Journal of Archaeological Method and Theory (2019) 26:1276–1326
https://doi.org/10.1007/s10816-019-09412-2

From Stone to Metal: the Dynamics of Technological Change in the Decline of Chipped Stone Tool Production. A Case Study from the Southern Levant (5th–1st Millennia BCE)

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Abstract

The shift from stone to metal has been considered one of the main technological transformations in the history of humankind. In order to observe the dynamics underlying the disappearance of chipped stone tools and their replacement with metal implements, we adopt an approach which combines two different levels of analysis. At the first, by focusing on the Southern Levant as a case study, we consider the developmental forces internal to the technology itself and the conditions favorable to the invention, spread, continuation, or disappearance of technical traits. At the second, by considering specific historical scenarios, we test the existence of general principles which guide technological changes. Flint knapping and metallurgy, and notably their relationship, are particularly appropriate to observe regularities which operate at different scales, the first one within the developmental lines of objects, techniques and technologies, and the second one within the conditions of actualization of technological facts. On the one hand, following the "rules" of technical tendencies, a techno-logic perspective allows observation of how metal cutting objects, overcoming the "limits" of knapping technology, represent the logical development of flint tools. On the other hand, the analysis of the socioeconomic contexts in which chipped stone tools were produced permits identification of regularities which conditioned changes in lithic production systems, their decline, and the final replacement with metal tools.

Keywords Technological change · Technological development · Evolutionary forces · Lithics · Flint · Metal · Levant

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Introduction

Influenced by modern emphases on ideas of progress (*e.g.*, Marx 1987), it is often assumed that later-developing forms of technology are necessarily superior to previous ones and that the replacement of "old-fashioned" objects by newer ones is the result of obvious, if not necessarily linear, processes. Although this deterministic vision of technological change has been deeply criticized (*e.g.*, Guchet 2005), the advantages between technological alternatives, usually perceived in term of effectiveness, are largely considered as the main criteria for explaining technological change (*e.g.*, Bamforth 1986; Bleed 1986; Hayden *et al.* 1996; Jeske 1992; Praciunas 2007; Torrence 1989). Historical narratives, however, have shown that sequences of technological changes are not so obvious.

Inspired by anthropological and sociological studies, numerous researches have observed the intervention of many factors which do not necessarily refer to the techno-economic domain (*e.g.*, Godelier 2000; Lemonnier 2010) but vary according to the socioeconomic and cultural contexts within which technological changes occurred and new technologies developed (*e.g.*, Akrich 1989; Collin and Latour 1981). These studies consider the social and historical contingencies within which certain objects are retained and others rejected, and how one technology rises against another (*e.g.*, Bijker *et al.* 1989; Callon 1989; Dosi 1982; Latour 1992; Lemonnier 1993; Mackenzie and Wajcman 1985). It is not possible to understand a technology without the social (in the broadest sense including economic, political, cultural, ideological aspects, *etc.*) and historical particularities which orient and determine its development (Bensaude-Vincent 1998). The success or failure of a technology is a social fact (Cresswell 2003), and technological changes can only be explained by actors' roles in specific socioeconomic and cultural realities (Basalla 1998). Chronological sequences of objects show great variability of trajectories and situations; the histories of technological change are not linear, predictable, or determined.

By way of example, electric- and gasoline-powered combustion engine cars, invented at the same time, show different histories connected primarily to specific social, economic, and political factors (for similar examples, see also O'Brien and Bentley 2011; Schiffer *et al.* 1994). Electric and gasoline carriages appeared in mid-nineteenth century and developed until the invention of the first gasoline combustion engine car in 1886 by K. Benz and the creation of the first electric car in 1891 by W. Morris. At the turn of the twentieth century, the number of electric vehicles was almost a third of the automobiles, which included both steam- and gasoline-driven vehicles (Georgano 1990). Although electrically powered cars were a popular method of propulsion, their common use did not last long. If the range of gasoline-powered vehicles, easily refueled, partially justified their success, it was the development of their mass production, and especially the introduction of the Ford Model T (which cost half of the price of contemporary electric cars due to the moving assembly line), which sealed the decline of electric vehicles (Hounshell 1984). Although they never completely disappeared, automobile markets were dominated by gasoline-powered cars which spread all over the world (Kay 1998). The increasing utilization of gasoline cars cannot be disconnected from economic aspects, such as the creation of factories, roads, gas stations, and fuel acquisition-distribution systems, as well as the construction of a specific cultural world where the automobile played an important role not only for its practical use but also for its social meaning (Setright 2004). The development of this socio-technical system, to the exclusion of alternative systems, has also been closely connected to other economic, ideological, and geopolitical aspects, such as the control and exploitation of oilfields, with major impact on government strategies and policies (Bresnahan 1987; Douglas 1996). In this regard, it is interesting to observe that after the shock of the oil embargo in 1973, interest in alternate power systems, such as electric engines, emerged again. The lessened availability of gasoline, its cost and accessibility, and the political involvement of states and nations as well pushed automobile industries to adopt other types of energy and incentivized technological research (Roby 2006). More recently, and especially after the Tokyo Protocol in 1997, interest in global pollution has resulted in increasing efforts to reduce gas emissions and has stimulated the adoption of other kinds of engines, such as the electric one (Durand 2009). These elements, not necessarily related, indicate that factors such as the automobile price, the cost and availability of gasoline or electricity, car autonomy, and range are only some of the criteria which, along with environmental evaluations and ideological perceptions, influence both individual choices and institutional strategies (Eckermann 2001).

Given the uniqueness of historical contingencies conditioning the narratives of technological change, different theoretical and methodological approaches have been developed for analyzing and understanding technological changes. Recognizing that variations in material culture are conditioned by a number of contextual factors and different agencies, descriptive grids have been suggested, such as those used by the behavioral archaeology analyzing the mechanisms and processes of invention, adoption, and selection in specific contexts (for a synthesis, see Schiffer 2011). Given the variety and complexity of interactions between people and technology, behavioral archaeology focuses on changing selective conditions (Schiffer 1996). Cultural changes depend on compromises between performance characteristics, that is, the formal properties of objects/technologies in relation to specific activities, and other interactions influenced by lifeways and social organizations (*e.g.*, Kameda and Nakanishi 2002; Schiffer 1990, 2007; Schiffer and Skibo 1987). Cultural selection is not the only approach for analyzing technological changes, and other evolutionary frameworks have been developed. Darwinian archaeologists have elaborated quantitative models (*e.g.*, Lipo *et al.* 2006) to describe and explain the mechanisms of cultural transmission and its effects on the variability of cultural traits (*e.g.*, O’Brien and Shennan 2010). Historical sequences of objects are analyzed as lineages of descendent with modifications (Lyman and O’Brien 1998; Shennan 2011). Explanations of continuity and discontinuity are related to the mechanisms which generate variation (*e.g.*, Eerkens and Lipo 2005; Lyman and O’Brien 2000), to their mode of transmission (*e.g.*, Bentley and Shennan 2003; Feldman *et al.* 1996), and to the selection of variants, which drive much evolutionary process and serve as testable explanations of change (*e.g.*, Bentley *et al.* 2004; Mesoudi and O’Brien 2008a, b; O’Brien and Holland 1990).

In order to study technological changes, we adopt another perspective which combines two different levels of analysis. The first one considers the developmental forces internal to the technology itself, while the second one refers to the conditions favorable to the invention, spread, continuation, or disappearance of technical traits. Starting from the assumption that technological changes are, by definition, particular historical scenarios (Gallay 1986), our aim is to highlight regularities which, although they occur and act in the course of the history, might represent “evolutionary laws”.

The Techno-Logic Approach

The first approach, called here *techno-logic* (Boëda 2013), considers the logical order of development of objects, techniques, and technologies and refers to general tendencies (Leroi-Gourhan 1943). From this perspective, it is possible to recognize an order in technological development which, independently of historical narratives, reflects regularities or "law" (*e.g.*, Château 2010; Ellul 1977; Gille 1978; Lafitte 1972). Each object has sense according to its position within technological or "genealogical" paths in relation to what precedes and follows it (Deforge 1985; Simondon 1989). Here, we must introduce two concepts, the "developmental line" and the "development cycle." Described in evolutionary terms by Simondon (1989) and Deforge (1985) who first defined them, we prefer not to use their terms "lineage" and "evolutionary cycle" in order to differentiate them by the concepts used to characterize cultural filiations in other evolutionary approach (*e.g.*, Barton and Clark 1997; O'Brien and Lyman 2000). Within a techno-logic perspective, the development of objects and techniques is not analyzed by using morphological or typological affinities as proxies (as in Darwinian archaeology) but on their "internal technological structure" (see below). Moreover, their logical sequences, which do not necessarily follow historical trajectories, are not the result of selection or other external factors but follow their own internal coherence which defines the potentials and possibilities of change (Guchet 2005, 2008; Deforge 1985; Simondon 1989; see also Boëda 1997, 2005, 2013).

Objects/techniques that share the same function and the same principle of operation are comparable and define a "developmental line" (Deforge 1985, p. 72). Within each developmental line, the concept of "development cycle" describes how objects/techniques follow one another (Simondon 1989, pp. 20, 40). Every object/technique is perceived in structural terms as a system composed of different elements/operations which, all together, permit it to function. Throughout a development cycle, the degree of synergy between these components changes following a sequence which consists of increasing integration fed by additive elements. There is a logical order which reflects different levels of structural organization. Objects/techniques logically develop from a state where the components are first juxtaposed to a state where these components are related and cannot be separated from each other, given their interaction in a synergetic fashion. Following this perspective, the dynamics of change are conditioned by the structure of the technical milieu and so, by some inherent capacity for transformation.

For each line of objects/techniques, at every stage of development, there is a latent potential for change related to the possible combinations between structural components. If we consider the case of the bicycle, for example, we can recognize a logical development which, from the first specimens composed of two wheels connected to a wooden frame and activated by the thrust of the feet, through the invention of pedals which powered the front wheel, finally culminates with the chain and gears which, integrated with both the wheels and the pedals, allow a synergy between all the elements (Fig. 1). The sequence of developmental stages can theoretically continue until the "endpoint" of its potential, after which the structure of the objects/techniques cannot change. When the integration between the elements composing an object/technique reaches a perfect synergy, the structure cannot be modified anymore, and the development cycle is completed. Nevertheless, introducing new functioning principles, technical development can continue with new developmental lines and new

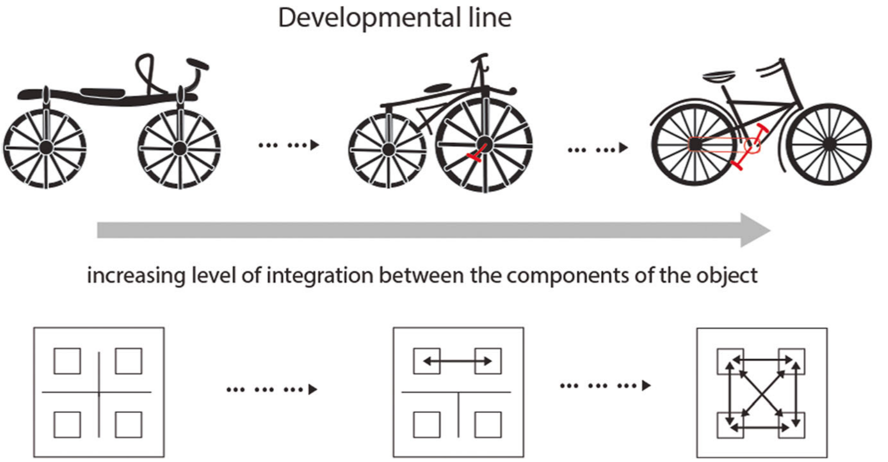

Fig. 1 The techno-logic approach. Within each developmental line, technological changes are conditioned by the structural characteristics of the technical milieu. Objects logically develop through an increasing synergy between their components, theoretically until the "endpoint" of their potential

development cycles. Taking up the previous example, the logical development of the bicycle reaches a stage of "pause" in its sequence with the system composed of chain and gears. In order to better adequate the bicycle with specific functions, minor adjustments (Simondon 1989, p. 39), that is, improvements, can also be made; thus, lighter materials can be used for racing bicycles or larger wheels can be adopted for mountain bikes. However, only a new principle of function permits continuation of technical development, as shown by the introduction of the engine in electric bicycles which originates a new developmental line.

The recognition of a logical path in technological development does not mean that these changes are predetermined and inevitable, nor that they are the same everywhere, but indicates a theoretical sequence. This structural approach permits definition of a framework within which technological choices can be made. There are external factors or "needs" (*i.e.*, social, political, economic, environmental, *etc.*) that act on techno-historical trajectories. Thus, different developmental lines and development cycles can coexist in the same historical context, some lines can disappear while others remain, or some technical solutions, which previously had disappeared or were abandoned, can reemerge (Deforge 1985).

The Actualizing Conditions of Technological Change

The second approach focuses on the external factors which condition technological changes. By analyzing specific historical scenarios, we focus on the socioeconomic processes which permit actualization of technological facts. We intend to highlight what might reflect cross-cultural regularities (Gallay 1986).

Empirical observations of anthropological and archaeological case-studies have shown the existence of recurrent patterns relating to the conditions favorable to the innovation, adoption, diffusion, conservation, or disappearance of technical traits (*e.g.*, Gallay 2011; Gelbert 2003; Gosselain 2000, 2008, 2010; Roux 2013, 2015a; Roux and Courty 2013). According to these studies, the analysis of the context of craft production, that is, its organization, and modes of transmission allows identification of the regularities which operate as "evolutionary forces" (Roux 2007a, p. 167). Technological changes are dynamic phenomena (Roux 2003) for which direct comparisons are not possible because each historical scenario has its own particularities. However, by focusing on the structure of the production systems (*i.e.*, domestic versus specialized, attached versus independent artisans, *etc.*), it is possible to recognize the regularities underlying technological change. By way of example, innovations are often associated with periods of new sociopolitical formations, and new technologies may be actualized not for their techno-economic advantages but for symbolic/social reasons (*e.g.*, Cresswell 1994, 1996; Roux *et al.* 2013). The fragility of technological systems, related to the size of networks in which they are transmitted, conditions the processes of continuity/discontinuity during changes of sociopolitical structures (*e.g.*, Roux 2007b); rapid and radical changes in technological and economic systems are often related to the expansion of one social group to the detriment of another (*e.g.*, Roux 2013). Given the limited number of studies that analyzes these regularities (the actualizing contexts), our study intends to test previously defined regularities with new historical scenarios.

The Decline of Stone Tools and the Replacement by Metals: a Case Study of Technological Change

The transition from stone to metal implements is traditionally considered as one of the major technological changes in the history of humankind. Nevertheless, there are few studies dealing with the relationship between the decline of lithics and the development of metallurgy (*e.g.*, Rosen 1984, 1996, 1997; beyond the Near East, see Bailly 2009; Edmonds 1995; Eriksen 2010; Ford *et al.* 1984; Runnels 1982; Young and Humphrey 1999). In the study of the shift from stone to metal, the general indifference to late lithic industries and the idea that the stone-metal replacement was a self-evident and automatic process (*e.g.*, Childe 1951) explain why the main focus has been on the new materials and technologies. The emergence and development of metallurgy have always been more attractive, and lithic production systems were usually neglected, considered relicts of prehistoric traditions.

However, metallurgy appeared, developed, and was adopted into a pre-existing technical system. The fact that flint tools disappeared, apparently in favor of metal objects, suggests a correlation between the decline of one technology and the development of the other. For a long time, archaeologists believed that the decline of chipped stone tools and their replacement with metals was automatic and implicitly explained by the greater efficiency of metal (*e.g.*, Forbes 1971). But archaeological record shows great variability, and the modalities of substitution were not always the same. The replacement of stone by metals can be recognized by comparing these two "cutting-edge" technologies, analyzing one in relation with the other. In this regard, a comparison of these technological systems can offer new insights and suggests new perspectives of analysis.

In the Near East, and especially in the Southern Levant, the transition from the use of stone to metal has been tackled by considering metals as a privileged subject (*e.g.*, Golden 2010; Heskel 1983; Ilan and Sebbane 1989; McNutt 1990; Muhly 1982a; Rowlands 1971). However, the development of analyses of chipped stone tools of the Age of Metals has shown potentials not only for the characterization of those societies producing and using flint tools (*e.g.*, Caneva 1993; Coqueugniot 2006; Edens 1999; Hartenberger *et al.* 2000; Hermon 2008; Manclossi *et al.* 2016, 2018; Perrot 1952; Pollock 2008; Rosen 1997; Shimelmitz and Zuckerman 2014; and beyond the Near East: van Gijn 1988; Högberg 2009; Humphrey 2004; Kardulias 2003; Lech *et al.* 2015; McLaren 2008) but, above all, to tackle the issue of technological change, notably the abandonment of chipped stone tools and their replacement by metal(s).

In the Southern Levant, after a long period of technological overlap, metallurgy became dominant and chipped stone essentially disappeared; however, this was not a sudden change but occurred over a long period of almost four millennia, from the Chalcolithic (late 5th millennium BCE) to the Iron Age (early 1st millennium BCE). The decline of flint has been mainly measured in terms of quantitative decline, typological or functional restriction, and an increase in expedient production and *ad hoc* use (Rosen 1996). But measuring decline is not automatically understanding the mechanisms of decline, a long and complex process showing different trajectories and rhythms. The description and analysis of lithic transformations, following a diachronic study over the long term and observing the contemporaneous changes in metallurgy, permit us to observe how they changed, evolved, remained stable, or declined, one in relation to the other. These elements are indispensable in order to understand technological changes during one of the key moments in the history of technological development, the transition from the Stone Age to the Metal Ages.

In order to highlight the conditions underlying the disappearance of chipped stone tools and their replacement with metal implements, we apply the two approaches previously described. Flint knapping and metallurgy, and notably their relationship, are particularly appropriate to observe regularities which operate at different scales, the first one within the developmental lines of objects, techniques and technologies, and the second one within the social conditions of actualization of technological facts. On the one hand, following the "rules" of technical tendencies, the techno-logic perspective permits observation of how metal cutting objects, overcoming the "limits" of knapping technology, represent the logical development of flint tools. On the other hand, the analysis of the socioeconomic contexts in which chipped stone tools were produced allows identification of regularities which conditioned changes in lithic production systems, their decline, and the final replacement with metal tools.

Methodology

The basis of our study is the technological approach developed in France, which combines the technical actions and activities implied in the production of tools with their organization in terms of socioeconomic systems (Inizan *et al.* 1995). However, according to the dual perspective adopted, the criteria considered vary. In the case of the techno-logic approach, the analysis is focused on the internal technical constraints characterizing knapping technologies and tools manufacture, while the reconstruction of the actualizing conditions of technical change is based on the socioeconomic contexts of production and on the modalities of transmission.

The Structural Analysis

As all other objects/techniques, chipped stone artifacts and knapping technologies can be analyzed in structural terms (*i.e.*, the techno-logic approach previously defined). According to their own developmental line, the integration of the elements/operations composing each object/technique allows identification of their developmental stages and thus, of their position within their own development cycles. Following the studies of E. Boëda and his team, lithic industries can be divided into two main lines of objects: the cores (*i.e.*, the production systems including the by-products of reduction) and the tools, each one offering independent insights on developmental paths (*e.g.*, Boëda 1988, 1997, 2001, 2005, 2013; Boëda *et al.* 2013; Bonilauri 2010; Chevrier 2012; Da Costa 2017; De Weyer 2016; Frick and Herkert 2014; Li 2011; Lourdeau 2010; Manclossi 2016; Pagli 2013; Rocca 2013; Rocca *et al.* 2016; Soriano 2000).

The intent is not to present an exhaustive study of all developmental lines and development cycles of knapping technologies and chipped stone tools, but to focus on the examples which can better show the "endpoint" of the potentials of the flint system. By considering its "limits," we are able to place the metal implements within the developmental line of cutting-edge tools and to show how metallurgy triggers a new development cycle.

The Lithic Production System

In the study of lithic production systems, two main developmental lines can be recognized by considering the knapping concepts which differ for their function and functioning: the procurement of a tool from a block of flint in the case of the *façonnage* and the procurement of blanks from a core in the case of the *débitage*. Within this last conception, it is possible to distinguish different developmental lines according to the target products which can be obtained: flakes, blades, and bladelets.

The structural approach analyzes the modalities defining the technical criteria of tools manufacture (in the case of the *façonnage*) and blank production (in the case of *débitage*). For each developmental line, the relationship between the effects of each removal and the criteria permitting the continuation of the reduction sequence allows characterization and definition of the structure of the production system, that is, the level of integration between the elements allowing the *débitage* itself. They change according to the volumetric exploitation of the cores, the criteria permitting the control of blank morphometric characters, and the modalities allowing blank detachment. Using these elements, and considering their degree of synergy, it is possible to recognize different developmental stages. Thus, the structural analysis of the *débitage* considers the target products (*i.e.*, their qualitative and quantitative characters), how the technical criteria necessary to obtain them are created and maintained during the reduction sequence, and what is their reciprocal relationship. If the goal of the production is to obtain blanks transformable into tools, the *débitage* is possible only if the core accords with the technical requirements specific to the *débitage* itself (*i.e.*, lateral and distal convexities, guide-ridges, angle between the striking platform and the knapping surface, *etc.*).

Previous researches have shown the existence of a logical sequence of development from the line of the *façonnage* to the *débitage* of flake, to the *débitage* of blades (for a synthesis, see Boëda 2013). In attempting to analyze the relationship between lithics and metals, it is this last line, and specifically its latest developmental stage, which proves to be the most relevant to show the "endpoint" of the potential of the lithic production system.

The Stone Tools

The structural approach considers chipped stone tools beyond a typological classification. It does not consider the specific functions of the tools but focuses on the relationship between the technical characters which make them functional (*i.e.*, the cutting-edge, the hafted part, *etc.*) and the modalities used to create them (Boëda 1997, 2001, 2013; Lepot 1993). As for the production systems, the structural analysis of tools places them within their own developmental lines, observing the specifics of their developmental stages. According to the role that lithic artifacts occupy in the construction of the objects, their "functioning mode" (Boëda 2013, p. 91), it is possible to distinguish two main developmental lines: (1) the objects "directly" gripped, where the hand-held stone artifact coincides with the tool *en toto* and (2) the objects "indirectly" gripped, where the hafted stone artifact no longer represents the entire tool, but only a part, usually the working edge.

Considering the degree of integration between the technical features which characterize chipped stone tools (*i.e.*, the morphology of the blank, the delineation of the edges, their section and angle, *etc.*) and the modalities used for their manufacture (*i.e.*, directly from the reduction sequence, the retouch, *etc.*), for each line, it is possible to recognize a sequence of developmental stages. Previous researches have shown the existence of a logical sequence from the line of hand-held tools to that of hafted artifacts (for a synthesis, see Boëda 2013) and, although in historical contexts, different development cycles and developmental lines can coexist, in our study, we focus on the line of the hafted tools, which is the most pertinent to show the "endpoint" of the chipped stone tools.

The Comparison Between Lithic and Metal

Flint knapping and metallurgy can be perceived as opposing technical systems, the one replaced by the other. However, in order to pursue the idea of "competing technologies," it is necessary to identify the properties permitting their comparison. Following a techno-logic perspective, lithic and metal tools are placed within the same developmental line because, despite the exploitation of different materials, their function as cutting-edge tools is the same. Although stone and metal can be used for other types of objects clearly produced without this intent (*e.g.*, the zoomorphic Egyptian figurines made on flint (Holmes 1992) or the Ghassulian copper crowns and scepters (Bar-Adon 1980), both produced during the 5th–4th millennia BCE), and despite different specific actions (*i.e.*, cutting, trimming, slicing, chopping, scraping, piecing, *etc.*), it is this "cutting-edge" character which permits a technical comparison and which allows us to analyze them together.[1]

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[1] The invention of metallurgy is not the subject of this paper. However, it is important to stress that their cutting-edge properties were not discovered with the first manipulation of metals, mainly used for the production of beads and pendants (*e.g.*, Birch *et al.* 2013), but were exploited only after the development of smelting, melting, and casting. At the beginning of its history, metallurgy was not comparable with the lithic system, and their "antagonism" emerged only after a functional convergence.

However, the comparison between lithic and metal systems is justified only if we consider the tools (*i.e.*, their structural analysis) because the mechanical principles which characterize their production systems (*i.e.*, the conchoidal fracture in the case of flint knapping and the processes of melting/casting-molding/forging in the case of the metals) are not comparable. This means that if the metal tools can be placed within the same developmental line of those made of flint, in the case of the production systems, there is a clear break, a change which determines a new development cycle. But, by recognizing the existence of links between the tools and their production systems (Boëda 1997), the comparison between the structure of lithic and metal implements will permit the reconstruction of the stages of this logical development.

The Chaîne Opératoire

The study of the socioeconomic contexts of lithic industries is based on the concept of *chaîne opératoire* (Lemonnier 1976; Leroi-Gourhan 1964), which considers the methods and techniques implied in the production process and tool manufacture, the knowledge and skills required in knapping procedures, and the spatial and temporal organization of technical activities (Inizan *et al.* 1995; Karlin *et al.* 1991; Pelegrin *et al.* 1988). Beyond typological classifications and morphometric tool variations, in our analysis, we use knapping methods (*i.e.*, the intentional process which refers to the organization of lithic reduction) and techniques (*i.e.*, the execution modalities of the flaking) as the main criteria for recognizing different technical systems which coexisted and changed through time.

The reconstruction of the contexts of craft production and transmission is based on the combination of the analysis of the knowledge and skill implied in chipped stone tool production systems, their "technical level" (Pelegrin 1991, 2007), with that of the organization of the production. By considering the relations between the natural resources, the needs for finished products, and the technical possibilities (*i.e.*, the procurement or raw materials, the reduction sequence, the operations used to modify the blanks into finished elements, the processes of tool manufacture and maintenance, *etc.*), each lithic industry is contextualized in wider scenarios. Qualitative characters (*i.e.*, knapping technology), quantitative evaluations (*i.e.*, intensity of production), and spatial data (*i.e.*, distribution of artifacts) are used to identify different socioeconomic contexts: domestic or specialized production systems (*e.g.*, Allard and Burnez-Lanotte 2012; Astruc 2005; Astruc *et al.* 2006; Binder and Perlès 1990; Brun *et al.* 2006; Hirth 2009; Perlès 1991, 1992, 2009) and different forms of specialization (*e.g.*, Brumfiel and Earle 1987; Clark and Perry 1990; Costin 1991, 2001).

The Stone-Metal Replacement

The analysis of the historical processes of substitution which occurred during the transition from the use of flint to the metals requires some preliminary observations:

1. Metallurgy was not invented and did not develop as an alternative to the lithic system. If these technologies are considered as competing, their competition emerged only after a functional convergence.

2. The intrinsic properties of metals are significantly different from those of flint, and they played an important role both in the manufacture and use of cutting implements. However, the idea that metals implements were more efficiently used than those made of flint is not always true. This depends on the metal (*i.e.*, copper, bronze, iron) and on the specific activities involved (*i.e.*, chopping, cutting, reaping, *etc.*). Equally, advantages (in terms of relationship between costs and benefits) during the manufacturing processes are related to a multitude of factors which consider both the specificities of the raw materials (*e.g.*, the differences between the casting of bronze and the forging of iron) and the socioeconomic contexts.
3. The skills, knowledge, and abilities required for the production of metals and the manufacture of metal implements are not comparable with those of flint knapping. Evaluations of the technical level can be made within the same technical domain (*i.e.*, in all technical systems, there are simpler and more complex techniques and methods, technologies that can be easily learnt, and others that require longer apprenticeship), but they cannot be applied to technologies referring to different crafts (see also Rosen 1993).
4. The *chaîne opératoire* of metal working is generally longer than that of flint knapping, and it can be schematically divided in two different, although complementary, technical systems, the production of metal (*i.e.*, melting, smelting, alloying, *etc.*) and the manufacture of objects (*i.e.*, casting, forging, hammering, *etc.*). The sequence of technical actions necessary for the production of metal objects, thus, is usually more articulated in time and space, and it can involve a large number of participants. As for other craft production, however, the socioeconomic contexts of production can vary and actually changed through time.

In our analysis focused on the stone-metal replacement, we consider the processes of change as evident in the disappearance of specific lithic production systems. This means that we do not directly focus on the development of metallurgy, but on the effects that the availability of metals and metal implements had on the lithics. Each lithic industry (defined on the basis of its knapping technology and target products) is individually considered in order to observe if and how its decline is related to the introduction of specific metal and tool types. However, given the diversity of the *chaînes opératoires* between stone and metal production systems, the incompatibility of technical levels, and the impossibility of directly comparing them, our analysis considers their socioeconomic contexts in the broadest sense. Thus, our analysis of the disappearance of flint tools focuses on the conditions for the substitution of one socioeconomic system by another one.

Body of Data

Lithic industries during the Age of Metals can be divided in three principal chronological groups: (1) the Chalcolithic Period (*ca.* 4500–3900/3800 BCE), (2) the Early Bronze Age (*ca.* 3900/3800–2000/1900 BCE), and (3) the post-Early Bronze Age, Middle Bronze Age through the early stages of the Iron Age (*ca.* 2000/1900–980/940 BCE). According to their techno-typological characters, chipped stone tool productions can be divided into five different main industries: the bifacial tools, the bladelets, the tabular scrapers, a blade-oriented production mainly used for the manufacture of sickle blades, and a flake-oriented production of *ad hoc* tools (Rosen 1989). Through time, these industries remained stable or changed at different rates, and if some production systems well coincided with specific chronological horizons, to the point that they can be considered as type fossils, others did not follow the same chronological periodization. In our analysis, we do not consider in details the disappearance of bladelets and tabular scrapers, neither of which can be directly associated with the development of metallurgy (Rosen 1996). We focus on the bifacial tools, on the blade-oriented production systems, and on the flake-oriented *ad hoc* industry which each shows some interaction with metal implements.

Bifacial Tools This group is composed of tools defined as axes, adzes, and chisels on the basis of their morphology and metric aspects. Despite different morphometric characters, these tools share the same knapping procedures of manufacture, and they were produced by *façonnage*. Relatively common in all the Chalcolithic sites (Hermon 2008), they often had polished edges that were re-sharpened during use, by removing the damaged and/or blunt extremities (Barkai 1999). According to some use-wear analyses, they were used for tree-felling and wood working (Yerkes and Barkai 2004), although other functions cannot be ruled out (Rosen 1997, p. 97). Known since the Natufian, in the Southern Levant, they disappeared at the beginning of the Early Bronze Age (Rosen 1997, p. 157).

Blade Tools The production of blades mainly used for the manufacture of composite sickles is one of the diagnostic lithic industries of the Age of Metals (Rosen 1982, 1997). According to their morphological and technological characters, it is possible to distinguish three main production systems (Fig. 2).

Chalcolithic blades were knapped using the direct percussion with organic hammerstone, for the most part on cobble and nodule cores (Davidzon and Gilead 2009). The blanks were transformed into standardized sickle elements (*ca.* 2–4 cm long; 0.8–1.2 cm large; 0.5 cm wide) through two principal operations; truncations shortened the blades and regulated their extremities, while backing reduced their width and created an abrupt edge necessary for hafting (Vardi and Gilead 2011). Then, these elements were inserted lengthwise into a handle in order to create a continuous, long, composite blade. Flint teeth were fixed with bitumen, re-sharpened to a minor degree in the haft, and substituted with others when the working edge was no longer useable and became too blunt (Vardi and Gilead 2013).

At the very beginning of the Early Bronze Age, Chalcolithic blades were replaced by a new large blade technology, the Canaanean blades (*e.g.*, Rosen 1983, 1997). Observations of morphometric parameters and technical attributes indicate the use of the lever-pressure technique for the removal of these blades from the cores (Manclossi *et al.* 2016). Once knapped, Canaanean blades were snapped with a controlled and intentional breakage and/or truncated. Length varied considerably without any sign of standardization (from 2–4 cm to 10–12 cm), as this was determined according to the position of segments in curved hafts (*e.g.*, Fischer 2008, p. 184). Their use was prolonged first by re-sharpening the working edge and then by reversing the blades in the haft, as the elements with two glossy edges suggest.

At the beginning of the 2nd millennium BCE, Canaanean blades were replaced by a new type of sickle blade, the large geometrics (*e.g.*, Rosen 1997). These elements were

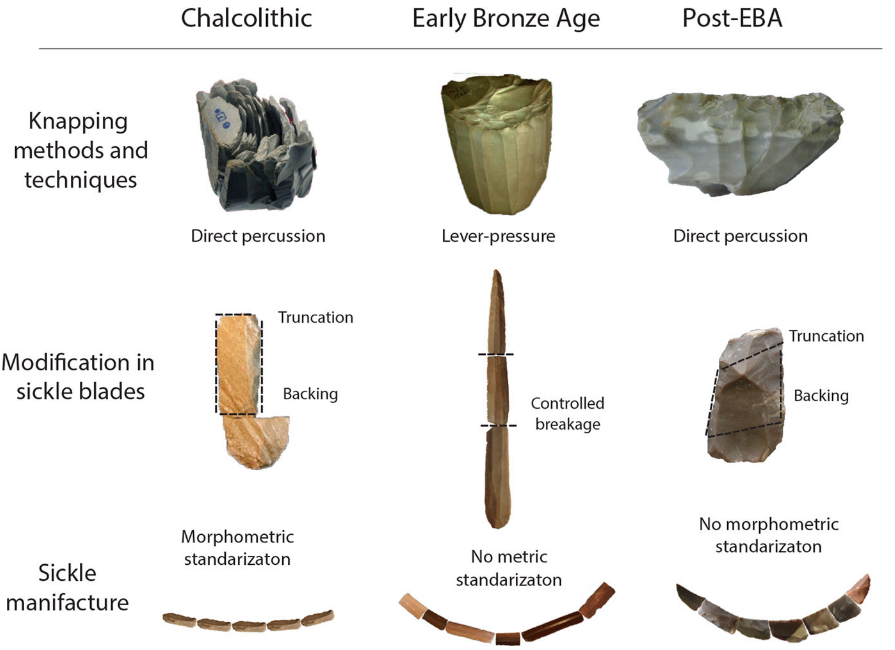

Fig. 2 Sickle blade production systems (not in scale). (The photo of the Chalcolithic blade core is a courtesy of I. Gilead [Gilead *et al.* 2010; Fig. 5], the photo of the Chalcolithic sickle blade is a courtesy of J. Vardi [Vardi 2011, p. 383], the photo of the Canaanean core is a courtesy of P. Jacobs [Lahav Research Project])

manufactured from relatively large blade-flake blanks, produced by direct percussion using hard hammers. These blanks were fashioned into sickle elements through abrupt retouch which gave them the final shape and size varying according to their position into the haft (Coqueugniot 1991; Mozel 1983). The truncations reduced and regularized their extremities, guaranteeing the perfect joint between the continuous pieces of composite sickles. The treatment of the side opposite the working edge, the back, was more varied because its nature (cortical, natural, retouched, *etc.*) was not so determinant in the hafting process (Manclossi *et al.* 2018). Deeply inserted in a layer of plaster, which immobilized the flint teeth and was more than a simple glue, the working edges of these elements (which were not reversible) were re-sharpened though repeated cycles of retouch, and when re-sharpening was no longer possible, they were replaced with new pieces.

Flake Tools During the Age of Metals, lithic industries were dominated by a flake-oriented production of *ad hoc* tools (*e.g.*, Rosen 1997) which show little techno-typological variation through time (Fig. 3). Although simple, the *ad hoc* tools comprised a coherent industry resulting from basic knapping strategies based on a few rules and simple flaking schemes (Manclossi and Rosen 2019a). Without any specific preparation and using direct percussion with hard hammers, this production system was characterized by short sequences of flakes showing a large range of shapes and sizes, all useable as tools. Among the retouched flakes (which generally show simple retouch varying in delineation, extent, distribution, and position), only a small percentage can be defined using typological lists as notches, crude scrapers, drills, borers, or denticulates. Generally, the retouch did not significantly modify the original blanks, and

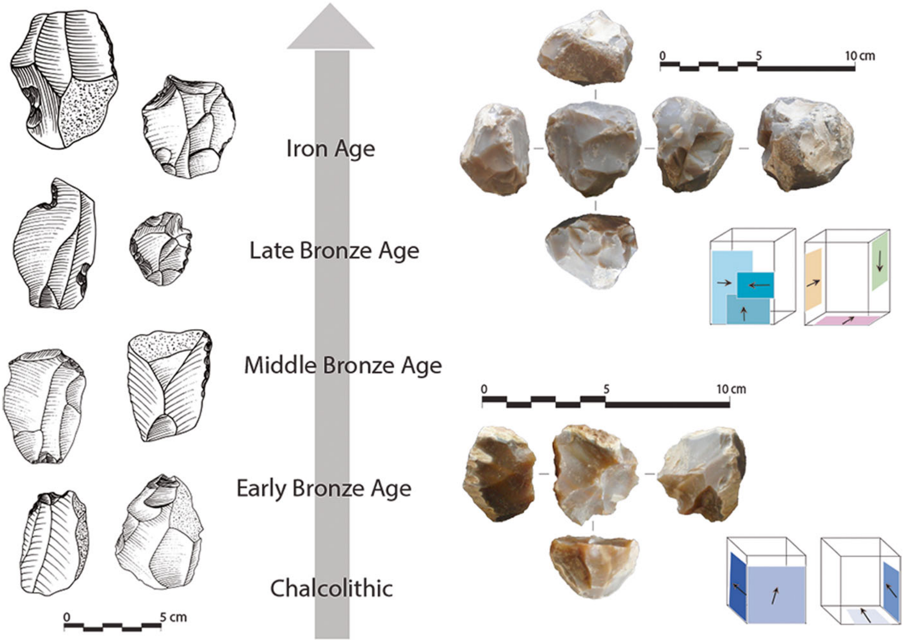

Fig. 3 Flake-oriented production of *ad hoc* tools

it was present on the more suitable edges which required little transformation (Manclossi 2016). The high percentage of flakes without intentional retouch might also indicate that this unretouched group composed the majority of flakes effectively used. Retouch was probably not the first intent of the knappers, and flakes were retouched only when necessary to create suitable edges which were not produced during the detachment of the blanks. The low incidence of re-sharpening retouch seems to indicate that these tools, after their utilization, were quickly discarded.

Metal Tools In the Southern Levant, the first metal cutting tools appeared during the Chalcolithic when they seem to have comprised only a small proportion of copper objects; the majority of which were related to cult (*e.g.*, Golden 2010; Levy and Shalev 1989; Moorey 1988). The "utilitarian" tools were piercing instruments (*i.e.*, awls, drills, *etc.*) and other tools belonging to the family of axes and chisels, both reproducing chipped stone tools which already existed in flint. Through the millennia, from the Chalcolithic to the beginning of the Iron Age, these objects followed different trajectories of development. If we consider the metals exploited for their manufacture, it is possible to recognize a sequence which, in general, characterized all cutting tool types, first copper, then bronze, and finally iron/steel.[2] If we consider the morphological aspect of these tools, instead, it is possible to discern two different paths. On the one

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[2] Chalcolithic and Early Bronze Age cutting tools were usually made of pure copper (*e.g.*, Shalev 1991, 1994; but for arsenic/antimony alloyed-copper tools, see, *e.g.*, Maddin *et al.* 2003; Nadmar *et al.* 2004); bronze (copper/tin) tools appeared at the end the 3rd millennium BCE (*e.g.*, Richard 2006) and became dominant during the Middle Bronze Age (*e.g.*, Philip 1991; Philip *et al.* 2003; Shalev 2009); iron/steel substituted the bronze implements at the beginning of the Iron Age (*e.g.*, Bauvais 2008; Stech-Wheeler *et al.* 1981; Yahalom-Mack and Eliyahu-Behar 2015).

hand, some tools, such as the awls, did not display any transformation and their morpho-technical characters were maintained unchanged over long period (*e.g.*, Chambon 1984; Ilan and Sebbane 1989; Khalil 1980). On the other hand, other objects, such as the axes and adzes, showed morphological and typological variations which can be used to recognize different chronological periods (*e.g.*, Miron 1992; Philip 1989).

But metal cutting tools (Fig. 4) were also and mostly characterized by new objects which did not have any lithic antecedents. They appear during the 3rd millennium BCE (Early Bronze Age), and through time, they showed important morphological, typological, and stylistic variations (*e.g.*, Gernez 2007, 2008; Philip 1989; Shalev 2004). These objects, commonly called spearheads, daggers, swords, knives, battle-axes, saws, *etc*., did not have clear flint parallels (for a synthesis of all metal cutting tools, see Manclossi 2016). The only exceptions were the iron sickles which replaced the flint equivalents by the end of the 10th–9th centuries BCE.

Results

According to the approach we used here, the analysis of late lithic industries and their relationship to the development of metallurgy allows us to outline different processes. On the one hand, the techno-logic analysis identifies the “limits” (or “endpoints”) of the lithic system and its logical relationship to the production of metal cutting tools. On the other hand, the socioeconomic contexts of different production systems, each one placed in a diachronic perspective, permit us to explain continuity or discontinuity through time, allowing identification of the conditions underlying technological change.

The Techno-Logic Approach

The logical development of knapping technologies and cutting-edge implements permits differentiation of two main paths which, although related, respectively concern the production systems and the tools.

The Lithic Production System

Within the developmental line of the *débitage* of blades, the latest stage is represented by reduction characterized by the lever-pressure technique, as well shown by the Canaanean blade system (Manclossi 2016). If we consider the volumetric exploitation of the cores, the criteria permitting the control of blank morphometric characters, and the modalities allowing blade detachment, we can recognize a perfect synergy between the various components of the production system. After the creation of the technical characters necessary for the detachment of the first blades, each blade is not only the objective of the production (*i.e.*, the target blanks) but also an element which acts on the entire system, simultaneously contributing to the maintenance and the continuation of the reduction itself (Fig. 5). This structural configuration is not a trait which characterizes only the *débitage* using the pressure technique (*e.g.*, a similar exploitation is recognizable also on the Chalcolithic blade cores), but the use of this knapping

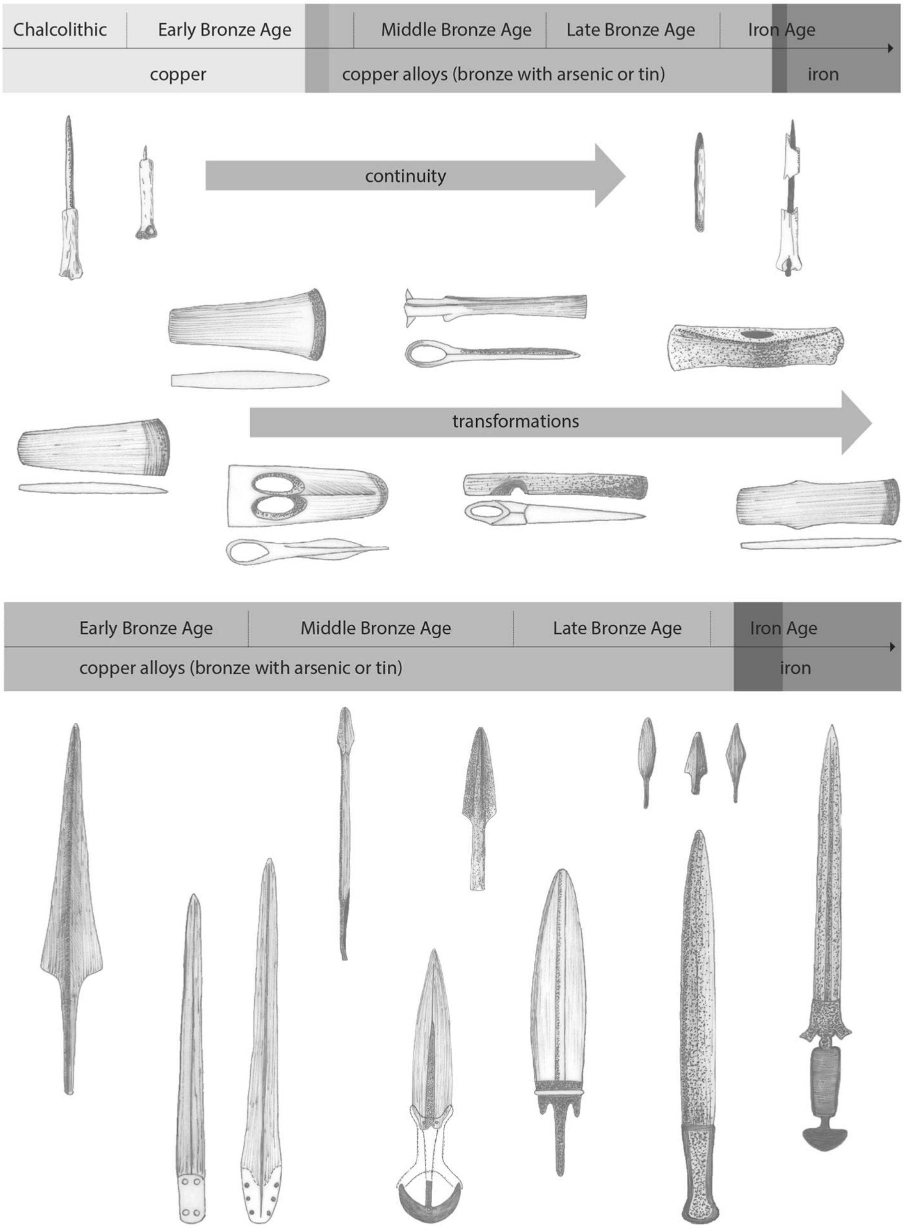

Fig. 4 Metal cutting-edge tools and implements from the Southern Levant. On the top, metal tools with flint antecedents, on the bottom implements without stone parallels (not in scale)

technique allows continuous reduction without other adjustments. On the one hand, the order and the rhythm of detachments guarantee the complete volumetric exploitation of the cores without the need to recreate specific configurations (as for example, in the case of the Chalcolithic blade technology or in the large geometric production system). On the other hand, the lever-pressure technique permits detachment of regular blades

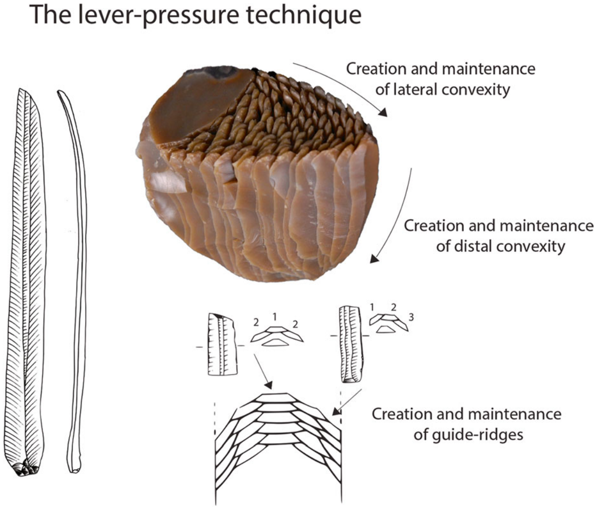

Fig. 5 The pressure technique is the latest stage in the developmental line of the *débitage* of blades. Once the criteria allowing the beginning of the production are created (*e.g.*, lateral and distal convexities, guide-ridges, angle between the striking platform and the knapping surface), the reduction sequence effectively can continue until the exhaustion of the raw material without the necessity of other operations. Each blade represents both the goal of the production and the element which permits the functioning of the reduction process. (The photo of the refitted pressure-blade core is a courtesy of J. Pelegrin, Technothéque de l'UMR 7055)

from orthogonal striking platforms and plain knapping surfaces and, differently from other flaking techniques, it does not require other forms of preparation (*e.g.*, beyond the initial core preparation, core-trimming-elements are extremely rare, and they are not structurally necessary for the success of the reduction sequence).

From this perspective, the function of the core is accomplished (*i.e.*, the mass production of standardized blades) and the use of the pressure-technique reflects a sort of hyper-specialization of the *débitage* itself. As well shown with the Canaanean blade system, the production of blades reaches a state of "saturation" which does not permit modification; once the production sequence is initiated, it is not possible to produce other types of blanks. Between all the components of the *débitage*, there is a sort of autoregulation which guarantees the functioning of a closed system. For example, if knapping mistakes occurred (*e.g.*, the detachment of hinged blades), the cores were often abandoned; a reconfiguration permitting reconstruction of the technical criteria necessary for the *débitage* is not inscribed in the structure of the cores. With the lever-pressure technique, the development cycle of the *débitage* of blades is completed. At this point, the knapping structure is perfectly integrated, and further developmental stages are not possible within the parameters of the technology as it was available. Nevertheless, as a knapping conception, its "limits" must be researched in the technical requirements of the tools which represent the other pole of the same phenomenon.

The Stone Tools

The latest stage in the logical development of composite tools is represented by "multiple composite tools" (Boëda 2013, p. 214) and, specifically, by tools with a continuous working edge, as well shown by the use of flint blades as sickle elements.

This tool conception is an independent developmental line originating from that of simple "composite tools," and is characterized by a higher structural integration between all the components (Manclossi 2016). In the construction of *composite tools*, the lithic artifact simply interacts with a "holder" (*e.g.*, haft, handle); in the construction of *multiple composite tools*, instead, each lithic piece, representing only one element of the working edge, is integrated both with the holder (*e.g.*, the frame within with the stone pieces are fixed) and with the other lithic artifacts which, juxtaposed, create the continuous working edge. Despite different technologies and type artifacts (*e.g.*, the techno-morphological features of flint sickle blades), the construction of multiple composite tools represents the outcome of the potential of chipped stone tools, the "endpoint" of their development cycle. However, it is important to make some remarks.

1. In the developmental line of *multiple composite tools*, considering the degree of integration between the technical features of chipped stone artifacts and the modalities used to obtain them, it is possible to recognize different developmental stages. Thus, the Chalcolithic sickle elements are quite integrated within their reduction sequence because the target blanks maintain their configuration and are little modified by truncations and backing. The Canaanean sickle segments, instead, are better integrated because all the technical features demanded for their use are directly produced during their reduction and, with the exception of an intentional segmentation, no other modifications are necessary. The large geometric elements, instead, are the less integrated within their lithic reduction sequence as shown by the modifications, truncations, and backing, which significantly transform the original blanks (Fig. 6).
2. The developmental stage of lithic artifacts does not necessarily coincide with the developmental stage of the multiple composite tools. Thus, sickles made with large geometric elements are more integrated than those made by Canaanean blades, although large geometric segment production is less integrated than the Canaanean blade system (Fig. 7). Even though in both the cases chipped stone segments are used to create continuous and curved working edges, the rectangular shape of the Canaanean blades permits only partial contact between contiguous elements which are simply juxtaposed at one corner of their extremities. The truncations of the large geometric elements, instead, allow perfect joints between the pieces, and the composite blade does not present any empty space. That is, the development of the multiple composite tools does not necessarily follow the development of specific lithic production systems. The example of the Canaanean blade and large geometric elements well shows that, faced with the impossibility of adapting a given production system to new requirements (*e.g.*, the creation of large pieces having perfect joints at their extremities), the return to a less integrated lithic system (*e.g.*, from the Canaanean blade lever-pressure system to the *débitage* of large geometric elements) may be the only possible technical solution (Manclossi 2016).
3. Technical features required by multiple composite tools, that is, a continuous and long working edge, cannot always be directly obtained from the lithics themselves. Particularly, flint knapping is not able to provide blades that are increasingly long, wide, or even curved. The longest blades found in the Southern Levant reach about 25 cm in length and 3 cm in width, but they are quite exceptional items (*e.g.*, Oshri

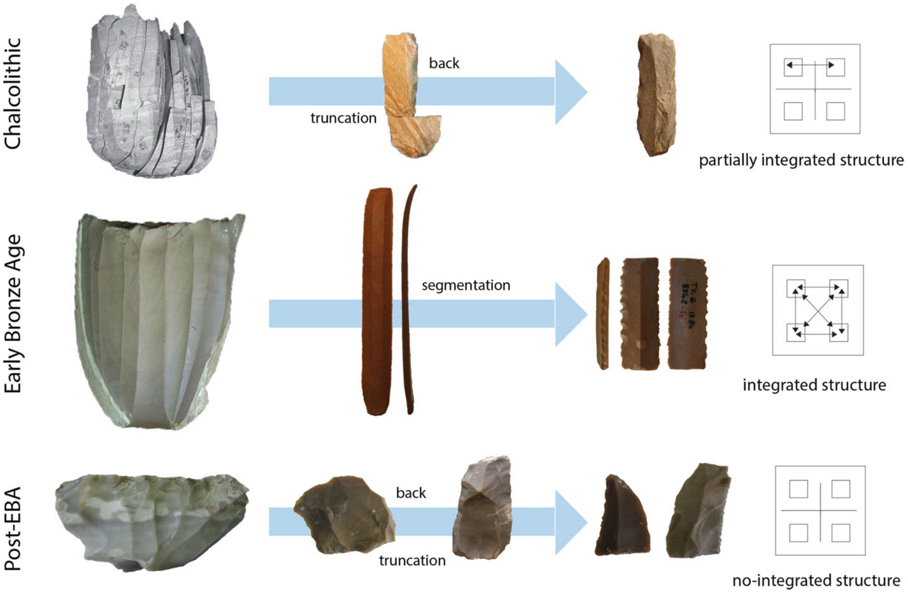

Fig. 6 Structural analysis of lithic artifacts. According to the relationship between the target technical features (*i.e.*, general shape, delineation of the edges, angles, sections) and the modalities used to obtain them (*i.e.*, directly from the reduction sequence, segmentation, retouch), it is possible to recognize different degrees of integration. (The photo of the Chalcolithic blade core is a courtesy of I. Gilead [Gilead *et al.* 2010; Fig. 5]; the photo of the Chalcolithic blade is a courtesy of J. Vardi [Vardi 2011, p. 383]; the photo of the Canaanean core is a courtesy of P. Jacobs [Lahav Research Project])

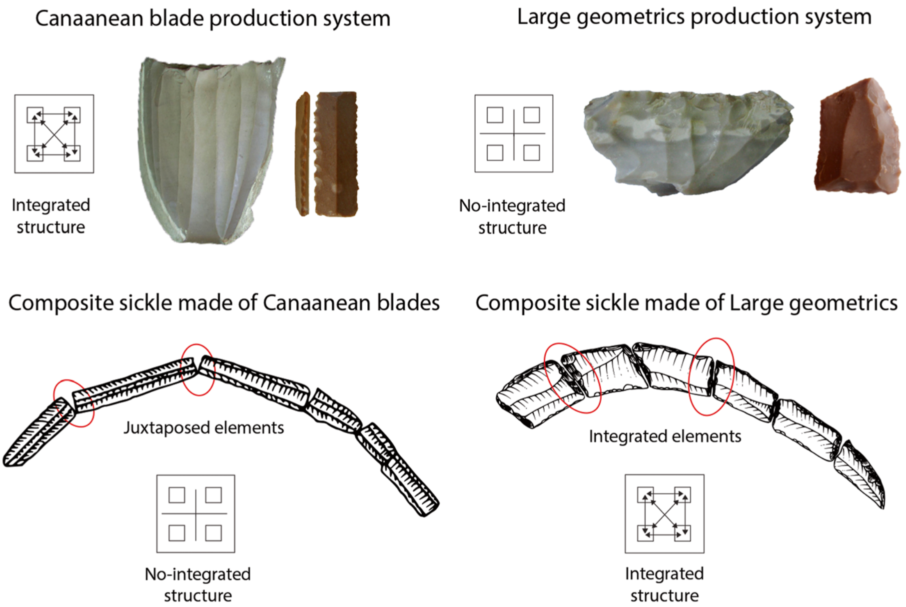

Fig. 7 Relationship between the structure of flint artifacts and the structure of multiple composite tools

and Schick 1998). Moreover, the utilization of these blades seems to pose some functional problems because of the physical properties of the material (*i.e.*, its fragility, brittleness, *etc.*), which might explain their lateral hafting and/or their segmentation. Thus, for tools requiring long cutting-edge, the technical solution is that of deconstructing the tool into several juxtaposed elements.

The Metal Cutting Tools

The invention of metallurgy triggers a new developmental line which is not directly comparable with that of lithics. However, the exploitation of metals for creating cutting-edge implements permits logical comparison between them and the stone tools. In this regard, observing the development of metal objects, it is possible to recognize two processes. The first one, characterized by the use of metals for reproducing objects which already existed in other materials, is a "technological transfer," while the second, characterized by the creation of new objects without lithic antecedents, is the expression of the new potentials inherent in the raw material. The recognition of these new characters allows observation of general trends which permit definition of the "limits" of lithics, and to explain the logical relationship between stone and metal tools. In this regard, it is possible to make several considerations.

1. The potential to produce bigger implements than those made of flint represents one of the new possibilities offered by the metals. Although their morphology and size change and vary according to their specific functions, cutting-edge metal tools are usually characterized by long blades. Thus, for example, the copper Chalcolithic axes can reach 30 cm in length and 5 cm in width (Miron 1992), the Bronze Age spearheads are 20–40 cm long and 8–10 cm wide (Philip 1989), while the Bronze and Iron Age daggers can exceed 50 cm in length (Shalev 2004) and up to 1 m, such as in the case of the sword found at Jericho (Eitan 1994), all significantly longer and larger than flint blades.
2. The use of metal implements permits multiplication and differentiation of the techno-functional characters of the blades. If within the lithic system, only the creation of multiple composite tools allows the extension of the working edge beyond a certain length; the use of metal offers a variety of tools not only longer and larger but especially characterized by two continuous and parallel cutting-edges convergent in a point. The blade of multiple composite flint tools has inevitably only one cutting-edge because the other side of the lithic artifacts has to be inserted into the haft. Metal blades, instead, not only can be longer and wider but, used following their longitudinal axis, they can exploit both cutting-edges and their pointed extremity.
3. The plasticity of metals allows the development of new hafting systems characterized by a greater integration between the artifacts and the hafts. In the potential to take on many shapes, metal can combine and integrate techno-functional characters that in chipped stone tools required multiple elements and technologies. Thus, for example, metal fastening system does not require elaborate shaped haft and adhesive, but metal implements can be socketed (El Mor and Pernot 2011) or directly inserted in their shafts, thanks to the creation of holes or collars (Gernez 2007; Philip 1989).

> Metal implements are not simply sharp blades, but the same item can also be integrated with other parts connected with handles or grips, until the creation of finished of long cutting-edge tools composed of a single piece of metal (Fig. 8).

The Socioeconomic Conditions of Tool Production Systems

Changes (or not changes) of lithic industries during the Age of Metals can be divided in two categories, the first one concerning the processes that took place within the lithic system and the second one referring to their disappearance and substitution with metal "equivalents" (Fig. 9). With respect to internal processes, the analysis of the lithic industries from the 5th to the 1st millennium BCE suggests two main trajectories: (1) the discontinuity of the sickle blade production systems through time and (2) the continuity of the production of *ad hoc* tools which qualitatively did not change. With regard to the replacement of chipped stone tools by metal ones, instead, is possible to observe other two trajectories: (1) the ax and the sickle production systems both terminated abruptly, albeit at different times and (2) the *ad hoc* system exhibited a gradual decline, ultimately disappearing at roughly the same time as flint sickles. Although the final result was the same, that is, the eclipse of stone tools, the processes in the replacement of flint by metals varied and changed according to the specific tool category and associated socioeconomic contexts.

The Ax Production System

Flint bifacial tools (*i.e.*, the group including axes, adzes, and chisels) and copper equivalents coexisted during the Chalcolithic period. However, if stone axes have been

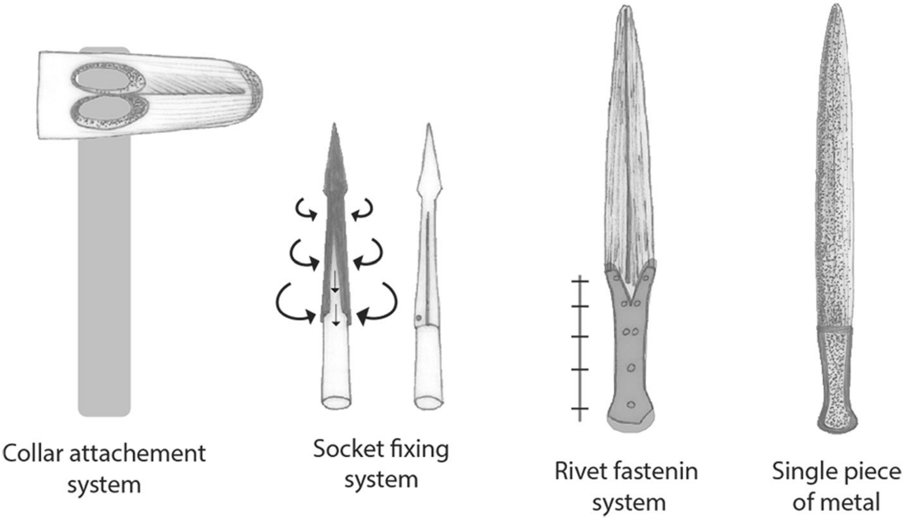

Fig. 8 The new technical potentialities of metal tools (not in scale) refer to the possibility of releasing the working edge of the blade (*e.g.*, longer and wider than those made of flint) and also to develop new fastening systems

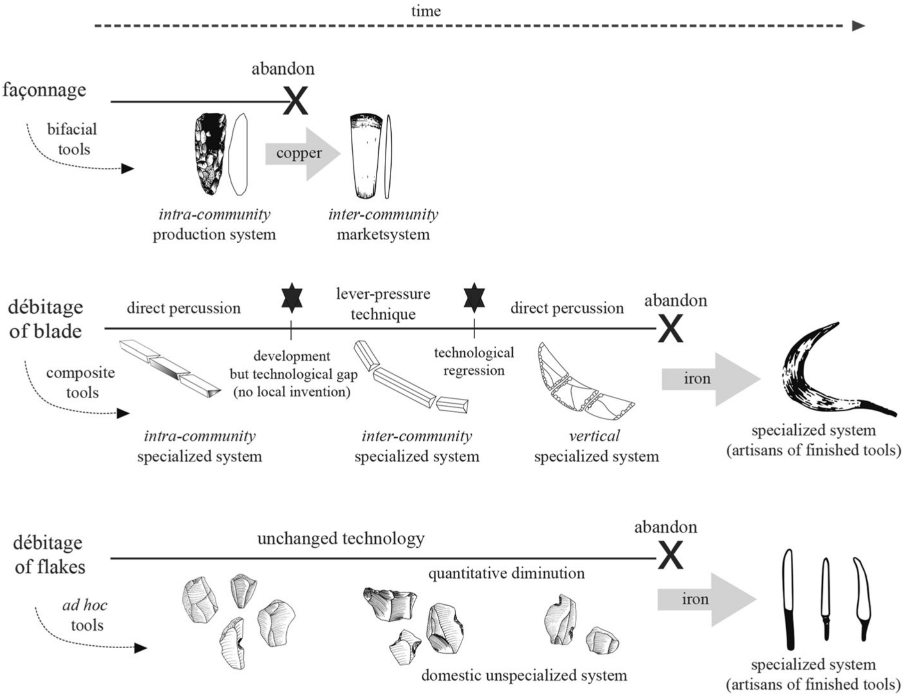

Fig. 9 From stone to metal tools. Each flint industry (*e.g.*, axes, composite sickle, *ad hoc* tools) was replaced by metal objects following different trajectories and rhythms. Despite different historical contingencies, the context of production acted as "evolutionary force"

virtually found in all the sites, sometimes in relatively high frequencies, copper axes were rare. At the beginning of the 4th millennium BCE, during the Chalcolithic/Early Bronze Age transition, the situation completely changed, and not only did copper axes increased in number, but flint axes completely disappeared.

The Chalcolithic Systems Despite their similarity (but great morphological and metric variability), flint and copper axes were not real competing types because they addressed different domains, the first more utilitarian and the second more symbolic. This is suggested by the abundance of flint bifacial tools (from one-two specimens to several tens in every Chalcolithic site [data in Barkai 2005; Hermon 2008]) and the rarity of copper axes (so far, only 46 copper axes, corresponding *ca.* 8.5% of the total of the metal artifacts of the period have been discovered [data in Gošić 2014]), by the frequency of damaged/broken flint axes (*e.g.*, Barkai 2005) in opposition to the apparently unused copper artifacts (*e.g.*, Tadmor *et al.* 1995), and by the particular contexts in which copper axes have been discovered (most of them have been found in hoards, caches, or burials, and only a few come from settlements [data in Gošić 2014]).

During the second half of the 5th millennium BCE, the production of flint axes was carried out in domestic contexts within habitation sites, or in specialized production loci usually nearby flint sources locally available. In these areas, axes were not only manufactured but also repaired and recycled (*e.g.*, Barkai 1999; Milevski *et al.* 2013). The technical skills required for their manufacture differed from those employed in the production of *ad hoc* tools and, in terms of flint knapping, the production of bifacial tools reflects a higher degree of expertise, as indicated by the use of the *façonnage* (the procurement of a tool from a block of flint which requires a coherent volumetric exploitation of raw material), by the predetermined planning of the reduction sequence (with anticipation of the effects of each removal for the continuation of the *façonnage* itself), and by a better control of the knapping movements (which, if not mastered, would compromise the production of the ax and would require restarting the production process). However, the limited use of polishing, usually restricted to the working edge and finalized at improving the effectiveness and duration of the tools, does not show high investment, again suggesting more practical function than symbolic value (*contra* Barkai 2005, 2006). The intensity of production was always low and there is no evidence indicating manufacture for external exchange or trade. Craftspeople, often defined as semi-specialists, operated within household contexts producing for their own needs or those of the immediate community.

Copper axes were probably not used for practical tasks (Golden 2009; Gošić 2014). Behind their extreme low number and the contexts of discovery, this hypothesis is also supported by the fact that pure copper was soft and not especially efficient for most tasks. Although the technology used for their production (*i.e.*, smelting/melting of pure copper and casting in open molds [Golden 2009]) was simpler than that used for the manufacture of other contemporary copper objects (*i.e.*, casting of arsenic/antimony/copper alloys using the lost-wax technique [Goren 2008]), the tools with simple shapes nevertheless seem to represent a component of ritual equipment (Rowan and Golden 2009). Only a few sites in the Beersheva area show evidence of metal working, from the smelting of ores to the casting of finished objects which were locally produced. At Abu Matar and Shiqmim, copper-related artifacts are randomly distributed within the site, suggesting household contexts of craft production, with apparently little intensification at the end of the period (Golden 2009). Scholars agree about the symbolic aspect of the Chalcolithic metallurgy, probably connected with ritual or religious practices (Gošić 2014), but different interpretations about the sociopolitical contexts have been suggested. Levy claims the existence of elites that monopolized this specialized craft in the context of emerging chiefdoms (Levy 1995; Levy and Shalev 1989), while Gilead and others defend the hypothesis of highly specialized craftsmen that were not attached or controlled by any political authority (Gilead 1988; Golden 2009; see also Rosen 1993).

In our analysis, we stress that the adoption of metallurgy for the production of "equivalent" flint tools was not actualized for techno-economic advantages but for symbolic-social reasons. Independently of the sociopolitical interpretation gave to the adoption of metallurgy, the two technologies addressed different domains; flint and copper axes were not really competing types, and there were virtually no points of overlap or intersection where replacement could be conceived (Rosen 1997).

The Early Bronze Age Systems At the beginning of the 4th millennium BCE, flint axes disappeared, apparently in a short time, and only the copper ones continue to be attested. During the EBA, the production of copper objects, previously addressed to the symbolic/ritual sphere, penetrated and extended to the more utilitarian one (Rosen 1996). This process was actualized by the development of more economic-oriented form of specialization resulting from the emergence of a copper trade–market system completely different from that of the Chalcolithic period (Golden 2009; Rosen 1993, 1997). Evidence of this new system, that fully developed during the EBA II–III, can be recognized from the beginning of the 4th millennium BCE (EBA I) when sites like Tell Hujarat al-Ghuzlan and Tall al-Magass in ʻAqaba (Klimscha 2011; Hauptman *et al.* 2009) or Wadi Fidan 4 in the Feinan (Genz 2000) show systematic production of copper for export indicating the emergence of regular exchange and distribution system between the desert areas, rich in copper ores, and the settled zone where the demand of this metal seems to have increased. According to Genz (2000), during the EBA I, copper objects were cast in small quantities in several sites. The intensity of production seems to reflect household level of production for exchange, probably involving part-time specialists that traded and distributed the final objects. Copper, imported into the region in form of bars and ingots or collected recycling scraps and damaged objects (Ilan and Sebbane 1989), was melted and quickly casted in molds permitting augmentation of the productivity of the artisans.

The disappearance of flint axes was one of the consequences of the development of this new socioeconomic system. The production of axes changed from a situation of one of self-reliance to one of dependence. The intra-community production of axes was replaced by a market, which not only modified the relationship between producers and the users of tools but also altered the value of flint and copper axes, ultimately resulting in the end of the chipped-stone axe socioeconomic system (Rosen 1996). However, despite the availability of copper,[3] which increased during the EBA II–III as shown by the intensification of copper extraction systems (*e.g.*, Hauptman *et al.* 2009; Hauptman and Pernicka 1999; Levy *et al.* 2002) and the development of more organized trade-networks (*e.g.*, Milevski 2009, 2011; de Miroschedji 1986; see also Rosen 2017), the stone-metal substitution affected only the axes, and other chipped-stone tools continued.

The Sickle Blade Production Systems

The blade-oriented technology for the manufacture of composite sickles showed profound techno-typological changes which occurred respectively at the beginning of the 4th millennium BCE (Chalcolithic/Early Bronze Age transition), at the beginning of the 2nd millennium BCE (Intermediate Bronze/Middle Bronze Age transition), and finally at the 10th–9th centuries BCE (Iron Age IIB/IIC) when flint sickle segments disappeared, replaced by iron equivalents. The technological analysis of these different production systems shows that every industry reflects a specific specialized craft and that technological changes were conditioned by the emergence of new socioeconomic contexts.

The Chalcolithic System During the second half of 5th millennium BCE, sickle blades were produced by direct percussion with organic hammerstones, and both the knapping technique and method significantly contrasted with those used in the domestic

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[3] During the entire EBA, copper was used also to produce other objects not directly comparable with flint "equivalents" such as, for example, the daggers, swords, spearheads, and battle axes (*e.g.*, Hestrin and Tadmor 1963; Maddin *et al.* 2003; Miron 1992)

production of *ad hoc* tools, indicating a higher level of expertise. Although sickle blades were manufactured on local raw materials, the high productivity of flint blades then transformed into sickle elements, the standardization in shape and size of lithic pieces, and their interchangeable nature indicate that the production of sickle elements was a specialized "intra-community" activity (Fig. 10a). In each community, only a few knappers participated to the production of sickle blades, each one manufacturing thousands of blades as well indicated by the workshop of Beit Eshel, where in a limited area, hundreds of cores and blades have been found (Gilead *et al.* 2010). These

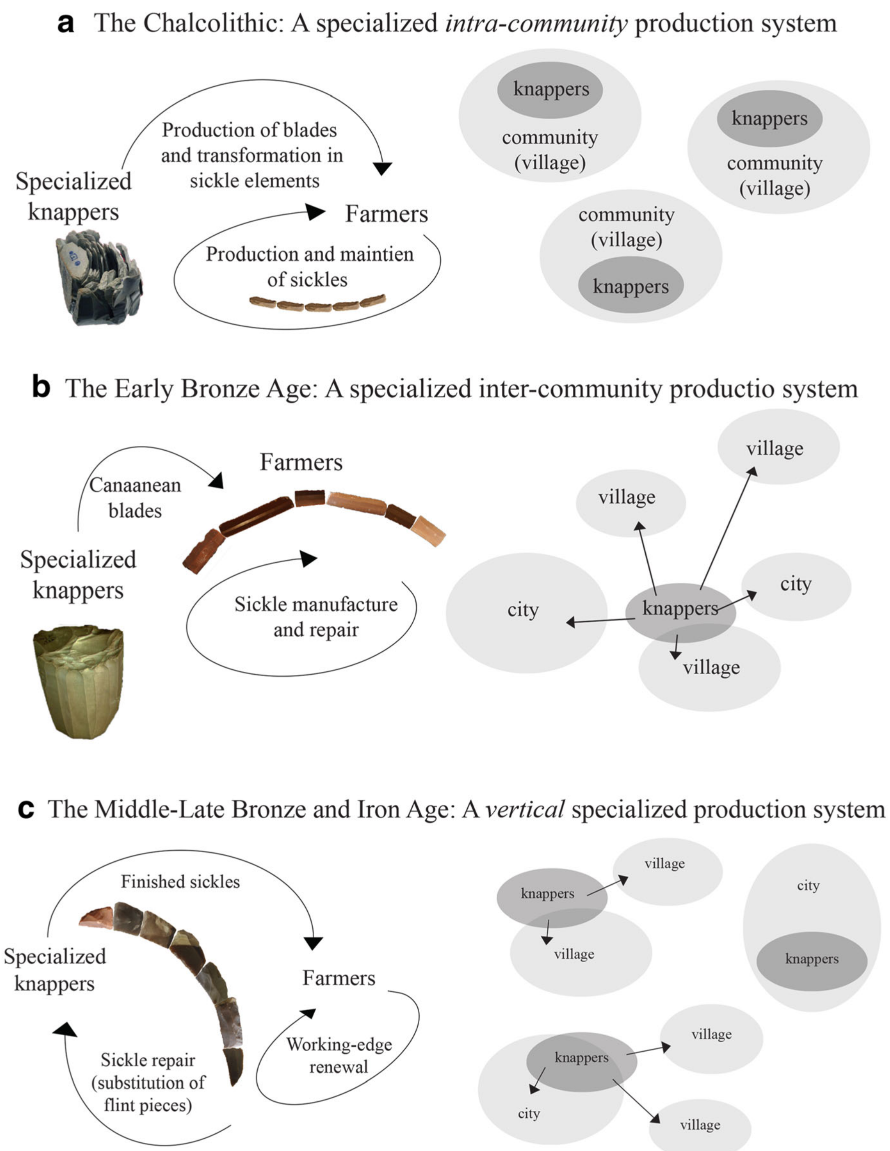

Fig. 10 The sickle blade production systems during the Age of Metals in the Southern Levant

knappers were village-based artisans that could integrate the intensive manufacture of sickle blades carried out in workshops with smaller scale episodes within domestic contexts in habitation sites (Hermon 2008). The knappers, probably family-based groups (Gilead *et al*. 2004), seasonally produced flint segments and finished tools for the other farmers of the community, who took care of the maintenance of the composite sickles, quickly and easily replacing the flint inserts which were little re-sharpened (Vardi and Gilead 2013). This system seems to reflect regular and differentiated technical tasks between villagers (Manclossi and Rosen 2019b) and well corresponds to a division of labor and interdependence between households of rural semi-autonomous communities (Gilead 1988).

The Early Bronze Age At the beginning of the 4th millennium BCE, Chalcolithic sickle blades were replaced by a new technological type. Canaanean blades were produced using the lever-pressure technique, one of the most complex knapping technologies requiring long apprenticeship and regular practice. If we consider the time necessary to master and learn this technique, the skills that have to be regularly maintained, and the investment in time and tools (implying high productivity and intensive production), we suggest that only a few specialists were contemporaneously active, supplying the demand of Canaanean blades in the region (Manclossi *et al*. 2016). The limited number of craftspeople producing Canaanean blades, probably on the order of dozen knappers with their apprentices for all the Southern Levant (Manclossi and Rosen 2019b), implies a different relationship between the specialists (knappers and traders of blades) and the farmers (users of blades and producers of sickles). The Canaanean system with a few knappers able to meet the demand of the mass consumption of blades implies the existence of an "inter-community" production systems characterized by socioeconomic relationships between individuals who did not necessarily belong to the same community (Fig. 10b).

In this regard, the spatial segmentation of the *chaîne opératoire* in different sites, with unworked nodules of high-quality flint, cores in different stages of reduction (*e.g.*, Futato 1996), waste of small knapping episodes (*e.g.*, Manclossi *et al*. 2016), caches of unworked blanks (*e.g.*, Marder *et al*. 1995; Rosen 1997), and/or partially used blades (*e.g.*, Fischer 2008), seems to indicate that the specialists not only produced the majority of blades in workshops (*e.g.*, Hartenberger *et al*. 2000) but they probably moved between sites. During their trips, the knappers brought with them a few cores, producing Canaanean blades on demand, and traded the blades directly to the consumers (Manclossi and Rosen 2019b). Once acquired, the farmers manufactured their own sickles snapping the blades and fixing each segment in the haft, and then intensively used and reused them, sharpening the edges and reversing the flint teeth (Rosen *et al*. 2014). Thus, the emergence of the Canaanean blades determined a new specialized system which coincided with a new socioeconomic structure; not only were the blades distributed within larger exchange networks (Milevski 2013; Rosen 1997), but the relationship between artisans (few) and consumers (many) reflects new socio-economic ties.

If the socioeconomic context which favored the technological change of the sickle blade production system was the emergence of an "inter-community" specialization, another aspect related to the Canaanean blade system concerns how the lever-pressure technique was introduced into the Southern Levant. Given the absence of requisite technological precursors to this technique, that is, the simpler modalities of pressure flake removal (Pelegrin 2012), and the lack of a technological background able to support local development, the emergence of the Canaanean blade technology reflects the movement of expert knappers (Manclossi *et al.* 2016), and it cannot be considered a local invention (*per contra* Shimelmitz 2009).

The Post-EBA System At the beginning of the 2nd millennium BCE, Canaanean blades disappeared, apparently within a short time, and they were replaced by the large geometric sickle elements produced by direct percussion with hard hammerstone. The manufacture of sickle blades continued to be a specialized system, as indicated by the use of high-quality raw materials different from those used for the *ad hoc* tools and often not available in the proximity of the sites (*e.g.*, Manclossi *et al.* 2018), the absence of flaking waste and cores in most of the sites, and the concentration of hundreds of unworked and partially modified blanks in specific production loci (Rosen 1997).

The spatial organization of the *chaîne opératoire* suggests that the artisans knapped large flake blades in workshops, probably at quarry sites, and then transported these blanks to secondary workshops where finished flint elements were produced (*e.g.*, Coqueugniot 2010; Rosen 1986). The great morphometric variability of the large geometric sickle elements indicates that they were modified, through truncations and backing, according to their specific position in the composite sickles, and it is likely that these operations were conducted by the same people who placed and fixed the flint teeth in the haft. This production system, which quantitatively exceeds the needs of simple domestic production, reflects a new form of organization in which the specialists were not only flint knappers but artisans who produced complete sickles for the farmers who, in turn, lost their role as manufacturers of their own tools (as in the previous period) and became simple consumers of finished implements (Manclossi *et al.* 2018). From the beginning of the Middle Bronze Age until the Iron Age II, the large geometric sickle blade system reflects a specialized "vertical" integration (Fig. 10c). That is, we see a new form of socioeconomic structure tied to a different relationship between artisans and farmers based on a changed division of the labor.

The Disappearance of Flint Sickles Despite the increasing availability of metals during the 3rd–2nd millennia BCE, sickles continued to be manufactured as composite tools made of flint elements. During the 10th–9th centuries BCE, however, flint sickles disappeared, replaced by iron ones which, as indicated by experimental tests, were more efficient (Steensberg 1943). This substitution did not take place with the earliest introduction of iron into the region (Yahalom-Mack and Eliyahu-Behar 2015), but occurred when the new metal became more accessible and probably cheaper. Despite functional and economic advantages, however, the conditions which favored the sickle stone-metal replacement were related to its socioeconomic context.

In the shift from flint to iron sickles, it is interesting to observe that the step preceding this ultimate replacement was characterized by a form of specialization where the users of these objects, the farmers, were no longer the producers, but acquired the finished tools from artisans. When iron technology appeared and developed, sickles were already manufactured by artisans in a vertical production sequence. Thus, once iron technology was available, the socioeconomic structure necessary for its large-scale adoption (*i.e.*, a clear division of the labor between producers and users of utilitarian tools) has already been present for almost a millennium. Obviously, the intrinsic properties of metal must have played an important role, but it was the socioeconomic structure which facilitated the replacement.

The *Ad Hoc* Industry

Simple irregular flake tools, either unmodified or retouched blanks, are quantitatively dominant in lithic assemblages from the proto- and early historic periods. Although this type of production is often defined as occasional, opportunistic, or expedient (*e.g.*, Binford 1979; Parry and Kelly 1987), we prefer to use the term "*ad hoc*." This was not makeshift production (such as, for example, one that would exploit the by-products of other knapping activities), but a specific production system mobilizing its own concepts, methods, and techniques and following a coherent and repeated logic (Manclossi and Rosen 2019a). Importantly, it was not the result of random technical behaviors, but referred to all daily activities requiring cutting tools (*e.g.*, McConaughy 1980).

Technological Continuity *Ad hoc* tools are associated with unspecialized and domestic contexts of production and use. In this case, the users are identified with the knappers who produced tools as needed, with little technical investment or special effort. Knappers produced a series of flakes and then selected the blanks with properties that make them appropriate for the technical activity intended. In relation to the organization of tool production and consumption (and probably to the tasks for which they were used), *ad hoc* tools reflected individual technical activity. In this regard, knapping technology and tool design offer us important insights. On the one hand, the low technical level is well evident in the solutions adopted by the knappers. The high frequency of knapping mistakes, usually associated with an incorrect gesture of the knapping movements, indicates the low level of expertise of the knappers who were not expert craftspeople. On the other hand, the lack of morphological standardization of the tools, to the point that typological lists are almost unusable as analytical instruments, suggests that flint knapping, although performed by all the members of the community, was carried out and transmitted within domestic units without influence from external contacts. This might indicate that technical tasks implying production and use of *ad hoc* tools were not carried out at the level of the community, within which people shared common technical features, but reflected individual (as opposed to group) activities.

The persistence of this unspecialized and domestic context of production and use explain the long continuity of the *ad hoc* production system through several millennia. Despite important transformations evident in other domains, the production of flint cutting tools used for daily tasks remained a domestic activity individually performed.

A Gradual Decline *Ad hoc* tools represent the main component of the lithic assemblages of the Age of Metals. However, the decrease of absolute number of tools and flaking waste from the 2nd millennium BCE seems to indicate a gradual decline of this industry (Rosen 1996). Knowing that *ad hoc* tools were used for many daily tasks (*e.g.*, McConaughy 1979, 2003), their decrease actually seems linked to the gradual introduction of bronze implements. If the rarity of metal artifacts in archaeological records cannot completely confirm this hypothesis,[4] other arguments seem to support it. For example, the analyses carried out on bone cut marks show that from the Middle Bronze Age, the tools most frequently used for this activity were no longer flint flakes, but metal blades (Greenfield 2013). However, bronze was still rare and relatively expensive and, as indicated by the quantity of chipped stone tools recorded in archaeological sites, most of the domestic activities demanding cutting tools continued to be carried out with stone implements.

The Disappearance of the *Ad Hoc* Industry The situation completely changed with the introduction of iron. If, on the one hand, the greater availability of iron, which was probably cheaper than bronze as raw material, facilitated its penetration into all functions requiring cutting implements, on the other hand, this process was favored by the complete disappearance of the domestic production system, where stone tools were individually produced and used. The disappearance of *ad hoc* tools (which chronologically coincides with the cessation of flint sickle production) well reflects this change. Thus, the end of chipped-stone tools was not only related to the efficiency of iron implements, but it was favored by a structural change in the relationship between tool producers and consumers (Rosen 1996). This distinction, first reflected in certain tools (notably, the flint sickles), came to an end with iron technology, which encompassed all other production systems, at all levels of society including specialized and domestic production.

Discussion

The transition from chipped stone to metals has generally been analyzed with emphasis on new technologies and materials, that is metallurgy. Archaeological studies have tended to focus on innovation, on new elements that did not previously exist. However, metallurgy fitted into a preexisting technical system and, although the lithic industries of the Age of Metals have often been considered uninformative, their study contributes to the analysis of technological change in the sense that they provide the essential background to the innovation. By combining two different levels of analysis, we suggest a “non-historical” and logical path in the development of cutting-edge implements, and we identify some socioeconomic conditions favorable to the adoption, continuation, or disappearance of technical traits.

The “Endpoint” of Lithics and Their Logical Relationship with Metal Cutting Tools

Following the techno-logic approach, the structural analysis of the lithic industries of the Age of Metal identifies their latest developmental stages. With regard to the production systems, this stage is represented by the *débitage* of blades detached by using the lever-pressure technique. In the construction of chipped stone tools, instead, the final phase in their developmental line is expressed by *multiple composite tools*. In

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[4] Most of the metal objects dated to the Bronze Age derives from tombs (*e.g.*, Philip 1988), and only a small percentage of items, usually awls and some axes, comes from villages and cities.

both the cases, lithics arrived at the "endpoint" of their development cycles which seem to have exhausted their potential for further transformation. Lithic industries reached a stage of "pause," a plateau in the development beyond which new innovations were possible only by adopting metallurgy.

With regard to the production systems, the developmental line of the *débitage* of blades seems to have concluded its development cycle, realizing its potential through great integration. In the production of Canaanean blades, the lever-pressure technique represents the apogee of flaking technology because all the elements permitting the knapping are perfectly in synergy with the others. The core, whose function is the provision of blanks, reached the maximum of its potential due to the intensification of production and the extreme standardization of the blades. Once the reduction sequence has started, the system is auto-regulated, and the synergy between all its components (*i.e.*, each removal) guarantees its functioning. However, this is a hyper-specialized closed system not only because its structure cannot be modified, but also because the lever allows detachment of the biggest blades that can be obtained by pressure (Pelegrin 2012). The system perfectly achieved its function, that is, obtaining of blanks with specific technical and morphometric features then directly useable as elements for multiple composite tools.

This tool conception has the potential to increase the length of the cutting-edge beyond the size that can usually be obtained from any knapping system. Thus, although very large and long blades can be produced using different knapping techniques,[5] and they have been found in several archaeological contexts, these examples are exceptional (Pelegrin 2007). Their utilization as complete blades seems to pose some functional problems, perhaps explaining their segmentation. Thus, for tools requiring long cutting-edges, the technical solution is that of deconstructing the tool into several juxtaposed elements. As in the construction of composite sickles, these can show different levels of integration between the components of the composite tools and between the individual lithic artifacts and their production system.

Although lithic production systems and tool construction are deeply related (Boëda 1997, 2013), their development cycles can show different developmental stages. In particular, it is interesting to observe that the developmental line of multiple composite tools continued even if the specific lithic production system had already achieved its latest stage, as in the Canaanean blade technology (for similar phenomena involving other lithic technologies, see Boëda 2013). The case of sickles made of large geometric elements well reflects this phenomenon, where the adoption of a less-integrated lithic production system permits development of more integrated multiple composite tools. However, despite the increasing synergy between all the components, no knapping system can produce long, wide, even curved blades, such as those made of metal. Thus, the conception of composite tools of multiple lithic segments represents a stopping point in the logical developmental path of cutting-edge implements. Blades of different shapes and sizes can be created with greater integration between all the lithic components, but in one sense, these can never achieve the full optimization seen in single-

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[5] For example, in Europe, at the Grand Pressigny, blades produced by indirect percussion can reach 40 cm in length (Pelegrin 2002), at Etiolles, some blades are 60 cm long (Olive *et al.* 2005), or in Varna necropolis, the longest blade produced by pressure reaches 43.3 cm (Manolakakis 2002).

piece metal blades. They will always have unexpressed possibilities, and the development cycle of the chipped stone tools finds a natural "endpoint."

Simpler composite tools made of one lithic element and a handle seem to reflect a similar phenomenon and, even if our analysis did not consider in the detail the structure of bifacial tools, the chipped stone axes also were part of the same trend. Stone axes, which were attached to wooden hafts with cord (*e.g.*, Benoit *et al.* 1961), were structurally composed of different elements simply juxtaposed. Lithics, differently from metal whose plasticity allowed development of more integrated hafting systems (such as those characterized by shaft, holes or rivets), was not adaptable for further technological development. Thus, not only the multiple composite tools but more generally all composite flint tools represent a stage of "pause" in their developmental path.

The case of the axes is interesting also for another point of view. Although in our study we have not considered the developmental line of the *façonnage* and bifacial tools, other researches have shown the existence of different developmental stages defined by considering how the techno-functional units are organized and created within the volumetric structure of the bifacial tools (*e.g.*, Boëda 2013; Chevrier 2012). Placed within their developmental line, in the first stages, bifacial tools resulted from a juxtaposition of parts differently arranged and independently created during the *façonnage* (*i.e.*, the first bifacial tools were a sort of assembly of tools), while in their latest stages, the artifacts were conceived as a single tool, whose different techno-functional parts were concurrently manufactured (for a synthesis, see Boëda 2013). Flint axes reflected this latest developmental stage because their structure is well-integrated; each artifact was perceived from the beginning as a specific tool, and the *façonnage* was oriented toward the progressive and simultaneous production of all its techno-functional units. For example, in the case of the *façonnage* of axes and adzes, which differ in their cross-section, the reduction sequence was specifically conducted according to the desired tool. From the beginning, the *façonnage* was oriented toward the manufacture of an ax or adz, and their production was differently organized without the possibility of modification (*i.e.*, an ax cannot become an adz during the reduction sequence and the re-sharpening processes maintained the same function of the tools unless to completely modify the original shape). This integrated structure characterizes different types of bifacial tools, not only the axes/adzes (*e.g.*, Chevrier 2012). However, in the case of Chalcolithic axes/adzes, the use of the polishing reflected the existence of technical adjustments specifically adopted for improving the specific function of the tools. The abrasion of the working edge (which exploits a physical principle other than that of the conchoidal fracture) created homogeneous surfaces that favored the even distribution of forces, reduced drag and friction, and reduced the formation of cracks and fractures. This treatment made the cutting-edge more resistant, increasing the endurance of the tools (Le Roux 1999). Despite these improvements, the structural "limits" of the *façonnage* and of the bifacial tools were not overcome. Lithic elements, whose structure was well-integrated and whose function was accomplished, thanks to technical adjustments, remained one of the components of composite tools made of juxtaposed parts (*i.e.*, the stone blade and the wooden haft fastened with cord). Lithics were not adapted to create tools with more integrated structure, as shown by metal implements in which there were "potentials" for greater integration and further new developments.

Metal cutting implements can be placed within the techno-logic sequence of flint tools because, in a sense, they continue their developmental paths. Metal objects represent the development of the flint tools because, by exploiting the properties of new materials, the "limits" of lithics can be overcome. This development is visible in two parallel, but complementary trajectories: on the one hand, by the possibility of creating bigger blades with longer cutting-edges and, on the other, through new constructions of tools characterized by a greater integration between the cutting-edge element and the haft. In the first case, longer and larger blades represent a further development of the phenomenon of "externalization" of the cutting-edge which, beginning with the first hafted tools and continued by exploiting the potentials of the blades, developed into the line of multiple lithic elements composite tools (Boëda 2013). In the second case, metal artifacts become more integrated within the construction of the tool from a global point of view. Due to the possibility offered by metals to increase the length of the cutting-edge, the distance between the hand and the cutting-edge, and the potentials to better integrate the cutting-edge with the haft, new and original implements, without lithic precedents, developed.

The use of metal not only permitted cutting-edge tools to improve on previous conceptions of forms and functions, but their structural properties allowed development and expression of new technical characters that, inscribed within the line of flint cutting tools, had remained unexpressed until then. New evolutionary paths opened up, literally inconceivable using the lithic technical systems. Although the structure of the first metal implements was similar to that of flint tools (*i.e.*, the first copper axes were structurally similar to the chipped stone ones, as indicated by the fact that blades made of both the materials were fixed to the handle with cords), metals were mainly used to create new objects. Despite different forms and morphologies adapted to the specific functions for which these implements were used, metal cutting tools were characterized by new technical features which permitted exploitation of new gestures. With the metals, there is a further development of a whole range of implements which make it possible to carry out new manual movements and exploit new forms of energy. Thus, long metal blades were used according to their longitudinal axis, which permitted simultaneous exploitation of the two cutting-edges and the point (in contrast to the flint system where long composite blades were hafted laterally, resulting in a single cutting-edge). Moreover, the better integration of the cutting-edge within its handle (*e.g.*, the collar attachment, the socket or rivet fixing systems), until the potential to create cutting implements made of a single piece of metal, is the expression of new forms of kinetic energy (for a similar tendency in other lithic technologies, see Boëda 2013). From this perspective, one understands why the use of increasingly hard and resistant materials accompanies this development. As soon as the morphology of the tools is no longer a direct function of the material (*i.e.*, metal objects can assume the same morphologies independently of the metal used), the specific properties of each metal (*i.e.*, its mechanical and physical qualities), often modified through manipulation processes (*e.g.*, hammering, alloys, carbonization), influence their hardness and strength (*e.g.*, Lechtman 1996; Pleiner 2006), and thus, the possible movements and gestures.

Finally, the use of metals overcomes another "limit," that of the raw material. Flint cores can be completely exhausted. However, even though in some cases it is possible to use almost all the material, there is always a "limit" that the *débitage* cannot overcome because the block/nodule cannot be exploited in its entirety. With metals, this limit no longer exists because, theoretically, the exploitable raw material is not only no longer bound to a given volume but it can be continuously transformed. A mass of metal is an unlimited reservoir of tools: not only it can take any form by transforming into any type of tools but it has the potential to retransform without limits into other similar or different objects.

The Socioeconomic Conditions for Technological Changes

The evolutionary trajectories of lithic industries during the Metal Ages, their continuities and transformations until the final replacement by metal implements, were conditioned by different factors involving the availability and cost of metals and their production and functional efficiency (*e.g.*, Rosen 1984, 1996, 1997). Our analysis, however, has specifically focused on the socioeconomic contexts which favored the adoption, continuation, and disappearance of different technical systems. By considering historical scenarios and the conditions for technological change, we distinguish between those occurring within the lithic systems and those involving the stone-metal substitution. With respect to the flint systems, our study concerns the sickle blade production system and the *ad hoc* industry.

The Sickle Production System

The first change took place during the Chalcolithic/Early Bronze Age transition, at the beginning of the 4th millennium BCE. Technological change was not simply the substitution of knapping technologies, but it was determined by the replacement of an entire production system with another. Historically, the introduction of the Canaanean blades resulted from the arrival of foreign artisans who brought a new and sophisticated knapping technology, the lever-pressure system, into the region. This adoption of the Canaanean blades was facilitated by the creation of a new socioeconomic structure which, compared to the previous period, was based on different division of the labor and roles between flint knappers and farmers. The emergence of this new production system occurred during a period of important transformations involving the abandonment of settlements, the displacement of population, profound modifications of the material culture and cultural traits and, as suggested by some scholars, sociopolitical organizations (for a synthesis, *e.g.*, Braun and Roux 2013; Rowan and Golden 2009). The adoption of the Canaanean blade system characterized by a few specialized knappers who mass-produced blades, then exchanged with the farmers who manufactured their own sickles, was concomitant with these transformations. In this regard, the rapid replacement of the Chalcolithic sickle blade production system with the Canaanean seems to attest the expansion of one socioeconomic group (*i.e.*, the specialized Canaanean blade knappers that operated within inter-community trade-networks) to detriment of another one (*i.e.*, the knappers existing within Chalcolithic communities).

Canaanean blades were a hallmark of Early Bronze Age, a long period characterized by the emergence (EBA I–II), establishment (EBA II–III), and collapse (EBA IV) of the first urban society of the Southern Levant (for a synthesis, *e.g.*, de Miroschedji 2014). In the case of the Canaanean blade production system, archaeological evidence indicates that flint specialists were independent of specific sociopolitical structures.

Thus, Canaanean blades were introduced before the emergence of urban centers and continued after their collapse. Moreover, during the urbanized phase, there is no evidence indicating that palaces/elites controlled the production of Canaanean blades, even though other specialized production systems, such as that of wheel-made pottery, were attached to them (Roux and de Miroschedji 2007). The specific function for which Canaanean blades were used, that is, the manufacture of sickles (*e.g.*, Gurova 2013; *contra* Anderson *et al.* 2004) employed in agricultural activities involving most of the population, might explain why elites were not involved into this production system, which remained independent.

Innovations involving sophisticated technologies are often connected with "elites" and/or symbolic reasons (*e.g.*, Roux *et al.* 2013). Numerous archaeological cases attest this association and within the lithic industries, for example, European large blades detached by using the lever-pressure technique and discovered in burials follow this trend (*e.g.*, Manolakakis 2002; Morgado Rodríguez *et al.* 2008; Skakun 2008). The case of Canaanean blades is interesting because, although the knapping technology was similar, the socioeconomic context was completely different. The contrast with other historical scenarios seems to suggest that the adoption of the Canaanean blades, reflecting a new socioeconomic system, was facilitated by the emergence of an incipient market economy which modified the relationship between producers and users of quotidian and utilitarian tools. During the Chalcolithic/Early Bronze Age transition, the availability of blades, mass-produced and exchanged by specialized artisans within supra-local reginal networks, broke off the intra-community specialized system of sickle blades. However, the domestic production of composite sickle did not disappear, and the farmers continued to manufacture their own tools in domestic contexts, even as they acquired the flint elements from specialized markets involving trade and exchange.

Another aspect of the Canaanean blade production system is that, although the specialized knappers were a small group of artisans, within which the lever-pressure technique was transmitted though long apprenticeship and practice, the system was not fragile. Even through significant fluctuations over time and across the region, the persistence of the Canaanean blade system from the beginning of the 4th to the end of the 3rd millennium BCE attests to the stability of this specialized inter-community and supra-local reginal system, independent of any specific sociopolitical structure, and addressed to the manufacture of utilitarian tools used in basic subsistence activities.

The second technological change within sickle production systems occurred at the beginning of the Middle Bronze Age, in the early 2nd millennium BCE, when sickles made of Canaanean blade segments were replaced by those composed of large geometric elements. The substitution of one lithic technology with another one was effected by a change in the socioeconomic contexts of production; a "vertical" form of specialization emerged, and the Early Bronze Age "inter-community" specialization disappeared. The main difference is that the artisans were not only flint knappers, as in the previous period, but producers of finished sickles, then used by the farmers who no longer manufactured their own composite sickles.

Historically, the introduction of this new socioeconomic system occurred during a period of important transformations involving the emergence of a new urban system and associated sociopolitical structures, modifications of the material culture and cultural traits (for a synthesis, *e.g.*, Burke 2014). Many of these changes are associated with the arrival of foreign groups with their own technical traditions. For example, the emergence of wheel-coiling vessels having morphological affinities with northern assemblages has been interpreted as the arrival of potters who produced ceramics in a few specialized workshops (Roux 2015b). Although the hypothesis that the new sickle production system resulted from the arrival of foreign artisans cannot be ruled out, the possibility of a local evolution is suggested by several considerations. The hard hammer direct percussion technique was always present in the region (it is similar to that used in the *ad hoc* tool industry), and its use for the production of sickle blades does not necessarily imply the arrival of external flint knappers with new technical traditions. Moreover, the use of plaster as binding material for the manufacture of sickles represents a feature typical of the Southern Levant and absent in other regions, notably in the north, where large geometric elements were fixed with bitumen (Coqueugniot 1991). If the socioeconomic contexts which facilitated the technological change of the sickle blade production system was the emergence of a “vertical” form of specialization, the processes acting on the technical sphere seem to reflect a local phenomenon, perhaps inspired by some foreign influences. Typologically, large geometric elements are attested in a large geographical area of the Eastern Mediterranean (from Greece, to Anatolia, to the Northern Levant, to the Egypt), and they appeared roughly at the same time (early 2nd millennium BCE). The similarity of shapes between sickles found in different regions might indicate some stylistic inspirations; archaeological data, however, are not sufficient to distinguish the modalities and directions of diffusion. Given the simplicity of the knapping technology and the morphological heterogeneity of these flint elements, techno-typological criteria are not the most appropriate for identifying technical traditions which, furthermore, might reflect different production systems (*i.e.*, Hartenberger and Runnels 2001).

Another possibility, which does not invalidate the previous one, is that the local emergence of large geometric sickles might have been influenced by other contemporary socioeconomic systems involving similar contexts of production. In this regard, the decline of domestic craft activities and the expansion of a market economy with specialized workshops producing for the entire population, such as those involved in ceramic or metal production, might have stimulated the emergence of a similar socioeconomic system for the manufacture of flint sickles. Archaeological data are not adequate for reconstructing how the innovation process took place, but two possible scenarios can be suggested. Either the Canaanean blade specialists abandoned the lithic technological over-investment and adopted a simpler knapping technology because the exchanged products were no longer the flint blades but the final composite sickles, or some knappers (operating in domestic contexts) started to produce the flint blades necessary for the manufacture of sickles and augmented their production for exchange. In the first case, the flint knappers might have adapted their production to a new market reflecting the decrease of domestic production systems. In the second individuals, who were users of flint elements and manufactured their own sickles, their production increased and complete tools were traded, developing new markets. Considering the number of secondary workshops discovered in several sites (*e.g.*, Gersht 2006; Rosen 1986, 1997, 2004; Rosen and Vardi 2014), and the technical skills required for their manufacture, it is likely that the craftspeople involved in this specialized system were more numerous than those of the previous period, and they probably produced finished tools for smaller and more localized markets (Manclossi *et al.* 2018).

The persistence of the production of large geometric sickle blades over one thousand years, despite the rise and fall of different economic and political identities (*i.e.*, rural societies, city-states, periods of foreign domination, small kingdoms, *etc.*), indicates that this production system was independent of any specific socio-political formulation (for a synthesis, *e.g.*, Steiner and Killebrew 2014). Sickle artisans were craftspeople operating within a market not attached to any specific political/administrative power system, and they were able to adapt to different social and political structures (Manclossi *et al.* 2018). As in the previous period, the nature of sickles as mass-produced and mass-consumed utilitarian tools used in agriculture could explain why elites made no effort to control their production; the adaptability of this vertical integration to different contexts (*e.g.*, cities, villages, estates, farms) is another important aspect which favored the long persistence of this specialized system.

The *Ad Hoc* Industry

Contrasting with the sickle blades, the continuity of the *ad hoc* industry through several millennia reflects the persistence of a domestic and unspecialized context of production and use. Despite the socioeconomic, sociopolitical, and cultural transformations which occurred from the Chalcolithic to the Iron Age, individuals continued to produce and use the simple chipped stone tools they needed. Even though this system remained stable, from the early 2nd millennium BCE, the quantitative decrease of flint tools indicates a gradual introduction of metal implements within the utilitarian and domestic sphere. In this regard, it is worth noting that this process was initiated at the beginning of the Middle Bronze Age, concomitant with the establishment of a market economy characterized by a clear division of the labor between producers and users of tools. Individuals started to acquire metal tools made by specialists and used them in domestic activities. However, these objects (for which we had only indirect clues such as the bone cut marks [Greenfield 2013]) comprised only one part of the domestic toolkit, and most of the cutting implements continued to be produced and employed within unspecialized contexts. This socioeconomic structure persisted for almost another millennium under its own inertia. Here, it is interesting to note that although the users of *ad hoc* tools and sickles were basically the same individuals, only a few categories of implements were acquired from a market that, during its development, was "selective."

The Stone-Metal Replacement Process

We have considered the socioeconomic contexts which determined the abandonment of lithics in parallel with the adoption of metallurgy. The development of different production systems involving the use of metals from the late 5th to the beginning of 1st millennium BCE is not the subject of our analysis. However, by observing the effects that these systems had on the lithic industries, it is possible to make some observations. The development of metallurgy, with the discovery of metals and the invention of metal working technologies, had its own dynamics and rhythms which were independent of the lithics. The overlap between chipped stone tools and metals occurred only in a few cases: (1) with the copper axes which replaced the stone axes at the beginning of the 4th millennium BCE, (2) with the bronze blades or knives which progressively replaced some components of the flint *ad hoc* tools during the 2nd millennium BCE, and (3) with the iron implements which finally replaced the flint sickles and all *ad hoc* tools in the 10th–9th centuries BCE. Although the historical circumstances differed, the conditions of their disappearance present some regularities. The disappearance of each lithic production system resulted from the demise of the socioeconomic context of their production, occurring in conjunction with the expansion of another system of production.

The stone-copper axes replacement occurred in the early 4th millennium BCE, after several centuries during which the two production systems coexisted, seemingly with little functional overlap. During the Chalcolithic/Early Bronze Age transition, significant transformations occurred within the metallurgical system for which many aspects are still unclear and are beyond the scope of this paper. However, with respect to the production of (pure) copper axes, archaeological evidence indicates that these tools not only continued to be manufactured by using the same technology as in the previous period, but they replaced the flint equivalents. This change was facilitated by the development of a proto-market economy supported by the growth of specific inter-regional trade-networks involving both the acquisition of copper from the desert, and the trade of objects within the settled zone (*e.g.*, Genz 2000; Milevski 2009; Rosen 1993, 1997). The local production of flint axes was replaced by a specialized system characterized by artisans that produced metal tools for exchange. This process was accompanied by a change in the function of metal axes which penetrated into the utilitarian sphere. At the beginning of the 4th millennium BCE, the production of copper axes, manufactured by specialists and exchanged within larger trade-networks, ended the more local production of flint axes, reflecting the expansion of one socio-economic group to the detriment of another one. This new production system, although involving different technologies and different "markets," had some similarities with the Canaanean blade specialized system that, in the same period, replaced the intra-community production of sickle blades. In the case of copper axes, the hypothesis of itinerant craftspeople or even larger groups of nomads or semi-nomads involved in their production has also been suggested (Genz 2000; see also Rosen 1993).

During the Early Bronze Age (4th–3rd millennia BCE), except for the axes, sometime found in very high frequencies (such as in the case of Arad where copper axes have been discovered in virtually every excavated house [Ilan and Sebbane 1989]), no other production systems were involved in the stone-metal replacement process. Despite the increase availability of metal, especially during the EBA II–III when people from the settled zone directly participated in the extraction of copper (probably sponsored by city-states or elites [Milevski 2009]), lithic industries continued their own development (see above). Metal was used for other categories of objects little overlapping with lithics, such as the weapons (Gernez 2007; Philip 1989).

In the 2nd millennium BCE, the organization of metal production systems changed involving long-distances trade-networks of copper and tin; copper was primarily imported from Cyprus (Philip *et al.* 2003), while tin came from Anatolia (Muhly 1985). Historical sources inform us about the role of political and administrative institutions in monopolizing metal production and use (*e.g.*, Michailidou 2001; Muhly 1982b; Sherratt and Sherratt 1991, 2001; Zaccagnini 1987). Despite this control, however, the use of metals for utilitarian and common tools is well attested not only by the axes, but also by the bronze blades/knives which progressively replaced the domestic use of *ad hoc* tools (see above). This means that, despite different metal production systems affected by sociopolitical fluctuations during the Middle and Late Bronze Age, a market oriented to the production of common and utilitarian tools expanded, progressively assimilated into the socioeconomic structure of the society. In this regard, several scholars have suggested the existence of "secondary markets," independent of the elite monopoly, that mainly used recycled scraps and damaged objects and operated within different trade-networks (Sherratt 2000). However, this market was limited to specific categories of tools or functions, and the domestic production systems continued for almost another millennium.

Sometime around the end of the 10th–beginning of the 9th century BCE, the systematic production of chipped stone tools disappeared, completely replaced by iron implements. Both the specialized production system of flint sickles and the domestic *ad hoc* tool production ceased. If within the lithic production systems, the manufacture of sickles and *ad hoc* tools represented two distinct sub-systems, as especially reflected by their different production structures, the large-scale adoption of iron implements suggests the emergence of a single specialized system producing different types of cutting tools, then used for different tasks. In terms of socioeconomic structure, this means that the users of cutting tools, both sickles and other types of implements, acquired them from a market which absorbed all other production systems, specialized and not (Manclossi *et al.* 2018). When iron technology appeared and developed, however, the socioeconomic structure necessary for its large-scale adoption (*i.e.*, a clear distinction of roles between producers and users of ordinary and utilitarian tools) has already been present for almost a millennium, even though limited to a few categories of tools/functions. Thus, it was the preexisting socioeconomic structure which facilitated the replacement.

If the substitution of flint with iron sickles was actuated within a similar socioeconomic structure, the disappearance of the domestic production of *ad hoc* tools attests that the division of the labor in craft production became a structural component at all levels of the society. The independent production of ordinary cutting tools disappeared, replaced by a specialized market. However, considering previous technological changes, we can observe that this was a gradual development anticipated by specific tools. Historically, it is interesting to observe that this occurred, first, for implements used in specific contexts/activities (*i.e.*, the axes, the sickles, the blades used for butchering), and later become a diffuse process (*i.e.*, the *ad hoc* tools).

Although in the Southern Levant the systematic manufacture and use of chipped stone tools ceased in the 10th–9th centuries BCE, flint implements never completely disappeared, and simple flakes have been found in many historical sites. However, the evidence in archaeological records is insufficient to support the hypothesis of systematic lithic production system, and these flakes are often intrusion/infiltration from previous periods, reuses and recycling of older tools, or opportunistic and occasional activities. Two exceptions must be cited, although their derivation from Bronze and Iron Age lithic industries is not clear. The first one concerns flint threshing sledge teeth, well known from ethnographic (*e.g.*, Whittaker 2000) and historical sources (*e.g.*, Littauer and Crouwel 1990), whose technological origin in the Southern Levant, however, is still debated (*e.g.*, Anderson *et al.* 2004 *contra* Rosen *et al.* 2014). The second example is the gun flints invented and used during the 17th–19th centuries AD (*e.g.*, Coutier 1952; Kent 1983) and probably derived from strike-a-lights known from Greek and Roman sources (*e.g.*, Sherwood *et al.* 1998), but probably invented in older times (*e.g.*, Pawlik 2004; Runnels 1994).

Conclusions

Technological changes that occurred in the decline and disappearance of chipped stone tools can be analyzed by observing two different levels of regularities. The same phenomenon, thus, requires a different sort of explanation depending on the scale at which it is apprehended.

Following the techno-logic approach, the stone-metal replacement process follows the internal "rules" of the development of objects, techniques, and technologies; the lithics completed a development cycle. The structural analysis of flint knapping technologies and chipped stone tools has underlined that both the production systems and the construction of cutting implements reached a plateau in their logical development, and that the adoption of metallurgy, introducing new chemical-physical principles, triggered a new development cycle.

With respect to the production systems, flint knapping and metallurgy cannot be directly compared because they refer to different developmental lines. However, their use for producing cutting tools permits us to consider the techno-logic relationship between flint and metal implements. Compared to chipped stone tools, the structure of metal objects is characterized by a greater synergy of its components, and this integration favored the development of new technical features. This development was "inscribed" in the lithics themselves, but it was not supported by flint technologies, both within the production systems and the construction of tools. Thus, for example, no knapping technology can produce blades longer beyond a certain length, and multiple composite tools have necessarily only one cutting-edge. With the metals, the development line of cutting tools continues because the new production system is better adapted to support it. Thanks to their plasticity, metals have the potential to assume any shape and many morpho-metric characters, allowing development of new conceptions of objects. Thus, very long blades with two cutting-edges or new hafting systems can be created. With the exploitation of metals, cutting implements continued their development, and the new materials were used for new tools which exploited and developed new gestures, movements, and forms of energy.

Even if the basic functions for which stone tools were produced remained the same, metal objects were not simple replicas of already existing implements but represented novelties that acquired increasing importance in proto- and early and historic societies. Although our analysis is limited to cutting-edge objects, it nevertheless reflects how technology was actively involved in the structuring of society, not only in the socioeconomic and cultural implications that the organization of the production/consumption systems entailed, but also in the new functional roles that these new objects developed. The case of weapons is probably the best example of this phenomenon (*e.g.*, Gernez 2007; Philip 1989). It seems significant that for much of the history of metallurgy, the development of cutting-edge tools was stimulated by weapons which could not have existed prior to metallurgy.

However, lithic industries did not completely disappear and, during the Metal Ages, stone tools continued to be a component of technical, socioeconomic, and cultural systems. They continued to be subject to changes which varied from one production system to another one. The analysis of their socioeconomic contexts has allowed recognition that, despite different historical contingencies, the contexts of production acted as "evolutionary forces," conditioning technological changes. Thus, the different sub-systems of lithics did not changed simultaneously but according to their socioeconomic structure, and technological changes were determined by the substitution of one production system with another one.

The recurrent pattern that we can outline is that much of the technological changes which occurred in chipped stone tool production systems were conditioned by the appearance of a market economy, based on a division of roles between producers and users of tools. The fact that flint cutting-edge tools were used for activities involving the majority of the population (either within domestic contexts or more specialized practices, such as in the case of the sickles used in agriculture) probably contributed to the development of a sequence of increasingly specialized production systems, which progressively differentiated the roles between producers and users. The emergence of specialized systems did not immediately result in a marked division of the labor, and the users of cutting tools continued to participate to the manufacture of their own tools for a long period. Observing the historical sequence of change, it is interesting to note that systems which were already specialized, in a form or another, were the first one to change, while the domestic and unspecialized production system took more time. The adoption of a market economy was "selective," and the division of roles between producers and users of utilitarian tools was a gradual process, occurring by subsequent steps. Similar contexts have been identified also in the disappearance of chipped stone tools in America after the contact with Europeans. These studies have shown that the patterns of adoption of metal and the abandonment of stone were catalyzed by the development of markets and trade-networks (Cobb 2003). Further researches are necessary to confirm these regularities, but it is interesting to observe that the adoption of metal tools was slow and selective, even though the metallurgy arrived in America in the 16th century AD already completely well-developed (Rodríguez-Alegria 2008). Despite different scenarios and historical contingencies, common conditions can be recognized to the socioeconomic contexts of production and use, which have to be assimilated by the structure of the society.

Acknowledgments We would like to thank the former journal editors Cathy Cameron and Jim Skibo, Valentine Roux, Michael O'Brien, and the other anonymous referees whose relevant comments considerably improved an earlier draft of the paper.

Funding Information This work was funded by the Centre de Recherche Français à Jérusalem, the Ben-Gurion University of the Negev, and the Université de Paris Ouest Nanterre- La Défense.

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