi Fora Formation. At Olduvai, some late Oldowan sites temporally overlap with the earliest Acheulean (Diez-Martín et al. 2015; de la Torre 2016).

We synthesize the main distinctive characters of the Oldowan lithic assemblages as follows: (1) stone tools were mainly cutting tools belonging to flaking processes, i.e., flakes; (2) stone knapping shows an advanced knowledge of stone fracture mechanics and was performed with a controlled hand-held percussion technique, rarely with bipolar percussion; (3) percussion devoted to activities other than knapping is scarcely documented.

Interestingly, the frequency of hammerstones and of other percussion/pounding tools in the early Oldowan is extremely low (e.g., Kibunjia 1994; Roche et al. 1999; Semaw 2000; Delagnes and Roche 2005). Percussion elements lack at Gona, Hadar, and LA1 in West Turkana. When found, as at LA2C, they document highly controlled percussion motions for hand-held knapping. The hammerstones display a high density of impact scars in circumscribed areas, which were produced by a precise and recurrent use, according to stable motor habits. Accordingly, the cores do not display impact damage from failed percussion, such as might be caused by an inaccurate appreciation of the required strength, or by inadequate manipulating or gripping (Delagnes and Roche 2005).

At Olduvai, percussion elements are abundant in all Oldowan sites and part of them are devoted to activities other than knapping, i.e., probably to food processing (de la Torre and Mora 2005; Mora and de la Torre 2005). This does not seem to reflect ecological differences between Olduvai and sites in Gona, West Turkana, Hadar, or Kanjera South, as the Oldowan sites are located in a mosaic of different landscapes, ranging from wooded areas to arid ones and open settings (e.g., Plummer et al. 1999, 2009a, b; Aronson et al. 2008; López-Sáez and Domínguez-Rodrigo 2009; Quinn et al. 2013). Hovers (2007) hypothesized that pounding activities documented in Olduvai do not represent the retention of earlier behavior, and that pounding possibly was rather "reinvented" during technological evolution. Nevertheless, pounding activities are not present in the sub-contemporaneous sites of Kanjera South, Fejej, and Melka Kunture. This means that, because of multiple but

[2] Recently, Harmand et al. (2016) announced the discovery of 2.3–2.0 Ma sites in the Nasura Complex (West Turkana), but detailed data are not yet available.

unknown factors, at Olduvai such activities might correspond to some kind of "resurrection" of a retained behavior—a behavior previously invented, experienced, and mastered for thousands of years.

At the dawn of lithic technology, knapper activities were associated with pounding on anvil rather than with hand-held core reduction. The small collection of stone tools from LOM3 is unlike any from Oldowan localities, mainly including flakes. On the opposite, most of the LOM3 artifacts are hammerstones, anvils, cores, and worked cobbles. Harmand et al. (2015) pointed out that LOM3 assemblage possibly represents an intermediate stage between a pounding-oriented stone tool use—as documented in modern non-human primates—and the flaking-oriented knapping behavior of Oldowan toolmakers.

The use of bipolar technique is not documented in all Oldowan sites. When used, it is often for flaking specific raw materials, such as quartz usually occurring as small cobbles (de la Torre 2004; de la Torre and Mora 2005; Diez-Martín et al. 2010; Delagnes et al. 2011; Goldman-Neuman and Hovers 2012). Nevertheless, even if difficulties in manipulating small-sized core blanks probably led to favoring bipolar technique as an alternative, as at Kanjera South, Fejej, and Olduvai, at Omo sites this technique is documented by just two quartz cores. The Omo knappers were so much in command of fine gripping skills, that tiny cobbles were not simply smashed but rather handled according to the same technical principles used in the exploitation of larger raw materials at Gona and West Turkana (de la Torre 2004). Just as percussion for food processing, bipolar technique for knapping, documented since 3.3 Ma at LOM3, was retained and reused as a proper solution for knapping over hundreds of thousands of year. However, the Omo evidence points to the fact that this resurgence cannot be always explained by raw material constraints.

Results from a functional approach to percussive technology recently demonstrated that stone knapping is guided by a rather specific set of mechanical constraints, more complex than those involved in nut-cracking (Bril et al. 2015). Freehand stone-knapping techniques require the ability of understanding the relationships among the parameters which define the conchoidal fracture, complex bimanual skills, and the fine motor properties of a firm precision grip. This means that the transition from percussive techniques, such as nut-cracking, to freehand knapping techniques required improved perceptual abilities, learning capacities, and a bimanual dexterity superior to that of any non-human primates. All this was experienced over approximately 700,000 years (Stout and Chaminade 2007; Stout et al. 2008).

Understanding conchoidal fracture mechanisms in parallel with systematic hand-held percussion, together with a sporadic use of bipolar technique and anvil percussion for food processing are the distinctive characters shared by the Oldowan assemblages when compared with the previous Lomekwian.

However, even if most or even all of the Oldowan assemblages known to date share the knapping principles, some intra- and inter-site variability appears and actually increases when analyzing the multiple steps of the chaînes opératoires.

In lithic resource acquisition, for example, the toolmaker selectively aimed at collecting fine-grained rocks from locally available raw materials (Stout et al. 2005; Braun et al. 2009b, c; Goldman-Neuman and Hovers 2009, 2012; Harmand 2009; Gallotti and Mussi 2015). Transport distances in the majority of cases are minimal, ranging from some hundred meters to a few kilometers. Nevertheless, an incipient exploitation of non-local raw materials involving longer distances is evidenced at OGS-7, at Kanjera South, and probably at A.L.666 (Stout et al. 2005; Braun et al. 2008a; Goldman-Neuman and Hovers 2012). We note that non-local and local provisioning systems may occur simultaneously in the same region, as at Gona. Accordingly, transport across the landscape cannot be explained in a straightforward evolutionary perspective, also because this behavior is not systematically documented at later Oldowan sites (de la Torre and Mora 2005; Barsky et al. 2011; Gallotti and Mussi 2015).

In some cases another criterion guiding raw material selection is any cobble/block angularity that facilitates the first steps of knapping. The preference for angular cobbles at Omo and Hadar sites is conceptually similar to the selection of angular cobbles at Fejej and Melka Kunture, of blocks at LA2C as well as of tabular clasts in Olduvai (de la Torre 2004; Delagnes and Roche 2005; de la Torre and Mora 2005; Barsky et al. 2011; Goldman-Neuman and Hovers 2012; Gallotti and Mussi 2015). The selection of blanks with serviceable striking angles implies that knappers were somewhat constrained by the raw material geometry. At LA2C, rounded cobbles were mainly used for simple flaking. The random production of few flakes apparently is a response to the difficult task of exploiting inappropriate shapes, rather than the outcome of poor quality in terms of grain and homogeneity. This also means that in this case the knappers did not strive to create any such angles. The importance of angular morphologies is also highlighted by the use of natural surfaces as striking platforms, which strictly speaking were never prepared, but somewhat rectified by a few removals (Delagnes and Roche 2005).

At A.L. 894, step and hinge scars were frequently produced when knappers were unable to maintain appropriate knapping angles but insisted flaking always from the same direction. Only cores with large surfaces were rotated in an attempt of rectifying the mismanagement, continuing the flaking process (Hovers 2009; Goldman-Neuman and Hovers

2012). At LA2C, the knappers insisted on the same surface producing successive series of flakes from multiple striking platforms, a practice that maintains a flat flaking surface (Delagnes and Roche 2005). On the contrary, at the sub-contemporaneous site of LA1 the knappers were apparently unable to apply this procedure. The cores bear evidence of frequent knapping accidents and repeated impact damage from failed percussions (Kibunjia 1994; Delagnes and Roche 2005). At KS5, knappers took advantage of the initial angular morphology, but they were also able to rotate the core and to create new angles (Texier et al. 2006; Texier 2018).

The perceived usefulness of a flat surface also directed raw material collection. At LA2C some large blocks were broken off-site in order to obtain a serviceable flaking surface. This behavior implies an incipient ability at fragmenting the chaîne opératoire, also visible at A.L. 894, where knappers tested cobbles at the source and imported them into the site already partly decorticated (Goldman-Neuman and Hovers 2009, 2012). Anyway, any chaîne opératoire fragmentation is unusual in the Oldowan and when specific components are lacking this is usually due to selective post-depositional mechanisms.

Although the search for raw materials with appropriate angles is recurrent at Oldowan sites, knappers also successfully flaked rounded shapes. Rounded elements were not just flaked ever since the first appearance of the Oldowan techno-complexes, but they were also flaked on more than one surface at OGS7, where bifacial and multifacial exploitations occur more frequently than unifacial ones (Stout et al. 2010).

On the opposite, core methods are mainly unifacial in the contemporaneous EG10 and EG12 sites, just as in the older Oldowan assemblages (Hovers 2003, 2009; de la Torre 2004; Delagnes and Roche 2005; Stout et al. 2010). At a final reduction stage few removals sometimes occur on a second face, documenting an occasional rotation of the core as at LA2C and Omo (de la Torre 2004; Delagnes and Roche 2005). Flake extraction from more than one surface, i.e., bifacial and multifacial exploitations implying a continuous core rotation, happens in the older Oldowan assemblages, but, except for OGS7, never represents the main flaking modality. Bifacial and multifacial flaking methods were more frequently adopted in the later Oldowan assemblages as at Kanjera, Fejej, Olduvai, Melka Kunture, and KS5, increasing the intra-site method variability (de la Torre and Mora 2005; Braun et al. 2009c; Diez-Martín et al. 2010; Barsky et al. 2011; Gallotti and Mussi 2015).

Simultaneous flaking of two or more surfaces warranties a higher productivity. Nevertheless, we underline that knappers at LA2C were able to detach a considerable number of flakes from a single surface thanks to specific procedures. The large size of LA2C core blanks definitely plays a role in this high productivity. This possibly explains why the extraction of a considerable number of flakes by creating and maintaining a single flaking surface is impossible with small cores like those from Omo (de la Torre 2004; Delagnes and Roche 2005). Conversely, elsewhere as at Gona, Kanjera South, Fejej, Garba IVE-F, and FLK North the absence of natural angles in rounded cobbles was overcome thanks to a more appropriate flaking modality: the unifacial centripetal method, which takes advantage of the core periphery as a striking platform, while the centripetal direction of flaking allows to detach more than one series of flakes with longer cutting edges (Semaw 2006; Braun et al. 2009c; Diez-Martín et al. 2010; Barsky et al. 2011; Gallotti and Mussi 2015).

However, as for unifacial cores, bifacial and multifacial exploitations correspond to an adaptation to the original cobble morphology. In the case of bifacial exploitation the notions of convexity maintenance, hierarchy between the two surfaces, and platform preparation simply do not exist. Bifacial centripetal methods are the proper solution when exploiting rounded cobbles and, when the convexities were exhausted, no attempt was made to restructure the core morphology. A multifacial multidirectional modality exploits several surfaces irregularly using any available angle <90° to produce the largest feasible number of flakes. Thus, blank morphology is respected and not modified during flaking. These practices were adopted in both early and late Oldowan assemblages, regardless of the relative frequency of the flaking methods (e.g., de la Torre and Mora 2005; Barsky et al. 2011; Gallotti and Mussi 2015).

From 2.6 Ma onward, the main objective of flaking was to maximize flake production rather than to detach flakes with specific technical aspects, notwithstanding high intra- and inter-site variability linked to variable technical solutions. Besides, flakes with one or more edges modified by retouch are only an occasional component of the Oldowan techno-complexes. When present at all, small tools are found in very small percentages and do not show any standardization (de la Torre and Mora 2005; Delagnes and Roche 2005; Semaw 2006; Barsky et al. 2011; Zaidner 2013). Nevertheless, there is also evidence of a specific technical process at Garba IVE-F, not recorded elsewhere in an Oldowan assemblage: the systematic search for small pointed forms on obsidian blanks. Most probably the small pointed tools are an occasional technological development driven by an unknown specific techno-functional purpose, certainly facilitated by the high knapping suitability of obsidian (Gallotti and Mussi 2015). This "invention" (*sensu* Hovers 2012) was not followed by any further production of similar tools in the early/middle Acheulean of Melka Kunture region (Gallotti et al. 2010, 2014; Gallotti 2013).

A fundamental question remains unanswered: who were the authors of the Oldowan stone tools? From 2.6 to 1.6 Ma, the data currently available indicate that several species belonging to various genera practiced hard stone knapping. This time period marks the transition from *Australopithecus* to *Homo* and the appearance of the robust *Australopithecus* species, in East Africa usually placed in genus *Paranthropus*.

The earliest Oldowan industries of Gona are not associated with any human fossils, but *Australopithecus garhi*, dated to 2.5 Ma, was discovered in neighboring Bouri. *Australopithecus garhi* so far is the only possible candidate as toolmaker of the oldest Oldowan industries (Asfaw et al. 1999). *Australopithecus garhi*, in turn, was sub-contemporaneous to *Paranthropus aethiopicus*, dated between 2.5 and 2.3 Ma. Until now, this robust species has been exclusively found in the Turkana Basin, i.e., not in the Awash Basin. Nevertheless, a recently recovered partial hominin mandible from the Ledi-Geraru area in the Afar region, dated to 2.8–2.75 Ma, extends the fossil record of *Homo* back in time by 0.4 Ma, making it a further candidate toolmaker of the Gona Oldowan (Villmoare et al. 2015). Besides, we know that from 2.3 to 1.5 Ma, representatives of the *Paranthropus* and *Homo* genera could have interacted in several regions. *Homo* aff. *habilis* is present at Hadar at 2.3 Ma. It had previously coexisted with *Paranthropus aethiopicus* in Omo and West Turkana, and later with *Paranthropus boisei* at Fejej and Olduvai (Leakey 1971; Walker et al. 1986; Kimbel 1997; de Lumley and Marchal 2004; Prat et al. 2005).

Since 1.9 Ma, a new *Homo* species appears, i.e., *Homo ergaster/erectus*, whose first recorded evidence is at ~ 1.9 at Koobi Fora (Lepre and Kent 2015). The recent discovery of a phalanx at Olduvai allows dating back *Homo erectus sensu lato* to >1.84 Ma in this region (Domínguez-Rodrigo et al. 2015). At Melka Kunture, ever since >1.7 Ma the Early Pleistocene fossil record points exclusively to genus *Homo*, i.e., to *Homo erectus sensu lato* (Condemi 2004; Di Vincenzo et al. 2015). *Paranthropus* and *Homo habilis* have not been discovered there. This possibly suggests that *Homo erectus* was the first and only species of the time able to adapt to mountain environments as the Ethiopian highlands (Mussi et al. 2015).

2.5 Conclusions

This review of fifteen years of techno-economic studies of Oldowan assemblages clearly demonstrates that the one-million-year-long technological stasis (Semaw et al. 1997; Semaw 2000; Stout et al. 2010) and the systematic techno-cultural homogeneity of the 2.6–2.3 Ma industries (de la Torre 2004) are both hardly supported when the analysis is detailed enough, developing beyond the basic principles of stone knapping and the simple presence/absence, or increase/decrease, of technical components.

Producing a conchoidal fracture allowing to knap stones is a single action. But ever since 2.6 Ma there are multiple ways of combining raw material selection and acquisition patterns, percussion motions, and flaking sequences. These multiple processes, in turn, are linked to manifold factors as landscape dynamics, climatic shifts, and biotic/abiotic resource availability.

In the Oldowan scene, as emerging from techno-economic analyses, we discover multiple actions intermingling without a temporal trend—i.e., no less to more “evolved” behaviors—or a continuous spatial distribution—i.e., no homogeneity and intra-site variability at Gona and West Turkana (Delagnes and Roche 2005; Stout et al. 2010). Rather than corresponding to two evolutionary technological steps, the distinction between early and late Oldowan assemblages has a chronological significance (e.g., Delagnes and Roche 2005). The only difference so far detected in late Oldowan assemblages (≤ 2.0 Ma) is the rather systematic intra-site coexistence of a panoply of flaking methods and practices, which at earlier sites were only tested and experienced at inter-site scale. This means that since 2.0 Ma knappers were able to simultaneously apply several technical solutions in order to exploit all the available lithic resources. Accordingly, it is difficult to support the idea of the one-million-year-long technological stasis (Semaw et al. 1997; Semaw 2000; Stout et al. 2010), which seems actually restricted to the 2.6–2.3 Ma sites. Intra-site variability and variation happen at Gona and West Turkana, but not at Omo and Hadar. In any case, variability and variation do not preclude stasis if there are no trends of temporal change through time. Nevertheless, an intra-site technical evolution is visible at West Turkana, where Delagnes and Roche (2005) have suggested that the differences between Lokalalei 1 (older) and Lokalalei 2C (younger) could be related to evolutionary processes. Besides, so far the Oldowan assemblages cannot be definitively attributed to a specific Early Pleistocene hominid lineage. The identity of the earliest hominid toolmakers remains elusive. The paleoanthropological diversity, coupled with the technological diversity, is not in accordance with a linear technological evolution, and it magnifies the difficulty of defining the tempos and modes of a possible technological stasis or evolution.

As a concluding remark, a clear definition of the Oldowan cannot be worked out without following back to the use of tool types as cultural markers. Vice versa, providing a comprehensive definition in a techno-economic perspective is a difficult and to some extent unresolved task. This is due to the very nature of the lithic productions of this age, rather than to the methodological approach. Even if Oldowan stone knapping shows an advanced knowledge of stone fracture mechanics, raw material constraints played such a determining role that the knappers again and again had to experiment the most proper technical solutions. The technical outcome happened to be alike or diverse at different levels and according to multiple factors. Obviously, if a definition of the Oldowan technology is unavailable in its homeland at the current state of the research, exporting this term out of East Africa to identify techno-complexes scattered in several continents over nearly two million years is just a sterile exercise, masking a strong epistemological incongruence.

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