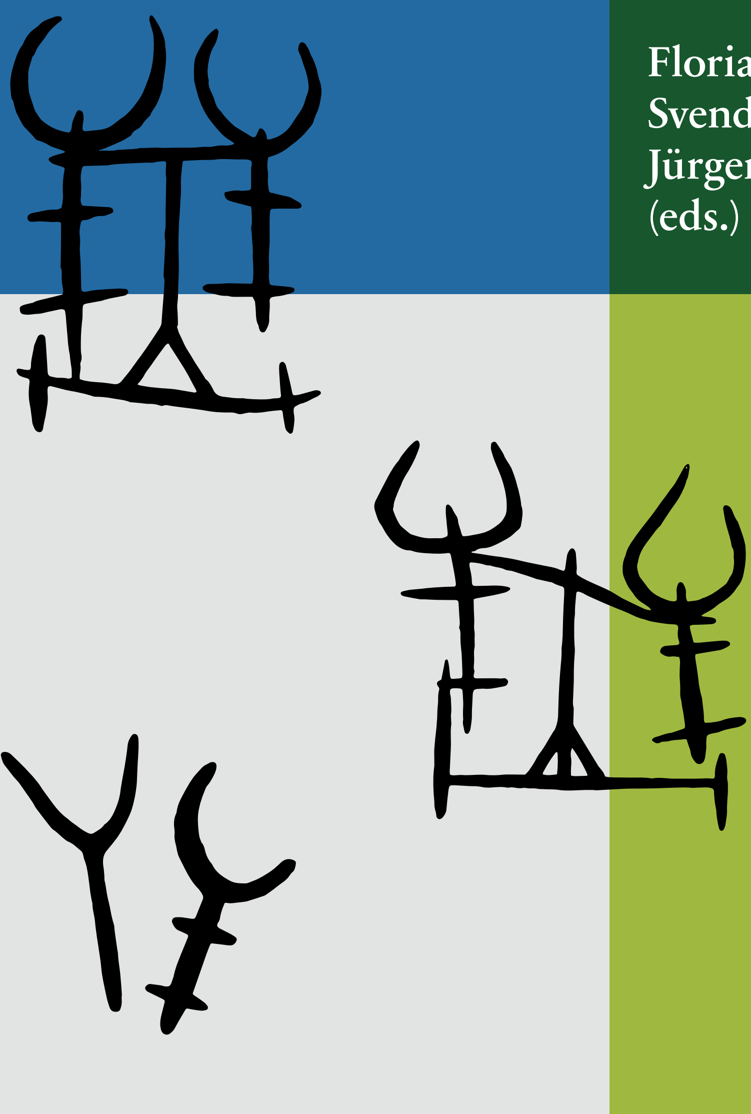
Contextualising Ancient Technology

FROM ARCHAEOLOGICAL CASE STUDIES TOWARDS A SOCIAL THEORY OF ANCIENT INNOVATION PROCESSES

Florian Klimscha
Svend Hansen
Jürgen Renn
(eds.)



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THE DIFFUSION OF INNOVATIONS from the Near East into the 'static' surrounding peripheries has become a well-known archaeological paradigm, often summed up as Ex Oriente Lux. While this conflicts with modern, scientifically controlled chronologies, it is difficult to explain as mere local developments and pure chance the appearance of large-scale communication networks, the transformation of power concentrations in the first states, or the diffusion of the wheel, alloyed metals, and writing. The papers in this volume follow two approaches to convene on new insights into the prehistoric and ancient innovation process. Theoretical perspectives attempt to challenge and modify traditional models of innovation diffusion that lack the chronological depth of archaeological sources, while case studies from the Copper, Bronze and Iron Ages of Europe, southwest Asia, and North Africa analyze the specific archaeological and sociopolitical contexts, the technological traditions of innovations, and the specifications of their emergence, spread, and improvements.

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Florian Klimscha, Svend Hansen, Jürgen Renn

Preface: Contextualising Ancient Innovations

Studying ancient innovations was for a long time an academic wallflower. After the work of V. Gordon Childe[1], the Ex Oriente Lux-paradigm seemed to have been cemented, and even when Colin Renfrew severely challenged Childe in a number of articles and books in the 1960s and 1970s the consequences were limited.[2] Even now archaeological innovation-research is often simply an application of a suitable theory, i.e. one which gives the desired results, on archaeological material or which explains how the archaeological record should be with minor regards to the implications of the archaeological record.

This book aims at moving towards a concept of ancient innovations, but also a theory of how these work beyond modern Schumpeterian notions.[3] It is the result of the international conference "Contextualising Prehistoric Innovations" that was hosted in the Max Planck Institute for the History of Science in Berlin, November 24th–26th 2014, and kindly financed by the Excellence Cluster TOPOI. The conference was part of the research program of the Digital Atlas of Innovations. We invited speakers to collaborate with us on a topic we felt was largely ignored by the scientific community: What are ancient innovations, how did they affect societies and how are they different from modern innovations?

The speakers came from a wide array of disciplines and contributed papers dealing with Eurasia, the Americas and Egypt. The topics included theoretical and empirical approaches and both detailed studies of a smaller region as well as so-called great narratives. Apart from the authors the following people also gave papers, but could not contribute to this volume: Steven Shennan (London), Reinhard Bernbeck and Susan Pollock (both Berlin), Miriam Haidle (Frankfurt), Tim Kerig (Kiel), Valentine Roux (Paris), Barbara Mills (Tucson), Randall Law II (Wisconsin-Madison), Cheryl Makarewicz (Kiel) and Peter Turchin (Conneticut).

How and why are innovations transferred between groups, cultures, time and regions? This is the question we also asked the authors of this book. The papers can be read in several ways to answer this question. The first way would be to put the chronological sequence as a central theme and thus gain an understanding how diverse innovations shaped human life during the various periods of our past. Chronologically speaking, the papers in this book start with the development of Palaeolithic inventions into innovations (Christian Jeunesse). Especially the question of how innovations changed the seemingly egalitarian social systems with little or no craft specialisation is the topic of several papers dealing with the Neolithic (Florian Klimscha and Jürgen Renn, Cathrine Frieman). Martin Furholt and Ianir Milevski analyse how bundles of innovations lead to changes in the North European Plain on the one hand and in the southern Levant, where they lead to the Early Bronze Age urbanisation, on the other. Finally, several authors chose the Metal Ages and the specific problems of innovations in state societies for their contribution (Barbara Helwing, Heidi Köpp, Ann Brysbaert, Katherine Gruel et al.).

The second leitmotif is the classical diffusion-graph as it has been popularized by Everett Rogers.[4] According to Rogers, innovation-diffusion is mainly a communicational process in which "the new" needs to pass several stages in which adopters decide whether they accept or reject it. In the course of these decisions, the

1 Childe 1936; Childe 1982 [1942]; Childe 1950; Childe 1951.
2 Renfrew 1969.
3 Schumpeter 1997 [1939]; Schumpeter 2008 [1939].
4 Rogers 2003.

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success of an innovation can be measured by the number of people adopting it. The papers written by Gerd Graßhoff, David Warburton and Svend Hansen offer theoretical overviews on how innovation research can be approached. While Graßhoff starts from a fairly modern example and offers a modified version of Rogers' scheme as a template for ancient innovation, Warburton takes a different position and argues that ancient innovation, and with this he refers to all innovations before the Industrial Revolution, are incompatible with modern models and need to be understood from ancient sources only. Svend Hansen points out that the major flaws in previous research on ancient innovations are a wrong chronology, a limited area of research and a simplistic understanding of technology. Hansen proposes to test whether modern innovation models also work when applied to ancient times.

Central to the discussion of innovations is the moment of the invention and the reasons why people invent objects and how this can be included into the shared social habits. This is tackled by Jochen Büttner's reflections on the invention of weighing. However, it is similar enigmatic how ancient people managed to develop an invention into an innovation without advertisement and modern departments for research & development. Christian Jeunesse calls this process the domestication and points out the necessary socioideological changes before the innovation process can start, Gary Feinman emphasises that apart from changing ideologies also the agency of individuals or social elites might hinder or push innovations. The next logical step in innovation models is the adoption of the new and is dealt with by Ann Brysbaert for the palatial craft-specialist in the Aegean Bronze Age and by Heidi Köpp for the wheel in Egypt.

After a successful adoption, the diffusion of an innovation starts. Jürgen Renn and Florian Klimscha as well as Catherine Frieman offer perspectives on the diffusion of innovations and tackle the question why there were borders which ancient innovations often did not cross for centuries or millennia. Barbara Helwing scrutinises an often overlooked detail in diffusion studies, namely the changing of the meaning of an innovation; she illustrates with the example of metal headbands how this happens just in the moment, when traditional models would identify the success, i.e. the large scale adoption of the innovation. Modern treatises on innovation often stress how dramatically new technology changes society and since the days of Childe this has been a valid argument for archaeological narratives, too. Ianir Milevski, Martin Furholt as well as Katherine Gruel, Olivier Büchsenschütz and Olivier Nillesse offer three case studies which strikingly show the variety of human-technology interaction. Future research might examine whether the models proposed here can be applied to antiquity in general or whether the models need to be modified according to the specific ancient context, but as a summary of the results Florian Klimscha proposes first steps towards a social theory of ancient innovations in the concluding chapter.

We hope that the papers in this volume are a stimulating and original experience and hope you will enjoy reading them!

Florian Klimscha, Svend Hansen & Jürgen Renn
Berlin, September 2017

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Gerd Graßhoff

Technological Innovations

Summary

Technological innovations occur over long periods of time in a close interaction of scientific discoveries, technological advances and economic demands as a collaborative result of many actors with different interests. Historically, the periods are short over a few years, but too long for individuals to produce technological innovations alone. In several phases of development, the implementation of an innovation is often disruptive.

Keywords: innovation; technology; scientific discovery; history of science; MASER and LASER

Technische Innovationen erfolgen über längere Zeiträume in einer engen Wechselwirkung von wissenschaftlichen Entdeckungen, technologischen Fortschritten sowie ökonomischen Anforderungen als kollaboratives Ergebnis vieler Akteure mit unterschiedlichen Interessen. Die Zeiträume sind historisch gesehen über einige Jahre Dauer kurz, doch zu lange, als dass einzelne Personen technologische Innovationen allein hervorbringen. In mehreren Entwicklungsphasen erfolgt die Durchsetzung einer Innovation häufig disruptiv.

Keywords: Innovation; Technologie; wissenschaftliche Entdeckungsprozesse; Wissenschaftsgeschichte; MASER and LASER

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1 Introduction

The study of innovation is currently one of the most interesting areas of research. It requires the most diverse fields to explain technological change in context of economic, scientific and social change. Thus, the production of knowledge – whether theoretical or practical knowledge – associated with the preparation and production of technical objects depends on an understanding of the global diffusion of knowledge and products. Hardly any other topic inextricably links knowledge, its application and product production as does the study of innovation processes.

Technological innovation has been a topic of study of many academic disciplines for a century now, and has consequently generated a vast amount of literature. The aim of this paper is not, however, to review the subject. Rather, by utilizing recent research in the philosophy and history of science, my intention is to provide deeper insights into the making of scientific discoveries in the field of technological development.

Precisely because of the popularity of the concept of innovation, it is not surprising that the understanding of its importance varies in a painfully large way even with the academic disciplines. Not only the innovation objects are considered to be of diverse kinds: in addition to the usually mentioned technological innovation this conference deals with social innovation as well as innovation of institutions, economic activities and much more. Given this conceptual diversity, it is pointless to demand a unification of terms by a unique definition. That is also not necessary, as long as one knows what precisely one is talking about. Much more important is how one theoretically treats the respective processes of innovation.

This aspect is currently the biggest challenge of any theory of innovation. Explaining the process of innovation by any theory requires to identify causally relevant factors, in addition to the clarification of the definition of innovation that can be shown to influence the process in a relevant way. Models of innovation always imply a selection process of the proposed determinants. Thus, logistic distributions are often cited as S-curve in relation to the diffusion theory of Rogers.[1] Together with the often-cited distinctions by Rogers for innovation phases it is often overlooked, however, that Rogers examined primarily communication processes and not market-relevant technological development processes. For many of the examined contexts in ancient innovation, it cannot be built solely on the evidence related to communication processes. Here, the dissemination of objects and the required knowledge for their production are in the foreground. Models to explain this process of change are entirely different from diffusion processes according to Rogers.

Conte gives a detailed overview on the development of economic models of technology change.[2] He decided not to subsume them under the term "models of innovation", as this concept is avoided by some authors who criticize it of containing too many presuppositions. In contrast, the concept of "technology change" appears neutral, implying no information on the market success of a technological innovation. The criticism of the term "innovation" focusses exactly on the fact that the term "innovative products" implies that these products are also successfully sold on the market. Indeed, for an adequate theory of innovation processes it is not important whether the categorization of technological objects implies certain properties of these objects on the market. Let us suppose that the description of each technological object as an innovation object implies its significant market success. Edgerton criticized that, taking that assumption for granted, the term technological development would be a selective and exclusive description of successful technological developments.[3] It would, in any case, neglect the development of – at least temporarily occurring – technological alternatives, which did not receive the support their inventors expected due to the market monopolization of specific companies or political or other circumstances.

Andrea Conte systematically summarized the seemingly unlimited amount of major publications on economic models of technological innovation and put the vast amount of information in chronological order. The diagram reflects the actual theoretical approaches presented in the current literature and their chronological classification as well as the conceptual heritages they draw on. Of course, such a diagram is simplistic: the theoretical approaches are neither self-contained nor comprehensive. It can also not be maintained that older the-

1 Rogers 2003.
2 Conte 2006.
3 Edgerton 1999.

ories are no longer valid. The theoretical approaches should not be treated as entities, which are to be accepted in their entirety or disapproved or abandoned. The table of contents also gives a picture of the theoretical development which considers the more recent approaches as more progressive and superior to the traditional theories regarding the development of scientific, especially physical theories and their reflection of reality.

Conte's table of content suggests a historical ordering of innovation theories, which each emphasizes few main concepts as key explanatory factors in the account of technological change:

1. The Foundation of Economics of Innovation (–1960)
   a. Technological Change among Classical Economists (–1910)
   b. An Analytical Setting for Technological Change (1910–11942)
   c. Technological Change and Growth. A Keynesian Approach (1935–1950)
   d. Technological Change and Growth. A Neo-Classical Approach (1950–1960)
2. Determinants and Diffusion of Technological Change (1960–1970)
   a. Mono Casual Explanations of Technological Change
   b. Technological Change and Capital: Vintage Models
   c. Technological Change and Labor: Learning Processes
   d. Technological Change and Diffusion: Epidemic and Probit Models
3. Alternative Views on Technological Change (1970–1980)
   a. The Foundation of an Evolutionary Theory of Innovation
   b. A two-way Explanation of Technological Change
4. Endogenising Technological Change (1980–1990)
   a. Path Dependence
   b. Technological Change and Diffusion: Some Extensions
   c. Appropriability and Market Structure
   d. New Growth Theory in the 1980s
5. Recent Approaches to Technological Change (1990–)
   a. New Growth Theory in the 1990s
   b. The Evolutionary Approach to Technological Change and Growth in Recent Years

The history of technological innovation should conduct such simplifying perspectives (Fig. 1).[4]

Characteristically, all innovation processes are long-time processes. For the understanding of these processes, the crucial insight is that innovation does not instantly generate new innovative items which will be successful in the future and find their value at the market. Innovations occur neither instantaneously nor in a single step: neither aircrafts, CD players, or digital cameras have been designed in one instant. No inventor has been able to develop innovative, marketable product in one design step. Edison's light bulb, too, was not created in one single step. With the permanent interaction of novelties in scientific knowledge, technological advance and market usability innovation theory as the endeavor to explain the creation of successful market objects should not confine itself to economic explanatory models exclusively. This would neglect dimensions of scientific and technological research with their own dynamic.

Yet, innovation processes are determined by the selection of market success. Innovation in which objects are developed on the basis of scientific knowledge, in combination with technological application, crucially depends on its market usability. During this process, innovation objects change their composition as well as their final use. Many innovative markets create their needs first. The process of innovation is causally determined: The determining factors cause innovation steps,

4 Conte 2006, 4.

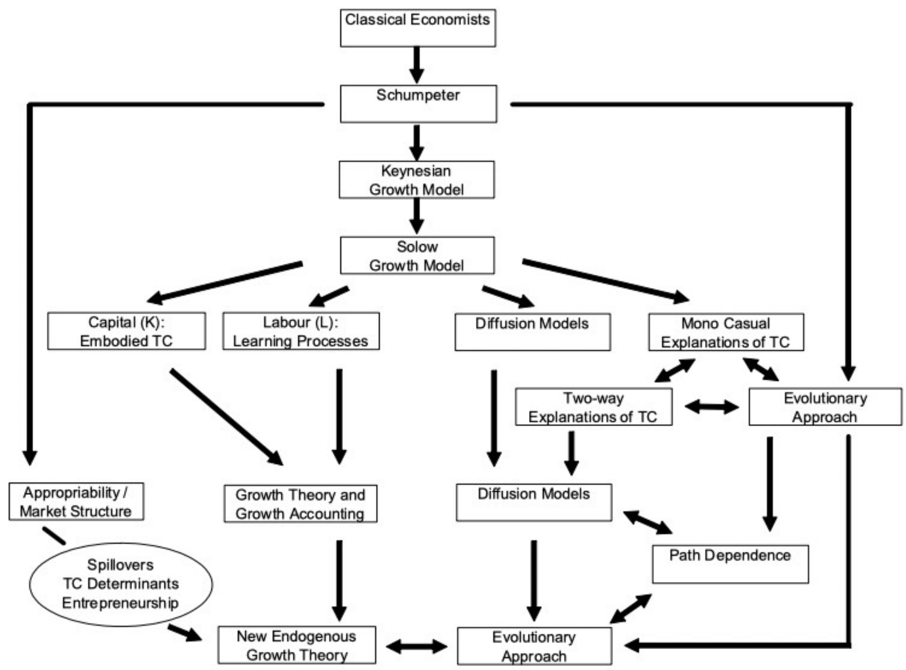

Fig. 1 A descriptive representation of the evolution of the literature on TC over time.

whose effect is the development of a new version of an innovative object.

The innovation process is enabled by supporting factors and impeded by hindering factors, without these factors being necessary for the innovation processes. This is not to claim that these factors are necessary or sufficient for the innovation process, even if they causally relevant for this process. Factors alone are not sufficient for the occurrence of an effect. Factors trigger innovation together with other cofactors; they are not necessary, because there are always alternative ways that could cause the innovations. A causal explanation is characterized by the fact that it will never completely gather all factors relevant for a process to take place. One has only the chance to catch a highly selective fraction of the causal bundle that governs the process. This is more than one might hope: a causally relevant factor might be required so that an innovation takes place in that specific context; or its absence prevents the innovation to take place.

The conceptual framework for describing and analyzing the proliferation of scientific knowledge has been applied to the innovation processes in technology, at least for a wide range of cases, during a long historical time frame: it can be applied to the earliest techniques of ancient civilizations as well as to the latest high-tech developments. Different case studies complement one another: rarely do two of them treat the same case situations or thematize the same phases of the innovation process of the same promoting or inhibiting factors. The theoretical framework developed here should allow us to create a comprehensive picture out of the various modern cases that interconnects with the conceptual relationships of innovation processes and that can also be applied to the earliest technological inventions. Historical studies will show whether generalizations are feasible and fruitful.

2 Three phase innovation model

This proposal should be treated as an explanatory model: it provides a partial view of the determining factors, the relevance of which can be demonstrated in characteristic cases. Yet, as with all causal factors, these cases, although relevant, are neither sufficient nor necessary for a given developmental process.

Since there is very little documentary evidence of the innovations (often only corroborated by a few surviving artifacts) made in antiquity, their significance in demonstrating the guiding factors of innovation processes is fairly limited. Even historical studies of twentieth-century innovations are evidentially scarce. So much effort is needed to acquire documents from critical periods of construction that only a small number of well-documented case studies have been conducted. From this small historical base, we hope to create a broader picture that will lead to more productive research. Thus, the proposed model of innovation will highlight the core features of the case studies, which, in their concrete form, can differ from case to case.

The innovation model differentiates between three phases of technological innovation, the properties of which can differ largely. Owing to other assessment criteria, these distinctions can also vary according to the historical context. Nonetheless, all three phases determine the pathway of a historical innovation. The wide thematic range of academic disciplines that have been involved in trying to explain "innovation" makes it clear from the outset that the innovation process is astonishingly lengthy and complex. Only after much deliberation, did a joint discussion group, preparing for the 2005 Einstein Year in Bern centenary on twentieth-century innovation processes, come to an agreement on a basic definition of the term: that innovation implies a largely successful process, which in most cases has led from a technological and scientific insight to the marketing of a developed product. The group's results were published in *Innovationskultur*.[5]

The deeper one delves into the past to find moments of invention, the more elusive they become. Innovation is a long-term process. Even the technological object in question can change during the process, and yet the literature is full of innovators and their moments of insight. Even more confusing is a survey of the actual usage of "innovation". However, this innovation model does not attempt to capture common usages of the term but is committed to proposing an explanatory model, taking into account that the innovation process requires various stages of development until it succeeds in the context of competing innovative products. This does not imply that less successful technologies or technological failures cannot be explained. Since innovation is a process, it can begin, the intention being that it succeed, and yet fail. Biological evolution might serve as a good metaphor: for evolution to create a biological species, it needs to succeed in some sense. Failures remain a variation of an existing and, therefore, successful species. There is no such thing as a failed species as there is no such thing as a failed innovation. Even the concept of knowledge implies truth, despite the historical fact that we are often deluded about our competences and that what is believed to be knowledge is wrong. There is no such thing as false knowledge.

Other uses of the adjective "innovative" might refer to a small component of an innovation, where some creative changes are performed, preceded by a period of preparation and sometimes deadlock, followed by periods of consolidation. Historical inquiry has shown that it is impossible to successfully distinguish between the actual invention of an object and a newly introduced preparatory part of an invention. Every single change contributes to the development of a technological object during the innovation process. Even during long periods of technological change, it might be the changes in production and competitive contexts that prove to be the critical moments in an innovation process. And although one often describes individuals as being innovative, typically they contribute only briefly to the invention of a product before leaving the process altogether. An invention, though, can only be called "innovative" (like a species) if a technological object has been produced for the market. Certainly, by then it is no longer possible to single out the individual contributions of a few people as being particularly relevant to the general success of the innovation. Thus, it makes more sense to assemble all the contributions of an innovation process. Looking at this globally, it becomes easier to realize that no single individual can fully grasp all the aspects of knowledge created during the innovation process, not even the final outcome of the developed object. Clearly, innovations are non- local technological phenomena.

3 Illusions about innovation

The jungle of literature that exists on the theme of innovation and the more popular descriptions of its history suggest that there is a common misunderstanding of the innovation process that can seriously damage academic work. Philosophy of science has for long advocated that

5 Graßhoff and Schwinges 2008.

a distinction be made between the discovery and the justification of an innovation, the former being a creative period of scientific insights and spontaneous reasoning, the latter being reserved for the validation and methodical testing of the new ideas. This distinction, however, cannot be corroborated through historical research. The situation concerning research on innovation is similar. There are four common falsehoods about the process of innovation that can severely harm contemporary theoretical accounts. Although all four views are false, they are all widely held:

- Innovation is an event that occurs at a specific point in time.

- Innovation is an event created by one person.

- Innovation is an event during which one new thing the object of innovation is instantly created.

- Innovation is an event that *occurs* at one place in history.

I shall now turn to a case of an important twentieth-century innovation that exemplifies the four fictional aspects of innovation and that serves as an outline for typical stories on the innovation of new technologies throughout history: the invention of the laser.

Few twentieth-century innovations have had as immense an impact on our daily lives as the laser, even though its introduction was much less obtrusive and obvious than, for example, innovations in the field of big technology, such as the airplane. Although lasers are not as present as cameras and the automobile in our everyday lives, they are incorporated into virtually all other complex technologies. In terms of economic importance, there is hardly an electronic object today that does not contain any laser components. Yet, when was it invented, by whom, and on which occasion?

Most accounts of the history of laser technology start in the year 1916, although that date could arguably be pushed back to 1905, when Albert Einstein published his first fundamental article on the quantum nature of light.[6] In 1914 Einstein was appointed director of the newly founded Institute of Physics in Berlin, and his supporters had high hopes that he would initiate innovations and not just carry out theoretical groundwork, while continuing his fundamental work on the general theory of relativity. However, Einstein's interest in the quantum nature of light continued to fascinate him. At first, however, his contemporaries had difficulty in understanding and accepting his fundamental theory of light quanta; the conviction that light should be regarded after many successful experimental studies as an electromagnetic wave in the classical sense was just too firmly established. When Einstein was finally awarded the 1921 Nobel Prize in Physics (after having been proposed unsuccessfully many times before by his colleagues), the Swedish Academy of Science carefully formulated its laudation on the scientist so as to avoid creating the impression that Einstein had been awarded the Prize for his contributions to relativity. At the time, Einstein's fame was based on his insights in the special and general theories of relativity. Arthur Eddington's apparent confirmation of the deflection of light in the vicinity of large masses by measuring the positions of stars during an eclipse in 1919 had made Einstein famous around the world; he had even made the front page of the leading British newspaper, *The Times*.

Einstein typically continued to publish lesser-known articles which – just like matches lighting a fire – nevertheless attracted the interest and curiosity of the few specialists working in the same field. In 1916, Einstein was working on experimental set-ups in which he could connect microphysical states in which light interacts with subsequent processes in such a way that he could finally observe them as macroscopic effects. This technique is characteristic of Einstein's earliest research work. Bohr's model of the atom (1915), which explains the quantified nature of light as a causal consequence of electrons jumping suddenly from excited states into lower energy states, supported Einstein's theory on the nature of light. Usually, it is possible to excite an atom, for instance by making it absorb energy through collisions with other atoms, so that it incorporates these atoms through the 'jumping' of an electron to a higher energy state around the atomic nucleus. An atom in such a state is referred to as an 'excited atom'. After

6 The following history follows Hecht 2010a.

a short time, the atom jumps back to the more stable, lower energy level, sending out light with a sharply defined frequency and with exactly the same energy difference of the two states. Einstein described a process by which an atom can be stimulated to an excited state by absorbing a photon first, before releasing it again.

In later years, Einstein's ideas were circulated by various scholars to research centers around the world not unlike the Olympic flame – until they finally developed into the phenomenon that we want to examine here. At first, scientists could barely manage to prove Einstein's mechanism of the emission of light by excited atoms. In 1928, Ladenburg reported that he had indirectly proved such a process for the first time, while far from the typical 1930s research centers of physics, the Russian physician Valentin A. Fabrikant presented a rough outline on how emissions of light, which are at first emitted randomly, can be reinforced and aligned in one direction. Initially, however, no one carried out any experiments to prove Fabrikant's hypothesis. Only Lamb and Rutherford in the United Kingdom formulated a technique that reinforced the emission process by so-called resonators.

Purcell and Pound eventually used this effect to experimentally prove the stimulated emission of radio waves. This research was heavily supported by military research on all types of radio and radar applications. In the next few years, research results yielded continuously shorter intervals of electromagnetic waves with basically two main objectives: first, to reduce substantially the long-wave radio waves and, second, to produce electromagnetic waves with a wavelength of light. The aim was to generate emission using as many different materials as possible, but the goal of a working apparatus for the very high frequency of light seemed unattainable. In 1954, Townes and Gordon finally succeeded in developing a directed emission of excited ammonia molecules, which was referred to by the acronym MASER (Microwave Amplification by Stimulated Emission of Radiation).[7] Between 1957 and 1959, the competition to realize the directed stimulated emission of light, which seemed to be the next step, was fierce. The research goal was clear to any high-level physicist: to find materials that could be placed into an excited state in order to emit light, while realizing a mechanism to reinforce this process so that the emitted light could be directed to go in a particular direction. The technical challenges of this transition from long to short wavelength light were huge. Townes initially thought that such a development was not feasible. In 1957, he began considering such an idea with his colleagues,[8] in particular with the then 37-year-old doctoral student Gordon Gould. The latter, starting out his academic career at a relatively advanced age, consider himself an inventor rather than an academic, since he had previously dealt with optical devices and had tried designing lucrative products. Townes remained unconvinced that further developments were possible and so returned to carrying out research on MASER.

Gould's conversations with Townes had given him the idea of identifying those experimental set-ups, among the known optical experimental set-ups, that could be successfully used to reinforce the direction of the emitted light. In November 1957, Gould drew an outline of the physical framework conditions of a classical resonator experiment in his notebook. And, as a diligent inventor, he had his authorship of the note confirmed by a notary. Later, the note was the focus of a thirty-year-long legal battle over the patent-worthiness of the invention and, of course, of the abundant royalties related to it. The title line of Gould's paper introduced the word LASER to modern terminology. Accompanied by "some rough calculations" this is clearly not a blueprint for an operational machine.[9] At the time it was not even known which material would be able to invoke light amplification. Gould's work caught the interest of the US military research group ARPA (creators of the internet IP network), which awarded him a generous research grant. Unfortunately, it led to nothing. One cannot even convincingly argue that the construction of the first operational laser would have been significantly delayed had it not been for Gould's contribution.

In the meantime, Townes had started collaborating with his brother-in-law and former colleague, Arthur Schawlow, at Columbia University.[10] Initially, they did not intend to submit their scientific findings in the usual way and instead co-authored an article on the "optical MASER" for *Physical Review*, which was published in December 1958.[11] Townes was awarded the Nobel Prize in Physics for his research that led to the development of

7 Gordon, Zeiger, and Townes 1955.
8 Hecht 2010a, 2.
9 Hecht 2010a, 51.
10 Hecht 2010a, 2.
11 Schawlow and Townes 1958.

MASER and the laser in 1964, even though he did not actually develop a laser light generating device himself. Gould never received an award for his work on the laser. Between 1959 and 1960, all the top laboratories had been working on ways to realize, materially and technologically, the generation of laser light, a process which had hitherto only been described theoretically. But at first no one could produce such a device.

At the other end of the United States, the Hughes Research Laboratories in California had hired the young physicist Theodore "Ted" Maiman.[12] Not endowed with a great theoretical mind, Maiman had been rejected by Stanford several times, and it was only after working for four years in the basement laboratories of Stanford that he obtained his doctorate in 1955, taken under the direction of Willis Lamp. After having spent all his money on a world cruise, he found employment at the Hughes Laboratories, where he was put to work on microwave research. As late as 1959 all the major laboratories were investigating the potential of laser stimulation.[13] Therefore, it is still difficult to ascertain who contributed what during the months that led to the successful creation of a ruby laser. In the end it was Ted Maiman who produced the first device that could emit stimulated red light. There was no unique moment at which laser technique came into being. Neither a specific individual, nor one laboratory can be singled out for having made the most influential contribution to the invention of the laser. It was a global process that eventually generated a new technology.

Although the intricate process of global research is historically known, common summaries of the innovation follow schemes that are more inventions by themselves. The following tabular representation reveals the significant milestones in the invention of the laser[14]:

- 1916: Albert Einstein proposes stimulated emission;
- 1928: Indirect evidence for stimulated emission reported by Rudolf Ladenburg;
- 1940: Light amplification by stimulated emission proposed by Valentin Fabrikant;
- 1951: Stimulated emission at 50 kHz observed by Edward Purcell and Robert Pound, Harvard;
- 1954: Charles Townes and James Gordon produce first microwave maser at 24 GHz at Columbia University;
- Summer 1957: Townes starts investigating optical maser;
- October 1957: Townes talks with Gordon Gould about optical pumping and optical maser;
- November 1957: Gould coins the word "LASER" and proposes Fabry-Pérot resonator in his notebook (Fig. 2);
- December 1958: Townes and Arthur Schawlow publish detailed "optical maser" proposal in
- *Physical Review*;
- 1959: ARPA issues $999,000 contract to TRG to develop a laser, based on Gould's proposal;
- May 16, 1960: Theodore Maiman at Hughes Research Laboratories demonstrates ruby laser;
- Summer 1960: TRG Inc., Bell Labs duplicate ruby laser.

This table not only shows a selection of all the events that are closely related to the innovation of lasers. This selection not only leads to a coarse-grained picture of the historical process. It systematically distorts our picture of the relevant factors determining the process. Standing for a large group of innovation accounts this table brakes down the innovation process of technological developments into three phases:

- A scientist 'discovers' a new effect.

12 Townes 2007, 654.
13 Hecht 2010a, 100–105.
14 Timeline after Hecht 2010a. In the beginning MASER and LASER were capitalized as acronyms. Quickly they became standardized technological terms.

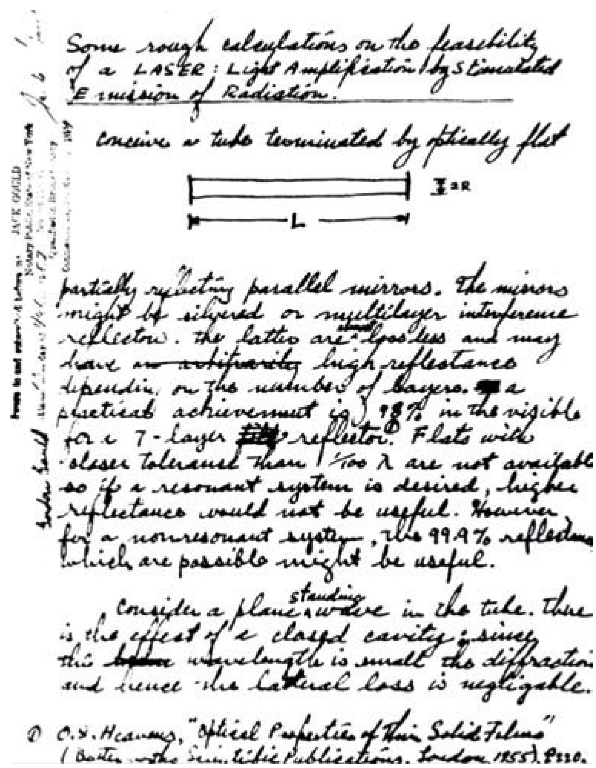
Some rough calculations on the feasibility
of a LASER: Light Amplification by Stimulated
Emission of Radiation.
Conceive a tube terminated by optically flat
partially reflecting parallel mirrors. The mirrors
might be silvered or multilayer interference
reflectors. The latter are lossless and may
have an arbitrarily high reflectance
depending on the number of layers. A
practical achievement is 98% in the visible
for a 7-layer reflector. Flats with
closer tolerance than 1/100 λ are not available
so if a resonant system is desired, higher
reflectance would not be useful. However
for a nonresonant system, the 99.9% reflectors
which are possible might be useful.
Consider a plane standing wave in the tube. There
is the effect of a closed cavity; since
the wavelength is small the diffraction
and hence the lateral loss is negligible.
① O.S. Heavens, "Optical Properties of Thin Solid Films"
(Butterworths Scientific Publications, London 1955) p. 220.

Fig. 2 Extract from Gould's notebook mentioning a Fabry-Pérot resonator.

– A technologist successfully applies and demonstrates it.

– A company finally produces it.

Such a clear-cut succession of phases does not happen in reality. Rather, one finds continuous, interwoven interactions between the scientific discovery, its technological development and its production. Hecht's book, *Beam: The Race to Make the Laser*, vividly demonstrates how many different inventive steps were taken by many different people working in many laboratories around the globe in order to arrive at the final operational product.[15] It is not hard to extend the scope of the narrative to include still relevant contributions to the process of innovation that encompasses half the world's physics community. That "everything is connected to everything else" to enable innovations to take place is far closer to the truth.

3.1 Thesis: Innovation is a long-term, globally distributed synthesis of collaborative contributions

In many cases, the main activities of the actors during the different phases of innovation can be visualized. In Fig. 3, for example, the three curves represent the indicators of activities in laser research, which have been divided into three phases: science, technology and production.

3.1.1 The three-aspect process of innovation

The three phases of activities into which the innovation process can be divided are shown schematically and in a normalized scale in Fig. 3. Publishing, patent applications and a willingness to invest are given as indicators for the activities. A large number of actors are involved in the entire innovation process. After an initial scientific discovery in another field (maser research), the number of scientific activities increases and reaches a maximum point in a short space of time. Technological developments then rapidly reach a maximum point, before decreasing again. Often, market success triggers new technological developments, which, after fifteen to twenty years, reach a second maximum point. During this second burst of activity, technology has, in the meantime, changed in such a significant way that the patent claims of the pioneering developers are no longer valid. In the case of the history of laser technology, the companies first involved in its development dropped out. During this process, the original laser materials were replaced by semiconductor materials.

Significantly, the phases should not be interfered with, in order to shorten the innovation process, for example. If the scientific activities are reduced too quickly, the basic scientific knowledge for developing the optimal technology may well be lacking. If a company enters the development process too late, it might no longer be able to acquire a competitive edge over other competitors. The users of innovations in the marketplace can experience a similar difficulty concerning innovation: it can be difficult to ascertain when best to start using a new product.

15 Hecht 2010a.

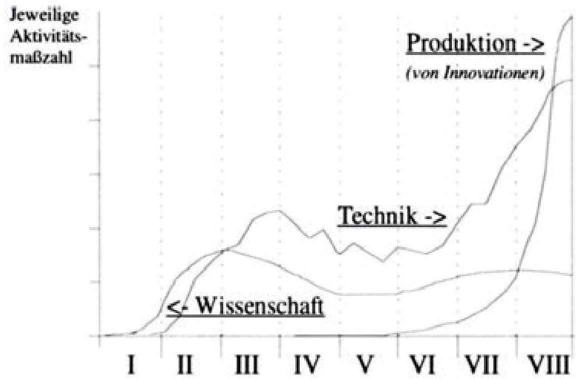

Fig. 3 Development of research and market activities related to laser after Grupp 2013.

In the field of high technology, especially information technology, the price-performance ratio develops consistently according to Moore's law. If product developers delay developing new technologies, it is because they are hoping to become more competitive at a later point in time, when the technology has improved and the costs have decreased. However, by waiting too long, product developers will lose the competitive advantage of the new products, and their products, equipped with outdated technology, will no longer be competitive. By contrast, if manufacturers switch too quickly to newly emerging technologies, the technology might have teething problems. The current fluctuations in the fortunes of the global camera manufacturing companies demonstrate that the transition from analogue to digital camera technology is fraught with difficulties.

3.2 Thesis: If each activity is given the same resources, the different phases of the innovation process cannot be shortened; only by significantly increasing the number of actors involved can the gradient of the stages be increased and thus the duration of the entire process shortened.

Albert Einstein played an important role in the application-oriented phases of an innovation process. If one considers Einstein's greatest scientific success, his general relativity theory of 1905, and, ten years later, its publication, it seems clear that during this period Einstein focused on carrying out basic research work. Undoubtedly, his fundamental discoveries have resulted in enormous consequences for today's technologies. But at first glance it might appear that he worked on his research topics primarily as a basic researcher, without taking into consideration how his work could be adapted, while other researchers developed these applications without focusing on basic research interests. The model of the innovation process as a collaborative process shared by different stakeholders seems to have found its perfect expression in the person of Einstein, who was a non-application-oriented basic researcher. Hubert Goenner has shown how leading scientists and industrialists of the German Empire hired Einstein expressly for the purpose of promoting a new field of physics for technological developments in Berlin.[16] Their expectations were high. Under the authoritative leadership of Max Planck, Walter Nernst and Emil Warburg, the Berlin-based scientists hoped that the new developments in the field of theoretical physics (that is, of elementary atomic processes, especially the quantum theory of light), would yield so many fundamental innovations in the fields of optics, solid state physics and physical chemistry that new technological applications would inevitably follow. The delegation wanted Einstein to head a new institute that would develop close links between industry, non-university institutes and other universities and that would combine its activities to form a thriving research cluster. Einstein was expected to invest a considerable amount of his time in supporting this new field of research.[17]

16 Goenner 2007, 160.

17 Goenner 2005.

Aside from this obligation, Einstein was completely free to conduct his own research. He was to be the sole director of the newly founded Kaiser Wilhelm Institute, and was given an unlimited budget with which to buy instruments and laboratory equipment. Initially, it was left to Einstein to determine the location and the process of equipping the institute. Furthermore, Einstein negotiated a special clause in his contract that freed him from teaching obligations at the University of Berlin, despite the fact that he was a professor.

According to Goenner, Einstein failed to meet the initial hopes of his appointment committee despite the almost paradisiacal conditions of his contract. For, although Einstein did indeed carry out work on the physics of atomic processes, he nevertheless spent most of his time elaborating the general theory of relativity, to the extent that he neglected his institutional work.

The First World War had significantly reduced the pressure to establish the institute. Yet, this pressure increased again in the early years of the Weimar Republic. Still, Einstein showed no interest in developing a scientific institute where its researchers would conduct their work according to his scientific objectives and which focused on applied science. In the early years of its existence, the Kaiser Wilhelm Institute's postal address was, in fact, Einstein's private address in Berlin; and his wife carried out the daily administrative work. When Einstein was finally forced to make use of his considerable budget, he developed a system that Goenner has called the "precursor" of an association of German science, which would later become the German Research Foundation *(Deutsche Forschungsgemeinschaft)*.[18] This system allowed researchers to submit a short outline for a scientific project; the project outline was then assessed by Einstein and his advisors, who decided whether or not it would receive funding over a limited period of time. Rather untypically for that time, the budget was predominantly used to promote short-term projects; medium-term research institutions were not promoted. It is, therefore, hardly surprising that the administration of the University of Berlin believed that, during this nevertheless exciting episode in his scientific career, Einstein had failed to implement the concept of an institute of applied research.

Looked at from another angle, however, the use of these generous resources to maximize scientific gain resulted in research subsidies that are comparable to modern funding instruments and an open competition that promoted independent research projects. Although it had initially appeared that Einstein and his collaborators had failed to encourage applied research, in actual fact they developed a fruitful, collaborative structure, which allowed competing researchers to carry out their research, without demanding that they combine basic research with the development of application-oriented technologies. The development of technological innovations is impossible to control, but highly efficient and innovative contributions tend to be the end results. According to Karl Wolfgang Graff, Einstein was extremely efficient and committed to his research activities, but he showed not the slightest interest in following through the innovation processes generated by his work.[19] He just sold the patent and did not try to develop it to a product.

3.3 Thesis: Even the most innovative, single-minded researcher is not able to actively shape the development of an object of innovation from beginning to end. The innovation process is essentially based on the large-scale division of labour.

Currently discussed innovation models exploit simulation models of social networks whose topology is organized hierarchically, thereby including the individual membership in groups and societies. The fundamental decision for the dissemination of an innovation object in these models is a balance between the usefulness of the object as an aspect of its subjective advantage, and the costs on the other side. An individual purchasing decision or acquisition may then be interpreted as a test of difference between these two opposing aspects. However, there is still not yet gained much, because the key is the theoretical filling of what means usefulness or is seen as a cost for the purchase decision. After all, such models meanwhile are studied in specific case studies, such as the dissemination and implementation of alternative energy sources, drives of automobiles or the technologies for communication and entertainment.

On the basis of my own study on the development of photo cameras based on chemical films I add some observations, arguing that not the proper definition of

18 Goenner 2007, 161.

19 Graff 2008, 202.

innovation is critical. Instead, understanding the nature of changes of the respective phenomena is pivotal.

The technical development of photo cameras was largely carried out over a period of 200 years, with an emphasis in the last 100 years. A total of 26 000 different camera types are documented that were launched on the market.[20] One quickly learns that not every successful camera was innovative or even novel in a narrow sense. Often particularly innovative but expensive cameras did not succeed in the market and are to be regarded as an innovation failure. The innovation process without such failed cameras is incomprehensible. They are part of the selection process and explain the success of others. In most cases it was unpredictable, whether a significant market share was gained or not. If you consider such developments as fully planned, one would misunderstand how economic competition influences technological developments. In the case of the study of history of camera technology some peculiarities can be noted: No model was able to successfully maintain a significant market over a longer period of time. The saturation curve of potential buyers quickly climaxed in a globalized world. Thus, the dominant distribution of roll film cameras after the Second World War reached their maximum market penetration in just 24 months, only to be replaced almost abruptly after six years by the 35mm cameras.

The beginning of the innovation shows a small diffusion of technological objects produced by a large number of different manufacturers hoping to attain market success. This number is reduced after a very short time to the very small group of successful brands, often even to the level of monopolization of a market sector. Technological diversity is thus reduced seemingly counterintuitively after the beginning of the innovation process.

The selection process among market participants is often so strong that even particularly creative technological innovation products are not able to gain their market share. It is a long way from concept studies to a good product. This often means that even the most well-equipped patent owner, although in retrospect he saw the potential technological development correctly, was not in a position to carry out the necessary technological developments for an economically reasonable price. The global crowd is a powerful competitor. Inventors are in most cases not successful innovators.

The evolution of successful technologies is determined by considering usefulness and costs, which does not always lead to the path to the most technologically advanced variations, nor does it enforce particular socially suitable developments. The conditions for the market decision-makers are critical for the selection of this process.

It can be observed that the number of producers is massively reduced in later stages of the innovation process. The omission of superfluous elements or features increasingly reduces the sophistication and technical quality of the produced objects. The designed object gets simpler.

During the innovation process, the utility of the innovation objects changes significantly. In the beginning, cameras were used for still life, studio photos, and landscape motives taken by professional photographers. The expertise of users shifted to the limited options of interested amateurs and their artistic interests. This of course influenced the camera design.

For the understanding of innovation processes and their dynamic factors it had proved extremely fruitful to expect strong changes of the utility of one and the same technological object. In the beginning there are special 'exotic' applications, claiming small market niches for specialists before they bring about the development of usefulness to other market areas. The corresponding variations of the technological properties determine strongly the costs of their production. So it is not only the "lead users", a concept from Eric von Hippel, who as particular experimental buyers improve even immature technological objects.[21] Their feedback promotes the improvement of technologies. The frequency distribution of objects found as archaeological and historical objects suggests that these end products are the results of the mature phase of innovation processes. They were produced in greater numbers.

So it is difficult to find the material evidence for all phases of innovation processes. I do not want to say that modern technological innovation processes are structurally identical with innovations in ancient societies. I just want to encourage a discussion about the underlying explanatory models.

20 The catalog of Günther Kadlubek and Rudolf Hillebrand is a comprehensive source and used for the analysis on which the following claims are based (Kadlubek and Hillebrand 2004).

21 Von Hippel 1995.

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Illustration credits

1 Conte 2006, 4. 2 From Hecht 2010b, 091002-2. 3 After Grupp 2013.

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Why Innovate?

Summary

The paper discusses modern and ancient innovation processes as a background to approaching certain questions traced in the contributions of this volume. The author's interest lies in the diffusion of knowledge and instruments – and their impact on human societies, quite aside from the effect societies have on innovation. The author contends that in order to understand ancient innovations, it is necessary that the historical reality of innovation and common attitudes towards innovation must be taken into consideration.

Keywords: innovation diffusion; modern innovations; ancient innovations; industrial revolution; rapid innovations

Der Beitrag diskutiert moderne und antike Innovationsprozesse, und nähert sich vor diesem Hintergrund verschiedenen Fragen an, die in diesem Band besprochen werden. Der Autor konzentriert sich auf die Verbreitung von Wissen und technischen Instrumenten und analysiert den Einfluss dieser Innovationen auf menschliche Gesellschaften. Er kommt zu dem Schluss, dass es essentiell für das Verständnis antiker Innovationen ist, die historische Realität ebenso wie historische Einstellungen gegenüber Innovationen zu überdenken.

Keywords: Diffusion von Innovationen; moderne Innovationen; antike Innovationen; industrielle Revolution; schnelle Innovationen

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1 Introduction

In this volume Gerd Graßhoff suggested that the history of the camera offered a hint at innovation processes in general. Among his most important points was that in his own research, he had discovered that, early on, few versions of the camera were able to keep up a significant market share for even as long as a decade, and thus one model followed another into oblivion. He has stated this coherently in another paper.[1]

Photography was a classic example of technological development in the later Industrial Revolution because it depended upon optics, engineering and chemistry, ultimately combining everything from lenses and shutters to negative film, special paper and chemical baths. Everything was connected to everything – and all of the participants were under substantial pressure. The livelihood of those who develop such technologies depends upon combining team-work and inspiration with specialist technical knowledge, whether independent entrepreneurs or salaried employees. Registering patents is a means of securing recognition as well as market share. The demands of art, science, forensic work, medicine and journalism (etc.) meant that demand and competition raised pressure and opened opportunities. The diffusion of the idea offered stimulation to competitors seeking to improve their own devices. Such phenomena dominate the way modern firms operate, both in terms of employment and sales strategies.

This is all quite interesting for the understanding of innovation processes. However, I will formulate another concept. Instead of drawing on modern concepts, I would suggest that if we are to understand antiquity we go back to the beginnings. Therefore, in this paper, I will offer an alternative understanding of ancient innovations.

2 Understanding innovation processes in antiquity

2.1 The *camera obscura*

The word 'camera' comes from the *camera obscura* and the reality is that the 19th century AD development of photographic equipment was based on changes made in the *camera obscura* method of projecting images onto surfaces where they could be traced (Fig. 1).

Lefèvre remarks that the device "developed from Aristotle until the eighteenth century".[2] In reality, however, Leonardo da Vinci was familiar with the device, and the version he used was probably the same as that known to Aristotle. In fact, it was only in Kepler's lifetime that the device began to undergo some minor modifications, and it was only in the suite that one can recognize those at the beginning of the 19th century which culminated in photography. Kepler refuted Aristotle[3] and these early changes may have aided him. However, Lefèvre's treatment neglects another aspect of the *camera obscura*. Jin Qiuping notes:

> [T]he outstanding Chinese scientist Mo Zi or his students performed the world's first experiment on pinhole inverse image formation nearly 2,500 years ago. Though they talked about "shadow" and not "image", the underlying principle is the same.
>
> The experiment was to perforate the wall of a small dark room [= *camera obscura*, DAW] facing the sun. An inverse shadow was formed on the opposite wall of a person standing outside facing the hole. The Mohists explained this strange phenomenon as light darting through the pinhole like an arrow taking a straight linear course. The head of the person blocks the light from above so that the shadow is formed below; his foot blocks the light from below so that this shadow is formed above, producing an inverse shadow. This was the first scientific explanation of the linear projection of light.[4]

1 Exzellenzcluster 264 Topoi, 11.
2 Lefèvre 2007, 32.
3 In Lefèvre 2007, 95.
4 In Mao 1983, 166–167.

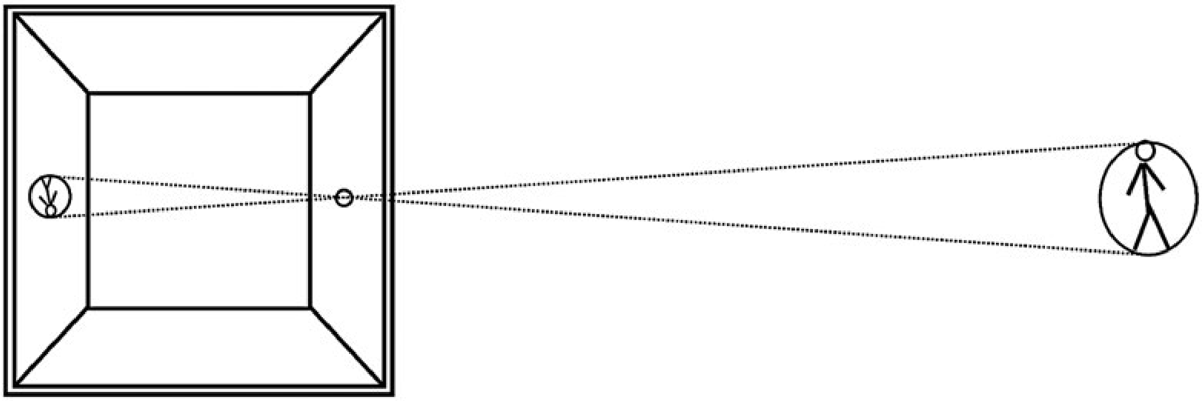

Fig. 1 Schematic view of the principles of the simplest version of a camera obscura. 6th century BC to Renaissance; China to Greece in antiquity. An image projected – by sunlight creating a shadow – from outside through a pinhole in the wall of a dark chamber appears, reversed and inversed, on the wall of the chamber opposite the pinhole.

This initial 'primitive' device was known to the ancient Greeks and the Chinese, with Mozi and Euclid both remarking that light travelled in straight lines based on observations which can be related to the same instrument. If Mozi was not really the first, whoever was, was still ahead of Euclid, whose *floruit* was almost two centuries later than the 5th century BC Mozi (who thus still lay before 4th century Aristotle as well).

2.2 Science, technology and theory

Needham et al. also note that when studying the Mohist text, one can see that the Chinese "conception is quite different to the Greek theory of the emission of rays from the eye in vision" and that the Chinese students "knew that [the person depicted] was giving off reflected light".[5] By the "Greek theory", Needham means Plato's version which seems to have been adopted by Euclid, although Aristotle may have had a different understanding. It follows that the Chinese may well not only have invented the device first, but also have been ahead of Plato in understanding light. Even though the device must have been rapidly diffused to Greece, Euclid apparently did not grasp whatever verbal information may have come with it, and developed his own thoughts in the Greek tradition. The device remained the same (i.e., no innovation), but the interpretations of the effects differed. This is quite interesting, as the subsequent story of the instrument is truly remarkable:

> From antiquity up to the Renaissance, the camera obscura never fell into total oblivion. Now and then, it was mentioned and occasionally used, mostly for astronomy. But it did not attract very much attention. At the end of the 16th century, however, its fortunes changed dramatically. The pinhole camera obscura was equipped with lenses and mirrors and transformed into the optical camera obscura of the early modern period.[6]

Significantly, this happened in the West and not in China – but not in antiquity. It was the later conceptual achievements of the Middle Ages, Renaissance and Enlightenment which were the preliminary steps leading to the technological breakthroughs of the 19th century, when photography came into its own. Then – once the modern development was on course – one version followed another so as to reach the stage of the development of cameras in a burst of technological innovation typical of the 19th century.

Thus the facts are that the ancients developed a simple method (the *camera obscura*) and diffused that all the way across Eurasia, and the technology stayed on the same level for the better part of two millennia, while philosophers reflected on how to understand the behaviour of light. Only in the early modern and modern eras did the innovative process take off, drawing ini-

5 Needham, Wang, and Robinson 1962, [= 4,1], 82.

6 Lefèvre 2007, 6.

tially on lenses and then on an understanding of light and chemicals.

Science played a very specific role in that the early philosophers reflected on the observable effect of the *camera obscura* itself and used their observations to draw scientific conclusions. The device itself did not seem to change very much until the 16th century, and even when translucent glass and lenses were introduced it remained the preserve of artists and philosophers. From the second half of the 19th century, 'market share' became a motivating factor in the manufacture of cameras.

It is typical of ancient innovations and knowledge, that although known to Aristotle, he did not understand how the *camera obscura* worked (e.g., why a circular image came through a square opening), nor did the Hellenistic Greeks understand the nature of vision in terms of reflected light. Thus the philosophers did not understand the effects and the mechanics were not interested in improving the instruments.

It is not without interest that very little technical improvement seems to have been made until the development of lenses. At this point, it would appear that the lenses had an impact on the capacity of various people (Kepler and Newton among them) to begin to think about optics and light. Yet more than a century would pass before further refinements were made. This was the result of the conceptual accomplishments of other thinkers in antiquity, the Middle Ages, Renaissance and Enlightenment. Greek, Arab, and Chinese scholars reflected on the procedure and eventually grasped how it worked, so that the Europeans took up the torch in the Industrial Revolution.

Lefèvre makes an important point in this respect:

> The influence of the optical camera obscura did not stop with physiology. It also induced fundamental changes to both geometrical and physical optics. The theories of optics developed in Antiquity and the Middle Ages juxtaposed rather than integrated these two branches. Geometrical optics dealt with how light moves; physical optics addressed the nature of light itself and the interaction between light and matter. With the camera obscura acting as a model for the eye, these two branches were forced together. Until this point, it was possible to study geometrical optics without worrying about questions posed by physical optics, such as whether light is emitted or received by the eye. The camera obscura changed all that.[7]

It would be very interesting if one could actually establish exactly when the Europeans began to understand vision and whether the instruments played a role in their grasping what the Chinese evidently intuitively understood already with the primitive *camera obscura*. In fact, the ancient Westerners did not intuitively understand the significance of the observations immediately, although Lefèvre seems to imply that one should have, since for Lefèvre it was the *camera obscura* which pushed this.

3 Celestial devices

It is generally agreed that at a minimum, Stonehenge is a type of solar calendar indicating the solstices and equinoxes of the calendar year. At a maximum, as a lunar device, Stonehenge may also have encoded Saros cycles, allowing predictions of periods when an eclipse might take place. However, if it did encode lunar cycles, Stonehenge was still not reliable enough to predict eclipses. Strangely, the major stones at Stonehenge are not part of the system, with the Aubrey holes, heel stone, etc. forming the most important aspect of the calendric system. This puts us in the first half of the third millennium BC. In fact, the Neolithic circular enclosures of the 5th millennium BC were probably also oriented towards the solstices, and thus if there was anything unusual about Stonehenge it was the links to the Saros cycles. Menghin is persuaded that a luni-solar calendar is recorded in the Berliner gold hat, which belongs to the European Late Bronze Age, ca. 1000 BC, and thus accepting such observations transformed and encoded into metal, wood and stone in Prehistoric northern Europe is probably not exaggerated.[8] Obviously, all of this is earlier than the earliest written records of observations from Greece. Thus the conceptual system and recording did not march in

7 Lefèvre 2007, 9.

8 Menghin 2010, 53–63.

parallel. Menghin is persuaded that such knowledge was the preserve of the few who kept it to themselves.

In the Near Eastern Bronze Age, the recording was probably instrumental for the observations, and these rapidly included the planets as well as the stars, sun and moon. Distinguishing the various bodies and tracing their movements was only possible if one understood the movements and recognized the bodies. Yet their calendars meant that they could not – and thus innovation came into the world as calendars were developed to be compatible with the movements. Ultimately, it was only the Greeks who managed this. The key was taking the year as the basic measure – and not the day or the month, as the Egyptians and Mesopotamians tried. Obviously, neither the day nor the hour is the key to Stonehenge, but rather the year, and this European realisation probably contributed to the understanding that the year was 365.25 days long – and not 354, 360 or 365.

And this brings us to what is technically and scientifically the most extraordinary object bequeathed to us from antiquity. The Antikythera mechanism is a pocket-sized turbo-charged version of Stonehenge, a work of craftsmanship produced in the eastern Mediterranean near the end of the first millennium BC. The prototype was probably created by the successors of Archimedes & Co. The item which has survived probably dates to around 100 BC. The bronze device combines astronomical and calendric knowledge with mechanical engineering, intended to allow the prediction of eclipses by turning dials linked to interlocking gears encoding the calendar and the movements of the heavenly bodies. Michael Wright is probably correct in suspecting that the instrument was originally developed to follow the movements of the sun, moon and planets – and that whoever made the instrument anticipated the elliptical movements of the planets recognized more than a millennium later by Kepler and Newton.

To unaccustomed eyes, the unparalleled device appears to be the product of generations of engineering and scientific observation. Yet technically and historically, it had neither ancestors nor descendants. Just as it was not influenced by earlier technology, it had virtually no influence on further developments. What happened much later took place well over a millennium after the ancient machine was developed – just as the observations upon which it depended may have been made over a millennium earlier.

Yet, viewing the Antikythera mechanism, Marchant suggests that:

> The mechanical tradition begun by Archimedes in Syracuse a century earlier was still going strong, with his original design being updated by the latest astronomical knowledge from Rhodes and elsewhere as it became available. The latest models were then shipped across the Greek-speaking world.[9]

In fact, a glance at the instrument itself might betray a slightly different interpretation. Firstly, the specific instrument which antiquity has bequeathed to us may have been produced in the 2nd century BC, but seems to have been based on an Egyptian solar calendar of 365 days which was already two millennia old at that time. Quixotically, the machine may have used a highly complicated combination of Saros cycles to take account of the calendar gradually being established by Hipparchus, as the Greeks were gradually reaching a consensus that the year was almost one-quarter of a day longer than the Egyptian make-shift calendric year. Secondly, Marchant herself realises that the month-names inscribed on the mechanism suggested Corinthian origins which pointed to the colonies on Sicily and Archimedes himself. As far as we can tell, the actual device preserved might have been produced in the eastern Mediterranean, far from the Corinthian colonies in Sicily. Thirdly, Marchant notes that Michael "Wright still thinks that the mechanism could have been put together from the pieces of two or three other devices".[10] In this sense, it was not being improved with updates, but rather with conglomeration. Thus the reality may well have been that Archimedes & Co. created a workable instrument which was widely and meticulously reproduced, at least up until the beginning of the Roman Empire for Cicero saw (at least) one and knew of others which functioned the same way.[11]

Altogether, one could suggest that the Antikythera mechanism was not really intentionally modified and

9 Marchant 2009, 288.
10 Marchant 2009, 299.
11 De Re Publica I, 21–22; Tusculanae Disputationes I, 25, 63.

updated. Like the Berlin gold hat, the parallel instruments may well have been slightly different, but not fundamentally so. Thus technicians were probably producing relatively similar copies far from its place and time of invention. The facts of the matter are that there is nothing else like it – and nothing else remotely like it was developed for well over a millennium afterwards. In antiquity, dozens of the instruments might have been manufactured, all with the same inadequate calendar and inaccurate markings. Furthermore, they will probably have been produced on demand, as commissions – and not simply produced for the market. Thus, I suggest that Marchant is anachronistically projecting modern concepts onto antiquity in proposing constant updates being shipped to the market.

Whatever knowledge was combined in the instrument was derived from northern Europe, Babylonia and Egypt. The parallel with the *camera obscura* is striking: although built on a broad basis, only in the Renaissance did the process continue after a thousand year pause, with an inventive 3rd century breakthrough preceded by a millennia long accumulation of knowledge. The calendric aspects of Stonehenge are as much a one-off as the Antikythera mechanism.

It is assumed that the Saros cycles were discovered by the Greeks or Babylonians sometime around the middle of the first millennium BC. Yet Stonehenge might suggest that they were known earlier – and in this sense the Antikythera mechanism might well have been a revolutionary device, but it might have incorporated theoretical insights which had been known for millennia. Rather than having a protracted process of development, it may have simply been masterfully assembled using all the relevant knowledge available at the time – and later copied or re-assembled.

Curiously, one could note that the most complicated mechanisms ever developed – whether in Europe, China or the Mediterranean – eventually converged on using gears to record the spatio-temporal aspects of the world, i.e., time and the movements of the heavenly bodies. The Medieval and Renaissance watch and clock makers likewise worked with gears. Only later were gears more generally incorporated into bicycles, etc. (It is possible that the idea of interlocking gears survived in the *saqiya* where interlocking toothed vertical and horizontal wheels were used to raise water, but this was restricted to a domain where wheels – such as water-wheels for irrigation and milling – were already in use, and thus not revolutionary).[12]

There is something terribly conservative about the idea of always using the same technologies for the same purposes for a long time – in this case, extending from Classical antiquity to the Renaissance. And those Renaissance gears will have ultimately rendered the Greek sundials superfluous. Thus, the Renaissance was a period of real innovation in which received technologies were re-awakened – and then given new roles which had an impact well beyond the whatever intentions the authors might have had (quite aside from the combined impact of clocks and astronomical observations in nautical affairs on map-making, etc.). The Renaissance was not a universal human experience, but rather a specifically European one which had global implications.

Thus, in the case of the entire development and elimination of the sun-dials, we should merely note that this was a momentous change which did not take place in antiquity. On the contrary, the simplest form of the sundial as a flat surface with a central needle is known from the Valley of the Kings in Egypt from the second half of the second millennium BC – and many of our modern sundials are not radically different. The Egyptians also developed stepped instruments which are 'shadow clocks' rather than sundials as we understand them. But we no longer need them to tell time – because we have clocks.

For a brief period, the Greeks experimented with various radically different versions based on variations in the grid spread over cylindrical, conical and hemispherical concave surfaces. This may have begun with the Pre-Socratic Anaximander and potentially been perfected by the 'spider's web' which Plato's student Eudoxos developed. The Romans adopted these, and various forms were used in parallel. An unfinished early 1st century BC piece from Delos suggests to some scholars that, although advanced technology was intended, the object was left to the stone masons to produce. Thus the designs may have been developed by philosophers, but the execution of a sundial was left to stone masons rather than being the reserve of experts. The Romans would appear to have adopted the Greek form. It is not entirely

12 Hickey 2007, 293.

clear that there was any kind of evolution, nor is it clear that the various forms competed against one another for market share.[13]

In the 17th – 19th centuries AD, the Chinese used 'bowl-shaped' sundials. These differed from the Greek forms in that the hemispherical cavity was sunk into a horizontal plane (rather than being set at an angle or the cavity being sliced or formed to less than hemispherical size, as was the case with the Graeco-Roman versions). A Western Han Dynasty (last centuries BC) sundial has a flat plane, but contemporary usage suggests that the Chinese generally inclined the plane rather than leaving it flat (either horizontal, as in the West, or vertical as in Islam).[14]

Thus, there were a wide variety of sundials in antiquity. Aside from the Egyptian shadow clocks, all were based on the concept of a needle throwing a shadow onto a grid. With variations, the basic design was maintained across the Eurasian continent from the first millennium BC until modern times.

4 Technology and innovations in antiquity

Thus far we have noted quite contrasting examples. In the case of the *camera obscura*, the technology was simple, widely used and maintained so for more than a millennium. Although far more complex and diverse than the *camera obscura*, all the sundials from antiquity seem to be largely based on the same principles with different forms of execution; they imply that the basic knowledge was broadly disseminated and maintained at more or less the same level for millennia. Variations existed in parallel.

In the case of the Antikythera mechanism, the technology was highly complex, but it certainly was not improved upon constantly. Even if I have exaggerated (by suggesting a complete lack of up-dating), it is clear that the device was not improved upon if it was indeed passed on to the Arabs (as was the case with so many other items in Heron's repertoire). But neither was the idea developed any further. Even if it was improved in the Hellenistic era after Archimedes, it was abandoned in the Roman Empire. This contrasts with the *saqiya* and *camera obscura* which survived unchanged until recent centuries. Thus rapid change was not typical of ordinary technology, and the basic contributions of the philosophers were of rather limited value. Nevertheless, innovations and the diffusion of innovations were known.

In fact, there was a great deal of technological development in antiquity, and there were domains where products were indeed perfected, as for example in jewellery, dying and painting. The number of different chemical compounds of paint products which have been recognized in Ancient Egyptian painting alone is staggering, as the craftsmen sought purer whites and different shades of blue and green, etc.[15] Clearly, the craftsmen will have been developing their own colours and probably tried to maintain a monopoly on their creations since this was their market advantage: disseminating the information would have undermined their positions. Yet such innovations were probably rapidly unlocked by partners and competitors. A craftsman working in one region could hardly be active in another at the same time, and thus communicating his ideas to others elsewhere may have slightly eroded the personal advantage of the inventor, but enriched craft production. Yet these were purely commercial ventures and not based on scientific analysis.

Even so, remarkable products may well have been regularly produced and imitated. Although the markets will have been limited, the existence of phenomenal technology must be recognized. And they were not discovered in the texts, but rather through an analysis of the objects themselves. The result of these processes of scientific analysis of ancient finds is available to all in Moorey[16], Nicholson & Shaw[17], and Oleson[18] which hint at the abundance of innovations and inventions in Egypt, Mesopotamia and the Classical Mediterranean claimed by archaeologists in recent years. Quite aside from the chemistry and techniques of jewellery, cosmetics and painting, we have architecture, mills, wheels,

13 For discussions, cf. Gibbs 1976; Schaldach 2001; Schaldach 2006; Rinner, Fritsch, and Graßhoff 2013; "Forscher finden altägyptische Sonnenuhr im Tal der Könige," *Neue Zürcher Zeitung* 14 März 2013.

14 Needham 1959, 302–313; pls. XXXVI, XXXIX, XL-XLIII.

15 Cf., e.g., Warburton 2010.

16 Moorey 1999.

17 Nicholson and Shaw 2000.

18 Oleson 2008.

levers, games, composite bows, sailing vessels, bricks, glass, wine, coins, etc.[19]

And this brings us to a very contentious issue which must nevertheless be recognized. Despite the sophisticated Hellenistic Antikythera mechanism, observers remain sceptical that the extremely primitive looking 'Baghdad batteries' dating to the early 1st millennium AD could possibly have generated or stored electricity. The first find – of a jar containing a copper cylinder with an iron rod stuck in asphalt – appeared unique. However, without much difficulty, König identified a number of similar finds, finds which were too specific and too similar to leave much doubt about the deliberate character of the items.[20] König stated bluntly that "With all of these finds, it should be demonstrated that already long before Galvini, "flowing" electricity – which we name "Galvanic" in his memory – was known."[21]

Despite the evidence, the devices have generally been dismissed. Yet despite the wide-spread scepticism, Keyser seems to be objective enough to accept that the items could have generated and passed on an electric charge.[22] Significantly, he stresses that the items were not appreciated by the Greeks and thus they never entered history. König originally proposed that they were designed for electroplating, but this has been dismissed by most, justly or unjustly. Although the specific lines of the criticism seem warranted, one has the impression that explanations for granulation techniques used in antiquity remain rather inadequate. Thus, I would tend to link the batteries with granulation rather than electroplating – but this is just a guess.

Keyser's own conclusion follows König and concedes that the things were batteries; his explanation is that the batteries were used for medical purposes by practitioners (who were not recognized by the Europeans).[23] Among the points Keyser makes is that we have no theoretical literary texts dealing with such a phenomenon, while we do have the magical texts and paraphernalia which accompanied the original discoveries. Putting the two together provides an argument which would recognize their nature while explaining why the phenomenon is unknown, for it did not enter the literary tradition. In general, the techniques used by craftsmen did not necessarily come to the attention of the philosophers, and thus a good deal of technical information has been lost – with only those bits being recovered that are accessible to archaeologists.

For decades, it has been assumed that the civilisations of antiquity did not have a very high technical level, and thus it is hardly surprising that the archaeologists dismiss the Baghdad batteries. In addition, we have the lack of literary references which is a typically tautologous supplementary logic re-enforcing the dismissal of the evidence. Yet, it was the archaeologists who found out all of the complications of making paint – without any need for the written sources. Even if we suggest that the 'Baghdad batteries' were capable of discharging an electric change, it would follow that they were technically primitive and must have remained more or less the same through time, used only for very special tasks which failed to come to the attention of the philosophers. These would be just one more example of what archaeologists find. In my view, rather than denying them, one should investigate whether the Baghdad batteries could have supplied adequate current to simplify the welding of jewellery.

The reality is that many types of technology were developed – but not with the help of science. And many of the recently discovered types of technology and knowledge were revealed through studies of the artefacts which were found by the archaeologists. In the case of the Baghdad batteries, it is the archaeologists who deny the interpretation. Yet the reality is that the archaeologists have demonstrated that we have an abundance of technological innovation. There is less and less reason to dismiss what evidence we have of a wide variety of technological innovations.

However, what we do not have is any evidence of progress as it was understood by our Victorian forbears – and I argue that this is decisive for understanding technology in antiquity. Whatever the 'Baghdad batteries' were and whenever they were invented, the story only

19 Fagan 2004.

20 König 1936; König 1940, 165–168.

21 König 1940, 168.

22 Keyser 1993.

23 Oddly enough, when discussing the purpose, Keyser always refers to König as having suggested "electroplating" (e.g., Keyser 1993, 81–82) as having been "the purpose", and thus Keyser presents his own interpretation as original and alternative. Yet König 1940, 167, also plainly stated: "It is conceivable that the magician of Khujut Rabuah was also a physician and healed using the electric current of such a battery."

continued at the end of the 18th century, at which point, the story moves forwards in leaps and bounds.

In antiquity, some technologies were developed and used for practical purposes. Other technologies were developed by philosophers, but they were neither improved nor put to practical use. However, what we really do not have is evidence of economic development as being related to the innovations which have been recognized. Nor do we have much evidence of that interaction which is so common today. The agrarian world dominated and was not the centre of innovation. Innovation was related to the small urban world – and this did not change the way of rural life, so much as the quality of life for the select few.

Iron

One amazing exception to these various innovations was the introduction of iron. In general, iron was precious and used sparingly throughout the Bronze Age. However, during the Iron Age, the price of iron fell – and it was widely used, replacing ropes with chains and anchor-stones with barbed iron. By the Roman era – in the Roman Empire and Han China alike – iron was widely used for the manufacture of ordinary agricultural and household implements, such as hammers and nails. In the Roman era, iron also replaced bronze for weapons – but up to that point, bronze weapons were still superior. Yet, sometime during the mid-first millennium BC, the concept of making steel emerged and by the middle of the first millennium AD, high quality steel blades were being used by warriors in Japan and the Vikings in Europe.

Thus, the story of iron seems to be quite straightforward. Yet, there were actually two subsequent eras when the use of iron expanded, once in the High Middle Ages, and again with the 19th century Industrial Revolution. Interestingly, the first expansion of the use of iron in the early Iron Age was associated with a fall in the price of iron: from being far more valuable than silver, it fell to less than 500 units of iron to one unit of silver. And, again in the 19th century, the use of iron increased as the price fell. In both cases, technological causes are associated with the fall in price. Thus, it was not merely the introduction of a new product, but of an affordable product. Here, the price obviously played a major role in market success – even in the first millennium BC when most iron was not really of the same quality as bronze.

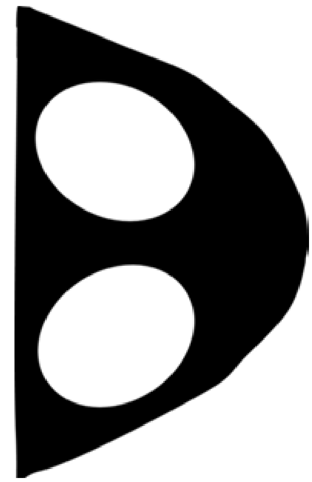

Fig. 2 Schematic version of a typical Middle Bronze Age fenestrated axe head (H: ca. 12–15 cm, but wide variation including miniatures). End third millennium-early second millennium BC; primarily Western Asia, Levant, Egypt. The left side was folded, designed to envelop the shaft, and the right side correspondingly strengthened to guarantee a strong sharp edge; weight was reduced by introducing the holes.

4.1 Weapons technology

However, prices are not the only moving force. Axes and sickles of bronze were known and modified, but remained largely the same for millennia. One place where there was real advance in antiquity was in weapons technology. Certain military items, such as swords and axes, reveal a rapid succession of forms and their diffusion is wide and rapid. The fenestrated axe (found from Mesopotamia to Egypt, Fig. 2) appeared late in the third millennium BC. This simple device consisted of a sheet of bronze folded to accommodate a shaft and pierced to reduce weight while offering a long cutting edge. In the Levant, it was replaced by the duckbill axe (Fig. 3) early in the second millennium. The duckbill worked on the same principle, but offered a smaller cutting edge where more power could be concentrated.

The duckbill was eclipsed by a variety of flanged and socketed axes before the middle of the second millennium. These were much smaller and designed to concentrate a compromise of minimal size, sturdy hafting, maximum weight, and piercing power. These various axes were in turn succeeded by simple blades, which were themselves pushed aside as Mediterranean swords and spears gradually came to the fore and eventually swept away the creations of the Near Eastern Bronze Age

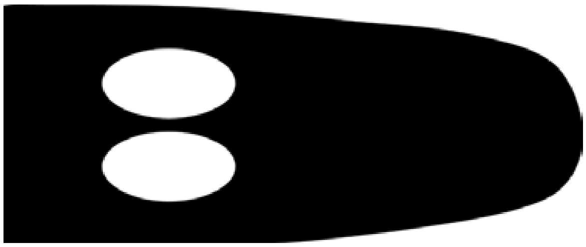

Fig. 3 Schematic version of typical Middle Bronze duckbill axe head (L: ca. 12 cm, with variation). Early second millennium BC; primarily Levant, Egypt. The form was designed to enhance concentrated striking power and cleavage.

civilisations. Here, it was not the price, but the design of the bronze instruments that made a difference and encouraged innovation. And the use of axes – of stone or bronze or iron – continued from the Neolithic (or rather the Palaeolithic) until the Middle Ages.

When viewing developments in terms of 'progress', a pertinent example of a transformative innovation in antiquity would nevertheless be the replacement of the axe by the sword. This was a revolutionary change in the nature of technology and combat. Yet, of course, the Franks were famous for the Francisca and the Vikings for their battle-axes which were used more than two millennia after the sword had appeared. In this sense, similar looking axes were used from sometime in the Lower Palaeolithic and through the Neolithic, Bronze, Iron and Middle Ages. Thus, the concept of parallel usage was maintained. In the pre-modern world (and still today, on the fringes of the modern Western world) one process did not necessarily exclude another.

But still, the swords are highly relevant to our question. In the case of swords, the development involved centuries of experimentation and improvement. The long-term story is the move from (a) short daggers (Fig. 4) where the hilt was attached to the blade with rivets to (b) long swords where the hilt consisted of wooden (or ivory or whatever) plates affixed to the proximal end of the blade (Fig. 5) whereas the distal end formed the tip. The long blades will only have been effective cutting instruments when used with a great deal of force, force which will hardly have been necessary with the short thrusting daggers that had been in use since the third millennium. Yet the impact of a cutting gesture put very strong pressure on the entire blade, probably resulting in early blades – affixed to the hilt only by rivets like the early daggers – snapping off at the hilt of early long swords. This experience will have inspired smiths trying to create long-bladed weapons, and there seems to have been a breakthrough in Central Europe or the Central Mediterranean. By the end of the second millennium, centuries of use by warriors and experimentation by smiths had created a sword which served the purpose; the Naue II was a strong weapon which would not ordinarily break where hilt met blade.[24] Bronze Age weapons development was dependent upon "the close interaction between craftsman and warrior".[25] Thus the collaboration was not philosophers and smiths, but rather smiths and warriors.

Significantly, for the most part, the technology of weapons was developed without consultations with the philosophers, and thus we have virtually no textual sources. Projectile-throwing devices were a different matter, and thus Archimedes actually makes an appearance, because of his catapults – but significantly, the written references come from the histories of Diodorus Siculus[26], and not the works of the philosophers as preserved. Similarly, Ctesibios supposedly dabbled with crossbows, but none of the treatises by these original thinkers are preserved. Curiously, although the crossbow was probably invented in the middle of the first millennium BC in China, we likewise only have references in the histories and archaeological artefacts – and no technical treatises from the early era. Thus, in the one area where the ancient scientists were called upon to participate in the innovations, the most important contributions were not considered to be significant enough to record – and their contributions were restricted to one specific marginal domain.

This last may be extremely important since neither in Greece nor China did the philosophers develop an accurate understanding of force. The theoretical shortcoming may have had an impact on understanding causality, which in turn may have had an impact on performance.

24 Jung and Mehofer 2005–2006 nevertheless discuss a 12th century BC weapon which did break at the hilt.

25 Mödlinger 2011, 153.

26 XIV, 42, 1.

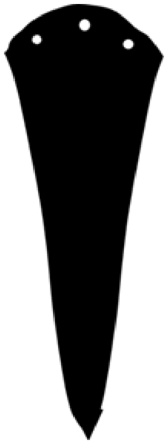

Fig. 4 Schematic version of short bronze dagger blade (L: 6 cm and more). Third-Second millennium BC. Europe, Eastern Mediterranean, Western Asia, Arabia. These blades were attached to a hilt with rivets – and corresponding broke either along the rivets or between hilt and blade. The less used the better.

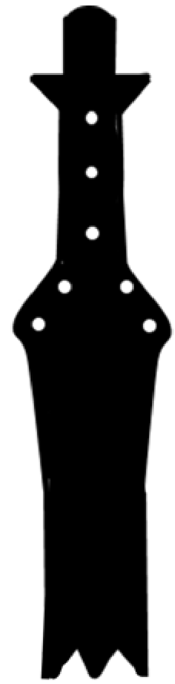

Fig. 5 Schematic version of hilt of Naue II Sword (L of section shown: ca. 20 cm). Late second millennium BC; eastern Mediterranean, Europe. This was the brilliant end of a long development where the hilt consisted of comfortable materials (wood, ivory and gold are all imaginable) attached to a hilt which was simply the extension of the blade. It did not have weak parts, and the only problem for smith and client was getting the length and weight correct for the user so as to assure maximum effect.

5 Industrial innovation

Innovation in the modern world has two distinguishing characteristics: (1) innovation processes are rapid and (2) innovations lead to the replacement of market leaders. Rapid development is typical of the early Industrial Revolution, with production coming to a halt or interrupted to resume with modified versions.

The 19th century was a period of rapid experimentation, producing intermediate models. For rifles, the process ended around the turn of the century; for cameras, the first experimental phase ended in the 1930s. There followed an era of new experiments, while the older versions remained in use. For cameras this ended with digitalisation. For the immediate future, amateurs will use smartphones and the passionate will adopt the digital SLRs: Cameras will be niche-markets, marginalized by other products.

None of these processes are relevant to understanding innovation processes in antiquity, where unchanging products continued in use and production for centuries or millennia – once developed. Rarely was a product marginalised, although marginal products were probably common. Overall, the innovations were created and fitted into societies rather than changing them and the world.

Military equipment will have played an important role in the ancient innovation process, but not been typical in the sense that one could point to a private counterpart such as the camera. State-of-the-art military weapons were always a very special market niche – as rifles have become today. The situation of antiquity was quite different. Even long after iron and steel swords replaced expensive bronze, swords remained expensive and exclusive. Obviously, among the warriors, the possibility of plunder meant that their financial means and motives were greater than those of the average person. The role of the states and warfare in pushing technological development, and the use of expensive metals for the use of special products is a hint that the main market for innovations and its requirements were matched by the means. Most people did not have the means to purchase much of anything at all, and thus a market share for exotic innovations will hardly have existed.

Most of the bronze artefacts we have from antiquity are clearly weapons (swords, shields, and battle axes) and many of those which might appear to be ordinary items may well represent military equipment as well (such as nondescript axes).

And contrary to the expectations of outside observers who expect to see at least some utilitarian objects among the innovations, one faces another disappointment. In fact, the early Iron Age was the era when the price of iron fell to the extent that it did not merely (eventually) replace bronze, but rather more significantly stone, wood and even rope. Only towards the end of the Iron Age were the smiths able to produce iron weapons which could really substitute for bronze; thus the Greeks still used bronze whereas the Romans adopted iron. In this case, one can see that the prohibitively high price of bronze assured that it was not employed for farm tools while the fall in the price of iron induced smiths to strive for steel: innovation and diffusion are related to price stimulation.

Extremely important for the understanding of innovation and the diffusion of innovation are the histories of the scythe and spinning-wheel, respectively. The scythe was known from Classical antiquity onwards but was not widely used for harvesting grain until the late Middle Ages or the Early Modern era. The sickle was used instead. Given the importance of rice in traditional Oriental agriculture, it is hardly surprising to note the absence of the scythe in Ancient China.

By contrast, the spinning-wheel was not introduced into the West until the 13th century AD. It would seem to have been known in China and India around the beginning of our era, in the Arab World during the late Abbasid Dynasty, and appears in Europe in the form of interdictions forbidding its use, as well as images in late 13th century art.[27] Strangely, in Europe, the development of spinning devices was immediately the object of improvements: already in the 15th century we see advances which foreshadow the 18th and 19th century breakthroughs.

Thus, the Chinese apparently invented the instrument which was suitable for silk, and subsequently used in cotton-producing India and textile producing England. Once introduced in Europe, it fed into the stream of innovations which reached their pinnacle early in the Industrial Revolution. This aspect was entirely practical and financial in that the instrument was related to exports – both in the Chinese silk trade and the Manchester cotton industry.

6 Innovation in antiquity, and innovation processes

Even if we have doubts about technology, we assume innovation to be natural. Yet this was not always the case, as stressed by a quote from the Han Dynasty (ca. 120 BC) *Huai Nan Zi* text that is worth citing:

> At the present time, the balance and the steelyard, the square and the compasses are fixed in a uniform and unvarying manner. […] These things are forever the same and swerve not […] A single day formed them, ten thousand generations propagate them.[28]

Thus, in antiquity there was no concept of 'protracted innovation processes' and constant modification. Instead, innovations were rapidly developed and remained the same. One recalls the history of the steam engine. Around the 1st century AD, Heron of Alexandria clearly understood steam power, as evidenced by the text and illustrations of his *aeolipile*.[29] Vitruvius was familiar with the same device.[30] We have no idea how much older this machine was at this time. Obviously the device was understood and recognized as the texts were copied through the Middle Ages. But no more. Yet, from the middle of the 16th century mechanics such as de Garay

27 Ludwig and Schmidtchen 1992, 112–115; 520–521.

28 Translated and quoted in Needham, Wang, and Robinson 1962, [=IV,1]: 17.

29 Heron, Πνευμαθικῶν II, 11.

30 De Architectura I, 6, 2.

and Savery attempted to exploit the concept of power rather than the mere illustration of the effect, but unsuccessfully. By improving a 17th century machine developed by Papin in France, at the beginning of the 18th century, Newcomen in England opened the way to Watt's success in the second half of the century.[31] The 19th century became the 'Age of Steam', as engines were built into locomotives and ships – quite aside from propelling the cotton industry.

Significantly, in his discussion of these developments, Landes notes that even "the Savery steam pump" of the 17th century hardly "disappeared": "Builders like John Wrigley in Lancashire were manufacturing improved versions of it to the very end of the eighteenth century".[32] Until the 19th century, the ancient pattern of the preservation of different quality models survived. It is a characteristic of the 19th and 20th centuries that models are left by the wayside as the improved models (rather than simply retaining the earlier versions) are adopted.

The ancient cases (axe, sundial, *camera obscura*, steelyard, compass and *aeolipile*) reveal that the role of science was quite different in the beginnings and the final phases. In antiquity, scholars used, observed and analysed without doing more than tinkering. Vitruvius remarks of the *aeolipile* that such devices "clearly reveal that an attentive examination of human inventions often leads to a knowledge of the general laws of nature".[33] The same is certainly true of the *camera obscura*.

6.1 The scientific breakthrough

Understanding these processes is complicated. However, the key detail is that somehow, in the West, a breakthrough was achieved whereby philosophers realised that they could demonstrate – on the basis of pure logic – that conclusions of one kind could be used to exclude various alternative assumptions, explanations or conclusions. I am persuaded that this type of thought did not exist in the Bronze Age, i.e., I suspect that it emerged in the Hellenistic era or later. Even if this did not happen at the earliest stage, i.e., in antiquity, it must be conceded that it did happen sometime around the Renaissance. In my view this process of logical deduction and logical exclusion is fundamental to serious science and thought.

I would hesitate to claim that the *camera obscura* was a causal factor in these developments – but rather that the reappearance of the *camera obscura* in the Renaissance is representative of a change in ways of thinking that were reflected in innovations by scientists working with instruments. Nowhere else and at no earlier time was this leap taken: and thus, this is the 'Western way of innovation'. What lies behind it? The question of why interaction, reflection and innovation meant that these technical changes transformed the nature of science is an important issue.

Of great importance is therefore the observation that Lefèvre correctly describes ancient thought as "juxtaposing" rather than "integrating". Thus, there are several separate issues involved. (1) One aspect concerns the invention and diffusion of technology. Another (2) concerns the philosophical discussions of technology. Another (3) concerns the fact that technology is not developed in a regular fashion. There are differences between (a) an instrument that is maintained more or less intact for 2000 years (400 BC–1600 AD), (b) an innovation process which transforms the *camera obscura* (ca. 1600–1800), and (c) an innovation process which transforms the *camera obscura* into a part of a smartphone (ca. 1800–2000). In the last few centuries, first slowly and then rapidly, the procedures of innovations have increased in speed. Another (4) is that, somehow, Western thought made a breakthrough which altered 'parallel' thought into 'integrated' thought. Before that, innovations were introduced and discussed, with the machines copied and the texts copied or adapted, with parallel versions maintained without inquiry.

Were one to write paraphrase Graßhoff's idea usefully, for today, one would have to say 'Market success is one possible outcome assuring the diffusion of innovations'. Thus, we separate the 'innovation' from the 'diffusion' of innovations. The innovation is the precondition for diffusion: no innovation, no diffusion. However, 'market success' is one potential outcome of diffusion, possible only if one has the market cornered or can claim royalties on patents. In the absence of control of the market, the diffusion will not offer any 'market

31 Mokyr 1994, 23.
32 Landes 1966, 331.
33 Vitruvius I, 6, 2

success' to the inventor. Although those copying and selling the innovation may be successful, the inventor may not benefit. Obviously such innovation is not attractive. More interesting than market success are grants from foundations and military contracts.

By Aristotle's time, wheel and waggon, plough and sickle, spindle and loom, bow and arrow, balance, *camera obscura*, and many other basic innovations had been perfected and diffused, available and used from the Aegean to China. The craftsmen who made the devices were rewarded for their labour, but the inventors will hardly have profited and few will have been interested in innovating either for the scientific or agricultural markets: it is hardly surprising that once perfected – whether in the Bronze or Iron Ages – most of these inventions and innovations were left more or less unaltered through the Middle Ages. Thus antiquity was hardly an era of 'protracted innovation processes'. Different instruments – such as axes – might have appeared, but the innovation process involved in the development of swords can be described as 'experiment through warfare'.

- In antiquity, non-military innovations were generally used where suitable and not improved once an adequate version had been developed.

- In antiquity, the diffusion of the devices is clear in space and time.

7 Conclusions

The technological dynamism of the 19th century is the tail-end result, the final Western stage, of a millennia-long process with its own origin. The failure to improve instruments in antiquity contrasts dramatically with later developments. Despite the gradually growing understanding of the principles of light diffusing across Eurasia, no real change took place until the Industrial Revolution. Curiosity and innovation did not march hand in hand until the Enlightenment. Antiquity was a prolonged time of innovative stasis.

Thus, what happened in the 19th century might be informative about the 19th century, but not relevant to understanding technological innovation in antiquity. It is not without reason that economists and others dismiss all economic history before the Industrial Revolution – the very concept separates this era from the past: we are talking about some 12 000 years of settled history, of which the last three centuries are a highly exceptional era. Thus, it is worth underscoring that there were no research institutes and no patent laws, and thus nothing like a market-share for innovations. Nor were there any real customers for such devices. This could be the basis for confirming that it was not the technology, which transformed the economy so that innovations were welcome, but rather the institutions (like patent laws, fiat money, growing middle classes, etc.) which were responsible for the enthusiasm for innovation. In this sense, the technological innovation is a symptom of a different set of economic causes, and thus the modern economic understanding of technological innovation is mistaken. There is no need to accept the modern understanding of technology and apply that to antiquity.

Innovation in antiquity was conceptual, technical and practical. Copying was easier than developing and thus diffusion is the life-blood of successful (*sic*) technical innovations. Confronted with new devices arriving by diffusion, those able to appreciate them often appreciated other aspects, potentially more important than the original intentions – and thus diffusion frequently lead to modifications and improvements (but only where these are useful – and very rarely in antiquity).

Technical innovation was important in the Neolithic, Industrial and Information Revolutions, by changing the environment in which rules were made. However, it was social changes which pushed the innovations (e.g., through crowding which led to sedentism and thus the domestication of plants and animals). It was only in the Bronze Age, and again in the Early Modern era, that conceptual innovations changed the rules (e.g., through the establishment of values, laws, measures, etc. which facilitated interaction).

However, technical innovation was indeed important in military applications in antiquity. Yet here, the cooperation between craftsmen and warriors – rather than that between philosophers and craftsmen – was decisive. Technical innovations which were of interest to the state and/or the wealthy elites also had good chances of being appreciated in antiquity (e.g., sundials).

In antiquity, innovations are visible through diffusion and one has little impression of important innovations being subjected to protracted development processes. Models were built, used, adapted, interpreted and modified – but there was no concept of an innovation process involving many participants (as e.g., oil presses). Indeed, it seems that philosophical innovations, combining scientific knowledge and practical technology, were rare in antiquity. Innovations probably diffused both as conceptual knowledge and actual instruments.

Above all, technical innovation did not play the role in antiquity that we ascribe to it in our society and this remains true regardless of the results of potential debates about the relative importance of markets, finance and science in pushing technical innovation in our society.

Curiously enough, what I have written here is succinctly summarised by Mokyr:

> The Industrial revolution marks a break [...] in that before 1760 stability was the rule and inventions the exception; afterwards, it was the other way around.[34]

One thing we can see is that in antiquity, the mechanics produced instruments (such as the sundial, *camera obscura*, balance), and that these practical items inspired reflection by philosophers. In antiquity these reflections had little impact on innovation whereas the innovative process was resumed in the late Middle Ages and Renaissance (culminating in the Industrial Revolution). In antiquity, items like batteries were probably never improved and never entered the literary tradition and thus evidently fell by the wayside – but perhaps not entirely forgotten. By contrast, craftsmen in the service of the elites will have, e.g., striven for perfecting colours in painting, aiming at whiter whites and blacker blacks. However this likewise remained a niche market and likewise never entered the literary traditions. Thus, there is a difference in behaviour where both market share and the transmission of information played a key role, when transformed in the modern age.

And thus the question, I posed: Why innovate? The answer, in my opinion, is that there was an economic change which pushed technological change in Europe in the late second millennium AD. My impression is that the acceleration of technological change – in the sense of innovation, consciously improving existing inventions with some purpose related to market share – has an economic cause as origin. Rather than the widely assumed tendency to believe that technology pushes development, I propose that finance pushes technoloigcal development. In this sense Graßhoff's proposition that market share drove innovation applies in recent centuries, but did not in antiquity. (I have discussed these changes elsewhere).[35] Obviously, as a consumer, already in the Bronze Age, the military adumbrated the concept of market share and competition inducing innovation (supported by state fiscal policies and the ambition of individual warriors and smiths). Although the military still flourish, private market demand has come to dominate in the modern and contemporary worlds, as illustrated by the development of the camera.

34 Mokyr 1994, 13.

35 Warburton 2016.

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1–5 D. A. Warburton.

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Svend Hansen

Research on Prehistoric Innovations. A New Theme in Archaeology

Summary

Technical innovations played a decisive role in the development of societies in Eurasia not only since the Holocene. This can be reconstructed in detail today on the basis of a stable 14 C chronology. But already in the 19th century technical innovations in archaeology played a fundamental role for the construction of the three-period system by Christian Jürgensen Thomsen. Gordon Childe followed this idea when he approximated the prehistoric epochs to Karl Marx's concept of production relations with the formula "Archaeological Ages as Technological Stages". Today, the study of prehistoric innovations is embedded in the concept of a global history of knowledge.

Keywords: prehistory; innovation; technology; knowledge; digital atlas of innovations; Childe

Technische Innovationen spielten für die Entwicklung der Gesellschaften in Eurasien nicht erst seit dem Holozän eine entscheidende Rolle. Diese kann heute auf der Grundlage einer stabilen 14 C-Chronologie im Detail rekonstruiert werden. Doch bereits im 19. Jh. spielten technische Innovationen in der Archäologie eine grundlegende Rolle für den Aufbau des Dreiperiodensystems durch Christian Jürgensen Thomsen. Gordon Childe folgte diesem Gedanken als er mit der Formel „Archaeological Ages as Technological Stages" die prähistorischen Epochen dem Konzept der Produktionsverhältnisse von Karl Marx annäherte. Heute ist die Untersuchung prähistorischer Innovationen in das Konzept einer globalen Wissensgeschichte eingebettet.

Keywords: Prähistorische Archäologie; Innovation; Technik; Wissen; Digitaler Atlas der Innovationen; Childe

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1 Introduction

Nowadays it is commonplace to read and hear in the media that innovations play a decisive role in the economic process. Those who do not supply the market with innovations with ever-increasing rapidity will lose their connection to international economics. Therefore, innovations are supported by governments and are tracked and measured throughout Europe.[1] Thereby, the concept of innovation, as used today, extends from revolutionizing new ideas that like the smartphone can change the physical movement of people in public or that address small details concerned with how to handle implementation, covering quite a broad scope of ideas.[2] The word 'innovation' is distinguished from the term 'invention'. An innovation is effective when it is introduced to the market or into production as a product or a procedure.[3] The spread of an innovation is called 'diffusion'.

In the Humanities this term is considered tainted, although few people actually know why. Like many terms in academic research, innovation can be seen as being vague.[4] Innovation can refer to a specific technical object, as well as to a process in the development of new procedures and the introduction of new products. At the same time, innovation can be a process of (re)newing, caused by technical, economic, social, and political change.

The modern use of the concept of innovation stems foremost from the Austrian-American economist Joseph Schumpeter. In his book on 'business cycles', he explains business cycles by drawing connections to the inner logic of the capitalistic economic system. Schumpeter started his theorizing from a state of economic balance (an area of economic balance), which theoretically was not disturbed but in a stationary state. This balanced state would be disturbed through innovations, through new products and/or new technologies in production. Innovators are followed by scores of imitators who ultimately compel the adoption of innovative processes, which in turn signifies the decline of non-innovators.[5] Thus, economic downturn precedes economic upturn.

Technical innovations (basic innovations) are also the basis of so-called 'Kondratiev waves'.[6] In 1926 the Russian economist Nikolai Kondratiev published his ideas on the existence of business cycles as occurring in waveforms that last longer than 40 to 60 years. Accordingly, the first wave in 1780 to 1840 was determined by the steam engine, the second wave (1840–1890) by the railroad and the steamship, the third wave (1890–1940) by chemical and electro technologies, the fourth wave (1940–1990) by the automobile, and the current wave (since 1990) by communication technologies (Fig. 1).

Schumpeter's use of the term 'innovation' is of decisive significance for the study of economic development. Namely, innovation is not merely a widespread popular expression, but instead a firm component of a theory on economic development. According to Schumpeter, massive investment in new techniques stands at the beginning of economic growth until the new techniques are adopted, and then investment declines.

A number of empirical and theoretical problems inspired to further discussions on this model. For instance, it is an open question as to whether or not investment in innovations are relevant to a stable economic balance or a recession.[7] Further, the dating of the waveform in business cycles is not uniform.[8] Yet, evidently, there is broad consensus in economics that innovations are generators of economic growth *par excellence*.

2 Innovations in Prehistory

The application of this economic theory to prehistoric and early historic societies seems at first glance hardly promising. This is especially so as, according to general widespread opinion, prehistoric and ancient societies were bound *per se* to traditional conventions, which was inimical to innovation. Moreover, all technical inventions and innovations were transferred from the centers of the oldest 'advanced civilizations' to the 'periph-

1 The European Commission tracks and measures the innovative achievements of individual member states: https://ec.europa.eu/eurostat/de/web/microdata/community-innovation-survey (last accessed 03/12/2021).
2 The basic introduction is found in Rogers 2003.
3 A differentiation is made in Schumpeter 2008 [1939], 92–94 (following Nordmann 2008, 164).
4 E.g. Burr 2014.
5 Schumpeter 2008 [1939], 143–144.
6 Kondratieff 1926; Schumpeter 2008 [1939], 172–184.
7 Müller-Prothmann and Dörr 2009.
8 Plumpe 2010, 52–53.

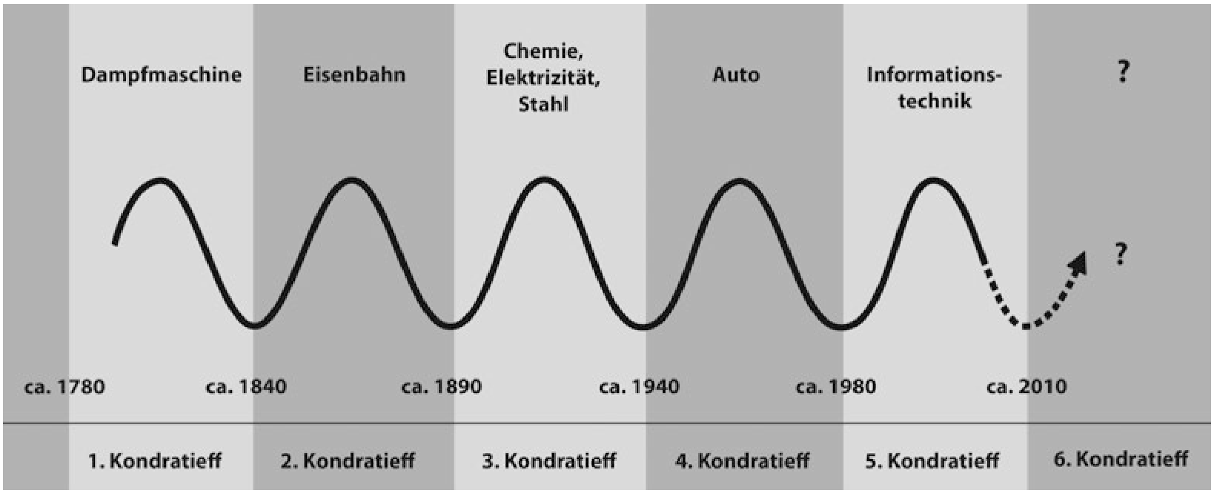

Fig. 1 Kondratiev waves.

ery'. These and similar ideas have long hindered considerations on research techniques.[9]

Two decisive changes have now created room for the implementation of new productive research. The first great change was the *radiocarbon revolution*, which has produced reliable absolute dates through the calibration of datings according to annual tree-ring curves. This brought forth a crucial change in the chronology of archaeology from the early Holocene forward. Thus, today we know that the beginning of crop cultivation and stock-raising in western Asia occurred as early as the 10th millennium BC, that metallurgy had already started around 5000 BC, that megalithic tombs were built 1000 years before the pyramids were erected, and that the wagon was known in the North Sea area as early as 3500 BC.

The second great change was the opening of the countries of the former Soviet Union for joint archaeological research. The historical developments in the region of Europe can now be linked much better with those in Eurasia, and the spread of innovations can now be assessed anew. For example, we now know that pottery of the Mesolithic Ertebølle culture of the western Baltic region did not come from the south, but instead from the east, from the Urals and that Bronze Age socketed axes were already long known in western Siberia and west of the Urals before they were adopted in the Carpathian Basin.

It is clear that this broadened perspective will ultimately lead to a more global view of the history of innovations and knowledge, despite considerable gaps in research in many parts of the world. The recently published history of the Stone Age by Hermann Parzinger is an example of how fruitful a global perspective can be.[10] Nevertheless, the statement "that just as there is only one history of life on this planet, there is only one history of knowledge" is equally as simple, as apt.[11] In the same sense, there is the revealing fact that the project of establishing a global history of knowledge has only recently been included as a subject in the scientific agenda. The enormous potential for new viewpoints and changes in perspectives of the emergence, transfer, and transformation of knowledge is fascinating.

Every time the world is measured anew, there is a need for new maps. The *Digital Atlas of Innovations*[12] not only presents illustrations, which visualize already known connections, it is also an epistemological instrument that discloses hitherto unknown connections. It can be useful not only for prehistoric and ancient studies, but also for research on medieval times and the modern era. Thus, the *Digital Atlas of Innovations* enables researchers to trace the introduction of agriculture during the Neolithic period, covering Anatolia and the Balkans to the Danube and Rhine river areas. It can, likewise,

9 For example Neuburger 1919. For an overview of research history, cp. König and Schneider 2007; for a current overview of ancient techniques, cp. Schneider 2007; Cech 2010.

10 Parzinger 2014.

11 Renn and Hymann 2012, 15.

12 https://atlas-innovations.de/en/ (last accessed 01/28/2021).

follow the adoption of falconry and veterinary medicine from Persia via Arabia to Sicily and Spain and to the royal court of Friedrich II and Alfons the Wise, from whence they were ultimately adopted by courts in northern Europe.[13]

The basic traits of the history of innovations in Eurasia can now be described, an accomplishment that was not possible twenty years ago (Fig. 2). The timeline shows the introduction of key techniques in Eurasia.[14] There was a cluster of innovations that was distinct in the time of the 'Neolithic Revolution' that included crop cultivation, stock-raising, pottery-making, and weaving, among others. Foremost to mention as an innovation in the 5th millennium BC is metallurgy, while in the 4th millennium BC essential basic innovations were introduced, including the wheel and wagon, alloy copper, the domestication of the horse, and breeding woolly sheep.[15] It was not a coincidence, therefore, that the first states emerged during that time in particular. Excavations in northern Mesopotamia in recent years have broadened the view of cultural development during the late 5th and 4th millennia BC. The picture of monumental architecture and early kingdoms in northern Mesopotamia is far more complex than previously thought, even only a few years ago. In fact, the path to urban planning and socioeconomic complexity might have begun in northern Mesopotamia.[16] This particular time was described as "the most crucial period in the growth of complex urban society and a phase that has recently been referred to as already representing a 'state-level'".[17] According to Gil Stein, the early 4th millennium BC was a time of powerful leaders, perhaps the first kings, in the context of the formation of urban centers and centralized administrative systems.[18]

In order to understand why the first elements of political and economic centralization become visible in northern Mesopotamia in particular, a thorough and precise examination of the state of knowledge that has accumulated or emerged in this area is imperative. The simple formulations by V. G. Childe, that metallurgy, the wheel, and the ox-drawn cart, as well as the sailboat, were the prerequisites for the urban revolution, are in this simplicity surely no longer correct.[19] It is evident that a large spectrum of innovative techniques in the late 5th and early 4th millennia BC caused the corresponding effects.

Concentrations of innovations in the Neolithic period and in the 4th millennium BC seem to confirm modern-day observations that technical innovations did not appear continuously and singly, but were instead discontinuous and appeared in clusters. According to Gerhard Mensch, they quite likely arose in times of crisis and thereby formed the prerequisite for a new long wave of economic prosperity.[20] This is the interpretation for technical innovations in archaeology too. New techniques allowed an intensification in production and with that enabled the realization of surplus supplies and the concentration of economic power in a few hands. On the opposite, these concentrations of innovations are also indicative of the basic conditions, which were favourable for the development of new technical processes. In general, an innovative technique is the product of social processes, which in themselves do not stand in regular relevance. Thereby, in best cases special support and freedom of creative thinking might be imaginable. Innovative solutions, however, might also represent a forced reaction to problems on the part of the power that controlled the course of production. Based on ethnographic material, Christian Sigrist concluded that the process of political centralization can trigger a chain of innovations, and that at least the transitional phase from an acephalous society to a centralized one holds more innovation potential than an acephalous society.[21] Among these innovations are, of course, also changes in kinship and legal systems, which cannot be directly proven archaeologically.

Most, though not all, technical developments and social upheavals in prehistory and antiquity, had consequences for large areas of Eurasia. Contrary to other continents, technical innovations in the Eurasian sphere

13 Fried 2009.
14 First published by Hansen 2014, 244, Fig. 1. Meller 2015, 27, uses a timeline with different dates. Here, it should be noted that the graphic allows some leeway as to what is viewed as a widespread active innovation or what was a regional occurrence (for example, stone pillars in Göbekli Tepe or warrior stelae of the late 4th millennium BC).
15 For details, cf. Hansen 2011.
16 McMahon, Sołtysiak, and J. Weber 2011, 201.
17 Oates et al. 2007, 598.
18 Stein 2012, 141.
19 Childe 1982 [1942], 97.
20 Mensch 1975, 149.
21 Sigrist 1979 [1967], 248.

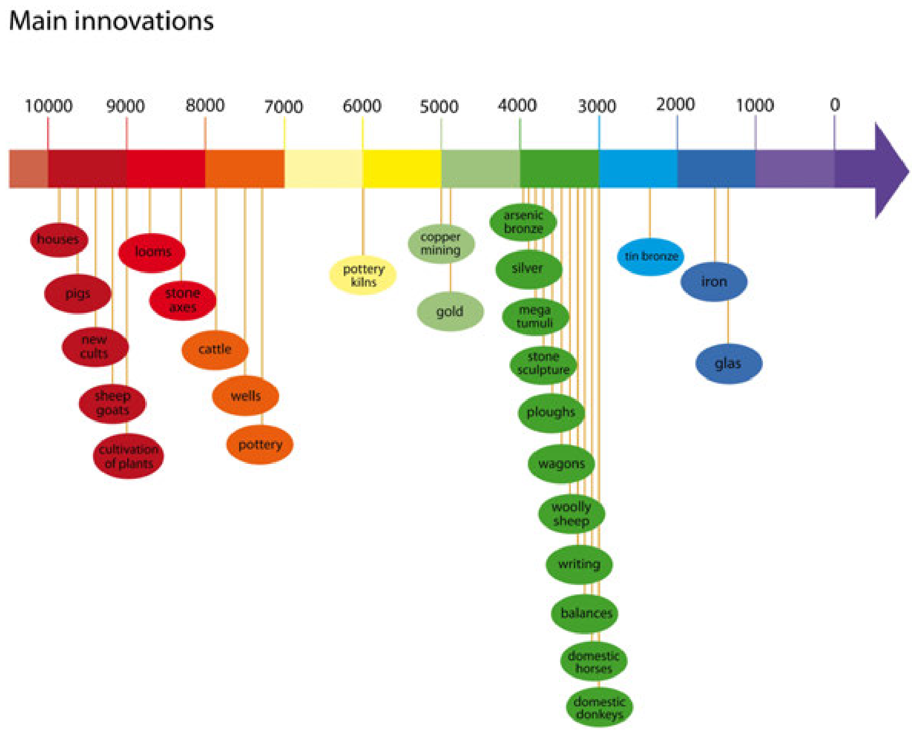

Fig. 2 The introduction of key techniques in Eurasia.

became widely disseminated over far-reaching parts of Eurasia by means of a relatively rapid transfer, and became a characteristic of innovations in this sphere. This dissemination is associated with – among others factors – the west-east axis of communication in Eurasia and also with a special form of a mobile way-of-life that emerged there during the late 4th millennium BC. During this time, Eurasia experienced an intensive exchange of ideas and technologies, through which the foundations for technical development were laid: developments that marked the daily life of people there until the 19th century and were eventually replaced by modern industry. The immensity that this geographic sphere presents, in particular, offers an extraordinary opportunity to study the dynamics of the interactions between technical innovations and social processes or forms of organization among ancient cultures of the two continents – Europe and Asia – in an archaeologically coherent manner. Innovations are not limited to handiwork techniques or technologies; indeed, they also include new forms of social organization and systems of symbols. Max Weber established a close association between protestant ethics and capitalistic economics.[22] Jacques Cauvin expanded Weber's basic thought on the Neolithic Revolution, that it requires a specific mental disposition to build a new economic system. He, thereby, pointed out the significance of the 'Revolution of Symbols'.[23] Cauvin developed a 'psycho-cultural' theory: the necessary prerequisite for the invention of agriculture was cultural maturity (*maturation culturelle préalable*), and this was not technical, but psychic (*psychique*).[24]

Thus, the concept of innovation is not technically limited, but also applies to the description of social and religious systems, and the changes associated with them. So, I do not write a traditional history of progress in technical inventions, but about the significance of techniques in, and for, cultural systems. As multifaceted as the theoretical perspectives and methodical access to the cultural-historically oriented history of technique may be, they all converge in the insight that the functionality of an implement is not simply a technical one; it possesses social and symbolic dimensions as well. Techniques ultimately are representations of forms of thought (*Denkformen*). I shall return to this aspect later.

22 M. Weber 1988 [1920], 17–205.
23 Cauvin 1994.
24 Cauvin 1994, 100.

3 Concepts in Prehistoric archaeology and technical innovations

The history of prehistoric innovations is, on the one hand, a new branch in archaeology, yet on the other hand, from the very beginning it was connected with prehistoric archaeology. One could say that from the very start, prehistoric archaeology was itself research on innovations. In his fundamental book *Ledetraad til Nordisk Oldkyndighed*, Christian Jürgensen Thomsen distinguished three prehistoric epochs: the Stone Age, the Bronze Age, and the Iron Age.[25] These were not mythical ages, as known in ancient literature, but instead the result of empirical studies. The examination of archaeological finds that had been brought together in the National Museum in Copenhagen led to a seminal advancement in the systematization of archaeological material. Thomsen recognized that stone was rarely associated with bronze, bronze seldom with stone and iron, and iron was never associated with stone. By means of simple combination, Thomsen constructed a sequence in time for the materials, a construct that has remained the basis of Eurasian archaeology to this day. With that, Thomsen initiated a scientific paradigm shift.[26]

The three-age system was groundbreaking not only in relation to chronology. Essentially, this system outlined a sequence of techniques or technologies. For the definition of the Stone-, Bronze-, and Iron ages, the use of these materials as cutting implements – axe, knife, and dagger – was decisive. Each new period was defined by technical innovations, and not simply the appearance of these materials.

The three-age system was soon adopted in all of Europe.[27] Christian Jürgensen Thomsen was a well-known public personage. In 1864 Jules Verne wrote his famous novel *Voyage au centre de la terre* (*Journey to the Centre of the Earth*), a story about Professor Lindenbrock and his nephew, who began their journey to the middle of the Earth in Copenhagen, where they visited the Museum of Nordic Antiquities and its director 'Professor Thomsen'.

The three-age system became the decisive basis for the rising (classical) evolutionism. John Lubbock strongly emphasized this scientific classification.[28] The works of Lubbock and Edward B. Tylor laid the foundation for the idea of historical development through technical advancement, which in the 19th century was a new and consequential idea. This idea gained a universal character through the explicit connection that Lubbock and Tylor drew between archaeology and ethnology. Ethnologists had defined the 'stages' through which human beings had historically proceeded in different social subsystems. 'Animism, Polytheism, and Monotheism' (Tylor) was such a three-stage system.[29] It was the field work of Bronislaw Małinowksi in the Pacific that brought this theory of 'stages' to an end: he observed how magical, religious, and rational forms of thinking existed side by side.

Karl Marx, too, deliberated on the historical stages. In the second edition of *Das Kapital* from 1873, he added a footnote in which he discussed tools and work implements as the characteristics of the society's production epoch:

> However little our written histories up to this time notice the development of material production which is the base of all social life, and therefore of all real history, yet prehistoric times have been classified in accordance with the results not of so-called historical, but of materialistic investigations. These periods have been divided, to correspond with the materials from which their implements and weapons were made, viz., into the stone, the bronze and the iron ages.[30]

Marx probably knew the three-age system through studying the ethnological works of John Lubbock and others.[31] This reception led to a "stormy relationship between evolutionists and socialists".[32] Unfortunately, this changed the idea of progress from a historical possibility to a necessary and unstoppable process.[33]

The archaeological periodization encouraged Marx to reconstruct history as a sequence of modes of production that corresponded to certain levels in the develop-

25 Thomsen 1836.
26 Kuhn 1967, 23–24.
27 Here and in the following, cf. Hansen 2001.
28 Lubbock 1874 [1865], 5; this reference also includes Nilson.
29 See e.g. Tylor 1871.
30 Marx 1986 [1873], 195. English Marx 1887, 135, note 7.
31 Marx 1976.
32 Foucault 1978, 48.
33 Salvadori 2008, 14–15.

ment that their material production required. He already implied this line of thought in the 1840s, when he wrote:

> Social relations are closely bound up with productive forces. In acquiring new productive forces men change their mode of production; and in changing their mode of production, in changing the way of earning their living, they change all their social relations. The hand-mill gives you society with the feudal Lord; the steam-mill, society with the industrial capitalist.[34]

So, the next step to a typology of pre-capitalist formations was not a large one: the primeval society, oriental despotism, slaveholder society in antiquity, and feudalism.

In the meantime, archaeology had celebrated its triumphs as a science with great public attention. In 1855 Ferdinand Keller discovered the first 'pile dwellings' along Lake Zürich; in 1856 skeletal remains of a human being were found in Neander Valley near Düsseldorf; as of 1858, the site of La Téne had been investigated; in 1861–1865 Napoleon directed that excavations be carried out in Alesia; in 1864–1865 J. Ramsauer conducted excavations at the cemetery of Hallstatt; as of 1871, H. Schliemann had excavated at Troy, Mycenae, and Tiryns; in 1875 excavations began in Olympia; and in 1879 the cave paintings in Altamira were discovered, just to mention a few examples.

Many of these discoveries had far-reaching consequences and were correspondingly the subject of controversial discussions; this applies especially to the cave paintings in Altamira. Debates about the authenticity of the paintings founded particularly on questioning the technical capability of the presumed primitive Stone Age hunters. It seemed unimaginable that the cave man had been capable of creating such subtle art. Scholars were far from having established a history of prehistoric techniques, although, the arch could have been spanned from Altamira to contemporary art, especially at that time.

Other paradigms came to the fore at the end of the 19th century, in particular, the explanation of social change initiated through the migration of people. Gustav Kossinna politicized prehistoric archaeology when he claimed that he could recognize the ethnic affiliation of objects.[35] Gordon Childe followed this paradigm from his earliest days of study, reaching a peak in a monograph about the Arians.[36] In 1933, however, Childe recognized the political dimensions of ethnic archaeology in Germany and broke away from this concept.[37] From this situation emerged a fundamental change in the paradigm. Instead of migrating people, Childe now recognized the motor of history in the Marxist productive forces, and went on to develop new "interpretative concepts and methods of explanation".[38]

Childe's relationship to Marxism has been the subject of numerous works and will not be dealt with in depth here.[39] Nonetheless, one detail should be noted: Childe linked the Stone Age and the Bronze Age (Thomsen's periods) with the concept of economic revolution. He said that, "Each new 'age' is ushered in by an economic revolution of the same kind, having the same effect as the 'Industrial Revolution' of the eighteenth century".[40] The term 'industrial revolution' in this quote was taken from its general use in everyday speech and not from the Marxist theory about modes of production. Furthermore, it was a catchy expression, just like 'Archaeological Ages as Technological Stages', with which he explicitly referred to Thomsen.[41] Like all of his contemporaries, until the end Childe too remained committed to a deficient or even false chronological concept in his reasoning and conclusions. Hence, it not surprising that most of his historical conclusions cannot be upheld today.[42]

In his last book *The Prehistory of European Society* (London 1958/2009), Childe questioned why European prehistory and history were so different from the history of North America or New Guinea. He emphasized the significance of early metallurgy (probably the only technique that was really of interest to him) for the emergence of early states, but also the sciences of later times.

34 Marx 1976 [1847], 122. German text: Marx 1964, 498 (= Marx 1983 [1847], 130).
35 Kossinna 1911.
36 Childe 1926.
37 Childe 1933.
38 Childe 1958, 69.
39 For example, Gathercole 2009; Faulkner 2007.
40 Childe 1936, 39.
41 Childe 1944.
42 Sherratt and Childe 1990, 8.

He wrote of a 'technological differentiae.' He propagated the role of technique and science as part of a 'distinctively European way.' Childe understood technology as the root of science, and was convinced that "by observation and experiment [one could] discover fairly accurately every essential step in the manufacture" of archaeological artefacts. Indeed, through this analysis, one could attain the knowledge of the craftsperson. In the 18th century, these techniques in crafts were already viewed as the precursors of science. Notably, the invention and processing of metals were recognized as the cause of the emergence of arts and handiwork, as well as science.[43] Metals were identified as the driving force behind practical inventions.[44] To the question of why European societies had been able to bring forth European science, Childe answered: "The explanation must of course be sociological, not biological. Science, like technology, is the creation of societies not race".[45] In 1958 this view, which is a matter-of-fact today, was still worth emphasizing.[46]

4 History of innovations and history of knowledge

It is quite obvious that the study of technical innovations and the effects of innovations on society is unimaginable without first making a study of the knowledge that was available at a specific time and in a specific place.[47] However, how can one approach the question about the knowledge possessed by past preliterate cultures?

An examination of the history of knowledge is a many branched and rapidly growing issue today, and yet the history of knowledge is a relatively young field of research. Nonetheless, there were already modern pioneers in this effort. The Polish physician Ludwig Fleck wrote in his work *Entstehung und Entwicklung einer wissenschaftlichen Tatsache* (*Genesis and Development of a Scientific Fact*), published in 1935 and mostly overlooked until the 1990s:[48]

> It is nonsense to think that the history of cognition has as little to do with science as, for example, the history of the telephone with telephone conversations. At least three-quarters if not the entire content of science is conditioned by the history of ideas, psychology, and the sociology of ideas and is thus explicable in these terms.[49]

He pleaded for a concept of knowledge that not only acknowledged the knowledge that was evident in the system, but also included the knowledge that had been excluded because it was seen as unproven, fantastic, or mystical. Such an open scientific concept is, therefore, suitable for the description of knowledge in prehistory and antiquity. Fleck maintained that cognition would not be an individual process of a theoretical 'consciousness at all,' but rather the result of social activity, since the respective state of cognizance exceeds the limits of the individual.[50] With that, Fleck undermined the idea of the scientific cult of geniuses. He referred far more to a 'thought collective' formed by the community of human beings who partook in the exchange of thoughts and from which new recognitions were generated. These thought collectives can generate collective styles. They share common features: the problems being investigated, the judgements they consider evident, and the methods they use as means of recognition. The formation of a common literary style can also accompany these collective styles;[51] however, they are not homogeneous.

Unlike Thomas Kuhn, who later emphasized the upheaval in scientific recognition caused by a change in paradigm, Fleck stressed the constant process of advancing modern science, comparing it to "troops on the march", differentiating between the vanguard, the main body, and the disorganized late-comers.[52] Fleck distinguished between a coincidental thinking-collective within the framework of sporadic (scientific) exchange and a stable thinking-collective, which he called 'communities of thought' or 'communes of thought.'[53] They

43 Plessing 1787, 182.
44 Orell 1786, 497.
45 Childe 1958, 9.
46 This follows the ground-laying rule of É. Durkheim, published in 1895: that which is social should be explained only by what is social itself (Durkheim 1984, 68). See also Green 2000.
47 On the difficult conceptual fields of 'technique' and 'science,' cf. Nordmann 2008, 123–146.
48 Fleck 1994 [1935], 32.
49 Fleck 1981, 21.
50 Fleck 1994 [1935], 54.
51 Fleck 1994 [1935], 130.
52 Fleck 1994 [1935], 163–164.
53 Fleck 1994 [1935], 136.

would possess a certain formal and contextual isolation, which could even be regulated by laws, like medieval guilds. This consideration has since been assumed by new sociological studies on knowledge.

'Communities of thought' should be viewed as indispensable for the advancement and transfer of practical experiences and for the rapid exchange of relevant information.[54] Furthermore, the concept of 'communities of practice' is also at home in the paradigms of 'thought collectives'.[55] Such a 'community of practice' is defined by the presence of variously trained craftspeople who learn and work together, and who share and pass on their knowledge. A 'community of practice' can be made up of different, specific social groups. In the context of Bronze Age civilizations, these would be the workshops in particular locations. Within this setting, the state of knowledge could be transformed from one craft and used for another craft and, thereby, represent a basis for further innovation.

According to Fleck, the simple communication of knowledge is always associated with transformation, with a re-forming according to style, intra-collectively with reinforcement and inter-collectively with basic changes.[56] Jürgen Renn, too, emphasizes the aspects of implementation and transformation of knowledge:

> The history of knowledge has traditionally been studied from a restricted perspective that favours innovation over implementation, transmission and transformation. In the past, historians of science and technology have often focused on the question of who was the first to discover a fact that later became a key innovation and when this took place. Much less attention has been paid to the question of what role these discoveries or inventions played in the contemporary context of knowledge and how they changed their meaning when transmitted to a different context.[57]

Indeed, there are very different ways of approaching innovations. Most people in Europe know – not least due to written documentation – that corn, potatoes, and tomatoes arrived in Europe from the New World in the 16th century. By contrast, in the creation myth of the Assiniboine of North America, the horse that accompanied the Spanish conquerors to America was created together with the first humans by the Assiniboine progenitor.[58]

For studies on preliterate cultures and those in which texts about technical processes do not play a role, the differentiation between diverse forms of knowledge is especially necessary.[59] Without question, some forms are held to be more important than others. Following Michel Serres, it can be stated that all knowledge is equally valuable: "What applies to humans also applies to knowledge".[60] All transmissions of knowledge occur through speaking in specific social contexts. Thus, the differentiation of explicit knowledge, which is expressed through thought and speech, and implicit or incorporated knowledge, which cannot be articulated in this way, is important for understanding the learning and transferring of knowledge in cultures without writing. Thereby, incorporated knowledge can be taken 'word for word'. Using swimming, marching, and walking as example, Marcel Mauss explained how certain techniques of the body can be collectively taught in a society through upbringing and imitation.[61]

Incorporated knowledge is recognizable in human beings, but also in objects. In objects, it is knowledge that is needed to produce the objects. It is amazing that this plays such a marginal role in textbooks, handbooks, and curricula on 'material culture' in Germany, in contrast to themes like "things as signs, language and things, script and things, landscape and things, gender and things, identity and things".[62] Exceptions to this are the studies of Pierre Lemonnier, which follow the tradition of the school of A. Leroi-Gourhan and the behavioral archaeology of Michael B. Schiffer.[63]

54 Heidenreich 1997.
55 Wenger 1998.
56 Fleck 1994 [1935], 145.
57 Renn 2015, 40.
58 Kohl 2011, 12.
59 For example, Renn and Hymann 2012, 12: intuitive knowledge, practitioner's knowledge, symbolically represented knowledge, technological knowledge, scientific knowledge, and second- and higher-order knowledge.
60 Serres 2005, 168.
61 Mauss 1989, 199–220.
62 Samida, Eggert, and Hahn 2014, V.
63 Lemonnier 1986; Lemonnier 2002; Lemonnier 2010; Schiffer 2004; Schiffer 2005; Hollenbach and Schiffer 2010.

Knowledge can be described with the *chaîne opératoire*. Every feature of an object is examined with regard to the steps needed for its production. Where did the raw material come from, how was it processed, what kind of tools were necessary, and how were these implements produced or accessed? André Leroi-Gourhan, from whom this concept arose, emphasized the empirical character of these chains of operation, which were transferred from generation to generation. In the course of evolution from Australopithecus to farmers and craftspeople to the Industrial Revolution, they became ever more enriched. The first machine-made production led to a qualitative change.[64]

Technical innovations mostly are not ingenious, individual achievements of inventors, but rather the (re-)combination of various knowledge that was already present. Therefore, research on these bodies of knowledge is crucial for a productive research on innovations. The example of Altamira shows the great extent to which the innovative aptitude of Paleolithic gatherers and hunters is underestimated. The development of tools and accompanying regeneration stimulated cognitive processes and, thus, are of central significance in the history of the evolution of humankind. Gerd-Christian Weniger has underscored the skill of cutting as a fundamental step in the technical development of humans.[65] The Neolithic period did not begin at point zero in terms of knowledge, but instead built upon the wealth of knowledge that had been amassed over millennia. Without the distinctive knowledge of gatherers and hunters, it would have been difficult to cultivate plants and domesticate animals.[66]

For the development of metallurgy, experience in pottery-making – which involved a related form of change in material through fire – was required and employed. Investigations on the blueprints of Neolithic houses have led to the strong impression that there was a kind of standard measure of length that was widespread in Europe that was used and passed down as a tradition by specialized architects.[67]

We are discovering – also based on better material-oriented analyses – ever more techniques in production and, with that, related groups of knowledge that date to a time long before the 'advanced civilizations' of Egypt and Mesopotamia or even the Neolithic Revolution. Craft specialization, which is clear through these examples, is much older that hitherto assumed. What role then did innovations play in the first cities and pristine states? Was the secret of success to create as many innovations or as much knowledge as possible from all directions and bundle them in one system? Any number of examples could be added.

5 Conclusion

It should be clear, from reasons stated introductorily, that only starting with the present times is it possible to write a well-founded early history of techniques and knowledge. Taking away a layer of out-dated assumptions we should now be able to gain new empirical evidence for the history of innovations of tools, weapons and other objects, which none too seldom had central influence on the life and death of human beings, from the Bronze Age onwards into modern times. This history can only be achieved with the perspective of the global history of knowledge, and archaeology can offer an important contribution with its (pre-)historical long-term perspective.

64 Leroi-Gourhan 1984, 317–318.
65 Weniger 2003, 128.
66 Fuller, Allaby, and Stevens 2010, 13–28.
67 Lüning 2005, 68–71.

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From Invention to Innovation: Technical Systems in Late Prehistory

Summary

The concept of technical system is a major tool to improve our understanding of the history of techniques. A technical system is a coherent set of interdependent techniques sharing all or part of their *chaînes opératoires* and forming a 'paradigm' of its own within the technical range of a society. The ultimate major technical system to be set up in the course of Prehistory is the 'mixing-and-combustion technical system' (MCTS). The MCTS is responsible for the invention of ceramic about 33 000 years ago. For the first time man allows himself to substantially modify his environment through a process which is a matter of both hybridization and empiric chemistry. The main inventions of the MCTS are of Palaeolithic age. Their turning into innovations is the very essence of the neolithization process.

Keywords: invention; innovation; Paleolithic; Neolithic; ceramic; technical system; history of techniques

Das Konzept des technischen Systems ist ein wichtiges Instrument, um unser Verständnis der Technikgeschichte zu verbessern. Ein technisches System ist eine kohärente Sammlung voneinander abhängiger Techniken, die alle oder einen Teil ihrer *chaînes opératoires* teilen und ein eigenes ‚Paradigma' innerhalb des technischen Bereichs einer Gesellschaft bilden. Das entscheidende technische System, das sich im Laufe der Urgeschichte herausbildet, ist das ‚technische Misch- und Verbrennungssystem' (MCTS). Das MCTS ist für die Erfindung der Keramik vor etwa 33 000 Jahren verantwortlich. Zum ersten Mal erlaubt sich der Mensch seine Umwelt durch einen Prozess, der sowohl eine Frage der Hybridisierung als auch der empirischen Chemie ist, wesentlich zu verändern. Die wichtigsten Erfindungen des MCTS stammen aus dem Paläolithikum. Ihre Entwicklung zu Innovationen ist das eigentliche Wesen des Neolithisierungsprozesses.

Keywords: Erfindung; Innovation; Paläolithikum; Neolithikum; Keramik; technisches System

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1 Technical systems and prehistoric inventions

Whereas the conditions under which innovations occur have set off many research works, invention remains the neglected stepchild of studies on the history of techniques in Prehistory. Although it may have a modest, even negligible impact on the evolution of the ways of life, invention nevertheless represents a crucial testimony on the development of cognitive abilities. Studying how invention switches to innovation is also an important source of knowledge concerning the functioning of the societies. We are consequently dealing here with an inseparable pair, which it would be absurd to consider separately within the framework of a general history of techniques. Colin Renfrew once reminded us that invention is "the discovery by an individual of a new process or form, whether deliberately or by chance", whereas innovation "implies the widespread adoption of a new process or form".[1] Specifically, innovation can be conceived as the encounter between an already existing technique and a practical need.

Researchers have been more interested in innovation since it corresponds to the moment when the process or the form in question gets a significant importance in everyday life or in the economy. The degree of change it provokes enables to easily insert it into a deterministic reasoning or a simple causal chain. The growing use of wagon and animal traction in Mesopotamia has for instance been connected to the huge quantities of building material required to erect the first urban centres. The technique itself has often been in use for quite a long time, but its visibility being poor until it is turned into an innovation, the consequences are two-fold: first, it is hard to demonstrate its existence, and secondly its discretion gives the impression of a gratuitous character that often leads to consider it as an epi-phenomenon. In this respect, the invention of ceramic during the Upper Palaeolithic speaks for itself. Since it has no incidence on the material life of the societies concerned, it is almost all the time treated as a mere curiosity and not, unlike the bow or the spear thrower, as a milestone event in the history of techniques. In this paper, we are going to concentrate on that particular invention. In order to perfectly apprehend all its aspects, it was decided to consider it within the broad framework of the technical system of which it is part, and not on its own. We are going to see indeed that the invention of ceramic is but one of the symptoms of a far-reaching conceptual revolution.

2 Technical systems

What I call "technical system" is somewhat far from the common use of this expression, and a few preliminary explanations may be necessary. Contrary to Marcel Mauss who uses this expression to describe all the "techniques, industries and skills" of a given society,[2] or to the French school of anthropology for which these words mean the addition of all the techniques and their associated representations in a given society,[3] I recommend using this expression to refer to what Leroi-Gourhan called a "technical set",[4] in other words, within the technical range of a given society, a coherent set of interdependent techniques sharing all or part of their *chaînes opératoires* and forming a technical 'paradigm' of its own. It is commonplace to say that the various techniques do not display the same degree of proximity and that they can be organized in families. To take a simple example, the stone knapping technique, pyrotechnics and basketry belong to different technical spheres and hence must be examined separately. They did not occur at the same moment of human history and testify to various practical and cognitive abilities, as well as different modalities of the symbolic relationship to the matter. They are of course linked by symbolic connections within the world of representations. Relying for instance on the analogy of form between a weir basket and a vessel, the weir basket could be called a vessel intended to receive fish, and yet this metaphorical use does not change the fact that both objects refer to very different manufacturing processes and belong to independent technical systems. As a matter of fact, what unifies and weaves together all the techniques of a society cannot be found in the techniques themselves, but in the way they are symbolically perceived within its own symbolic system.

1 Renfrew 1978, 90.
2 Mauss 1947, 29.
3 Lemonnier 1983; Lemonnier 1986.
4 In french: « ensemble technique » (Leroi-Gourhan 1971 [1943], 39).

As a consequence I suggest saving the notion of "technical system" to the study of the techniques themselves, regardless of the representations which, for me, pertain to the analysis of the symbolic system. Of course, this does not question the close intertwining of both fields, the influence of representations on the technical choices and the strong feedbacks between technological change and social change. But for the sake of clarity and in order to avoid any confusion, a clear distinction between the two levels of analysis is necessary. The technique has to be analysed also for itself, and for this purpose we need specific concepts. Between the whole range of techniques used by a group and each technique considered individually, there is a gap which the notion of technical system can, in my opinion, effectively fill. It is better than that the notion of "technical set", which lacks references to the systemic dimension. It also allows giving an objective content to the fact that the technical range of the human groups is made of clearly distinct families, formed by related techniques sharing technical principles, portions of *chaînes opératoires* and the nature of the finished product. Ceramic, production of lime plaster and metallurgy have actually in common, aside from the technical traits we will later develop, that they all point towards the production of artificial or artificially recreated materials, which is obviously not the case for basketry or stone knapping.

If a generalized interdependence of the techniques used by a specific group can be observed in the realm of representations, that is to say the symbolic system, the technical interdependence takes place mostly inside the technical system. A technical system is thus a coherent set of interdependent techniques that share all or part of their *chaînes opératoires* and form a technical 'paradigm' of its own within the technical range of a society. The necessity to assume its existence, to acknowledge it as a research field on its own and to name it by a specific concept is particularly important for Prehistory, where the analysis of the occurrence, evolution and specificities of the various technical families is a major challenge. As we will see later, this approach is far from missing any symbolic dimension. Because of the lack of texts or direct contact, the way each ethnical group includes in a global symbolic system the representations associated with the various technical system used, remains out of reach of the prehistorians. Taking into account the symbolic dimension can only be considered through a phylogenetic point of view. What we have access to, as I hope this paper will prove, is what the occurrence of each technical system implies for the evolution of the symbolic relationship to matter, space and time.

3 Ceramic, bread, and the mixing-and-combustion technical system (MCTS)

The ultimate major technical system to be set up in the course of Prehistory is what I call the "mixing-and-combustion technical system",[5] or in a nutshell, the MCTS. Its occurrence dates back to the Upper Palaeolithic, a time for which, regarding major inventions, specialists in the history of techniques are more likely to evoke mechanisms such as the bow, the spear thrower or the eye needle. The two inventions that mark the appearance of the MCTS in the first half of the Upper Palaeolithic, namely artificial dyes and ceramic, are most often overlooked or, at least, underestimated. And yet, they represent a momentous evolution since, aside from the fact that they allow the domestication of matter to take a giant step, they result for the very first time in the manufacturing of artificial materials.[6] For brevity's sake, we will concentrate on ceramic, which moreover offers the advantage of having set off more publications than the dying process issue.

Both techniques call on similar *chaînes opératoires* in which mixing and combustion hold key positions. In these chains the key links are breaking totally from the former technical gestures, directed towards a modification of the form through a mechanical action on natural materials such as wood, bone or stone (knapping, abrasion, polishing, etc.). Their occurrence represents a major qualitative step forward, much more spectacular, in terms of the evolution of the cognitive abilities, than the invention of the spear thrower, which actually simply amplifies the arm's strength. We rise from the

5 Jeunesse 2008.

6 The well-known citation of André Leroi-Gourhan "The human act *par excellence* is perhaps not so much the creation of tools as the domestication of time and space" (Leroi-Gourhan 1993, 313) shows that the omission of the matter is shared by the most brilliant specialists of the history of techniques. The right formulation would, for me, end as follows: "[…] time, space *and matter*".

direct confrontation between the hand, the tool and a raw material picked up in the environment and whose intrinsic properties are not fundamentally modified by the treatment it undergoes, to an utterly new process which implies the use of fire and hence implementing a kind of energy different from the muscular strength. As far as ceramic is concerned, this action results in the simultaneous creation of both a form and a raw material unknown in nature. Grinding, mixing (thus creating alloys), kneading, modelling and baking are the main steps of this *chaîne opératoire*, one specificity of which is to necessarily go through a liquid and viscous phase. We prefer the MCTS notion rather than the pre-existing one of 'pyrotechnology', which gives an exaggerated importance to the action of the fire and would force to take into account technical processes which don't imply any mixing, such as, for example, heating the flint prior to knapping, a process which, though not completely unrelated to MCTS, belongs nevertheless to another technical system. The creation of new materials has a demiurgic dimension: for the first time man allows himself to substantially modify his environment through a process which is a matter of both hybridization and some kind of empiric chemistry.[7]

The MCTS does not include two other techniques that are sometimes compared to ceramic technology and presented as milestones of the history of the techniques requiring complex cognition. Processing pitch with birch tar, a technique already mastered by the Neanderthals[8] involves the use of controlled heat[9] but no mixing and, besides, does not lead to the creation of a new form, as is the case for all examples treated below. The same is true for the processing of compound adhesives, a technique first attested in the African Middle stone age, 70 000 years ago.[10] It consists in mixing resin, wax and ochre, but there is no combustion, heat being used only to accelerate the drying and, ago, there is nothing like the creation of a new form.

The earliest ceramics date to around 31 000 cal BC[11] and were discovered in several Gravettian sites from Moravia (Dolní Věstonice, Pavlov I, Petrkovice and Predmostí). The assemblages are composed of zoomorphic and anthropomorphic figurines (Fig. 1) that have been deliberately broken.[12] The use of the ceramic technique remains at that point limited to a small area; it did not last long and vanished without issue during the Gravettian period. A second, somewhat later (between 17500 and 15000 BP), series was recently discovered in Vela Spila, Croatia.[13] This assemblage is composed of 36 figurines, or fragments of figurines, part of which zoomorphic. Here again this is a temporary phenomenon, which is not subject to an expansionary dynamics and is dedicated to the sole production of figurines. The emergence of pottery in China is roughly contemporary.[14] The earliest ceramic artefacts from the Near-East are figurines as well, for instance those found at Mureybeth and dated to the second half of the tenth millennium.[15] In the latter case, the technique does not vanish after a while, as in Moravia and Croatia, but is there is a 2000 year gap between these figurines and the appearance of a real utility pottery, in other words the moment when ceramic gets the status of innovation.

In the Near-East, ceramic is not the first innovation depending from the MCST, and two building materials are concerned as well. First of all there is lime plaster,[16] proved to be present in a Natufian level from Hayonim cave (Israel) dated to the second half of the eleventh millennium.[17] Here again one can notice a huge gap between the invention in a pre-Neolithic context and the moment when the use of this new technique has become commonplace, lime plaster being commonly used in architecture only after 8000 BC, during the PPNB.[18] Secondly, there is daub, whose use has been attested as early as the eleventh millennium BC[19] in the eastern Al-Jazira province (Syria).[20] Both inventions refer to the same

7 For Gordon Childe, ceramic represents "the earliest conscious utilization […] of a chemical change", Childe 1936, 76.
8 Boëda et al. 1996.
9 Koller, Baumer, and Dietrich 2001.
10 Wadley 2005; Wadley 2010.
11 Bujda 2016, 62.
12 Vandiver et al. 1989; Verpoorte 2001; Farbstein and Svoboda 2007.
13 Farbstein, Radić, et al. 2012.
14 Kuzmin 2013; Wu et al. 2012.
15 Cauvin 1994, 48.
16 Lime plaster is obtained by the calcination and rehydration of calcium.
17 Kingery, Vandiver, and Prickett 1988; Thomas 2010, concerning lime plaster in the Natufian culture, see also Lengyel and Bocquentin 2005.
18 Aurenche and Kozlowski 1999, 109.
19 Aurenche and Kozlowski 1999.
20 Even though one cannot talk of real baking, since it hardens by natural drying, daub is the result of a mix and indisputably constitutes a new material.

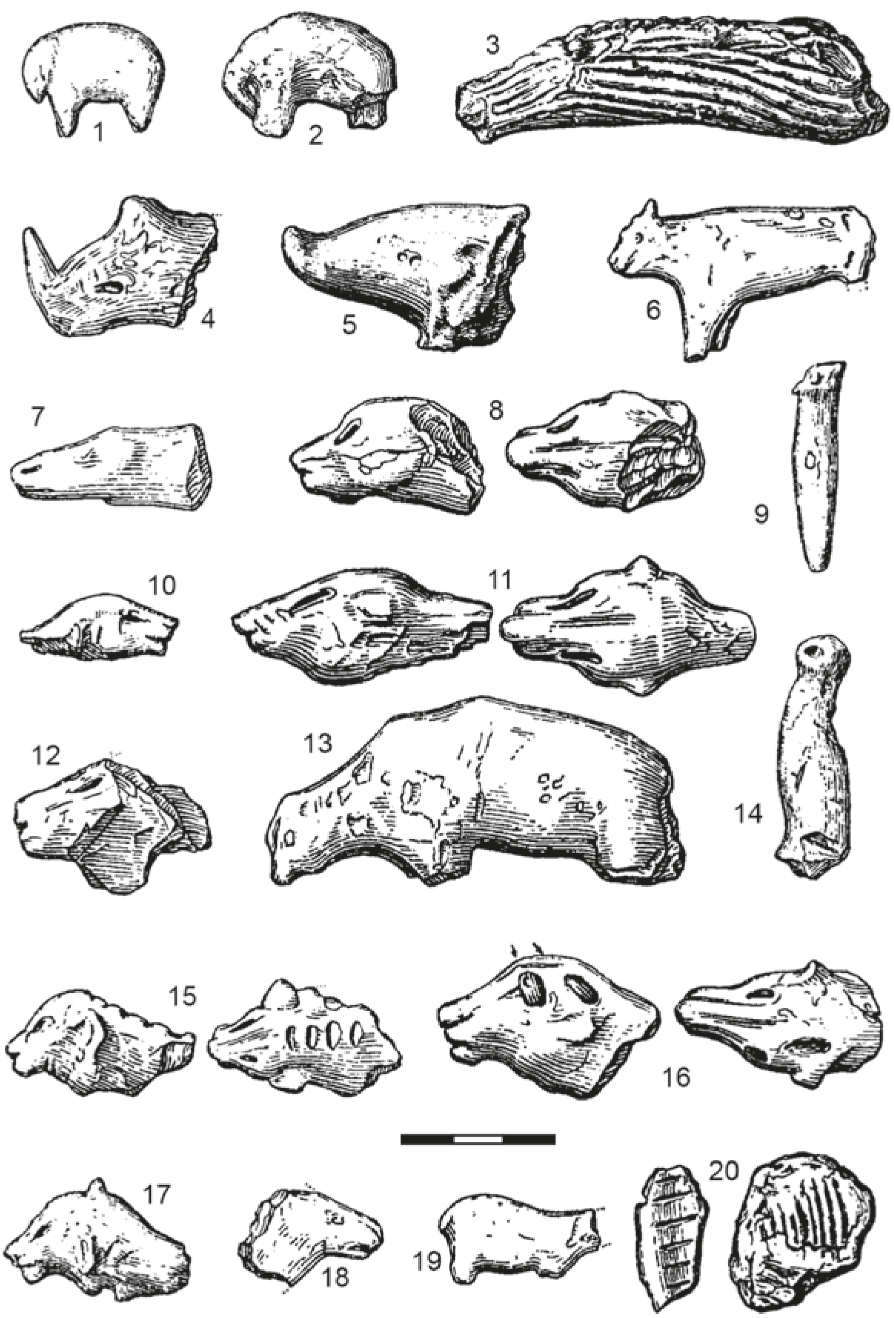

Fig. 1 Ceramic zoomorphic figurine from Dolní Věstonice (Moravia, Czech Republic).

technical system as ceramic; this system can be divided in several processes which all display more or less the same *chaîne opératoire* (even though the operations order differs slightly from one process to another) and share the same purpose, the creation of an artificial material. Same applies several millenniums later for the copper metallurgy, with the slight difference that in this case the aim is not to create a material unknown in the environment, but to artificially re-create an already existing material. The MCTS has also generated other applications that do not spontaneously come to mind, partly because the corresponding products are difficult to identify; for instance bread, which is an artificial material obtained through a series of gestures that reproduces almost identically that of the ceramic technique (grinding, mixing, kneading, modelling and baking). The elaboration of a new mate-

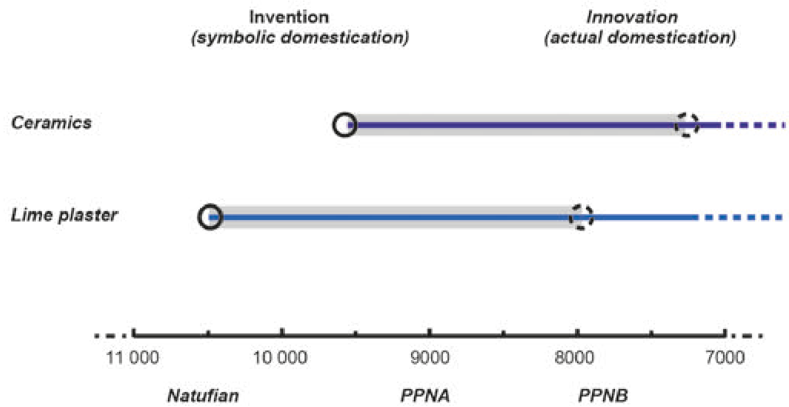

Fig. 2 The chronological gap between invention and innovation illustrated by two major inventions of the MCTS in the Near East.

rial is here completed by the creation of a brand new texture and taste, which makes us say that the MCTS can be considered as one of the sources of gastronomy.

These processes obviously refer to some kind of proto-chemistry,[21] and their appearance represents a giant's step in the process of the domestication of matter. The Palaeolithic birth of the technique they pertain to is often commented, yet its incidences on the general evolution of both the techniques and the relationships between man and the matter on the technical and symbolic levels have received few attention. Many authors consider it as a remarkable event indeed but they hardly ever say why. As the materialist and functionalist approaches prevail in the field of prehistoric research, invention is definitely less attractive than innovation.

4 From Palaeolithic inventions to Neolithic innovations

In Palaeolithic Moravia and Croatia ceramic was an ephemeral technique which disappeared rather rapidly without issue. In the Near-East, there are huge gaps between the first occurrences of the MCST related techniques and the moments when they are being more currently used to respond to utility needs, 2000 to 2500 years concerning ceramic and lime plaster (Fig. 2). The response to elementary needs thus takes place much later than the cognitive and conceptual step that marks the point of invention. From a strictly utilitarian point of view, the invention of ceramic in Europe and the Near-East looks gratuitous: it is not a response to a situation of shortage and does not reflect the will to improve the living conditions. As Jacques Cauvin once guessed, it leads the way to a symbolic domestication that precedes and prepares the actual domestication, directed towards the satisfaction of elementary needs.[22] Gordon Thomas is in the same spirit when he describes the invention of lime plaster as a "domestication of stone".[23]

In the Near-East, the gap between the first ceramic figurines and the appearance of a utility ceramic spans about 2500 years. Thinking in term of needs, nothing can explain why the time of innovation took place so late, or why it happened precisely near the end of the 8th millennium BC. The bearers of the Natufian culture (13 000–9500 BC), who were at least partially fixed, had to respond to the crucial problem of storing wild cereals and painstakingly manufactured stone vessels, would certainly have found it very useful to produce earthenware vessels for everyday needs. The same applies of course to the pre-pottery Neolithic communities from the 10th, 9th and 8th millenniums. If the shift from invention to innovation had been a mere question of opportunity, it would certainly have happened more rapidly. Assuming a specific innovation as the encounter between an existing technique and an emerging need is

21 Chemistry can be presented as "the science of transactions and material creations" (Gordon, Giullerme, and Maurel 2021).
22 "It all happens as if every important discovery, since it results from the mastery of a new material or of a brand new way of handling a usual material, would fill its first productions with such prestige that it would keep them for sectors more "valorizing" than the satisfaction of biological needs. That's why I think that every invention of this level goes at first through a "symbolic" time, and that this phase seems all the more necessary as this invention is at the end richer in revolutionary applications" (Cauvin 1978, 103).
23 Thomas 2010.

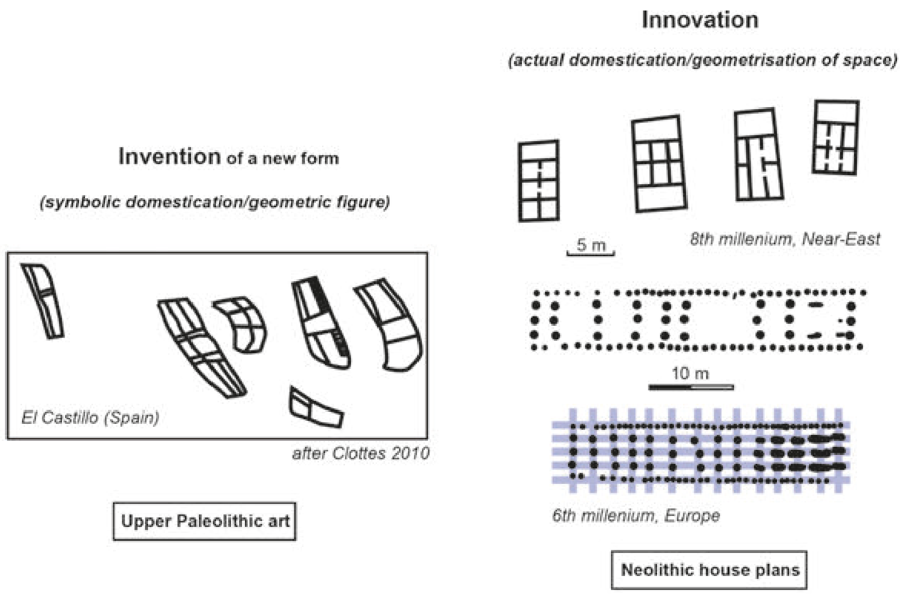

Fig. 3 Domestication of space. From the first geometric figures (Upper Paleolithic) to the geometrisation of space.

in this case indefensible. It seems more realistic then to consider the gap between invention and innovation as the necessary time range for the complete fulfilment of the symbolic domestication. It all happens as if the transgression which lies behind the use of the new technique was at first conceivable only in a ritual context, and as if its trivialization could take place only after a long and necessary gestation period.[24]

The great inventions based on the MCST have in common a Palaeolithic or Epipalaeolithic age. They consequently originate in the hunters-gatherers' world. The same applies to animal domestication, known to have begun with the dog in the second part of the Upper Palaeolithic. The neolithization process in the Near East is in fact nothing more than the gradual transformation of these great Palaeolithic inventions into innovations. Neolithic is in a way the accomplishment of the dreams made by the anonymous inventors from the Palaeolithic. It has been long acknowledged that ceramic, lime plaster, the earliest domestic animals and the first attempts at geometrizing the space (domestication of matter, life and space) are not Neolithic *inventions*. It cannot be stressed enough that their turning into *innovations* represents the very essence of the neolithization process.

In the case of the domestication of space, the appearance of orthogonal house plans around 8500 BC, is nothing but the concrete projection (actual domestication) of an ideal geometry (symbolic domestication) invented by the Palaeolithic cave painters at least 10 millennia earlier (Fig. 3). Like the first ceramic of Moravia, Croatia and the near-East, this invention of a new form without equivalents in the environment took place in a magical-religious context.[25]

5 Conclusions

Long before any use for an economic purpose, the new technical system appears in a world where technique and religion are tightly intertwined. We all know that a ritual is more efficient with the implementation of sophisticated techniques. This process is usually considered as the appropriation of various practices or techniques borrowed from the 'serious' world of the ordinary production for the benefit of the religious sphere. The study of the Palaeolithic inventions made us favour the opposite approach: the new techniques are in fact elaborated within the crucible of the ritual, being much later at the source of 'secular' applications. The conceptual revolution truly takes place before the economic revolution.

24 René Girard has shown that invention (for which he uses the word "innovation") was till the 18th century, in the western world, "practically synonymous with heresy" (Girard 1990, 7).
25 Jeunesse 2008.

Through the example of the Gravettian figurines from Moravia, we clearly see that the emergence of the MCTS cannot be distinguished from the creation of imaginary worlds, of which the Palaeolithic art gives us a reduced picture. Materials and forms still unknown in the environment are elaborated in the same 'workshop' as the mythological ideas which form the substance of these parallel universes. At that point, ceramic as a material cannot be dissociated from the forms it enables to model. One does not produce ceramic 'ingots,' but figurines whose production itself is obviously part of a ritual. And it is precisely in the ritual that we must look for the driving force of the inventions which accompany the various forms of the symbolic domestication of the environment. It favours the emergence of new processes and materials, yet at the same time it confines them within the narrow limits of the sacred, from which they will be able to escape much later, after a very long gestation period, that is to say the gap between invention and innovation. Concerning the earliest great inventions based on the MCTS, they all emerge within the Upper Palaeolithic. Their desanctification, which later leads to the actual domestication of matter, will be a Neolithic business. The MCTS represent thus far more than just a new technical system and its importance in the evolution of technique in Palaeolithic times has to be reassessed. The concept of "technical system" is for me one of the tools that will facilitate this goal.

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Before Weighing

Summary

This paper presents some prefatory considerations concerning the emergence of weighing. Hardly any other technique has more permanently influenced the development of early civilizations than weighing. Using scales and weights, things could be compared in an entirely new way. Equivalencies measured and expressed as the weight of precious metals created the preconditions for a new method of estimating value and facilitating exchange. This set the course for historical developments that continue to have effect even today.

Keywords: weighing; weight; scale; value; exchange

In diesem Beitrag werden einige grundsätzliche Überlegungen zur Entstehung des Wiegens angeführt. Kaum eine andere Technologie hat die Entwicklung früher Zivilisationen so nachhaltig beeinflusst wie das Wiegen. Mit Hilfe von Waagen und Gewichten konnten Dinge auf eine völlig neue Weise verglichen werden. Äquivalenzen zu Edelmetallen gemessen und ausgewiesen durch Gewicht, schufen die Voraussetzungen für eine neue Methode, der Wertbestimmung die den Austausch von Gütern erheblich erleichterte. Damit waren die Voraussetzungen für historisch ökonomische Entwicklungen geschaffen, die bis heute nachwirken.

Keywords: Wiegen; Gewicht; Waage; Wert; Austausch

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1 Introduction

Today, we find ourselves deeply entangled in a reality so profoundly informed by weighing and its immediate and more remote consequences that it is difficult to perceive of a situation in which weighing is unknown. Arguably, this provides an explanation of why most historical accounts of the development of weighing are perceived from the end. It is often uncritically presumed that the intention to measure weight, that is, to weigh objects, must account for the emergence of weighing.

This position is incongruous, if not paradoxical, as will be argued in the following. It insinuates that weight measurement was a problem-driven innovation. The fallacy it entails lies in the unreflected assumption that what is solved from a post-fact perspective, namely, the quantitative determination of weight with respect to a universal, arithmetical weight scale, can be perceived as a problem largely independent of any concretely given material and conceptual preconditions.

This view is replaced here with an understanding of the act of weighing as a complex technique, which could not have been an instant innovation created from nothing to answer the problem of weight measurement. According to all evidence, the technique of measuring the weight of objects by means of a balance scale and balance weights, representing the units of an established weight system in place, first emerged around 3000 BC, as will be detailed below. It will be argued that weighing must have been preceded by other techniques, without whose mediation the development of weighing in the more restricted sense of measuring weight would have hardly been possible. A hypothesis as to the stages through which weight measurement developed is presented here. According to the position argued, the quantitative determination of weight rather than the incentive must be considered the result of this innovation process.

Focusing on weight measurement, that is, on the quantitative determination of weight, should not be mistaken as an attempt to universally and ahistorically define what weighing is. Today the term weighing is usually understood to refer to the quantitative determination of mass rather than weight.[1] In this article, the conception of weighing as a fundamental technique without pertinent predecessors, which historically is either given or not, is dispensed with. Instead, weighing is used as the genus name for a sequence of historically evolving practices or techniques. These techniques are related to each other by a developmental logic, that is, prior stages are among the factors accountable for the emergence of later ones. From this perspective, weight measurement can be viewed as a particular stage of this development, and referring to this stage as the inception of weighing is revealed as a convention.

Yet the specific question of how weight measurement emerged is justified. Not because weight measurement can be attributed with a particularly pivotal role in a broader perception of the development of weighing. Rather, the quantification of weight with reference to a weight system of sufficient synchronic penetration can reasonably be expected to have left a uniquely identifiable trace in the archeological and historical records. For reasons to be discussed below, the same must not necessarily hold true for techniques which, according to the hypothesis presented, likely preceded weight measurement, evidence for which can be expected to be indirect at best.

2 The origin of weight measurement

All evidence currently available points to an origin of weight measurement in Egypt.[2] The earliest object classifiable as a weight and dated with relative certainty, as well as – according to present knowledge – the earliest surviving balance scale, both come from Egypt. Notably moreover, both can be dated to roughly to the same period.

The identification of objects as balance weights is fraught with difficulties. The presence of several objects of the same weight in one find context, for instance, cannot be taken as evidence of a weight system, and not even

1 The distinction between mass and weight, i.e., the force exerted on a body by the gravitational field of the earth, was made only in the seventeenth century. We have no sensory perception of mass, but perceive weight as heaviness. Though gauged to show mass, modern balances usually measure weight. When talking about weighing in this article, I refer exclusively to the determination of weight.

2 I am deeply indebted to David Warburton with whom I have conducted a study of the development of weighing in Egypt. A substantial article is in preparation from which a number of passages have been taken over almost verbatim here.

as evidence for the existence of balance scales, as has occasionally been done. Equality in weight, for instance, can also be the contingent result of a division according to equal size.

To avoid false positives, Lorenz Rahmstorf has developed a list of criteria to be applied when attempting to identify objects that are assumed to have served as balance weights.[3] Based on these criteria, an Egyptian piece of quartzite on which the name of King Narmer is inscribed is presently regarded as the oldest object clearly identifiable as a balance weight, while at the same time being securely datable. Indeed, the spelling of the name is typical of the time and thus the weight should date to the reign of Narmer around 3100 BC (Fig. 1).[4]

Fig. 1 Piece of quartzite inscribed with the name of the king Narmer weighing 1750 gramms.

The earliest balance scales have received far less attention than the weights.[5] A small scale made of brown limestone, today part of the permanent collection of the Petrie Museum in London, is commonly referred to as the earliest surviving scale (Fig. 2, left). Some authors have placed this scale in the fifth millennium, a dating that still continues to haunt popular accounts of the history of weighing.[6] The scale was acquired by Flinders Petrie whose only comment was to the effect that the piece was made of "a material often used in Prehistoric Egypt but seldom later." Petrie's notes give rise to the assumption that the scale comes from Upper Egypt, possibly from the region between Abydos and Naqada where the large cemeteries of the Predynastic and Early Dynastic periods can be found. The missing evidence of writing and administrative structures, however, argue against a Predynastic dating. Where exactly the scale originated from will probably remain unknown. When one supposes that it was a burial object in an Early Dynastic tomb, its localization in Upper Egypt, at a time before the main cemeteries of the elite were relocated to Memphis, is plausible.

Doubts as to whether the object in question actually served as a balance at all are removed by the currently earliest known representation of a balance scale. This representation is part of the decoration of the tomb of Hesyre, a high official of the Third Dynasty. On the walls of the tomb, several chests are depicted that contain experts' tools and instruments. Two of the chests contain two scales, each with their associated sets of weights (Fig. 2, right). The scales in the depiction are virtually identical to Petrie's scale, lending additional support to its dating to the Early Dynastic period.

The designation of Egypt around the turn from the fourth to the third millennium as the place and time of the emergence of weight measurement is attended by the usual caveats. As a rule, a technology becomes visible in the archeological records only once it has reached a certain penetration of the relevant cultural domains. New archaeological evidence may surface at anytime and, given the rather poor state of research on weighing, relevant evidence may indeed already be present in the inventories but have so far been overlooked.[7]

There is little reason to assume, however, that future research will substantially alter the overall picture. Weight measurement became available in an intensely

3 See Rahmstorf 2006.
4 Egyptian chronology is a notoriously debated matter. The absolute datings given in this article follow Krauss, Hornung, and Warburton 2006.
5 This and the following paragraphs have been adopted from my contribution to Hansen et al. 2016.
6 Jenemann 1992 has meticulously reconstructed the origin of the dating of the Petrie balance to the fifth millennium. Quite amusingly a presentation board in the Science Museum in London thereby apparently played a decisive role in generating this misconception.
7 This of course is not to devalue the excellent individual contributions to the topic, such as those by Rahmstorf or Michailidou cited in this article.

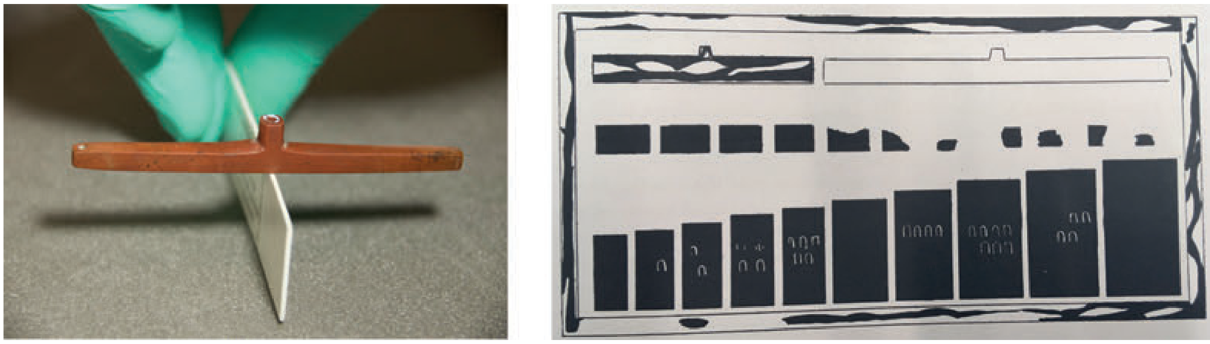

Fig. 2 Left: Balance beam from Egypt, probably dating to the late 4th or early 3rd millennium. Right: Depiction of a box containing balance weights and two balance in the tomb of Hesire, a high official of Dyn. III (ca. 2600 BCE).

communicating world which began to document and control its exchanges with the help of early bureaucracies. It was the administrative structures of the early city-states that made the implementation and guarantee of required standards possible in first place and thus helped to ensure the successful implementation and spread of weight measurement. Weight measurement swiftly became the prerequisite for a new way of valuation, simplifying exchange. In effect, it transformed the Bronze Age world. Once in existence, weight measurement spread rapidly and by the mid-third millennium we find balance scales, weights and weight systems virtually everywhere, from the Aegean to the Indus valley.[8]

An integrated history of weight measurement as a socio-technique, deeply intertwined with various domains of cultural activity and its momentous and far-reaching consequences, remains to be written. What this article will focus on in the following is not the history but rather the prehistory of weight measurement, which, as already indicated, is not usually considered. The emergence of weight measurement is commonly seen rather as a conceptual leap, whereby the necessity to measure weight led to the creation of weight measurement. A number of arguments can be adduced against this view of weight measurement as a problem-driven, radical innovation, that is, an innovation characterized by the high degree of technical differences when compared to previous innovations.[9]

3 The prerequisites of (weight) measurement

To begin with, perceiving weight measurement as a problem presupposes an understanding of weight as an extensive and quantifiable physical quality. Such an understanding of weight, however, is apparently not innate in humans and thus cannot be simply supposed to be present, in particular in cultures that have not yet developed the technique of weighing. One of the roots of this claim lies in developmental psychology where it is backed by empirical studies. Developmental psychologists in the tradition of Jean Piaget have long studied the formation of fundamental concepts such as quantity, number causality and also weight in the cognitive development of children. According to Piaget's theory, cognitive development proceeds through a number of distinguishable stages based on the experience gained by a child in its interaction with the world.

Characteristic for the empirical study of concept formation in this tradition are so-called conservation tasks, which test a child's ability to see that a particular physical property is conserved or invariant after an object has undergone certain transformations. Among the conservation tasks already proposed by Piaget himself are some concerning weight conservation.[10] More concretely, children are tested to see if, or better when, they start to assume that weight, as a characteristic property

8 Concerning the spread of early weighing technology, the reader is referred to the work of L. Rahmstorf, in particular Rahmstorf 2006; Rahmstorf 2010; Rahmstorf 2011b; Rahmstorf 2011a. Whether weight measurement was developed independently in the Indus valley culture of the Bronze Age, or whether it arrived there by diffusion, is an open question.

9 An instructive discussion of the concept of radical innovation, including bibliography, can be found in Murmann and Frenken 2006.

10 See in particular Piaget and Inhelder 1975.

of matter, distinct in particular from bulk, is conserved under first, changing the form of an object and second under the division of an object into parts. In Western societies, children generally build up a conservation expectation for both cases between the ages of eight and nine.

According to Piaget's own theory, the development of the concept of weight is primarily due to the inner dynamics of cognitive processes and should hence progress more or less universally through the same stages, resulting in the same concept of weight in individuals of different cultures. Alternatively, it has been assumed, and this assumption is shared here, that the formation of a concept of weight may hinge on culturally specific experiences and therefore differences should potentially be observable in cross-cultural comparative studies.

Weight conservation tasks formed part of a study by Katja Bödeker in which the development of intuitive physical thinking in Berlin preschoolers was compared to that in children from the Trobriand Islands.[11] The use of balance scales is uncommon on the Trobriand Islands so therefore questions concerning how and if the practice of weighing contributes to the formation of a concept of weight could be addressed. In the study, noticeable differences with regard to both cognitive content and the development of the concept could be observed. For instance, only about 50 percent of the unschooled adults interviewed assumed conservation of weight under partitioning, and not a single individual assumed that weight would be conserved under deformation.[12]

That someone endowed with such an understanding of weight could reasonably develop the idea to measure weight is hardly conceivable. Indeed, if weight is not conserved under partitioning then no (easily quantifiable) relation between the whole and its parts exists and it becomes difficult to perceive how weight could be quantified meaningfully at all.[13] On the other hand, if weight were not conserved under deformation, then weight measurement would be possible in principle but deprived of its relevance for all practical purposes as in order to meaningfully compare objects by weight, these objects would have to be brought to always assume the same shape before the measurement, thus essentially reducing the problem of weight measurement to that of volume measurement.[14]

Conferring results of cognitive anthropology to early societies is problematic, and it is not claimed here that humans five thousand years ago had a concept of weight comparable to that found today in a particular group of people on the Trobriand Islands. Instead, what the example underlines is that an understanding of weight according to which weight is a quality prone to quantification in measurement is not innate and thus can in no way be universally presupposed.

The example given, moreover, draws attention to the specific practices and experiences potentially leading to a concept of weight against which weight measurement can indeed be perceived as a meaningful technique. As will be detailed below, weight judgments based on our sensory apparatus alone are insufficient and it can be presumed that the relevant practices involve specific material artifacts not universally available in every culture. Such practices may of course differ widely in different cultures at different times, and what these practices were when weighing first emerged remains open.

Upon closer inspection, weight measurement, as performed at least since the turn of the fourth to the third millennium, turns out to be a more intricate technique than initially assumed. Weight measurement integrates different operations in a specific combination. Closer analysis insinuates that the concrete realizations of the required individual operations and their specific combination constituting early weight measurement are very unlikely to have been achieved contemporaneously

11 See Bödeker 2006.

12 Concerning the differences observed, Bödeker states: "Die quantitative Differenzen in Inhalt und Entwicklung, die für zwei der untersuchten Konzepte […] auftreten, lassen sich durch den Einfluss kultureller „Mittel" auf die konzeptuelle Entwicklung erklären. Am deutlichsten waren die Unterschiede zwischen den Kulturen beim Gewichtskonzept", Bödeker 2006, 373.

13 Additivity is not a necessary requirement for measurement. As Stevens writes: "Physical addition, even though it is sometimes possible, is not necessarily the basis of all measurement. Too much measuring goes on where resort can never be had to the process of laying things end-to-end or of piling them up in a heap", Stevens 1946. Measurements that are based on procedures satisfying the condition of additivity are sometimes referred to as fundamental measurements, and it is this type of measurement that we are exclusively concerned with here. For an excellent introduction into the philosophy of measurement, see Tal 2015.

14 From a post-factual perspective, it is precisely the invariance of the weight of bodies against a broad spectrum of physical changes preserving matter that can be held accountable for the success of weighing.

as a radical innovation. The analysis rather insinuates that the different constituents emerged successively and, moreover, a concrete sequence is suggested. Comparison of weight measurement to the techniques of length and volume measurement, which developed earlier, proves to be instructive.[15]

Measurement can be defined in the broadest sense as the assignment of numerals to objects or events according to rules. The assignment happens by way of concrete empirical operations, which usually but not necessarily involve some sort of mediation by material resources.[16] From such an abstract perspective, early length, volume and weight measurement follow the same scheme: An object to be measured is exhausted by the appropriate composition of a measure. The measure need not to be of the same kind as the object measured, but merely endowed with the quality in question. Through measurement, the ratio between the magnitude of the quality in the measure, and that of the same quality in the object being measured, becomes known and, assuming the measure to be the unit, can be expressed as a number. In the measurement of length, volume and weight, we can thus in principle distinguish between the operation of composition and the operation of comparison. The comparison operation serves to determine whether the composite matches the object measured in the relevant respect, that is, whether the object has been exhausted by the composition operation.

As far as length measures are concerned, in principle any extended object can be used as a measure. In view of the concrete operation of composition, in which the measure is successively transposed in space to, as it were, line up with itself, or more precisely, with its own prior position, certain objects are more appropriate than others.[17] Objects that have one or more distinctly discernible axis and well-defined borders are preferable. Such objects are universally given, for instance, as sticks, or even in the form of body parts such as the foot, hand or finger. If used for measuring length, such objects, besides being the measure, can also be addressed as the measuring instruments, at least in the restricted sense that they facilitate the composition operation by way of their own special properties. In contrast, no special instrument is needed for the comparison operation.[18] Congruence of the result of the composition operation with the object measured, or the lack thereof, can typically be judged by visual inspection alone.

What applies to length measurement applies in a similar fashion to volume measurement, at least for bulk material or liquids.[19] Any container can be used to successively remove portions of equal volume from the bulk material until it is depleted. In this case, the identity of the individual portions of the measure is guaranteed by the concrete operation. Thus, the capacity of the container is the measure, while the container itself also serves as the instrument of the composition operation.[20] Appropriate containers are not universally given but became available in cultures long before weighing.[21] As in the case of length measurement, no special instrument is needed for the comparison operation. In all practical contexts, whether the bulk material is exhausted by the comparison operation or not can be immediately perceived by the senses. In both cases, moreover, the concrete actions making up the composition operations are essentially familiar from other contexts, for instance, the laying out of bricks of equal size in a row over a given distance, or the use of one and the same container to successively take away equal portions from a given supply or else to fill a larger compartment such as a silo. In their simplest forms, length measurements and volume measurements for bulk materials thus pose relatively few demands on the concrete actions to be performed or on the material resources used.

In the case of weight measurement the situation is fundamentally different. Weight measurement already in the earliest form we encounter involves a highly specialized instrument. The instrument used is a mechanical lever balance in which a rigid beam is allowed to turn

15 "I judge the […] weight system to be the youngest of the three primary systems of metrology, i.e., length, capacity, and weight", Powell 1971, 208.

16 Cf. Stevens 1946.

17 Utilizing this procedure is of course based on implicit preconditions, in particular: "Wenn zwei Strecken einmal und irgendwo als gleich befunden sind, so sind sie stets und überall gleich", Einstein 1921. For the relation between early measurement of length and concepts of space, see Schemmel 2016.

18 A length measuring instrument that instrumentally supports the comparison would for instance be the Vernier calliper.

19 What counts as a bulk material, which, can be measured by volume depends of course on the concrete practice. Thus, we have evidence, for instance, that fish was bartered in baskets in the Uruk period. See Cancik-Kirschbaum and Chambon 2006, 202.

20 In a sense, material measures are produced with the help of the container as the reference capacity and it is the concrete operation that ensures their constancy and identity in the procedure.

21 See H. Piezonka in this volume.

around a point of suspension that divides the beam into two equal parts. The weight of the item to be weighed on one arm of such an equal-armed balance is compensated (exhausted or, literally, "balanced") by the identical weight of one or more standardized balance weights placed on the other arm of equal length. In the simplest case, all balance weights represent the same measure, that is, they are all equal in weight. The weight of the goods weighed can then be specified with reference to the measure by simply counting the weight pieces that have been added to achieve equilibrium. Balances changed over time but their operational principle, and thus the technique of weight measurement, remained the same for roughly the first three thousand years in the history of weight measurement.[22] Essentially, the same technique is still being practiced today and is familiar to the modern reader, though it is certainly in decline.

Not only is the balance a highly specialized instrument, which, as opposed to stick and container, could not have been simply selected among the objects universally or culturally given in the period in question. It fulfills a quite different function with regard to weight measurement than does the stick or bowl with regard to length and volume measurement respectively. What the equal-armed balance as a material resource of weight measurement primarily mediates is not the composition but the comparison operation. It reacts mechanically to the condition of weight equilibrium and thus makes fulfillment of the weight exhaustion condition susceptible to visual inspection.

Thus, the equal-armed lever balance is first and foremost not an instrument for measuring but for comparison. In this sense, it has to be distinguished from modern balances which are instruments that weigh in a quite different manner. Modern balance scales reify the different operations making up weight measurement.[23] To signal this difference, in the following I refer to the equal-armed balance as the comparison balance or, more generally, as a weight comparison instrument.

The use of a comparison balance for the purpose of weight measurement presupposes the accomplishment of the corresponding composition operation. At first sight, this may appear utterly banal as it requires the mere assembling of objects of equal weight in one location, that is, on a scale pan. However, objects of equal weight are not given trivially. They may be produced, for instance, by fabricating objects of identical shape and size from the same homogeneous material.[24] Yet whether the objects thus produced indeed satisfy the requirement of weight equality, and thus represent the same weight measure, ultimately can only be controlled by means of the comparison balance.[25]

This double role of the comparison balance for weight measurement – as the comparison instrument and as an indirect prerequisite for the composition operation – provides another argument against the assumption that weight measurement emerged from scratch as a problem-driven solution, that is, without the mediation of any relevant predecessor techniques. Where would someone hypothetically trying to solve the problem start? From the balance? Hardly, because the balance is meaningful for weight measurement only if appropriate weight measures are given. From the weight measures? Hardly, because they require a balance as the precondition for their selection or fabrication.

4 Weight comparison before measurement

A way out of this vicious circle lies in recognizing that weight comparison is a meaningful practice outside and before weight measurement.[26] Practices encompassing weight comparison can account for the emergence of the comparison balance, as will be argued, and in turn comparison operations with this balance can account for the emergence of weight measurement. Unlike weight measurement, which implies an understanding of weight as

22 For the concept of operational principle, see Polanyi 1997.

23 For the idea that material resources reify human actions, understood as partial technical functions, see Ropohl 2010.

24 An interesting case where the production of standard weights seems to be mediated by their geometrical shape and size, and thus ultimately by volume, are the Harappan cubical stone weights. See, for instance, Ratnagar 2003.

25 Until the introduction of the spring balance in the eighteenth century, where the weight is compensated by an elastic force, all balances operated on the principle of weight (more correctly momentum) compensation and thus weight comparison as the basis of weight measurement indeed remained without alternative for almost 5000 years.

26 I am of course not the first to hold the view that the "invention of the balance scale with two pans perhaps preceded the invention of weights", Michailidou 2001, 54.

an extensive property that can be quantified, an understanding of weight or heaviness according to which the weight of an object can be smaller, equal to or larger than the weight of another object suffices as the basis for weight comparison as a meaningful constituent of different practices.

Studies in psychophysics show that, based on our sensory apparatus, we can in fact tell reasonably well whether two objects are equal in weight and order them according to their weight if they are not found to be equal, that is, we can judge which of two objects is heavier. The human ability to compare weight differences, that is, our ability to tell if the weight difference between two objects is smaller, equal to or bigger than the weight difference between two other objects, is restricted and so is our ability to judge the weight ratio between two given objects, that is, to judge, for instance, if an object is twice as heavy as another object. However, it is precisely the latter two types of judgments, which from an abstract perspective, distinguish weight measurement from weight comparison.[27] Thus weight, with respect to our sensory perception alone, does not become visible as an extensive magnitude. Our perception of weight rather resembles that of, for instance, loudness or temperature.

Our ability to distinguish objects by and order them according to weight necessarily results in experiences in which weight comparison is implicit, for instance, when carrying two objects. This will quite universally lead to actions which from our perspective can be described as explicit weight comparison, such as choosing the lightest to carry or the heaviest to keep when lifting two objects. Such explicit weight comparisons are not ends in themselves but fulfill a particular function in more extended practices or techniques.

Studies in psychophysics show that our ability to detect weight differences, also referred to as the just-noticeable difference, underlies certain restrictions.[28] The just-noticeable weight difference, like a large range of other physiological sensations, obeys a Weber law; it is, for a wide range of stimuli roughly proportional to the size of the stimulus. Thus, in absolute terms, our ability to distinguish between two weights diminishes with the increasing weight of the objects being compared. Moreover, Weber fractions for weight comparison are rather high. They typically range in the order of magnitude of 10 percent, that is, when comparing two weights, each of for instance roughly one kilogram, on average we are able to detect a difference only if it exceeds 100 grams.[29]

Sensory weight perception is also affected by additional factors. For instance, it not only depends on proprioceptive (force on muscles) cues but is also mediated by cutaneous perception, that is, perception of pressure on skin. Hence, of two objects of equal weight, the one that has the smaller contact area will usually be judged the heavier.[30] Sometimes perceived heaviness seems to be entirely incommensurable, for instance, when comparing a small lead ball with a fold of cloth. Furthermore "the perceived heaviness of an object can be drastically affected by its [other] physical properties." Thus when comparing objects of different size but equal mass, people tend for instance to underestimate the weight of the larger object, a phenomenon known as size-weight illusion.[31] Even color has been shown to have a slight effect on perceived weight.

From a modern perspective, it is therefore obvious that the limits of our sensory perception of weight put a limit on the practices in which weight comparison by means of our body alone can be meaningfully applied. With regard to the comparison of small weights, for instance, our ability to discriminate by size has been shown to be more superior under appropriate conditions than our ability to discriminate by weight. In a recent study, test subjects were able to "discriminate differences in carob seed weight of around 5% by eye."[32] In view of the fact that the average weight of a carob seed is about 2.5 mg, this far surpasses the results achievable by direct weight comparison.

It can thus be conjectured that the introduction of a weight comparison instrument was contingent on certain practices, which encompassed weight comparisons and which developed in such a way that the limits of sensory weight perception could start to be perceived as

27 Cf. Stevens 1946.

28 For a survey see Jones 1986.

29 Different ways of arriving at weight judgments have been tested in the literature, such as successively lifting an object in one hand or holding it in both hands. Weight judgements based on active lifting have been shown to be somewhat superior to passive holding, yet the Weber fraction hardly moves below 3 percent. Cf. Jones 1986.

30 Cf. Bergmann Tiest, Lyklema, and Kappers 2012.

31 The classical reference is Charpentier's1891 paper on the size-weight illusion republished in translation with helpful notes and comment. Cf. Murray et al. 1999.

32 See Turnbull et al. 2006.

Fig. 3 Iconographical interpretation of the body as a balance; tomb of Kairer, ca. 2300 BCE. Anachronistically this can be understood as reflecting the origin of weight measurement in weight comparisons based on human sensory weight perception.

limiting practice (Fig. 3). Thus, the onset of systematic alloying in the fourth millennium may for instance have substantially raised demands on the accuracy of the comparison of the weight of source materials.

Accuracy, however, is not the only limit that weight comparison by unmediated sensory perception may run into. Weight comparison judgments are difficult to objectify, especially in view of the multiple influence factors mentioned above. Under the drastically changing social conditions, in particular in second half of the fourth millennium, certain practices involving comparison by weight, possibly the rationing of certain commodities by weight, may have successively posed higher demands on the intelligibility of the underlying operation and thus the degree of intersubjective agreement that could be reached. It is noteworthy in this context that, as mentioned above, the equal armed balance makes the condition of weight equilibrium susceptible to visual perception and can therefore be understood as an instrument that, besides making it more accurate, renders weight comparison more objectifiable.

At best, the concrete examples given above remain educated guesses. Contextualizing the innovation of weighing calls for the scrutinizing of evidence for practices in which non-instrumentally mediated weight comparison may have played a role, and to explore whether these practices may have undergone a development that created the necessity for a new way of comparing weights.

This is not meant to imply that in the case of the weight comparison instrument necessity was the mother of creation. In line with the general stance taken in this article, the emergence of a weight comparison instrument, rather than a necessity or problem-driven invention, can likewise be conceived as the result of a less directed, that is, a non-problem-driven exploration of the potential of existing techniques. Both positions are not mutually exclusive but must be understood as marking the extremes of a continuous spectrum. Thus, necessity certainly reinforces the process of creation and, moreover, could explain why a weight comparison instrument, once available, would assert itself and quickly spread.

Candidates for techniques involving mechanical contrivances from which a weight comparison instrument may have developed are ones that embrace the establishment of equilibrium. A technique to which this applies is the carrying of loads by means of a shoulder or carrying pole. The shoulder pole is a carrying instrument, yet in order to facilitate its primary function, the weight of the load carried is distributed in such a fashion that equilibrium is reached. The technique of carrying by shoulder pole is testified for many cultures and is presumably very old. The earliest evidence known to

Fig. 4 Left: Depiction of a stand Balance in the tomb of Mahu, Dyn. V or early Dyn. VI. Right: Carrying loads by shoulder pole in modern day China.

the author, however, postdates the onset of weight measurement.[33]

Carrying by shoulder pole makes new experiences possible regarding weights in equilibrium and indeed only a slight modification allows the shoulder pole to be put to new use. Thus, it could have provided a model for the technical realization of a comparison balance, as has already been claimed, albeit rather uncritically.[34] Evidence for the development of the shoulder pole into an early weight comparison instrument, however, is very indirect at best.

Shoulder poles are still in use in different parts of the world today and often use baskets as containers for the goods to be carried. Some of the earliest depictions of balances preserved from Egypt show balances that are likewise equipped with baskets attached to hooks. Thus, these baskets were not yet an integral part of the instrument. For weighing, this solution is unfavorable and was soon replaced by scale pans as a fixed component of the instrument.[35] The baskets of these early balances could thus potentially be interpreted as typological rudiments of a prior stage of development, and the instruments depicted are indeed remarkably reminiscent of the carrying devices still in use today, as illustrated in the figure below (Fig. 4).

In the anglophone world, the shoulder pole is also referred to as the milkman's yoke and its morphology often resembles that of a yoke. Strikingly, the ancient Greeks and Romans referred to the balance beams of equal armed balances by the very term they used for the yoke. Both languages developed much later than the comparison balance, and the terminology is more likely to reflect morphological similarity than common ancestry. Yet the example urges us to exploit all linguistic clues, where available, when attempting to contextualize the innovation of weighing.[36]

Finding direct evidence for instrumentally mediated weight comparison before weight measurement may prove difficult, if not impossible. Predecessor instruments to the equal armed balance may not have been permanent structures, for instance, they may have resembled a see-saw, constructed for operation and then dismantled again. The parts preserved separately, if at all, would likely not bespeak their original function as parts of a weight comparison instrument. From the moment such instruments assumed a configuration comparable to that of the equal armed beam balance, we are no longer able to tell, based on inspection of the instrument itself, if it was used exclusively for weight comparison, or already served as an instrument for weight measurement.

33 For evidence of the shoulder pole in China and its possible relation to the development of weighing technology, see Zhang and Renn 2006, 3–4. Needham has remarked that the "balanced shoulder-pole […] appears in Mesoamerica comparatively late" and has indeed proposed an investigation of weighing techniques used in the Amerindian cultures in connection to this, Needham and Lu 1985, 40.

34 See, for instance, Stecchini 1961.

35 Michailidou 2008 presents ethnographic evidence of non-metallic scale pans.

36 The Greek *zygón* as well as the Latin *iugum* for yoke can both likewise signify an equal armed balance. See Rohmann 2017.

5 From weight comparison to proto-weighing

A plausible scenario as to how weight measurement developed from weight comparison with the comparison balance as a catalyst is suggested. In the most elementary case, weight comparison applies to two directly compared objects of the same kind. Repeated operations of this type reinforce the perception that smaller, equal and greater in weight are transitive relations and thus open up the possibility of comparing two objects by means of an appropriately chosen third object which, due to the function it serves will be referred to as the comparision-third in the following.

This applies equally to length, volume and weight comparison and is indicated, for instance, in situations when the objects to be compared cannot be brought together diachronically and/or synchronically, as a direct comparison necessitates whether this is instrumentally mediated or not. Objects cannot be brought to assume the required spatial and temporal congruence because, for instance, they are too heavy to be moved or immobile, or because moving them is simply impractical. Alternatively a given object may have to be compared to another object, which for various reasons becomes available only at a later point in time, for instance, when the weight of raw material is compared to that of a secondary good produced from it. Other motives for the introduction of a comparision-third may come into play as well. The original object may be transformed, as in the example just given, it may decay or for other reasons not be suitable for storage or it may have been consumed or otherwise used up at the time when the comparison object first became available.

As regards weight, such comparisons via a comparision-third or comparison measure are attested. Weight stones are known from Egypt, which are not related to the units of a weight system in place. Rather, they have been shown to have served as the means for concrete comparisons. It has been established for a particular group of such objects that they "were used for the distribution of portions of dried fish to labourers in the mines in the Sinai peninsula."[37] If portions are produced by making them equal to the weight of such a weight stone, then the stone must be considered to be a comparision-third by means of which the intended weight equality of the portions among each other is assured, as well as the equality of the portions given out at another time.[38] The stone must not necessarily be perceived as an abstract representation of weight but, together with knowledge of the operation, represents a standard portion and is thus tied to a concrete context of application.[39]

That such objects served as comparison measures is knowable to us only because inscriptions such as "weight for fresh, cleaned fish" (Fig. 5) more or less explicitly tell us so.[40] This particular inscription moreover tells us that when the object was used, the concept of weight was already detached from the concrete operational context. This, however, is not particularly noteworthy as the object bearing this inscription far postdates the onset of weight measurement, as do all objects that have so far been identified indubitably as weight stones. Without such clues from symbolic notation, we would probably not able to tell whether a particular object served as a comparision-third. Whether weight stones or similar comparison measures were used for weight comparison well before the onset of weight measurement may thus remain an unanswerable question.

When using a comparision-third, the concept of 'comparison measure' as distinct from the objects compared starts to emerge. Initially, such comparison measures were presumably equal to one of the objects to be compared with respect to the relevant property. They will hence be referred to here as "equal comparison measures," for example, a rope in which a knot is tied in the

37 See Michailidou 2001, 42, where the archeological evidence of weight stones is extensively discussed.

38 The rationing of wool, which is difficult to measure by volume and which cannot be preserved indefinitely, could have played a decisive role in the development of weighing. Thus, the wool unit, the *mana* of approx. 500 g, which later became the *mina*, seems to be among the oldest units in different ancient weight measuring systems. Cf. Büttner 2018. See also Michailidou 2001, 179–186.

39 This is more obvious in the case of volume measurement. Of a silo filled with grain we can say that it provides a capacity measure of its content. The grain, however, was certainly not put in the silo to measure volume but for storage, and this contingently enabled certain types of comparison that we from a modern perspective can address as comparisons by volume, an abstraction that does not seem required on the part of the actors.

40 Michailidou 2001, 63.

appropriate position as the result of comparison with an object. Equal comparison measures allow the judgement of whether a second object is smaller, equal or larger in the same regard. In the majority of cases, control or production of the equality of two objects in a certain respect, such as in rationing, may have initially provided the motive for comparison in the majority of cases.

An equal comparision-third can of course be composed of more than one object, for instance, when a rope is not long enough to measure the length of a field and a second rope needs to be tied to it. If an object is to be compared to another object separated in time and/or space, as in the field example, the composition of objects used as the comparison measure needs to be preserved until the operation has been completed. Besides transporting and/or storing the composite objects, this may also require transmitting information concerning their recomposition.

The decisive step towards measurement is made when equal parts are used for the composition. Although it may appear self-evident to the modern reader, this step is revealed as meaningful only under a strong precondition, namely, the ability to count. It is only by counting that a composition of equal parts proves more advantageous for comparison than a composition of unequal parts.

There are natural configurations that provide a model showing how direct comparison between two objects can be substituted by comparing the count of identical equal parts within them. Laying out more bricks of equal size will result in longer walls. By abstraction, the operation can be reversed, and by comparing the number of bricks it can be judged which of two walls made from the same bricks is longer. Experience will also show that the equality of the parts is the necessary condition for this to work. The physical qualities of objects, however, do not usually fall into distinct equal parts that can be counted naturally. It is exhaustion by composition of equal parts that first makes them susceptible to counting.

Exhaustion by composition allows smaller comparison measures to be used. Moreover, given an appropriate composition operation, only one material manifestation of the measure is needed.[41] This is operationally advantageous but requires counting. Counting itself, and with it arithmetical concepts, developed from correspondence, via concrete counting, to abstract counting.[42] Comparison by means of the composition of equal parts seems to require at least concrete if not abstract counting. Based on abstract counting and the corresponding arithmetical knowledge, the full potential of exhaustion by composition of equal parts unfolds. To compare objects in a certain respect, one need only compare the count of measure composites because of the rank order of the number sequence.

Fig. 5 Inscribed (weight of cleaned fish) witness-stone from Deir el-Medina.

Yet the sequence of natural numbers has stronger arithmetical features than just rank order. It represents in particular a ratio scale. When counting objects, the arithmetical structures of the number sequence are imposed on the objects counted. In the case of exhaustion by composition, by means of a small comparison measure the counted objects are the identical discrete parts from which the quality of the object under consideration can be perceived of as being composed as the result of the exhaustion operation. In particular, it can now be recognized that the difference between an object composed of for instance 10 identical parts to one composed of 7 is the same as the difference between one composed of 5 to one composed of 2 of the same

41 Before measurement, ropes with knots tied at equal distances, as used in Egypt for length measurement, could be used as a means of direct comparison. Cf. Schemmel 2016, 37.

42 For the development of counting, see Schmandt-Besserat 1992; Damerow 1996 and Damerow, Englund, and Nissen 1988.

identical parts. Moreover, an object composed of 10 length/volume/weight parts can now be judged to be exactly twice as long/voluminous/heavy as the one composed of 5 parts. It is exactly these kinds of judgments representing concrete operations that played an important role in the administrative contexts of the early city-states where quantities were not only compared, but increments determined or consumptions calculated.[43]

Should the above reconstruction prove to be essentially correct, then the comparison of weights – based on an understanding of weight as a quality that can be smaller, bigger or equal than the same quality in another object, as implied by our sensory perception of heaviness – eventually resulted in a technique that involved the counting of composite parts as a means of such comparison. The arithmetical structures thus imposed therefore resulted in an understanding of weight as an extensive quantity.

As concerns the composition of the weight of objects by parts of equal weight, it could be argued that just as a row of equal bricks provides a model of an object which, as a composite, is made up of parts of equal length, so a pile of the same bricks provides a model of a composite object made up of parts of equal weight. But this is begging the question. Whereas length equality of the parts is immediately perceivable in the former case, weight equality in the latter case, to the extent that it even applies, is much less apparent.

The use of non-equal comparison measures in weight comparison must arguably have its roots in practices where weight equality, produced or controlled by means of a weight comparison instrument, played a role. The reason for this is that no operation is available with regard to weight that would allow the weight of an object to be exhausted by the composition of just one small comparison weight measure. Indeed, unlike the cases of length and volume measurement, different material manifestations, that is, appropriate copies of the same comparison measure were required as the basis of the composition operation in weight comparison, and this remained the case for almost 5000 years.

Larger portions may be produced by adding up smaller portions. If the production of a smaller portion was mediated by equality to a weight comparison measure, as in the case of fish distribution discussed above, transitivity insinuates that a larger composite portion is equivalent to a corresponding composition of the comparison measure. Just as the comparison balance allowed the production of portions equal to the weight of the comparison measure, the production or selection of other appropriate measures of equal weight is also allowed, which could then be used in combination as a comparison measure for the larger portion. Once composites of identical comparison measures are used in weight comparisons, we can properly speak of proto-weighing.

6 From proto-weighing to weight measurement

The gradual transition from proto-weighing to weighing can be understood as encompassing two steps, which in their respective realizations must have mutually reinforced one other: the increasingly universal use of one or a limited set of comparison measures for weight comparisons; and the increasing emancipation of the comparison to the comparision-third as an operation in its own right.

As the example of the weight stones indicates, comparison by weight measures was probably initially restricted to locally confined contexts, as well as to the comparison of objects of the same kind. The transition to using the same measure to compare objects of different kinds is an abstraction that is preconfigured in the use of a comparision-third, which itself is usually already of a different kind, for example, a stone and not a fish.[44] The increasingly non-local use of the same measures is ultimately a matter of standardization "a time honoured prerogative of central authority."[45]

The emancipation of the comparision-third from a means to an end of direct comparison, as indicated above, hinges on counting but also on new ways of symbolically recording and storing the results of such

43 Cf. Cancik-Kirschbaum and Chambon 2006, 191.

44 Conceptually comparing the weight of a fish to that of a basket of wool is not suggested but is operationally convenient once weight comparison instruments and measures are available. In principle, nothing speaks against the use of the same weight stones used for comparing the weight of a fish for also comparing the weight of wool. This, however, implicitly entails comparing fish to wool by weight.

45 Kopcke 1987, 257.

counts. These were developed in the second half of the fourth millennium against the background of the need for accounting in the complex administration of the first centrally organized city-states.[46]

What emerged in the transition from proto-weighing to weighing was the second-order abstraction of a scale or metrological system based on one or a limited number of standardized units of measurement with shared and conventionally fixed ratios. This scale became the abstract entity against which objects were compared in weight measurement. It represents weight as an extensive physical quantity, specified with regard to a conventionally chosen unit, which is materially manifest in balance weights. Measurement understood in this sense, that is, as a comparison against the scale as an abstract object, is normally not an end in itself. Indeed measuring the weight of an object purely for the sake of determining its weight seems to be an aim that only developed science would pursue. Initially, weight measurement, that is, the comparison to the scale, was motivated by the fact that it enabled objects to be compared to one another. Yet, a second comparison no longer had to be concretely anticipated, nor did the comparison have to be carried out with respect to same quantity. Indeed, it was the possibility to couple the abstract weight scale with other abstract scales, in particular such of value, which ultimately accounts for the overwhelming success and impact of weighing.

The transition from proto-measurement to weight measurement certainly deserves further scrutiny but would exceed the scope of this article. What remains to be emphasized here is that this transition flourished after the establishment of the first metrologies. Metrological systems for counting discreet objects, and for measuring time, length, volume and area, are all documented in the archaic Uruk period.

It is not surprising that measurement emerged in the early city-states of this time, where the required material and conceptual means first originated, and where the measurement of quantities such as length, volume or area could be exploited for the administration of the increasingly complex modes of distribution and production. The development of measurement and the means required went hand in hand. Indeed, it was the counting of discrete objects—the most fundamental form of measurement—that gave rise to the conceptual and symbolic revolutions which in turn not only led to further arithmetical abstraction, but also made other forms of measurement possible.[47]

None of the systems identified on tablets from the archaic Uruk period has been identified as a weight system, however.[48] With great certainty, weight measurement could therefore not have been part of any administrative activities, which in turn can be taken as significant evidence for its absence in the Uruk period. The earliest scales and weights from Mesopotamia are indeed considerably later than those from Egypt, namely from the mid-third millennium, as is the earliest weight system from this area, which is attested to in writing.[49]

The earliest metrological systems obey irregular ratios between the different units on which they are based. This has been interpreted as reflecting the fact that they emerged from the fusing of different metrological scales rooted in different natural units. In contrast, the earliest weight system documented from ED III is fully arithmetized with a sexagesimal system. Jens Høyrup has already maintained that this is a "consequence of this late development of weight metrology."[50] The understanding and expertise gained in the establishment, implementation, enforcement and upholding of the earlier measuring systems for length, area or volume could be transferred to weight measurement, which was established

46 Once numbers are assigned by comparison to a small comparision-third and symbolically recorded, further unanticipated comparisons become possible because the number recorded and stored can be compared to a later record, provided the same comparison measure is used.

47 For the relation between symbolic representation and the development of arithmetical abstractions in the period in question, see Damerow 1999.

48 Nissen, Damerow, and Englund 1993 provide a survey of the archaic numerical sign systems. The identified stems and their application contexts are listed on pages 28–29. None of the systems has been identified as a weight system. Of the so-called EN system, E of unknown application, the authors merely state that it was "possibly used to note weight measures", Nissen, Damerow, and Englund 1993, 28. Fryberg claims somewhat stronger that "[...] features of systems E seem to suggest that system E was a system of weight numbers, with the upper half of the system used to measure amounts of silver and the lower half of the system use to measure smaller amounts of the 16 times more precious gold." Friberg 2007, 377.

49 The main metrological units are attested in Mesopotamia from ca. 2600 BC (Fara) onwards. The earliest preserved balance and set of weights in a well-dated context in this region come from the Royal Palace G of Ebla (c. 2400–2300 BC). Cf. Peyronel 2012 and Peyronel and Ascalone 2006.

50 Høyrup 1994, 75.

much later in Mesopotamia. This concerns far more than just the mathematical structures that Høyrup is primarily focused upon: it concerns the methods by which measuring standards were set, how their use was enforced and how the compliance with these standards was controlled. It also concerns the authoritative measures taken to implement the standards and the social and technological processes involved. Measuring as a comprehensive sociotechnical system is difficult to delineate.

In this respect, it is equally noteworthy that the origin of weight measurement should lie in Egypt where, at the time in question, we have no indication that other metrologies had already been established, at least for a substantial period of time. In Egypt, the onset of weight measurement coincides conspicuously with the first recordings of quantity to have been passed down. These testify to abstract counting, along with the first recordings of length measurement.[51] This leads one to speculate that a technological package, including counting, metrology and writing, could by diffusion have arrived in Egypt around this time, and could have potentially encountered an established practice of instrumentally mediated weight comparison. Such an encounter could have resulted in a rapid transition from proto-weighing to weight measurement along the lines of development sketched above. But this of course remains an open question.

7 Weight measurement: quasi-instantaneous, problem-driven innovation or result of an extended, stepwise development?

I have taken my point of departure by arguing against an understanding of weight measurement as a problem-driven innovation, characterized by its large conceptual and technological distance to preceding techniques. Evidence from cognitive and cultural psychology as well as from psychophysics has been presented. This suggests that the problem of weight measurement cannot be perceived on the basis of an understanding of weight as simply resulting from sensory experience with heavy objects. Weight measurement has been demonstrated to constitute a complex sociotechnical system which, in contrast to earlier measuring techniques of length or volume, has always required, in particular, a highly specialized instrument: the comparison balance. This argues against the assumption of a creation of weight measurement quasi *ex nihilo*.

Based on an analysis of early weighing, it is instead proposed that a sequence of successor techniques mediated the development of weight measurement. The developmental steps have been postulated on the premise that what can be perceived as a problem in a given situation is restricted by the material and conceptual means given at that particular moment. In addition, recurrent exploration of possibilities opened up by each new step led to the formation of new practices, and thus to the emergence of new techniques, which could not have been anticipated at the beginning of the process.

It has been hypothesized that weight measurement began with comparisons intended to test which of two objects is heavier, or if two objects are equally heavy. The limits of our sensory ability to compare weight, it was argued, may have become manifest with the evolution of certain practices in which such weight comparison played a role. This resulted in instrumentally mediated weight comparison, where the comparison balance employed likely unfolded as the adaptation of an existing technique. Direct weight comparison led to weight comparison via a comparision-third, initially an equal comparison measure. This in turn opened up the possibility to use smaller comparison measures to exhaust an object by composition, and to thus replace the direct comparison by weight with a comparison of counts. This, however, presupposes counting. The arithmetical structures that govern counting were brought to bear on what was counted, that is, the equal parts of object that could now be perceived as composed from same small weight measures. Abstraction, facilitated by the new means of symbolic notation, led to the concept of weight as an extensive property of matter comparable or measurable against an abstract scale.

51 The earliest document with numbers from Egypt is the "Narmer Macehead" dating to the reign of King Narmer; Millet 1990. The famous Palermo stone, probably from the mid to the late fifth dynasty, records measurements of the greatest heights reached by the Nile flood. Cf. Hsu 2010. These recordings go back to the beginning of the first dynasty.

A historical reconstruction is not provided, but evidence is given of some of the postulated stages prevailing after weight measurement was established. This may lend plausibility to the hypothesis that these stages had been attained earlier, but for now it has not been possible to show that they played any postulated role in the proposed developmental sequence.

The historical development culminating in weight measurement may have been similar to the sequence postulated. Some steps may have been skipped, others may have practically fallen together. This is suggested because weight measurement emerged much later than other measurement techniques, and transfer certainly played a decisive role in its development. The development may have an altogether different historical path and we may never know due to the lack of evidence. Even so, I believe that an argued hypothesis of how weight measurement could have developed is more beneficial than the bold claim that it was invented for the sake of measuring weight, which, from the perspective argued in this paper, is about as meaningful as claiming that it fell from the sky.

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1 Staatliches Museum Ägyptischer Kunst, München; Inv. Nr. ÄS 5847. Photo Marianne Franke. With friendly permission. **2** Left: photo by Jochen Büttner, with kind permission of the Petrie Museum. Right: Quibell 1913, 23, Fig. 5. **3** Dawood 1997. **4** Left: DAI Kairo. Negative number D-DAI-KAI-F-19301. Photo: Dieter Johannes. With friendly permission. Right: photo by Kurt Brown. With friendly permission by the photographer. **5** Art & History Museum, Brussels. Inv. Nr: E.07041, with permission.

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Flying Cars and Polychrome Vases: Cross-Cultural Perspectives on Technological Innovations and Their Connection to Social Inequality

Summary

Technological change is often seen as an independent process; yet invention and innovation are both intertwined in their social contexts. This analysis examines technological innovations in the context of broader cross-cultural patterns of socioeconomic inequality. A model is outlined that links variable relations of power and inequality and specific kinds of innovations. Collective forms of governance and greater degrees of equality are associated with innovations that have broad-based implications, while innovations at times of autocratic political-economic formations are prone to result in and benefit those with concentrated wealth and power. Two brief examples, one from the past and the other more contemporary, are advanced, broadly conforming with the expectations of the model.

Keywords: innovation; invention; collective action; cooperation; Mesoamerican writing; flying cars; technological change

Technologischer Wandel wird oft als unabhängiger Prozess gesehen; doch Erfindung und Innovation sind in ihren sozialen Kontexten miteinander verwoben. In dieser Analyse werden technologische Innovationen im Kontext größerer kulturübergreifender Muster von sozioökonomischer Ungleichheit untersucht. Ein Modell, das variable Macht- und Ungleichheitsverhältnisse mit bestimmten Arten von Innovationen verknüpft, wird skizziert. Kollektive Herrschaftsformen und ein höherer Grad an Gleichheit werden mit Innovationen assoziiert, die weitreichende Auswirkungen haben, während Innovationen in Zeiten autokratischer politisch-ökonomischer Strukturen dazu neigen, zu Gunsten derer mit konzentriertem Reichtum und Macht zu erfolgen. Es werden zwei Beispiele, eines aus der Vergangenheit und eines aus der Gegenwart, angeführt, die im Wesentlichen mit den Erwartungen des Modells übereinstimmen.

Keywords: Innovation; Erfindung; kollektives Handeln; Kooperation; mesoamerikanische Schrift; fliegende Autos; technologischer Wandel

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In the heroic treatment, historical change is shown to have been generated by the genius of individuals, conveniently labeled 'inventors.' In such treatment, Edison invented the electric light, Bell the telephone, Gutenberg the printing press, Watt the steam engine, and so on. But no one individual is responsible for producing an invention *ex nihilo*. The elevation of a single inventor to the position of sole creator at best exaggerates his influence over events, and at worst denies the involvement of those humbler members of society without whose work his task might have been impossible.[1]

James Burke's statement from his book *Connections* capsulizes my central argument: the key to understanding technological change is to contextualize it in social networks that include the people and institutions that devise, use, and spread it.[2] I employ this broadly social constructivist theoretical frame[3] to critique two streams of technological determinism, while also advancing the prospect that cross-cultural examinations should recalibrate how we conceptualize the interplays between technological change and large, cooperative social networks or 'societies.' To illustrate the approach, I discuss two cases, one, somewhat conjectural, from our modern world and one from Mesoamerica's deep past.

The first example stems from the contemporary world, and, as a child of the 1950s and 1960s, it is part of my lived experience. In short, why were predictions by mid-20th century science fiction writers and futurists so off base about the technological changes that occurred after that era? Where are the flying cars?[4] And for that matter, what happened to the robots that were going to sweep our floors and to the teleportation pods? No doubt, significant technological advances have been part of the last 30 to 40 years, but most of them relate to information technologies, finance, communication, and medical breakthroughs, so not the kinds of innovations that were predicted to change fundamentally the nature of basic human lifeways and work. A facile answer to this question might be that technological change occurs independently, and so is and was unpredictable. Yet I would question this view because, a generation or two earlier, the futuristic visions of Jules Verne, including submarines, lunar modules, and television news, hit closer to the actual mark.

The second example, situated during the prehispanic era in Mesoamerica, concerns shifts in the use of writing by the lowland Maya of the Classic period (ca. AD 300–900). The Classic Maya wrote numerous texts, many of them rather long, much more extensive than those of their contemporaneous neighbors. They employed a diversity of media, including carved stone stelae, polychrome vases, and painted murals, for these texts.[5] A significant number of carved stones with writing were dated with long count calendar dates, a system that tracked temporal cycles of tens of thousands of years.[6] But during the 10th century AD, the Maya uses of writing shifted, including a decline in the frequency of texts. Written records with long count dates ceased.[7] This shift in prehispanic Maya information technology was once viewed as an indicator of cultural decline, the fall of the Maya Classic and decadence of the Postclassic Maya.[8] Yet as with the first case example, this spontaneous and seemingly commonsensical interpretation requires greater scrutiny and contextual analysis. I return to both examples after discussing conceptualizations of technological change, human cooperative networks, and their interrelation.

1 Framing technological change

More than 50 years ago, V. Gordon Childe reasoned that archaeologists could more easily infer ancient technological and economic behaviors than other spheres of human life.[9] His views dovetailed with contemporary theoretical ideas, such as those of Leslie White, who promoted the causal primacy of technology for defining the form and content of human cultural systems.[10] They also were broadly in accord with long-standing empirically observed constructs in archaeology, such as the Three Age System.[11]

1 Burke 1978, 288.
2 Hughes 1983.
3 Adams 1997; Killick 2004; Pfaffenberger 1992.
4 Graeber 2012.
5 Houston 1989.
6 Marcus 1976.
7 Marcus 1976.
8 Thompson 1966.
9 Childe 1956, 45–56.
10 White 1949, 378.
11 Heizer 1962.

The strong material underpinnings of archaeological practice and research are undeniable. I also adhere to a vision of the archaeological endeavor that is systematic, conscientious, and firmly rooted in the careful marshaling of empirical evidence to evaluate alternative interpretive perspectives. Nevertheless, in my opinion, archaeologists must guard against conflating the significance of the material record for our investigations with uniformly privileging the technological and material when we endeavor to understand and explain the processes and causes of change for the key transitions that mark the human career.[12] Just as the notion of a free market, disembedded from other cultural behavior, is no more than an illusory ideal or political talking point,[13] the idea that technology deterministically drives history, though oft-repeated, remains misguided. As Robert McC. Adams wrote:

> [I]t is a reifying distortion to isolate inventions and innovations as triggering events that at least in each major case, started a new clock ticking with a self-contained, autonomous set of propensities for change. It supports the misleading implication that each such discovery tends to contain within itself […] a consistent set of directions for its unfolding further development.[14]

Technological determinism, simple, direct, and free of human agency, has a zombie-like appeal, appearing and reappearing in different guises as an interpretive frame. At its most all-encompassing, the broadly framed argument that technological shifts somehow independently drive other societal change has been challenged repeatedly.[15] On empirical grounds, Carneiro keenly noted decades ago that the major urban centers and civilizations of ancient Mesoamerica (at least prior to later in the Classic period [ca. AD 700–900]) relied purely on stone-age tool technologies.[16] On a conceptual level, few have put it more succinctly than the historian of technology, Lubar, who quipped "[i]f technology is indeed part of culture then technological design must reflect the culture of the men and women who develop it."[17] Fortunately, what has long been an academic perspective based on in-depth studies of major technological breakthroughs[18] also is now gaining increased public recognition, as exemplified by Walter Isaacson's recent examination of digital-age technological advances, which he continually situates in complex processes and extensive teamwork. [19]

Although the coarsest and most overarching visions for technological determinism have not had a central place in archaeological theory in recent years, a narrow stream of determinist thought has been advanced, specifically in regard to the process of invention, which Darwinian approaches in archaeology have separated somewhat artificially from the process of diffusion or spread. This argument begins with the reasonable premise that technological creativity or changes are not simply products of necessity. After all, not all problems or challenges get met with ready solutions.[20] But Darwinist theorists then proceed to a polarized alternative,[21] that the generation of new variation or inventions is a necessarily random, undirected process, which is only later behaviorally mediated through the subsequent process of spread or diffusion. As Fitzhugh has cogently argued, this view is too rigid, as it fails to recognize "changing opportunity costs related to technological tinkering or investment."[22] In certain situations, experimentation with new techniques has a lower potential payoff than the devotion of time and energy to extant technologies. Conversely, in other contexts, experimentation should be favored. As scholars in several disciplines have argued, in such circumstances, the tempo of invention may be "stimulated"[23] and/or "directed"[24]. Social reinforcements from kin and colleagues also may help focus the time and energy invested in tinkering and experimentation in specific contexts. Intentionality should not be conflated with omnipotence or omniscience.[25]

12 Hawkes 1954.
13 Feinman and Garraty 2010; Lie 1991.
14 Adams 1996, 5.
15 Adams 1996; Adams 1997; Hughes 1983; Pfaffenberger 1992; Wajcman 2002.
16 Carneiro 1974, 180–181.
17 Lubar 1987, 253.
18 Hargedon and Yellowlees 2001; Hughes 1983.
19 Isaacson 2014.
20 Elster 1983.
21 Neiman 1995.
22 Fitzhugh 2001, 127.
23 Schiffer 2005.
24 Acemoglu 2002.
25 Pagel 2006, 360.

For the examination of technological innovation-diffusion, there is broad recognition that contagion or viral models in and of themselves generally are not sufficient to explain transmission.[26] That is, to understand the adoption of new technologies, we cannot look exclusively to design criteria, environmental learning, and/or the size and density of social networks to explain the paths and tempos of change. Technological transfer is an interactive process for which both social influence and social learning are other key elements affecting individual adoptions.[27] Yet, technological change is not a process that should be strictly conceptualized at the scale of the individual actors. Clearly, there is no need to look farther than the oft-shown image of the Korean peninsula at night to recognize that institutions also have a key role in the adoption and transmission of technologies.[28]

Invention and the spread of new innovations are two critical dimensions in the process of technological change. But a fresh perspective on this process also requires a rethinking of how we conceptualize large human networks or societies and their component institutions. The examination of technological change in archaeology has often challenged extant paradigms through sharp scalar fissures[29] that force consideration of both individual transfer and adoption decisions along with their broader scale implications as well as effects and constraints, as with Korea, on those individual choices. The theoretical framing of episodes of technological change across deep history requires archaeology to face up to its long-standing micro-macro problem,[30] how to conceptualize the micro-foundations of processes with macro-scale consequences.[31]

2 Modeling the social in technological systems

From its inception as an academic practice, archaeological research has retained a focus on technological change and transfer across space. Early studies in the discipline, limited by inadequate empirical knowledge, often reasoned inductively, guided by the premise that observed artifactual similarities were generated by contact and transmission/adoption, thereby leading to broad-brush models of cross-continental diffusion.[32] These models often operated at the scale of societies, whose members were envisioned to adopt new innovations to address presumed societal needs. The logic and empirical foundations of these diffusion models often were sufficiently weak that, for a generation, subsequent archaeological investigation tended to emphasize (and often artificially bound) the local, frequently downplaying longer-distance connections and transfers.[33] But, in the last several decades, new empirical findings, often grounded in compositional data,[34] have illustrated the significance of distant networks and connections in the past for understanding episodes of social and economic transition.[35]

In accord with dominant paradigmatic frames in archaeology, recent approaches that explicitly probe episodes of technological transmission have tended to take one of two principal tacks. One places near-exclusive weight on the agency of elites[36] in adoption decisions, while the alternative basically ignores the nature of social relationships, focused exclusively on specific design attributes and basic population parameters, such as size, hewing closely to a frame in line with methodological individualism.[37] As already discussed, the problems with this latter approach are that they leave little to no role for an entire suite of social factors in technological invention and innovation, nor do they leave room for an institutional role in this process.

The former approach, as exemplified by Kim's contrast between the spread of iron near the end of the Bronze Age in Denmark and Korea, recognizes not just the importance of power differentials in the diffusion of new technologies, but that the specific nature of those differences may constrain how new technologies are

26 Davis 1983; Henrich 2001; Montanari and Saberi 2010.
27 DiMaggio and Garip 2012; Ralph and Arnold 1988; Wejnert 2002; Young 2009.
28 Acemoglu, Johnson, and Robinson 2005; Acemoglu and Robinson 2012.
29 Carneiro 1985; Mesoudi, Whiten, and Leland 2006; Read 2006; Rindos 1985.
30 Schelling 2006.
31 Carballo, Roscoe, and Feinman 2014; Feinman 2013a.
32 Trigger 1989, 150–174.
33 Wolf 1982.
34 Golitko and Feinman 2015.
35 Hall, Kardulias, and Chase-Dunn 2011.
36 Kim 2001.
37 Neiman 1995; Telster 1995.

used.[38] The earliest iron in Denmark (ca. 1200–900 BC) was employed ornamentally and as a prestige good in burials, much as bronze was and continued to be for centuries after the earliest iron was found. Iron rarely has been recovered outside high-status contexts for that time. In the ruler-centric networks of Bronze Age Denmark, metal served as a prestige good, whose circulation was monopolized by elites. New, non-ornament uses for iron did not materialize for more than 500 years, and this change took place after societal shifts in exchange networks, land use practices, revenue appropriation, and governance.[39]

The introduction of iron into southern Korea (200 BC) proceeded entirely differently. From the time of its appearance, iron was utilized in ways very different from the prior uses of bronze, which served mostly for ornaments and ritual grave goods. Early Korean iron was cast as farming implements, wood working tools, and axes, basically replacing stone tools. Also, unlike bronze, iron in Korea was broadly distributed and not localized to elite contexts. As with the eventual spread of iron in Denmark, the rapid spread of iron tools in Korea occurred during an era of agricultural intensification. Although Kim makes a strong case linking the different uses of iron in these regions to the contrasting ways that power was wielded and funded, his assignment of agency only to elites leads him to argue that Korean elites distributed iron tools to farmers, a point for which no evidence is presented.[40] The study fails to answer why did Bronze Age Korean smallholders adopt and use iron tools? Despite the strength of Kim's comparative observations, it is hard to see this technological shift as a top-down mandate.[41]

What is needed are frames that balance individual self-interest, differentials in roles and power, and the significance of institutions without making assumptions that all members of a group or institution will necessarily act in lockstep for the good of the whole. In my view, the bases for such conceptual approaches are met in the literatures on cooperation, collective action, and social network analysis.[42] I outline the key tenets of this approach before returning to reconsiderations of the two case examples in the introduction.

3 Networks of cooperation and collective action

For archaeology's disciplinary history, the constructs employed to examine social foundations of technological change have seesawed among basically functionalist approaches, which presume that all participants act in the interests of society, selectionist (Darwinian) constructs that tend to downplay social relationships and institutions,[43] and Marxist and culture history frames, which tend to assume that agency and action flow strictly from the top-down. As noted for the introduction of iron in Denmark and Korea,[44] institutional relations of power and inequality have been shown to have implications for the nature, directionality, and tempo of economic and technological outcomes.[45] What has been challenging to achieve is a balance between the recognition that agency is not restricted to the elite with a consideration of the role of institutions.[46] Yet institutions, even governments, are, in a general sense, a set of rules that structure a specific suite of interactions and relations between individuals.[47] The rules and social understandings or contracts may be simple or highly elaborate. Institutions may be large or small, but ultimately, they are composed of people whose interpersonal relations take different forms.[48] Frameworks that focus on individuals and/or sets of individuals provide an analytical means to consider the micro-foundations of macro-processes. These frames offer a means to recognize imbalances of power and position, while not restricting agency to only those who are privileged.[49]

Core features of human sociality, as relevant to this analysis, can be grounded in a number of tenets, none of which seems especially controversial, and some of which I have outlined before.[50]

38 Kim 2001.
39 Kim 2001, 452–454.
40 Kim 2001.
41 Kim 2001.
42 Blanton and Fargher 2008; Carballo 2013; Mische 2011.
43 Blanton and Fargher 2013.
44 Kim 2001.
45 Acemoglu, Johnson, and Robinson 2005; Granovetter 2005; Knutsen 2012; Piketty 2014.
46 Holland-Lulewicz et al. 2020
47 North 1990.
48 Blanton and Fargher 2008; Levi 1988; North 1990.
49 Levi 1988, 39; Sewell Jr. 1992.
50 Feinman 2013a, 301–303.

Theoretical frame	Agency	Scalar focus	Boundedness
Culture history	Elite?	Culture	Closed
Cultural evolutionary systems	Elite	Society	Closed
Marxism/Marx-influenced	Elite	Society, class (rarely)	Potentially open
Sociobiology (narrow Darwinian)	All	Individuals, kin	Not adequately considered
Postprocessual	Elite (situational for commoners)	Society	Mostly closed
Collective action/cooperation	All	Explicitly multiscalar	Open

Tab. 1 Perspectives on the Preindustrial Past.

1. The evolutionary legacy of our species has tendencies toward both dominance hierarchies and high degrees of sociality. Human social behavior has roots both in primate tendencies toward status and gender hierarchies, and in the genus *Homo*'s long dependence on living in groups and interpersonal cooperation.[51] These countervailing tendencies can be manifest in diverse ways with implications for relations of trust, authority, and compliance.[52]

2. In accord with Sewell and others, all people have the capacity for agency, but it is constrained by structure, affiliations, and resources.[53] "To be an agent means to be capable of exerting some degree of control over the social relations in which one is enmeshed, which in turn implies the ability to transform those social relations to some degree."[54]

3. Most human groupings, independent of size, tend to be open and permeable, albeit to differing degrees. Even established boundaries rarely are closed for long periods of time.[55]

4. Humans participate in multiple groupings and networks simultaneously. Consequently, multiscalar perspectives are essential for understanding human social relations as processes and dynamics vary with scale.[56]

5. Human social, political, and economic behaviors are relational, and the resultant networks of relations generally are not tightly bounded. The webs of these relations may be more productively conceptualized as social networks rather than as discrete, closed groups.[57]

Over the past half-century, five main theoretical frames or paradigms (Tab. 1) have been broadly employed in archaeology (culture history, cultural evolutionary systems, Marxism or Marx-inspired, sociobiological/Darwinist, and postprocessual). Each of these approaches, however, does not align well with one or more of the tenets just discussed.[58] Fortunately, a sixth – collective action – approach that builds on the works of the political scientist, Margaret Levi[59], as well as the archaeologists, Richard Blanton and Lane Fargher[60], does, while it also can serve to highlight provocative parallels

51 Boesch and Tomasello 1998.
52 Blanton and Fargher 2013; Feinman 2013b.
53 Sewell Jr. 1992.
54 Sewell Jr. 2005, 143.
55 Barth 2000; Wolf 1982, 4–7.
56 Kowalewski 1995; Kowalewski 2003; Levin 2010; Manson 2008.
57 Mische 2011; Smith 2005.
58 Feinman 2013a.
59 Levi 1988.
60 Blanton and Fargher 2008; Blanton and Fargher 2016.

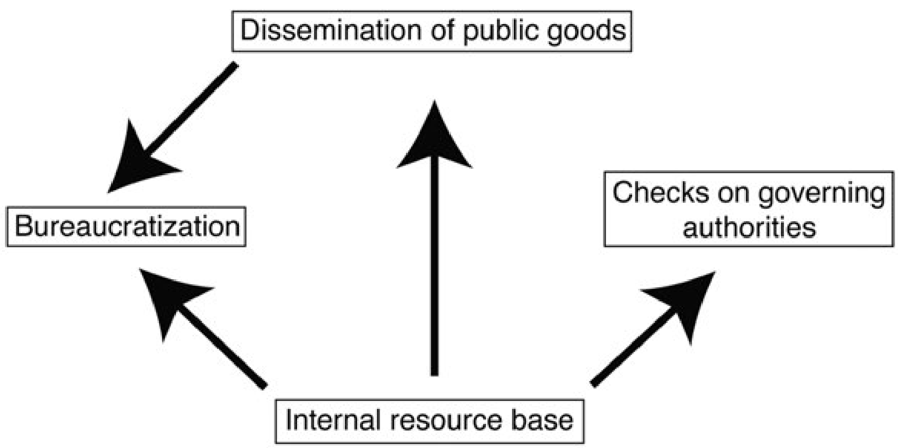

Fig. 1 Fiscal Model of Collective Action.

with the contrasts Kim discussed regarding the introduction of iron into Denmark and Korea.[61]

Briefly, Levi outlines the necessarily dyadic nature of rule between rulers and the ruled.[62] She argues that all rulers are constrained, albeit to differing degrees, and that access to revenues is a key constraint on institutional rule (Fig. 1).[63] Both the quantity and the ways that revenues are appropriated are important elements for the relative degrees of clout that rulers hold. All else equal, the greater the proportion and quantity of resources held by a ruler, the more apt they are to be predatory, oligarchic, and self-serving. Alternatively, the more rulers appropriate from and depend on their local population for revenues, the more voice the ruled are likely to have. Blanton and Fargher build on these constructs to contrast more predatory governance institutions with more collective forms.[64] In a historical analysis, they found correlations between internal revenues (dependence on the local population), public goods expenditures, and more collective forms of governance on the one hand, and on opposite end of the continuum, a reliance on external, free-floating resources, fewer public expenditures, and more autocratic/oligarchic rule.

I employ this theoretical frame to bring a revised perspective to iron's introduction in Denmark and Korea[65] as well as to the innovation and spread of metal working in prehispanic Mesoamerica (ca. AD 600–800), where its earliest uses were mostly ornamental and ceremonial, and it mostly circulated through high-status networks.[66] Metal in Mesoamerica was mined first at the peripheries of this prehispanic world during the Late Classic and Early Postclassic periods by elites who were tied into prestige good exchange systems. As in the Danish Bronze Age, the Mesoamerican regions where metal use first flourished were ruled by rather ostentatious elites, who were tied into exchange networks that served as a key basis of their revenue and power. In both regions, artisans attached to high-status networks added value to the metal by crafting it into decorative and sacred forms.

The broader sociocultural contexts were markedly different in Korea and Denmark at the times when iron was smelted into more utilitarian tools associated with the expansion and intensification of farming. In these settings, both rulers and followers had incentives both to intensify agrarian returns per unit of land and to expand the quantities of land under the plow. Governing institutions had turned to taxes based on agricultural production, while farmers had incentives to increase their crop production to maintain their standards of living in the face of taxes and pressures on land holdings with population expansion.[67] In western Mexico, where prehispanic Mesoamerica's earliest and eventually most intensified metal work was undertaken, parallel shifts occurred (to a lesser degree) during the last two centuries of the prehispanic era. At that time, some copper and bronze tools were made into hoes, axes, and other utilitarian tools for

61 Kim 2001.
62 Ahlquist and Levi 2011; Levi 1988.
63 Levi 1988, 10–40.
64 Blanton and Fargher 2008.
65 Kim 2001.
66 Blanton, Feinman, et al. 1996, 12–13; Maldonado 2009.
67 Kim 2001.

Fig. 2 The Great U-Turn in Income Disparities in the US.

agriculture. These implements were used by farmers at the core of an increasingly bureaucratized Tarascan empire, but rarely are found in commoner contexts distant from the empire's core.[68] Thus, at least for early metal use, the case could be made that the institutional bases of power, and the nature of socioeconomic relations between rulers and ruled, may be as important as the properties of the different metals when it comes to how they were first utilized.

4 Why no flying cars?

As mentioned, the easy answers to the queries of "why no flying cars" and "why did mid-20th century predictions of future technological innovations misfire so badly" rely on the unpredictable and serendipitous nature of this process. Undoubtedly, this answer is partly correct, as the path of history is always to degrees sinuous and contingent. But it is also worth probing the issue a bit more, and looking at the last five decades, with a focus on influential innovation and key changes in the sociotechnological context in the United States. Although predicting the future is a precarious enterprise, an examination of the scope of major innovations during different eras is an enlightening and worthwhile consideration.

The period from the 1940s to the 1980s was a time of economic expansion, although far from an idyllic era in the United States. Many significant innovations were adapted for widespread use, and their distributions swept across the country and the world. Some, of course, were weapons, but many had broader utility and appeal, such as autos, airplanes, indoor plumbing, refrigerators, commercial telephone service, and television. Many of these innovations improved the conditions under which much of the population lived. These shifts in the quality of life were timed with decreases in income disparities that began after the Great Depression and the Second World War, a trend termed "The Great Compression."[69]

68 Maldonado 2009; Pollard 1987, 745.

69 Goldin and Margo 1992.

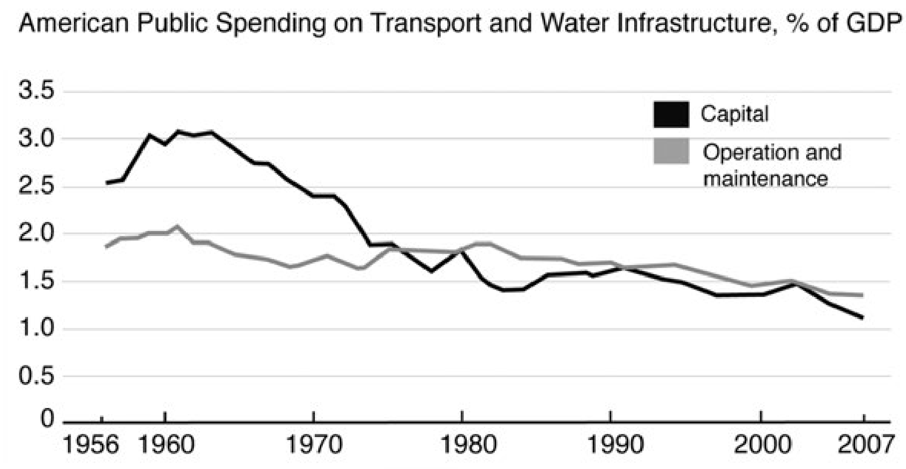

Fig. 3 American Spending on Transport and Water Infrastructure between 1956 and 2007.

At the time, manufacturing and agriculture were prime foci of the American economy, in part to supply an increasing number of families at a middle tier of income. Hence, in 1953, when the CEO of General Motors (Charles Wilson) was being interviewed in Congress for a Cabinet post, he could say "I thought what was good for the country was good for General Motors and vice versa."[70] Large infrastructural investments, including universities, the interstate highway system, airports and the establishment of flyway paths, all facilitated the application of the new technologies. One can understand in this context, how those looking toward the future might expect continuations of these trends, possibly leading to flying cars, robots to do housework, and teleportation devices, none of which has been forthcoming.

What was unanticipated was the "Great U-Turn,"[71] a very significant shift in wealth and income disparities in the United States (Fig. 2) and the world, which began in the 1970s,[72] but has intensified during recent years.[73] These imbalances have been linked to an expanding role of money in political decision making,[74] which is itself affecting policy making and implementation, thereby in turn, hastening disparities in wealth distribution.[75] At the same time, as wealth and power are concentrated, expenditures on public goods (Fig. 3) have been trimmed. The cornerstones of the American economy have shifted from farming and making things to finance and the transfer of money and commodities. A greater share of capital and investment is now being channeled to create more wealth, rather than to spur technologies that expand wages.

If we survey the key innovations of the last 40 years,[76] there are at least four technological domains that seem favored, areas associated with economic financialization (computing, ATMs, credit cards, fiber optics, big data), personalized communication and consumption (internet, cell phones, personal computers, fiber optics), surveillance (drones, cell phones, internet, big data), and medical innovations mostly directed toward extending life (as opposed to, for example, lessening infant mortality).[77] Each of these focal areas for innovation has a range of implications, but they always include an enabling or enhancing of the interests of those with the most economic and political power (the 0.1%). No wonder that Peter Drucker, a guru of modern technology, opined: "if an innovation does not aim at leadership from the beginning, it is unlikely to be innovative enough."[78]

But the roadblocks for flying cars extend beyond the preferences of the 0.1%. When asked about them in October 2014, Elon Musk, the CEO of electronic car manufacturer Tesla, rattled off various collective issues, such as altering skylines, noise pollution, and things falling on your head.[79] Also, there would be issues about the definition of drive paths to be followed in the sky. But

70 Hyde 2008.
71 Harrison and Bluestone 1988.
72 Thurow 1987.
73 Piketty 2014; Piketty and Saez 2006.
74 Freeland 2012; Noah 2012; Reich 2007.
75 Krugman 1996.
76 CNBC 2011; Graeber 2012.
77 Wilkinson and Pickett 2011.
78 Drucker 1998.
79 Harn 2014.

these issues are less insurmountable impediments and more reflect the absence of collective public will and political polarization in the context of increasingly plutocratic governance in the United States for which even the expansion of airports, the construction of a fast rail system, or even the public health steps necessary to put the clamps on a deadly virus[80] seem too much and too expensive to undertake. Add to that the shrinkage in real purchasing power for people at modal income tiers,[81] and flying cars seem decades, if not farther, away in the United States. As with the introductions and different uses of metals in the deeper past, variation in relationships of inequality and power has been intertwined with the specific arrays of innovation during recent times.

5 Classic Maya: numerous, lengthy written texts and the long count calendar

The second example concerns a dramatic shift in the way and the extent to which Mesoamerican people, with a focus on the prehispanic Maya, used their writing system. As noted at the outset, the absence of long count dates as well as lengthy Maya texts on stone stelae after the 10th century often has been attributed to societal decline or cultural decadence. But again, by providing greater context, I outline a more complex set of circumstances that feature the role of shifting relations of inequality and power in a series of episodes of information technology change and diversity. To understand the aforementioned shift in Classic-to-Postclassic Maya writing and calendrics, I situate it in a longer temporal context beginning with the evidence for the earliest writing in prehispanic Mesoamerica.

Mesoamerican writing first appeared around 600–500 BC in the highland Valley of Oaxaca and the Gulf Coast.[82] Several centuries later, during the last century BC, long count dates on stone were carved both on the Gulf Coast and at sites along the Pacific Coast of Chiapas and Guatemala. The contexts for this earliest writing are not uniform. It was not until after 300 BC[83] that writing was utilized at lowland Maya sites, the region where most long count dates and the longest texts were ultimately written. The first definitive use of the long count by the Maya in this lowland region did not occur until the 3rd century AD.[84] Both the earliest lowland Maya writing and the use of a long count date are linked to Maya lords/rulership and its legitimation, a functional association that endured through the Classic period (AD 250–900).

For the most part, Classic Maya governance was heavily personalized and ruler-centric,[85] and lowland Maya states during that period tended to have greater differences in access to portable wealth (in life and death) as compared to most other contemporaneous Mesoamerican political configurations at the time.[86] Writing and the long count calendar were employed to track key life events (accession to rule, military victories, death) and dynastic histories of the Maya rulers, often over multiple generations. These written texts, mostly in stone, served as materialized monuments to political and ideological legitimacy (the tracing of ancestral ties), and hence to justify special exalted status. Writing also was employed on polychrome vases and brilliantly colored murals that covered interior spaces, in each case to record and display the accomplishments of specific lords.

Even though the lowland Classic Maya are now thought to have had interactions with foreign emissaries sent from Teotihuacan (situated in the distant Basin of Mexico) during the 4th century AD,[87] we have no indication that use of either the long count or the Maya script was ever borrowed by the Central Mexican visitors, who themselves had only a mural painting tradition that featured the most rudimentary elements of a writing system.[88] Teotihuacan was much larger, more densely settled, and architecturally more monumental than any of its lowland Maya contemporaries, but its political organization was strikingly different, seemingly with less individualized, more collective rule,[89] with few, if any, named or specifically portrayed rulers. In its application, the Maya writing system and the long count may have been

80 McNeil Jr. 2020.
81 Cynamon and Fazzari 2014; Stiglitz 2013.
82 Marcus 1976.
83 Saturno, Stuart, and Beltrán 2006.
84 Sharer and Traxler 2006.
85 Feinman 2001.
86 Blanton, Feinman, et al. 1996; Cowgill 1997.
87 Stuart 2000.
88 Millon 1973.
89 Cowgill 1997; Feinman 2001; Feinman and Carballo 2018; Froese, Gershenson, and Manzanilla 2014.

so tightly intertwined with how the Classic Maya employed these information technologies that Central Mexican borrowing did not occur, even though a fair number of other stylistic elements and supernatural conceptions diffused in both directions during this same period.[90]

The Maya continued to employ their writing system and long count dates in this manner until the 10th century AD, when the erection of stelae with individualized dynasts ceased. Although the Postclassic Maya (AD 950–1520) maintained a writing system, it was employed more selectively in folded books and not, as far as we know, to legitimate personalized rulers or in conjunction with long count dates. The Postclassic Maya calendar cycled at a shorter temporal duration[91] and was not utilized in surviving records of dynastic histories. Although these shifts have been interpreted as due to collapse, decline, and decadence, the transition in late prehispanic Maya organization is more accurately described as a "transformative relocation"[92] in which both the location of the major Maya centers shifted (mainly north) and the nature of Maya political institutions changed from more overtly ruler-centric Classic-period formations to political configurations in which power was more broadly shared during the Postclassic.[93] Few Postclassic Maya books survived the Spanish onslaught, but later writing mostly recorded supernatural tales, quasi-historical legends, and texts that detailed appropriate ritual and religious performance.

In this new political environment, rulers rarely were depicted in art, and rule was neither reckoned nor legitimized as it had been earlier.[94] Exchange remained important, but routes and mechanisms of economic transfer were more broadly open, so more people could advance through their own labors. In this context, the socioeconomic distance between elites and commoners was less marked than during the earlier Classic period,[95] and the nature of communications between them undoubtedly was altered. Some Postclassic Maya centers continued to be inhabited by thousands of people who resided around monumental architectural structures, yet with the institutional shifts in political relations, writing, and the calendar – always restricted to those of high stature – no longer were marshaled to communicate information and legitimate special status in the ways they had been during the earlier Classic period.

6 Concluding thoughts

In focusing on metal and the extensive Classic Maya use of writing and the long count, I have isolated two key technological innovations whose development and spread were closely linked to less collective institutional arrangements with individualizing elites. Yet I do not want to convey an impression that prehispanic Mesoamerican technological change was restricted to or necessarily more prolific during such times. It was just different from transitions and innovations during eras of more collectively organized institutions. For example, two key forms of residential plan, compact hilltop terrace communities[96] and multifamily apartment compounds[97], are significant innovations in community arrangement that first spread and prospered during the Middle Formative period Valley of Oaxaca (ca. 500 BC) and Early Classic period Teotihuacan (ca. AD 200–300), respectively eras when more collective formations were in place. Likewise, the tortilla griddle or comal[98] was a ceramic innovation, still employed today to make a portable food, that was first produced early in the history of Monte Albán, a time when this polity was collectively organized and labor/production practices were shifting. These are cases in which large numbers of people lived in dense communities with high degrees of connectedness and collective action, and where the major resource bases were agrarian and localized.

My argument – that cross-cultural patterns of technological change are not merely systemically intertwined with broader socioeconomic relations but are associated with specific institutional configurations of power and inequality – should be somewhat less surprising than it might initially seem. In point of fact, there is rapidly accumulating evidence that across time

90 Braswell 2003; Feinman and Nicholas 2020.
91 Sharer and Traxler 2006, 113.
92 Nelson, Chase, and Hegmon 2014.
93 Masson 2000.
94 Sharer and Traxler 2006, 627.
95 Masson 2000, 346.
96 Kowalewski et al. 2006.
97 Cowgill 1997.
98 Blanton, Feinman, et al. 1996; Feinman 1986.

and space the tempo and nature of past and present economic growth often is related to the kinds and degrees of inequality that are present.[99] Likewise, different networks of social relations impact economic outcomes in different ways.[100] These streams of recent and empirically underpinned research are a far cry from earlier economic theorizing[101] that simply postulated an alternative view in which continued economic growth ultimately would prompt diminished inequality, an expectation that the last 50 years has illustrated repeatedly to be entirely unsubstantiated. Alternatively, since technological innovations are broadly recognized as important components in the pace and direction of economic growth,[102] it seems conceptually and empirically reasonable to expect that technological shifts, like growth, would have a significant link to distinct patterns of institutional inequality as well.

99 Acemoglu and Robinson 2012; Boushey and Price 2014; Knutsen 2012; Piketty 2014; Piketty and Saez 2014.

100 Granovetter 2005.

101 Kuznets 1955.

102 Rosenberg 2004.

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Paths to Glory. Modelling the Diffusion of Innovations in Western Eurasia during the 5th and 4th Millennium

Summary

The article deals with the reasons behind long-term innovation-barriers. It examines the example of the spread of metallurgy into Europe and discusses the reasons why the diffusion regularly stops for longer time periods. It is argued that the necessary know-how for the adoption of significant improvements in the 4th millennium is based on the significantly earlier adoption of metallurgy in a stage when it was mainly used for the production of prestigious items in the 5th millennium.

Keywords: metallurgy; Copper Age; Bronze Age; technical know-how; diffusion of innovations; path dependency

Der Beitrag untersucht die Gründe für langfristig wirksame Innovationsbarrieren am Beispiel der frühen Metallurgie und deren Verbreitung nach Europa. Die Gründe für sehr lange Pausen in der Diffusion metallurgischer Technologien werden vor dem Hintergrund der Speicherung und Verbreitung von Wissen erörtert. Es wird argumentiert, das die Adaption von signifikanten Verbesserungen in der Metallurgie im 4. Jahrtausend nur dort möglich war, wo diese Technologie bereits in einer frühen Stufe im 5. Jahrtausend, als daraus hauptsächlich Prestigeobjekte gefertigt wurden, übernommen wurde.

Keywords: Metallurgie; Kupferzeit; Bronzezeit; Technisches Know-how; Innovationsdiffusion; Pfadabhängigkeit

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1 Introduction

How did some people get rich while others stayed poor? This is the opening question of Jared Diamond's bestseller "Guns, germs and steel".[1] In it, Diamond popularized the idea that the unique environmental conditions of the Eurasian continent were responsible for a specific technical and cultural evolution that was in the very long run responsible for the military dominance of European nations in the 2nd millennium AD, colonisation and the great discrepancies in wealth seen today.

Diamond's narrative is remarkable because it actually focuses on archaeological arguments to explain the early modern history of human societies.[2] The economic success of a region is explained by its long term succession of innovations, going back to the Neolithic. At first glance there is much that speaks for Diamond's argument. Not only was southwestern Asia the home of wild forms of essential plants and animals for subsistence, transport and movement, but the east-west extension of the Eurasian landmass limited the amount of climatic zones to which these innovations had to be adapted. Following the narrative, this would have caused a significantly quicker diffusion of ideas than in the Americas and Africa and led to a more rapid technical development. However, when scrutinized such a view is rather simplistic, even though it highlights a potential of large-scale diffusionistic studies in Eurasia and North Africa: Several technical innovations with great impact, like pottery, agriculture, the wheel, glass or iron metallurgy, appear in this region significantly earlier than elsewhere in the world. It is also here, that from the 5th millennium onwards dramatically divergent cultural evolutions, ranging from pristine states in the southwest to hunter-gatherers in the north, can be studied.

On the other hand many innovations, which did change human history, were used and diffused completely differently; their full potential was not realised and their distribution limited often for centuries. The picture is much more complicated than Diamond's book wants to make us believe. The Eurasian continent is divided by deserts, mountain chains and climatic borders, and diffusion-routes do not simply go from west to east (or vice versa), but are channelled by such obstacles as well as they are enabled by the multitude of waterways. The ideal possibilities for creating networks in such an environment are reflected in the diverse and rich archaeological record of Europe, Egypt and southwestern Asia, and indeed, the movement of styles, ideas, techniques and people seem to have been a defining element during prehistory and antiquity.[3] Taking these environmental advantages into account, it is still a conundrum, why so many innovations do not diffuse regularly, but seem to have limits, which are unexplainable by natural barriers.

It is at such 'invisible' barriers, that Diamond's model breaks apart. The diffusion of innovations is not regularly paced, but steps, deviates and changes according to a multitude of factors, and it can be moderated, accelerated and steered by social and technical preconditions as well as human and non-human agents.[4] Such effects are also visible in the study of archaeological innovations, for instance with metallurgy. Warburton has provokingly suggested that a major flaw in technodeterministic models lies in the notion that ancient innovations are appropriated by societies, but do not change them.[5]

Our paper aims to offer a fresh perspective on 'arrhythmic' innovation-diffusions by focussing on the creation of technological necessities in a *longue durée*-perspective and thereby to explore the reasons behind cultural barriers in prehistoric societies.

2 The chronological notion of ancient innovations: the need for a new understanding of prehistoric innovation processes

The importance of technical innovations for prehistory was realized already very early, but due to the lack of independent dating-methods it was mainly used as a chronological indicator. Without successive innovations in the production of cutting tools and weapons, the beginnings of prehistory as a science would not have been possible. The lack of other dating methods led to a

1 Diamond 1997.
2 Cf. the paper by S. Hansen in this volume.
3 Cunliffe 2011.
4 Cf. the papers by S. Hansen and D. Warburton in this volume.
5 Paper by D. Warburton in this volume.

framework in which technical and stylistical elements were used to synchronize archaeological finds between Europe and the Near East to establish their *chronological* relationship,[6] as well as Gabriel Tarde's formulation of the theory of diffusion ("*Les lois de l'imitation*"[7]). The age of finds outside this 'core-region' could thereby only be determined, if either a regularly paced sequence of technical development or diffusion thereof was assumed. It was neither possible to realise any irregularities or rhythms of the diffusion nor any origins of innovation-processes outside of the core. The origin of innovations *had to* be within the Near East.

Within technology-focussed narratives, metallurgy has often been given a special place within the evolution of complex social systems. The smelting and melting of metals ('extractive metallurgy') must have been the result of long series of experimentation,[8] and its diffusion involved the reproduction of complex technical knowledge through time and space.

V. Gordon Childe stressed the importance of metallurgy for the structural shifts of production and trade that was part of his Urban Revolution,[9] while Colin Renfrew based his argument on the, at that time still controversial, C14-datings and saw a connection of emerging metallurgy and the production of graphite pottery, which required high-temperature firing.[10] Whether metallurgy emerged in the Balkan region[11] or may have Near Eastern predecessors[12] is still hotly debated. New discoveries and changes within chronology have shown that the general sequence for metallurgical innovation have become obsolete. Yet, the underlying notion of successive technical change remained unchanged until today. In all regions of the world metallurgy has antecedent lithic industries, and neither is iron ever the first metal used, but the result of a longer technical development beginning with copper, lead and gold.

Modern studies have moved away from the determining notion of metallurgy for social change.[13] In recent years even the socio-economic relevance of metallurgy was denied. Even though metallurgy was probably not *the* technology which single-handedly pushed the evolution of complex societies, it is still considered to have been a catalytic convertor for social change: There are a number of regions, for instance the Levant[14], the Black Sea Region[15] or Iran[16], where metallurgical innovations are still closely interlocked with key social transformations.

The diffusion of metallurgy was a multi-facetted process[17] that led to a variety of developments.[18] Unless we shift our focus and start to realise that metallurgy was by far a conjugate process, archaeological research will still repeat the diffusionistic narratives of the past, only with a slight shift of the assumed centres, whereby innovations are grasped in a top down manner in which models are imposed on the archaeological record. Prioritizing quantitative aspects of the archaeological records over its qualitative features is a dangerous task, which all too often ignores the natural and cultural blurring of archaeological data-sets and thereby emanates interpretations from highly questionable foundations.

Prehistory was no static continuum without changes into which innovations (originating from assumed centres) broke like waves. On the contrary a multitude of chatoyant 'influences' can be identified at least from the Neolithic onwards. The problem is rather how to cope with the different qualities of 'influences' and how to model innovation diffusion from such a bottom up-approach. To emancipate the archaeological discourse from being just an illustration of modern innovation theory (in a top-down manner), specific archaeological research on ancient innovations is necessary.

6 E.g.: Montelius 1903. Originally, Thomsen's three period system was dissociated from an absolute chronology: Thomsen's successor Jens Jacob Asmussen Worsae explicitly stated that the different periods could exist contemporarily in different regions (Worsaae 1881, 163–70), and thus made clear that they did not represent absolute chronologic units which were meant to be contemporary worldwide, but basically technical stages which were dissociated from an absolute chronology.

7 Tarde 1890.

8 Strahm and Hauptmann 2009.

9 This aspect is elaborated in the paper by S. Hansen in this volume.

10 Renfrew 1969; Renfrew 1973.

11 Todorova 1981.

12 Roberts, Thornton, and Pigott 2009; Garfinkel et al. 2014.

13 E.g.: Burmeister and Müller-Scheeßel 2013, however cf. also: Levy 1995; Levy 2007.

14 Klimscha 2013.

15 S. Hansen 2013.

16 Helwing 2013.

17 Burmeister and Müller-Scheeßel 2013.

18 Burmeister, S. Hansen, et al. 2013 and the papers therein; Radivojević, Rehren, et al. 2011; Garfinkel et al. 2014.

The study of prehistoric innovations needs to identify how prehistoric societies constructed the social necessities for metallurgical developments, and how contexts were made available in which such re-inventions were seen as useful or could happen accidentally – i.e. how did societies create the equivalent of modern Research & Development departments or the sociotechnical substructures necessary for technical development? What were the limits of the prehistoric discourses on an innovation? In which contexts and by who was new knowledge produced and how and why was the distribution of this know-how limited? This, in turn, will allow a better understanding about why and how certain trajectories were set in motion and how these dominated the sociotechnical evolution of prehistoric societies.

Metallurgy is a good example to illustrate the potentials of such an *archaeology of technique* (*Technikarchäologie*) and will therefore be use used for this case study.

3 The Diffusion and Reinvention of Early Metallurgy

There is not one development of metallurgy, but there is still a larger zone in which metal is treated in similar ways, which remains constant over several millennia: In it several innovations concerning metallurgy can be seen between the 10th and the 3rd millennium BC:

The earliest stages of the use of metal ('cold working, annealing and tempering') begin in the 10th millennium and are still limited to the core area of the Neolithic Revolution in the fertile Crescent,[19] but from 5000 BC onwards ores are smelted and objects are cast into the desired shapes and the respective technology is adopted as far west as Italy and the Alpine region.[20]

It is impossible to identify any particular area in which smelting was invented – yet it is striking that the earliest evidence is not from the 'core' of the Neolithic Revolution, but that the evidence is roughly contemporary, derives from several regions and shows different typological and technological traditions. Around 5000 BC smelting of copper ores can be found in several areas relatively far from each other and showing not only different metallurgical traditions but also different characteristics.[21] Long-distance communication and its effects for the transfer of technical knowledge are not understood very well during the time in question. Therefore it is difficult to assess in how far these different craft traditions might have influenced each other. Theoretically it would be possible to argue for several separate inventions of metallurgy, although the complexity of the process makes this option rather implausible, or the archaeological record has to be seen as the result of an even earlier technology transfer, which has already been adopted to various local specifications. The seemingly contemporary first usage of smelting thus seems to be the result of a yet archaeologically invisible experimentation phase of Neolithic metallurgy.

The differences in the archaeological record around 5000 BC therefore suggest a relative complex diffusion process in which technical know-how but not a canon of forms was transferred. The most sumptuous record derives from the western Black Sea region, where from the 1st quarter of the 5th millennium onwards small chisels, flat axes and shafthole axes are made,[22] but this does not necessarily mean that smelting was invented here. Indeed, the scarcity of data is difficult to interpret, but if the chronological window is slightly broadened, technical similarities within a larger geographical region can be seen during the 5th millennium. These include the production of awls and pins, shafthole tools and weapons, flat axes (slightly later daggers[23]) but also alloying and lost wax-casting. This can either be the result of separate technical traditions aiming to solve similar problems, i.e. to reproduce lithic and organic objects in metal, or a yet barely visible communication network in which technical information are distributed. In any case, the visible connections in ceramic styles, lithic technoplexes and raw-materials suggest that even in the case of separate technical traditions, these were not isolated but took influences also from outside, and also the chronological vicinity of the respective events makes multiple independent inventions less probable than a quick diffusion of the fundamental knowledge.[24]

19 Schoop 2005.
20 Roberts, Thornton, and Pigott 2009; S. Hansen 2013.
21 Garfinkel et al. 2014.
22 Most recently: Borić 2009; Radivojević and Rehren 2015.
23 Paper by C. Frieman in this volume.
24 Cf. Craddock 2001.

Thus, the early stages of the innovation process of metallurgy, i.e. its development from an invention into an innovation, took place within a larger communication-zone. What can be seen in the archaeological record of the early 5th millennium are different technical and cultural styles applied to the same material (copper ore), resulting in geographically distinct different artefacts traditions.

It is probably justified to assume that significantly more objects than have been preserved were in circulation, and that part of them were used for a variety of activities. Yet, the new material was rare and costly and not at all superior when it came to practical aspects; flint axes, as has been shown by extensive experiments, were not only cheap to produce but also more efficient than copper axes.[25]

But why then were people attracted so much towards metal?

In some respects, copper had indeed practical advantages, for instance when shaping flint with indirect hits or as a wire, and it was also used for a wide variety of small tools.[26]

The ability to accentuate social differences by new exotic shapes and a new brilliance on prestigious objects was also important. Traditional materials like stone, shell, antler or bone could only be worked by subtracting substance from a given piece, but metals, the earliest being copper and gold, allowed a completely new way to shape things.[27] Metal allowed many new possibilities to transform matter into things: The possibility to recycle broken artefacts is another advantage. During their use lithic tools were successively repaired and modified, and this resulted in consistently shorter and smaller shapes, which at some point had to be disposed and exchanged by new tools (Fig. 1). Metal tools could be recycled and thus allowed a limited independence from raw material supply. Apart from that, however, metal allowed to stress other aspects in artefacts.

Size, for instance, was a defining factor for the social value of prestigious items in Neolithic Europe,[28] and copper allowed the production of significantly longer and heavier axe-blades than most stones. The colour and gloss of polished metal also offered a new aesthetic quality that was different from anything previously known. The beginnings of smelting are a crucial junction, in which different *social* strategies in the use of metal can already be grasped that result in further innovations. The high visibility of the Balkans is due to better research, but also due to a different treatment of the innovation. This becomes clear, when looking at the end of this junction, when metallurgy has spread over an area, which will define its limit for several centuries. Around the middle of the 5th millennium, new social dynamics can be seen involving the use of metal items in ritual contexts, of which the famous cemetery of Varna[29] and the renowed hoard from the Nahal Mishmar cave[30] and slightly later the cemetery of Susa[31] are the best known examples. The techniques used for their production ranged from relatively simple to highly elaborate.[32]

Our knowledge is best where early metals were intentionally deposited in ritual contexts. This is often misunderstood as early metallurgy being just a matter of dysfunctional prestigious items.[33] Copper was used for a number of practical activities. The earliest cast metal objects were not purely prestigious, but included a variety of tools and were far more common than has been assumed only a decade ago.[34]

However, in contrast to the practical use of small tools, the exploitation of economic possibilities of metallurgy is very limited. Within the southern Levant lost wax casting and alloying are used to produce elaborate objects with a shiny, silvery surface,[35] while other regions used a much simpler technology to create heavy reddish shafthole tools of extraordinary size.[36] The idea to use arsenical-copper alloys for specialised or more efficient tools was realized centuries later even though it seems only a small step forward.[37]

25 P. V. Hansen and Madsen 1983; Jørgensen 1985.
26 E.g. Георгиев and Ангелов 1952, 70, Fig. 30–31.
27 S. Hansen 2011, 278.
28 E.g. Højlund 1978 and Jeunesse and Pétrequin 1995 and the papers therin; Pétrequin, Cassen, Croutsch, et al. 2002.
29 Fol and Lichardus 1988. A final publication of the site is currently under preparation.
30 Bar-Adon 1980.
31 Helwing 2013.
32 Boroffka 2009; S. Hansen 2013; Klimscha 2014.
33 Gošić and Gilead 2015.
34 Vandkilde 2006 for a contrary view.
35 Klimscha 2014.
36 Vulpe 1975; Todorova 1981; Schubert 1965.
37 When in the second half of the 4th millennium saws, flanged axes and gouged chisels were created using harder alloyed copper. Cf.:

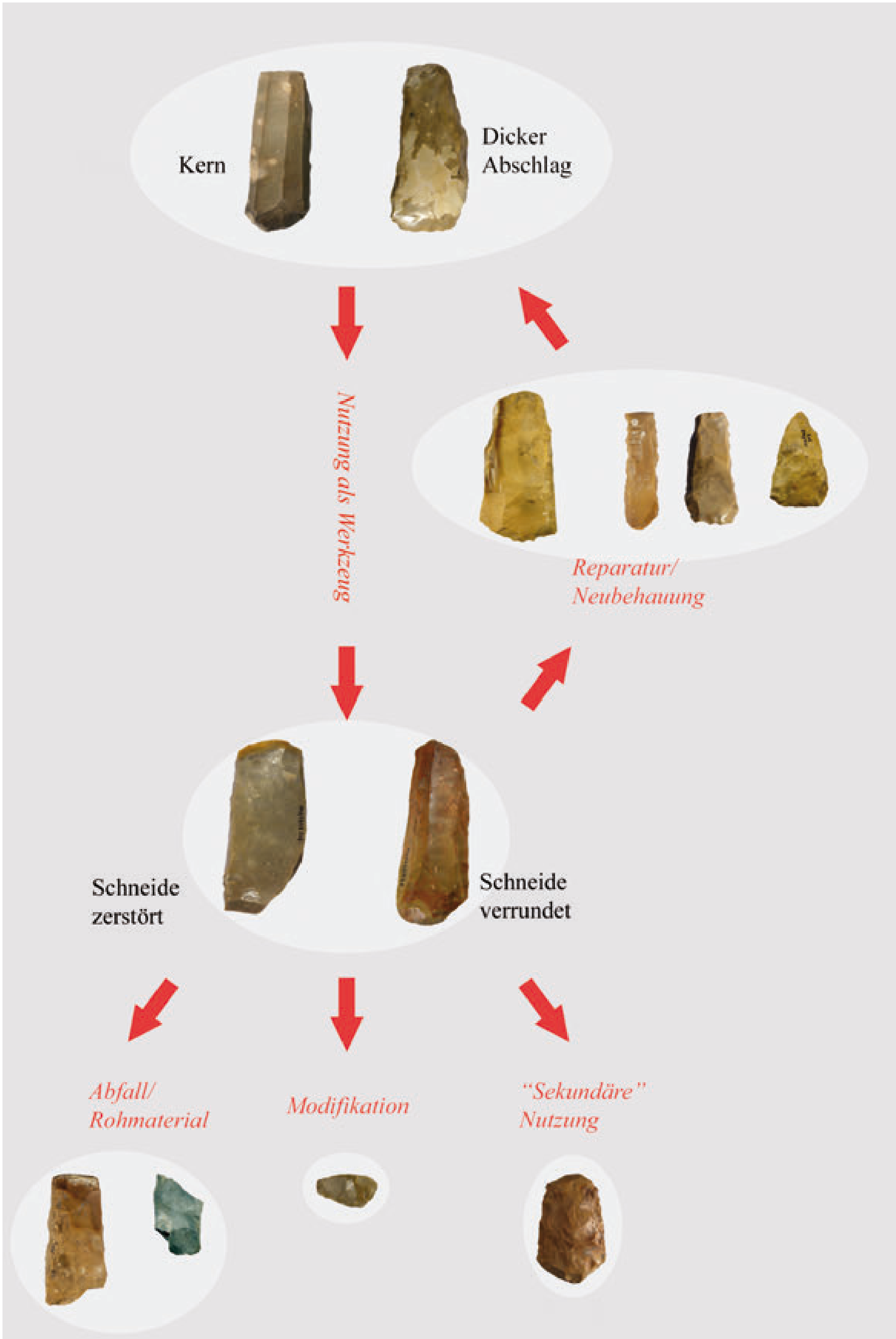

Fig. 1 Use- and reduction chain of flint axes as exemplified by the Copper Age settlement of Pietrele-Magura Gorgana, distr. Giurgiu, Romania.

Societies aimed to reproduce socially valuable objects, and this is the reason why copper was used in so many different ways already in its earliest stages. Thereby they 'invested' into specific technological developments, which in the long run enabled new options and further innovations. The inclusion into several communication networks, in turn, enabled the diffusion of these 're-inventions' of the original technology.

Even though most archaeological narratives stress the rapidity of the diffusion, the emergence of metallurgy was a process of several centuries:

S. Hansen 2011; Klimscha 2010.

The complexity of this initial phase of the innovation-process resulted in the spreading of metallurgical knowledge around the Black Sea, in Iran and Anatolia and along the Levant during the first half of the 5th millennium. Metallurgy was regularly practiced in the Carpathian Basin from before 4600 BC and reached the Alps by the 44th/43rd century BC.[38] It spread along the Mediterranean coast, but then took considerable time to go further north or west, which was only in the early 4th millennium.

4 Copper in the north

Already in the 5th millennium, copper items were moved outside the production areas and were treated as exotic goods in regions as distant as southern Scandinavia, still settled by hunter-gatherer-fishers at that time.[39] This is possible, because they fit into a *Code of Power* that seems to be shared over large parts of Central and Western Europe, where axes in all shapes are an important means to signify status, masculinity and the access to valuable raw-materials. It could be said, that it was the ability to cast axes that allowed the translation of metallurgy into Neolithic Europe. Yet, while societies all over Europe were fascinated by the new material, many groups, for instance hunter-gatherers, treated it like an exotic stone. It is here, that amplifiers which predetermine the future developments of metallurgy in the 4th millennium can be seen:

The technology to reproduce such objects did not cross the initial zone[40] for nearly two millennia. Finished products from the 5th and 4th millennium copper industries, however, travelled much further, but preferably when they could be integrated in the local power codes.[41] The large-scale production of highly elaborate flint axes, greenstone axes and flint daggers by Neolithic communities of Northern Central and Western Europe was connected to the development of highly valued prestigious copper axes and daggers.[42] It is important to stress, that the lithic artefacts are not simply a cheaper way of making a copper item, but share a high quality raw-material, often with very limited availability, as well as elaborate (often specialised) production techniques. They are the result of large amounts of labour concentrated into rare exotic raw-materials, whose acquisition made delicate long-distance-relations necessary.

Even though they had many practical and social advantages, copper artefacts do not replace their lithic counterparts in southwestern Asia for more than a millennium[43] and even longer in Europe. Was it a cultural choice to develop other designs of prestigious items made from exotic stones as a substitution for copper items or simply the cheapest way to imitate the innovation? The longer tradition of prestigious axes made from stone could be read as either an argument for the first possibility or a basic mechanism of Neolithic societies in Europe; however the inability to reproduce metal artefacts is also a factor.

The dependence on exotic goods to accentuate social differences made it possible to challenge social status with technical innovations. This motivated gaining new or more exotica. This might have resulted in blocking exactly those innovations, which could have threatened status. Fear of losing social status was one reason, why innovations did not enter every society easily. Another more pessimistic possibility could, of course, be that individuals or social groups, within those societies, were not able to accumulate enough status to invest in the long and costly *chaîne opératoire* necessary to make their own copper artefacts. Whatever the reason, for more than 1500 years, the metal record of large parts of Europe[44] consists mainly of axes, jewellery and a few early daggers, while the economy was still based on stone tools.

The cultural specifications of the adoption of copper metallurgy constructed different boundaries for its further development. Trajectories of possibilities, within which prehistoric metal workers could experiment, were defined. Whether it was socially acceptable to work on better metal shafthole axes depended on the notion on these artefacts by one's own society. That is the reason why the two most radical and influential designs, the

38 Bartelheim 2007, 42, Fig. 10; Bartelheim 2013.
39 Klassen 2000.
40 I.e. the Alps and the northern Carpathian Mountains to the north and into Western Europe to a very limited degree.
41 Klassen 2004; Govedarica 2010; J. Müller 2013.
42 Klimscha 2012; Frieman 2012; Pétrequin, Cassen, Errera, Klassen, et al. 2012.
43 Rosen 1997, 151–167.
44 Meaning the part of Europe north of the Alps and Carpathians.

Pločnik-type around the middle of the 5th millennium[45] and the Baniabic-type in the 2nd half of the 4th millennium[46] emerge between the Balkans and the northern Pontic regions, and not in Mesopotamia or the Levant.[47] Maceheads, on the other hand, are one of the most significant symbols of power in southwestern Asia and the dominant design, the pear-shaped macehead, appears in the second half of the 5th millennium around the Dead Sea – in copper.[48]

The division between tools for everyday use and prestigious items were fluent: similar technology was used to make awls and pins on the one hand, and pendants and ornamental needles, small chisels and large axes on the other. The lock-in point for the experimentation of copper technology, was mainly limited by its possible use for social distinction. Experiments in alloying started in the Levant already in the 5th millennium. These were probably in the beginning relatively simple,[49] and aimed to modify the colour of prestigious items.[50] A more elaborate stage of the same technology appears with the production of copper daggers, battle-axes and early swords significantly later – from the second half of the 4th millennium onwards – and in a different, urban, context. It is only then that arsenic copper is also used for new types of chisels, saws and other tools.[51]

While daggers and axes can be found in peripheral areas such as Northern Germany, the distribution of specialised wood working tools is limited to roughly the same area that has been defined by the emergence of metallurgy. Bladed weapons were compatible with the social specifications of societies north of the Alps and Carpathians, while better tools were not – in any case again, the knowledge to produce arsenical copper alloys did not spread with the finds made thereof.

It is not easy to find explanations for such an extreme picture. Metallurgy did not have difficulties crossing climatic zones, the necessary resources were available in many parts of Eurasia and the fascination for the objects was great. Yet, in contrast to the relatively quick and regular diffusion from the core area of metallurgy during the 5th millennium, its rejection in other parts is of great interest, and the mechanisms which blocked the diffusion of metallurgy for such a long time need to be scrutinised more closely. This can best be done by re-evaluating the impact metallurgy had on the social structure of copper age societies.

5 The impact of metallurgy and the social structure of Copper Age societies

To understand the effect metallurgy had on Neolithic societies, a closer look on the changes, brought about seems necessary. While most scholars agree that a true “Copper Age” is limited in the 5th millennium to the circumpontic zone, there is still dissent about how far those societies also influenced their neighbours and were able to create power-structures that were different from the previous Neolithic.[52]

Tobias Kienlin, for instance, argued that the political power of early Copper age potentates was only local and did not have any permanency – thus, for him, even the elite burials in Varna are simply influential members of a typical Neolithic society which use new technology to furnish their graves.[53] The complexity of both the *chaîne opératoire* involved with metallurgy as well as the delicate networks for other prestigious goods, which were controlled by these groups, are far beyond the simple and sporadic import of exotica that defines the northern periphery (or previous time periods). New research has demonstrated that copper tools, graphite pottery, superblades, large flint axes, jadeite axes and gold were indeed in regular use in a typical copper age settlement.[54] What Kienlin’s interesting point therefore fails to concede is what effect the acquiring of copper had for the accumulation of knowledge and the elaboration of organisational structures. Copper Age elites were able

45 Govedarica 2001.

46 S. Hansen 2011.

47 The extremely early development of halbeards (‘*Stabdolche*’, i.e. horizontally shafted daggers) with a midrib in the Carpathian Basin could also be added; cf. Horn 2014.

48 E.g. Bar-Adon 1980; cf. for the dating: Aardsma 2001; Klimscha 2013; Gošić and Gilead 2015.

49 Lechtman and Klein 1999, 509; cf. also: Lechtman 1991.

50 Shalev 1991.

51 S. Hansen 2013.

52 Cf. e.g.: the papers in Lichardus 1991 for a rather optimistic yet outdated narrative.

53 Kienlin 2011, 49.

54 Манолакакис 2002; Klimscha 2007; Reingruber 2014.

to acquire prestigious goods on a regular basis for at least 400 years and still amassed enough thereof to remove significant amounts from the economic cycle in graves or hoards: If competition for prestigious goods is accepted as a major factor in determining status in Neolithic ('egalitarian') societies, then the intrusion of goods, which offered unique aesthetic qualities on the one hand, and could be monopolised on the other, was not simply a new way to show off the same social relations, but a structural change within the whole system: To be able to compete for status now necessitated the participation in trade networks (or the control thereof) as well as close relations (or control) of people with the knowledge of smelting and melting. The acquisition of metallurgy therefore favoured groups that were able to control resources, humans, knowledge and space.

6 The path of metal reconsidered

This could be the reason, why its initial diffusion was not a continual story of success. There were ample raw-material sources in Central and Western Europe, which could have been exploited (and, indeed, were expoited in later times), but maybe the social preconditions were not sufficient. Technology could not change societies drastically, but these had to have both the technical and social preconditions to adapt the 'new'. Another point worth considering is the pyrotechnical knowledge available in those groups. Neolithic societies in the Near East had already knowledge in the form of pottery kilns[55], tempered and annealed copper[56] and glazed beads[57], while the graphite-pottery of South-eastern Europe was also fired at high temperatures.[58] Comparable pyrotechnical preconditions cannot be found outside of the core area and hindered the diffusion of extractive metallurgy.

When Europe is scrutinized, it becomes clear, that metallurgy in the 5th millennium is in large parts closely connected with a specific ideology seen best in grave furnishings like at the Varna cemetery.[59] Even when an "optimistic", i.e. very short, chronology is assumed for the diffusion of metallurgy to the north and west, it is the result of events taking place within numerous generations, which need not include personal contact of people living at the far ends of the area in question, although exactly that has been proposed.[60] On the other hand, it cannot be denied that within the zone, in which extractive metallurgy is shared in the 5th millennium, the frequency and quality of contacts is significantly higher, including, for instance, raw-material exchange[61], similarity in funeral rites or the use of figurines.[62]

The intensity of contacts can be understood as reflecting regular exchange of goods and people, that can be modelled, for instance, as gift-giving relations.[63] It is in this respect that another obstacle for the diffusion of metallurgy further north and west can be imagined.

The area, in which copper was produced, was significantly more limited than the area, in which the finished goods were exchanged. It was suggested that this is the result of metallurgical knowledge being reproduced within descendance-groups and that the complex production-process might have been kept secret from outsiders.[64] If metallurgical knowledge was indeed located within specific kinship groups, then its diffusion and reproduction must also have been limited by the relations defined by kinship. It has already been stressed further above, that during the diffusion of metallurgy in the 5th millennium BC, the archaeological record allows identifying ideological similarities between the

55 Hansen Streily 2000.
56 *Inter alia*: Yalçin 2000.
57 Bar-Yosef-Mayer et al. 2004.
58 Renfrew 1969.
59 Cf. the inventories in: Fol and Lichardus 1988. Similar graves can be found as far west as Transdanubia, where a recently discovered Lengyel grave at Alsönyek is based on the same idea as the richest burials in Varna. The relationship between the graves is on an abstract level; while they both include a similar set of objects, these are made from different raw materials and show, that they were not members of the same society. The common structure of including a sceptre, a shafthole axe, a flat axe and long flint blades in a rich grave reveals the close affinity of the ideologies of both groups. Even farther is the connection that can be seen in the exchange of exotic goods: The best examples are the golden diadem in the grave at Paulhiac in the Gascoigne, which is closely related with Transilvanian finds (Born and S. Hansen 2001, Fig. 12), and axes of a western Alpine design and raw material are deposited as far east as Central Bulgaria (Pétrequin, Cassen, Errera, Tsonev, et al. 2012; cf. also Klassen, Cassen, and Pétrequin 2012 with a longer discussion of other known finds).
60 Boujot and Cassen 1991; Klassen 2004, 265–267.
61 Klimscha 2007; Манолакакис 2002.
62 M. Müller 2013; S. Hansen 2007.
63 Mauss 1990; Godelier 1999; Lévi-Strauss 1948.
64 Kienlin 2008.

groups sharing similar metallurgical styles. The correlation of technical networks with other prestige good networks thus would suggest that exchange relations (marriage, gift-giving) were especially prominent between those groups who also shared technical knowledge.

It is difficult to decide whether the gift-giving network defined the borders for metallurgy or vice versa, but once such a network was established, participation in it was significantly more difficult for groups without metallurgical knowledge if reciprocity was the foundation of that network.

But, if copper was the entry fee into exchange networks guarding the secret of its production, how could such networks emerge at all? The pyrotechnical traditions of pottery kilns, the firing of floors or glazing and the experience of cold-working and annealing of copper were essential that groups could experiment on new ways to treat metal and thereby create the sociotechnical foundations for its emergence.

Marrying into specialist-groups or the forceful extraction of such specialists would be two possibilities for groups without any of these preconditions. The latter option would have a short-term effect and is probably invisible in the coarse net of the Neolithic and Chalcolithic dating-schemes. While a marriage into a metallurgical kin-group might have been a prospect, this would need to be developed into a marriage cycle to cause significant archaeological condensation. Thereby the political level of traditional marriages has to be taken into account,[65] and the question, what such societies were able to give in return, suggests itself.

In this short paper, we are not able to answer this conclusively, but maybe the question should be asked differently and in an economic sense: What were societies willing to give to be included in exchange circles, which included the marriage of metallurgical specialists?[66] As long as a society was structured in such a way that the practical possibilities for metal tools were negligible in comparison to the prestigious aspects, it was probably easier to simply look for other, easier available sources. Short episodes of experimentation – if they happened – will probably not have resulted in the discovery of the complex *chaîne opératoire* of metallurgy and resulted in proved and tested artefacts.

Thus, the early adaption of metallurgy can be seen as a lock-in point for its future development. Prehistoric communities quickly realised the great potential of metallurgy for the production of jewellery and prestigious items and it was introduced into gift-giving relations, marriage cycles as well as religious offerings.

This, however, will have created not only a technological asymmetry with non-metal using societies, but also influenced ideologies and economies. The differences between the metal using societies of the Carpathian Basin and Southeast Europe are greater when these are compared to the rest of Europe than when they are seen within the context of the southwestern Asian Neolithic/Chalcolithic. Possibly this cultural slope might also have limited the amount of exchange that was *possible* between Southeastern and Central Europe. Studies have shown that single objects did travel indeed as far to the north,[67] but the mode of operation seems to have been rather a down-the-line exchange than regular trade. There were people and objects moving but the quantity of this exchange had very limited effect. It is not before the middle of the 4th millennium, during the Baden culture, that large-scale communication networks do have a major impact on ceramic styles, stone weapons and copper metallurgy.

The difficulty to establish exchange with copper-producing regions might also be the reason for the immense creativity of many Neolithic societies regarding the production of stone items.

Metal thereby also isolated those societies using it from their neighbours, though it did not necessarily connect areas as diverse as Thrace and Iran.

7 Conclusion: rhythms of innovation diffusion in Western Eurasia

The early metallurgy of the 5th millennium was not *per se* prestigious, but it fitted well into the prestigious goods exchange that defined many Neolithic societies. Thereby it was introduced into archaeologically perceptible contexts, but the limits within which experimen-

65 Lévi-Strauss 1948.

66 Of course, a different scenario could also explore that from the other end and ask: Why would people share complex knowledge with other groups?

67 Klassen, Cassen, and Pétrequin 2012; Govedarica 2010.

tation and further development were aimed, were also set. We want to suggest, that the early adaption phase of smelting around the middle of the 5th millennium was decisive for its subsequent diffusion by creating both the socio-technical substructures necessary for metal-production as well as the desire to experiment on metallurgy.

There is no uniform development, like the grand narrative of Diamond[68] might suggest, but, on the contrary, there are different technical 'styles' as well as designs within a zone limited by the Alpine region in the west, Iran in the east, the Black Sea in the north and the southern Levant in the south. This area remains constant over millennia and is also home of all further improvements on metallurgy. The connections within the zone are strong enough to cause technical developments to quickly spread and thereby initiate new innovations. At another place, one of us has argued to imagine prehistoric Europe as a *polynodal* network,[69] and the task for the future will be to define why innovation-diffusion only happens within parts of this network. A worthwhile task could be to further research the internal structure of that network, for instance, in the distribution of technologies that require intense exchange, like domesticated species.

Metallurgical knowledge is only in very few cases really exploited, and neither the filters of the archaeological record nor the technical limitations of the 5th millennium may explain this. Rather we need to look at the contexts of the sources again and reconstruct the stages of the *chaîne opératoire*, which took place after the production. Apart from a huge lack of clarity, there is evidence, that, for instance, the copper industry of the Southern Levant was used within a ritual context of a socially elevated elite,[70] while the copper industries of the Balkans have been linked with the showing off of social status by similar groups.[71]

Even though the first contact with copper caused change in many Neolithic societies and set in motion elaborate and complex technical systems, the production of efficient tools and weapons is significantly younger, and it is only during the first half of the 4th millennium, that the disappearance of stone axes and the majority of flint tools from the archaeological record marks the dominance of copper counterparts in southwestern Asia and Egypt.[72] This development, however, cannot be seen in the region, where many scholars currently locate the invention of smelting.[73] It stresses how important local contexts and their specific developments of technologies are for the 'big picture'.

Top down-perspectives do not help to understand why innovation diffusion and re-invention did not diffuse regulary, but it is necessary to focus more closely on the archaeological record. Innovations in metallurgy are difficult to pinpoint within the described communication-sphere: Even though the distribution map is still sketchy, a trend is visible, when looking at the distribution of copper artefacts at a grand-scale. There is a long-term division on the line of the Alps and the northern Carpathians. Along and south of this line the archaeological record offers a significantly higher amount of cast metal items as well as evidence for their production.

South-eastern Europe thereby reveals itself as the western point of the Pontic and Iranian metallurgical traditions, i.e. a part of southwestern Asian technical 'influences', while the Levant can be seen as its southernmost point. The role of Anatolia in the 5th millennium is still unclear, but the relatively low level of research in comparison to the other areas should not be forgotten. A good picture of the connections within this large area can be seen when objects with cast shaft-holes in the 5th millennium are mapped (Fig. 2): The distribution of copper axe-adzes and hammer axes of the 5th and early 4th millennium[74] has similar borders as that of copper daggers of the 4th and early 3rd millennium (Fig. 3) – the only difference is that the Near East and the Mediterranean parts of southern Central Europe are included: Technical substructures, i.e. pyrotechnical knowledge and kin-groups with metallurgical know-how, which are established at the very beginning of the innovation-process, remain constant and are not diffused for approximately a millennium.

68 Diamond 1997.
69 Klimscha 2017.
70 Kerner 2001,129–152.
71 Klimscha 2012.
72 Cf.: Rosen 1997.
73 Radivojević and Rehren 2015.
74 Klassen 2004, 268, Abb. 144.

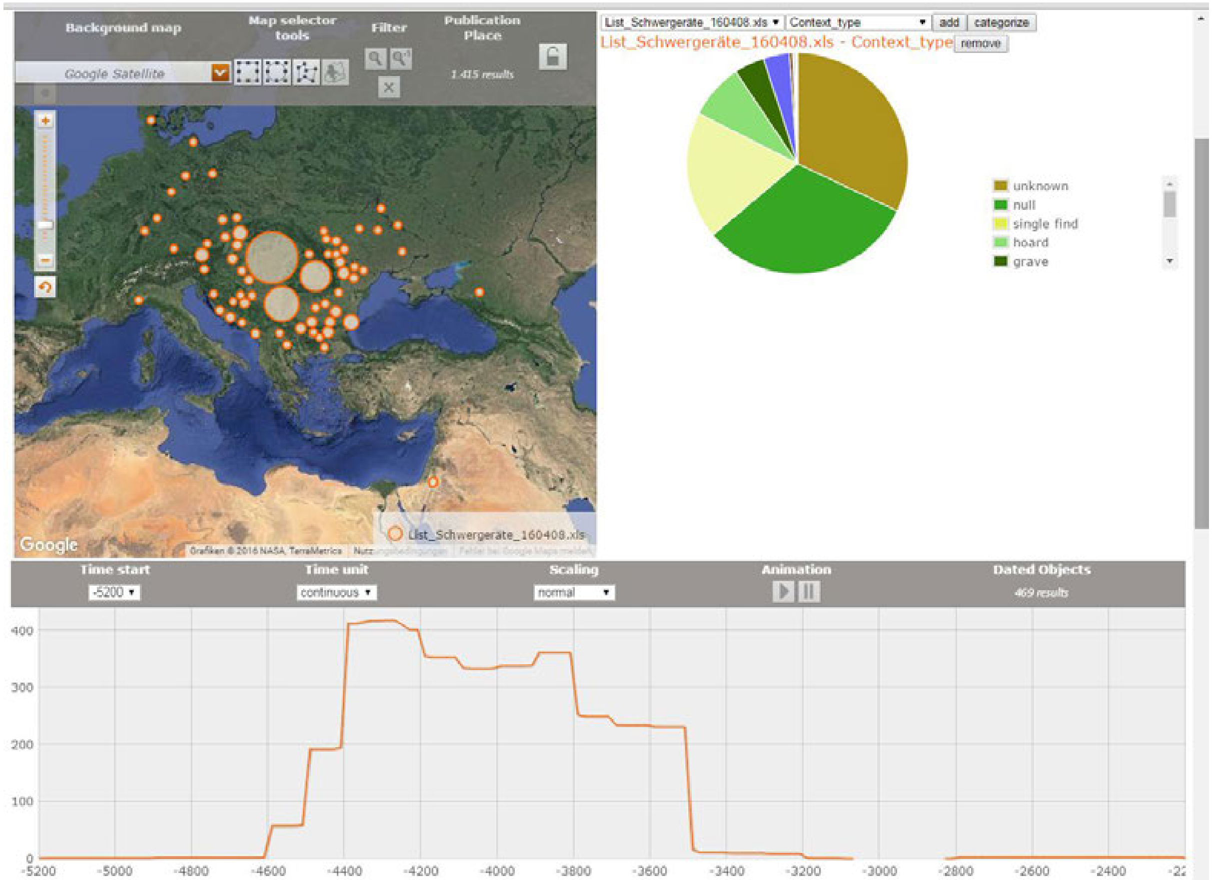

Fig. 2 Distribution of heavy copper shaft-hole axes and shaft-hole axe-adzes in the 5th and 1st half of the 4th millennium BC.

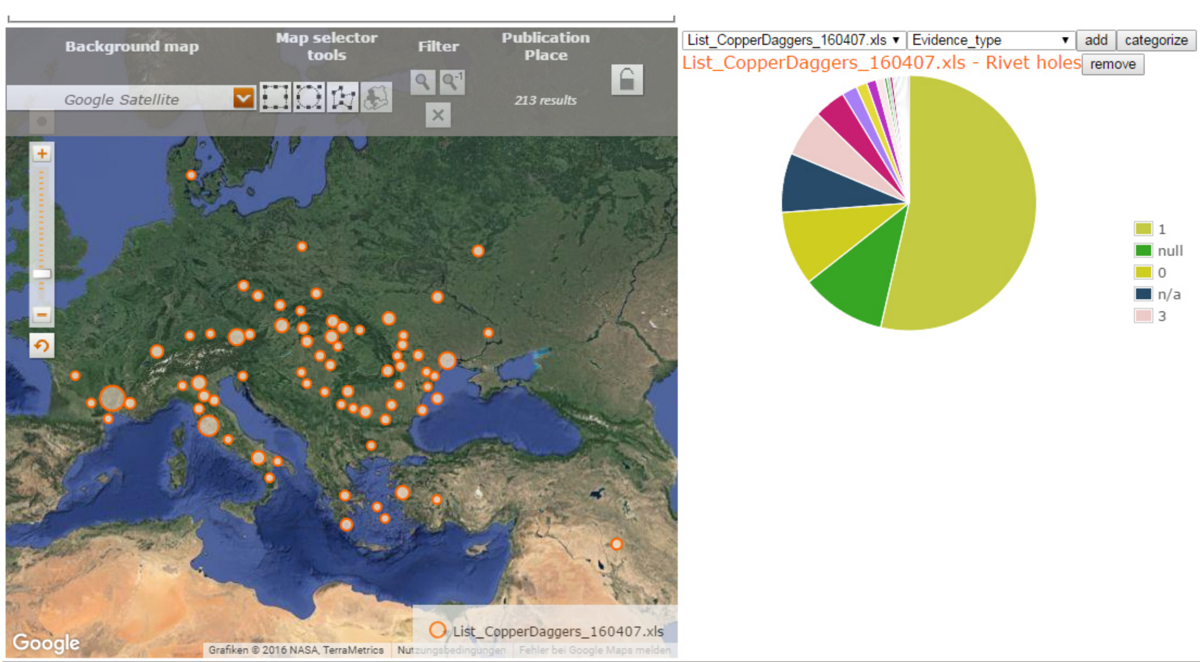

Fig. 3 Distribution of heavy copper daggers in the 4th and early 3rd millennium BC. The border north of the Alps, Pyrenees and Carpathian mountains remains constant.

Certainly there are also different trajectories within this metallurgical zone, but the development of pyrotechnical innovations only sees major changes in the 3rd millennium with the beginning of the Bronze Age. Metal did indeed matter[75] and was *one* of the decisive technologies, though probably not the only, which was responsible for the special development of a communication zone between the Eastern Mediterranean, the Anatolian-Iranian highland and the Black Sea.

75 Cf. the title of Burmeister, S. Hansen, et al. 2013.

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Make New Things but Keep the Old: Imitation, Innovation and the Communication of New Ideas

Summary

Innovation and innovativeness are key themes in contemporary social science research; but, in general, archaeology has not engaged with this wider debate in a systematic way. Our focus on the oldest and earliest objects, technologies and practices obscures the underlying social process that allows new ideas and novel technologies to be widely adopted. This paper builds on the anthropological and sociological literature around the *process* of innovation to demonstrate the ways archaeologies of innovation can be more nuanced. Through the case study of Late Neolithic/Early Bronze Age flint daggers, I demonstrate that even with the limited data available to archaeologists, the slow process of adoption and operationalisation of innovations can be charted and examined.

Keywords: innovation; flint daggers; Bronze Age; lithic technology; skeuomorphism

Innovation und Innovativität sind Schlüsselthemen in der zeitgenössischen sozialwissenschaftlichen Forschung; aber im Allgemeinen hat sich die Archäologie nicht systematisch mit dieser breiteren Debatte befasst. Unser Fokus auf die ältesten und frühesten Objekte, Technologien und Praktiken verschleiert den zugrundeliegenden sozialen Prozess, der es ermöglicht, neue Ideen und Technologien auf breiter Basis zu übernehmen. Dieser Beitrag baut auf der anthropologischen und soziologischen Literatur rund um den Innovationsprozess auf, um aufzuzeigen, wie Archäologien der Innovation nuancierter gestaltet werden können. Anhand der Fallstudie der spätneolithischen/frühbronzezeitlichen Silexdolche zeige ich, dass selbst mit den wenigen Daten, die uns zur Verfügung stehen, der langsame Prozess der Übernahme und Operationalisierung von Innovationen erfasst und untersucht werden kann.

Keywords: Innovation; Silexdolche; Bronzezeit; Steinzeittechnologie; Skeuomorphismus

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1 Introduction

Innovation, both technological and cultural, is a key driver of social change; but the adoption of innovations is only one of many possible end results of a long process of experimentation, research and total or partial rejection.[1] Furthermore, the underlying social structures which predispose a society to welcome or oppose innovations are poorly modelled and barely understood. Archaeological studies into innovation tend by necessity to be *post hoc* research, centring on mapping the movement of new ideas after (perhaps even generations after) they were successfully adopted.[2] Alternatively, and in direct opposition to the conceptualisation of innovation developed by sociologists and anthropologists,[3] some archaeologists have taken the perspective that innovation happens at a societal level, investigable only through evolutionary paradigms and occurring as a largely separate phenomenon to the variability of social practice and human agency.[4] However, it is my contention that careful and contextual archaeological analysis which takes into account the centrality of material culture and technology to human social relations can give use a much more nuanced perspective into the adoption of new ideas and technologies than evolutionary archaeologists allow.[5] As archaeologists, we have thousands of years of data and countless examples of total and partial acceptance or rejection of a variety of innovations, from new technologies to new social practices and belief structures, around which to develop models of innovativeness.

In this paper, I will use the example of flint daggers from prehistoric Europe to discuss the ways in which new ideas, new objects and new technologies were developed, communicated and operationalised in the prehistoric world. My focus will be on the process of innovation, rather than the appearance of the new objects or technologies themselves. The questions I seek to answer are (a) why did specific types of objects, in this case daggers, appear across central, northern and western Europe in the fourth and fifth millennia and (b) what links, if any, exist between the appearance of daggers and the adoption of metal and metallurgy? While flint daggers are often described as copies of more valuable metal tools, I argue that both the flint and the metal daggers derive from the same phenomenon and a simple one-to-one comparison overlooks their importance to the developing social structures which promoted technological specialisation and allowed for the widespread adoption of metal objects and metallurgy, among other materials and technologies.

2 Innovation in society

Technology and material culture are deeply embedded in human social interactions.[6] and technological change and innovation are inextricably tied to larger social and material spheres.[7] Not only is the impulse to innovate or to accept an innovation socially conditioned, but the desire for a new object, practice or technology develops out of a pre-existing process of learning about and testing it (Fig. 1).[8] Furthermore, innovations are most likely to be successfully adopted when an individual member of a society, an 'early adopter', is closely involved in the development and acceptance of innovations within the larger group. They use their connections within their immediate cohort and with others, as well as their knowledge of the specific innovation in question, to encourage and support other people to test and accept the innovation.[9] Essentially, they create bridges in practice and knowledge between tradition and innovation, a process referred to in archaeological studies of material culture as "envaluation".[10] Through contact with early adopters, more people become aware of the new practice, thing or idea; they seek information about it; they test it for advantages and disadvantages; they try it out; and, finally, they adopt it fully into their day to day lives.[11]

The speed with which people move from one stage in the process of adoption to the next varies based on a variety of different factors, including people's perceptions of the innovation, the structure of their society, externally precipitated events or crises, environmental

1 Rogers 2003; Rogers and Shoemaker 1971.
2 E.g. Roberts, Thornton, and Pigott 2009.
3 Barnett 1953; Rogers 2003.
4 E.g. O'Brien and Shennan 2009.
5 Frieman 2021.
6 Dobres 1999; Dobres 2000; Dobres and Hoffman 1994; Gell 1998; Munn 1986; Munn 1990; Strathern 1988.
7 Barnett 1953; Lemonnier 1986; Lemonnier 1992; Lemonnier 1993; Rogers 2003.
8 Barnett 1953; Rabey 1989; Rogers 2003; Rogers and Shoemaker 1971.
9 Rogers 2003.
10 Taylor 1999; Frieman 2012b.
11 Rogers 2003.

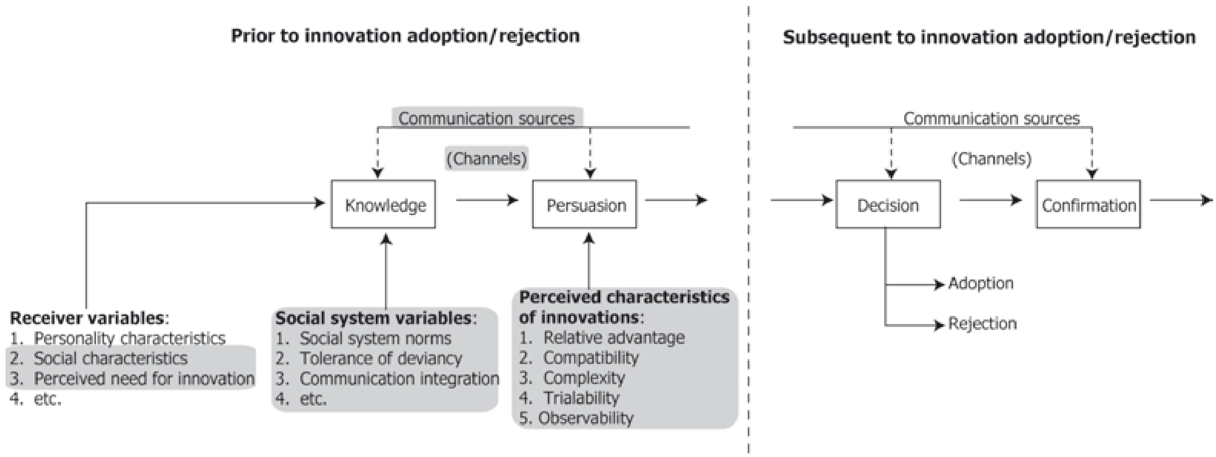

Fig. 1 The process of innovation adoption. Highlighted values are those parts of the innovation process prior to the actual adoption of rejection of an innovation which are accessible to archaeological inquiry.

or demographic pressure, etc. Moreover, the act of finally accepting an innovation is not a passive one; and the innovation itself is altered by its slow incorporation into a new social structure.[12] Barnett illustrates this point with the example of the early twentieth century Palauan adoption of Singer sewing machines which, when they were in working order, were used by both men and women unlike in the contemporary western societies in which they were women's tools.[13] When not in use, they were placed with pride in the centre of the front window. Although Palauans adopted many aspects of western culture, including dress and mannerisms, the gendered practices associated with sewing machines shifted upon their incorporation into Palauan society. At the same time, their functionality changed: sewing machines were not just tools used to complete a task, they were valued objects which became part of status displays and competition.

Although contemporary, western society demonstrates a clear proclivity for innovation and preference for innovative activities, this orientation is far from universal. Innovations are regularly rejected, not just on functional grounds but for arbitrary reasons that are difficult to assess, being grounded firmly in cultural attitudes towards the newly altered practices, technologies or ideas.[14] Wetmore's study of technology in Amish society, an ethic group widely known for being religiously restricted from the wholesale adoption of new technologies, makes clear that the choice to adopt a new technology, even one in heavy usage by one's neighbours, may have wide-ranging and unexpected results.[15] The Amish, according to Wetmore, do not reject innovations out of hand, but carefully weigh the potential of new technologies, on the one hand, to help Amish people and Amish businesses and, on the other, to disrupt their way of life, undermine their value system and affect social and religious relationships between Amish people and communities. Even in innovation-positive cultures, rejecting innovative practices is far from rare and seems to relate to questions in the potential adopter's mind about how compatible the innovation is with pre-existing practices, the difficulty of enacting it and communicating it to others, and the ease of testing it on a small scale prior to adoption.

Objects or practices without pre-existing cultural referents cannot, by definition, be adopted,[16] but new ideas can be developed to explain – and, consequently, normalise – the never previously encountered innovation.[17] Schieffelin and Crittenden point out that, in their first encounters with steel objects, Indigenous Papuan people were alternately mystified and horrified by the unrecognisable material which was rejected out of hand.[18] Yet within decades, steel axes were highly sought after by most, and explained by those who rejected their

12 Barnett 1953.
13 Barnett 1953, 331.
14 Rogers 2003.
15 Wetmore 2007.
16 Barnett 1953.
17 Cf. Frieman 2012b.
18 Schieffelin and Crittenden 1991, 101–102.

use as "strange objects [from the Origin time] [...] that should not be touched or used by mortal men".[19] However, as noted above, not all of the ideas which contribute to a novel practice or technology are forcibly adopted together. For example, among the Yurok, a Native American group based on the California coast, obsidian blades were traditionally displayed as objects of wealth and for prestige even after the adoption of gold coinage from local Euro-Americans. The idea that coins represented wealth in the same way as obsidian blades was not adopted; and the two were not considered to be in the same conceptual category.[20]

2.1 Archaeological research into innovation

Archaeologists approach this process at a distinct disadvantage owing to the incompleteness of the archaeological record leading to a paucity of evidence for the early stages of innovation adoption (Fig. 2) and, in preliterate contexts, the lack of any contemporary commentary on the nature or desirability of the innovation in question. In consequence, archaeological studies of innovation have largely focused on discovering the first or oldest example of a given innovation and identifying its technological or economic benefits.[21] Further, Dobres and Hoffmann note that archaeological perspectives on innovation often view it as an isolated event separate from the larger social and technological trends which are actually crucial to the development and acceptance of new ideas and forms.[22] The unfortunate result of this default position is a body of research into innovation which fails to engage with the technology, practices and values out of which innovations developed.[23]

That said, there is a growing interest in the evolutionary roots of cultural transmission and innovation.[24] In these studies, innovation is seen as part of a linear model of cultural evolution and frequently framed as the development of more efficient or more technologically functional objects, materials and processes.[25] Certianly, the efficiency of new techniques and technologies, their reproducability and their integration with longstanding processes is one factor contributing to their adoption; but more abstract concerns about political or social status, traditional technologies and artisinal practices and the disruptive role innovations can play in social organisation also have considerable, tangible consequences when a new technology is encountered. In other words, these sorts of approaches explicitly remove innovations from the interlocking social and material networks described above. In fact, these models represent a regression in social theory away from the complexity of agent-centred models of social change and back towards a fixation on the technological capacity and advantages of various materials and processes, regardless of different socio-cultural contexts of use and production.

Anthropological studies indicate that the adoption of new practices is a continuous process that allows people to cope with constantly changing social and technological environments;[26] so the difficulty facing archaeologists lies not in identifying innovation but in identifying its significance. A major hurdle to this sort of research lies in the fragmentation and incompleteness of the archaeological record. Innovations are generally not archaeologically visible until they have been widely accepted.[27] Furthermore, our failure to recognize the complexity of the various technologies which had to be mastered in order to carry out new technological processes or social practices can lead to overly simplistic explanations of how and why people developed new practices and technologies.[28] Instead, to address innovative activity in past societies we need to develop an understanding of those societies' 'internal logic' through wider analyses of their material cultures and the practices associated with it[29] and 'look forward' from the archaeological record.[30] Thus, prehistoric innovation can be approached through close study of archaeological materials, but in order to do so a wider chronological and material context must be considered. The solution to this problem lies in developing more robust methodologies which take into account not just technological

19 Schieffelin and Crittenden 1991, 68.
20 Barnett 1953, 338.
21 Dobres and Hoffman 1994; Leeuw and Torrence 1989a.
22 Dobres and Hoffman 1994, 245.
23 Leeuw and Torrence 1989a, 8.
24 E.g. O'Brien and Shennan 2009.
25 Eerkens and Lipo 2007.
26 Rabey 1989.
27 Leeuw and Torrence 1989b, 304.
28 Brown 1989.
29 Sørensen 1989.
30 Leeuw and Torrence 1989b.

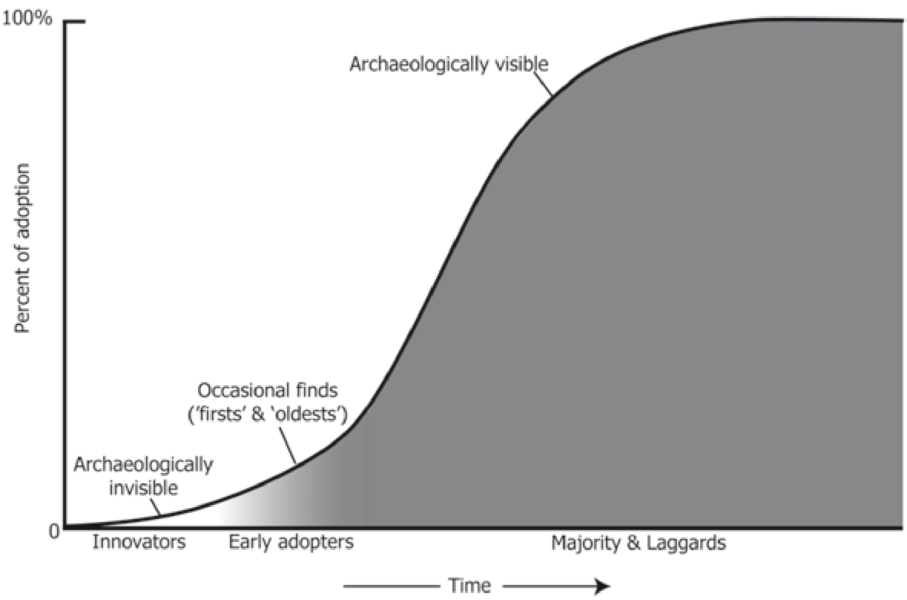

Fig. 2 The S-curve of innovation adoption over time with archaeological visibility indicated.

changes, but the material and social context of those changes (Fig. 1).

3 Daggers and the birth of the Metal Ages

The adoption of metal in Europe was neither a rapid nor a linear process.[31] The earliest traces of metallurgy in Europe date to a very early fourth millennium context in the Austrian Alps;[32] and copper metallurgy seems to have been practiced in the Alpine Neolithic, among the Cortaillod and Pfyn groups. Whilst some metal objects circulated as widely as Scandinavia within the next several hundred years,[33] metal technology does not appear to have been widespread; and largely disappears from northern and western European contexts around 3000 BC. Yet, after several centuries of archaeological invisibility, metal technology re-emerged and appears to have been rapidly and widely taken up. By the late third millennium BC, all of western and Central Europe were more or less regularly producing and using metal objects, including copper, tin-bronze and gold.[34] Instead of a clear progression from primarily stone-using to primarily metal-using societies, the adoption of metal was a punctuated process with some areas taking up metal briefly before ceasing to deposit it for many subsequent generations.

Moreover, in its earliest appearances, the metal we see circulating around Europe is not necessarily the technologically superior material it was traditionally assumed to have been. Evidence for early copper technology suggests that a specific process of metal making was communicated with few changes over great distances, perhaps through kin networks,[35] a process some have speculated was more ritual than technological or economic.[36] The physical properties of metal, what Bray calls its "metalleity"[37], were not fully exploited until centuries after its initial adoption and popularisation. In the fourth millennium BC, in particular, the small copper tools circulating in northern and central Europe would not have withstood much hard use. In short, the early adoption of metal cannot be linked directly to its functionality or technological superiority. Interestingly, we see a distinct

31 Roberts 2009; Roberts and Frieman 2015.
32 Höppner et al. 2005.
33 Klassen 2000; Klassen 2004.
34 Roberts and Frieman 2015; Shoda, S. and Frieman, C.J. Forthcoming. "Just a coincidence? The Similar but Contrasting History of Bronze Adoption in Northeast Asia and Northwest Europe". In *Making Metals and Moulding Society: a Global Perspective on the Emergence of Bronze Age Social Complexity*. Ed by T. Rehren, X. Tianjin, C. Jianli, L. Nickel & P. Rui. Oxford: Oxbow (forthcoming), with references.
35 Kienlin 2008.
36 Budd and Taylor 1995.
37 Bray 2012.

standardisation in the forms of the earliest circulating metal objects. From Iberia to Scandinavia, the earliest metal-using phases saw the circulation (if not local production) of copper flat axes, sheet copper 'trinkets' (small ornaments) and (rather flimsy) dagger blades (Fig. 3).[38]

Daggers in particular are a key feature of the beginnings of the European Metal Ages. Daggers, particularly copper or copper-alloy daggers, seem to have been extremely valued and symbolically important objects. They appear in rock art,[39] are present in some burials[40] and are deposited in hoards in wet locations alongside other valued materials.[41] Many archaeologists have noted the significance of the dagger at this time and gone on to suggest that daggers may have functioned in this early metal-using era in the same way that swords are thought to have functioned in the Bronze Age: as the quintessential male status item linked to emerging warrior ideals, if not directly to a class of elite warriors.[42]

At the same time metal (and metal daggers) were starting to circulate around Europe, flint daggers begin to be produced as well.[43] Major centres of flint dagger production are well-known and have been found in many places, including central and northern Italy[44], central France[45], and southern Scandinavia[46] as well as smaller centres in the Alpine region[47], the British Isles[48] and the Baltic down to northern central Europe[49]. Many of these flint daggers circulated quite widely, and were occasionally copied in local flint sources far from their points of origin. Early 4th millennium BC flint daggers from Italy have been recovered in Austria, Germany and Switzerland.[50] Long double-edged blades made from flint from the Massif Central in France have been found from the Pyrenees to northern Germany in contexts dating to the 3rd millennium BC.[51] Most famously, the extremely technologically sophisticated late third millennium BC flint daggers from Scandinavia have been found in contexts from Norway to Iberia; were circulated even after having been broken; and clearly inspired the British late third millennium BC flint dagger industry (Fig. 4).[52]

The appearance of these flint daggers is regularly described as a response to metal use, with prehistoric people being presumed to have made the flint tools in imitation of the more valuable, prestigious or visually striking metal prototypes.[53] However, recent research has demonstrated that, in some regions, the flint daggers appeared before copper daggers, which then took forms in imitation of lithic prototypes;[54] and, in others, the production, use and deposition of flint daggers are so different from those of the suggested metal prototypes as to preclude a direct, imitative relationship.[55] In fact, the flint daggers share many similarities among themselves. The majority are highly sophisticated tools made with great skill. The production of most flint dagger varieties required specialist knapping techniques which were probably developed through structured apprenticeships and considerable practice[56] and may have been carried out, at least in part, out of public view.[57] Moreover, the flint raw materials chosen for dagger production were clearly highly valued and carefully chosen for their high quality and suitability for the production of long-thin blades; many flint daggers were made from mined or other specially acquired flints.[58]

38 Frieman 2012b; Frieman 2012a, with references. There is some evidence that heavy copper objects originating in southeast Europe were also circulating into northwest Europe. The famous example of the copper knob-butted axe from Scania, Sweden seems to be the northwesternmost find, but Klassen's (Klassen 2004) map of southeast European copper artefacts clearly shows that these objects were travelling, probably along rivers, great distances from where they were produced.

39 Harrison and Heyd 2007.

40 Steiniger 2010.

41 Reinecke 1930.

42 E.g. Earle 2004; Sarauw 2007; Heyd 2007.

43 Frieman and Eriksen 2015.

44 Steiniger 2010; Mottes 2001.

45 Mallet 1992.

46 Lomborg 1973; Kühn 1979; Apel 2001.

47 Honegger 2006.

48 Grimes 1932; Frieman 2014.

49 Czebreszuk and Kozłowska-Skoczka 2008; Šebela 1997–1998.

50 Guilbeau 2015; Honegger 2006; Honegger 2011; Honegger and de Montmollin 2010; Mottes 2001.

51 Delcourt-Vlaeminck 2004; Ihuel 2004; Ihuel et al. 2015; Mallet, Richard, et al. 2004.

52 Apel 2001; Frieman 2012a, with references; Frieman 2014.

53 Strahm 1961–1962; Heyd 2007, 344–47; Earle 2004; Vandkilde 1996; Vandkilde 2001.

54 Steiniger 2010; Steiniger 2015.

55 Frieman 2012b; Frieman 2012a.

56 Apel 2000; Apel 2001; Apel 2006; Apel 2008; Ihuel et al. 2015; Pelegrin 2002.

57 Apel 2001; Mallet and Ramseyer 1991; Millet-Richard 1994; Mottes 2001.

58 Barfield 1995; Barfield 2001; Frieman and Eriksen 2015; Ihuel et al. 2015; Sarauw 2006b; Sarauw 2006a.

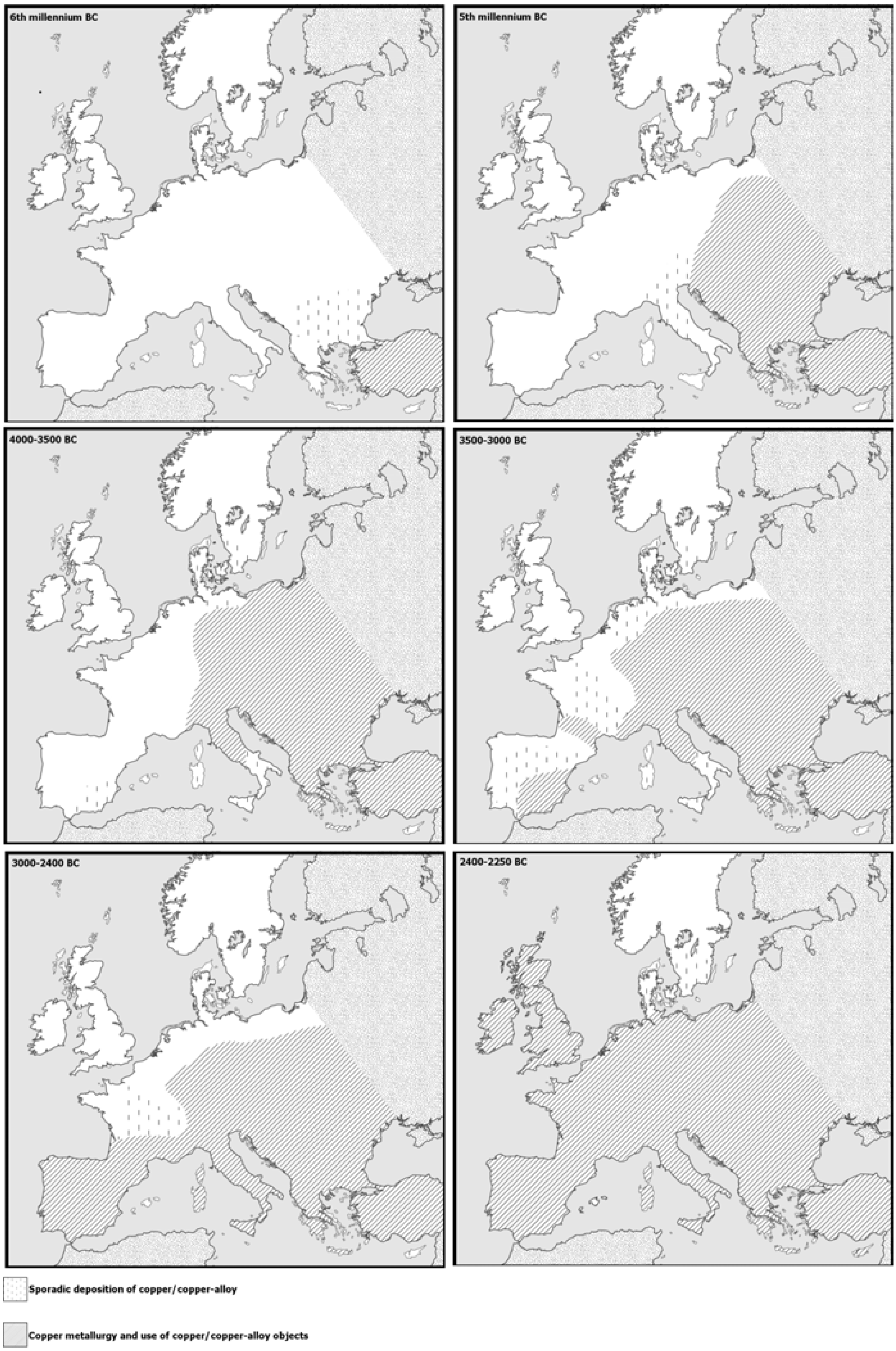

Fig. 3 The gradual spread of copper into and around Europe. Stippled area not mapped.

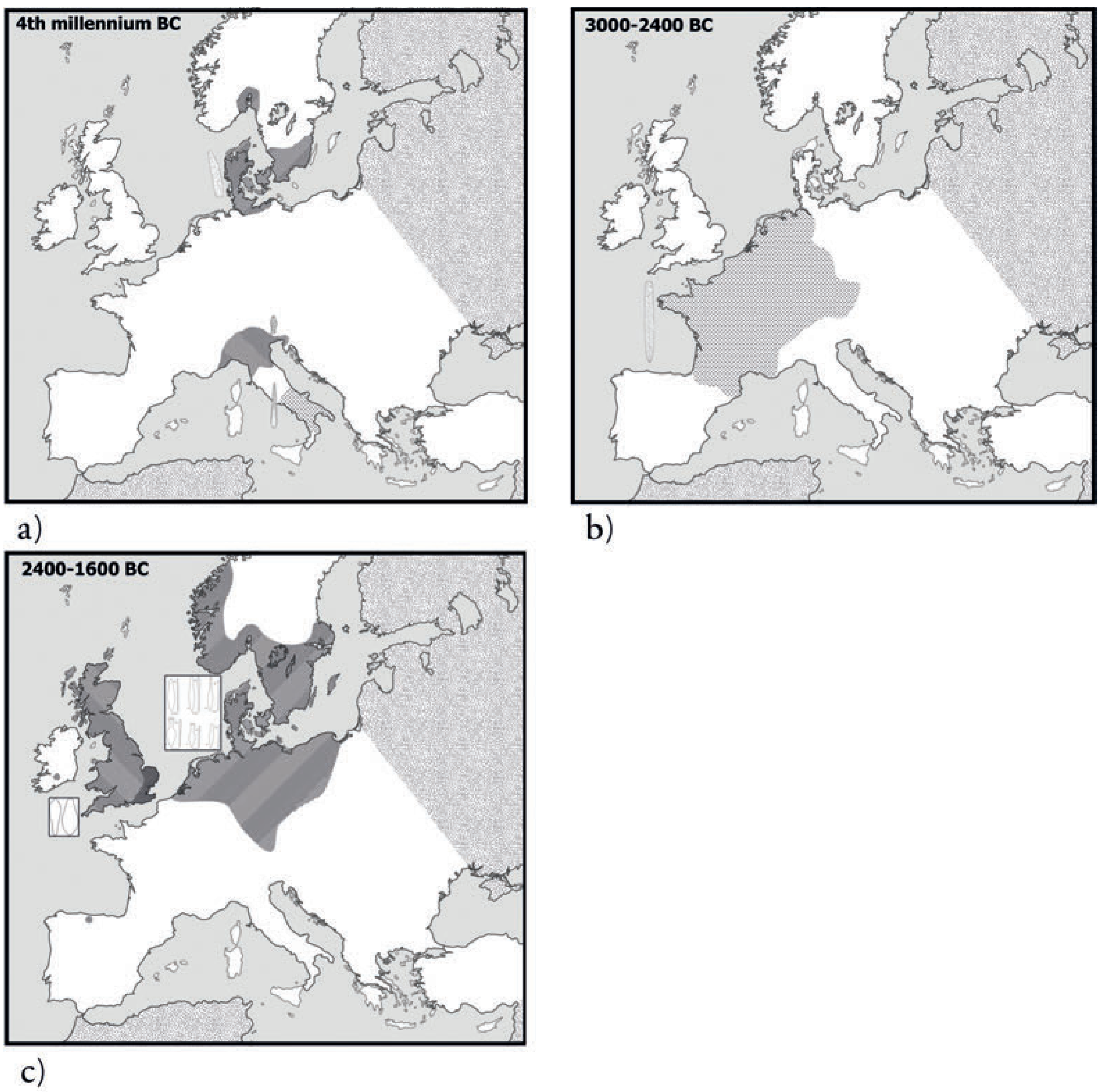

Fig. 4 Lithic daggers in Europe from the fourth to the second millennia BC (Iberia not mapped). a – 4th millennium BC; b – First half of the third millennium BC; and c – mid third to mid second millennia BC.

In previous work, I have suggested that their value derived both from their striking forms and from the technological sophistication – especially the specialised production processes – which underlay their manufacture.[59] Metallurgy too was a specialised process and one with an apparently delimited sphere of communication. The uniformity of ancient metallurgy in Europe suggests that copper was adopted slowly via kin or lineage networks which served as vectors for the dissemination of not just the technological aspects of metallurgy but a whole set of norms, values and beliefs.[60] Clearly both flint and metal daggers were drawing on, and gaining value from, this association with specialisation. More than that, the dagger form itself, a new morphological shape without real precedent in pre-metal-using Europe, seems to have taken on a special value because of its production through these specialised techniques.

From this, I have argued that the 'dagger idea' was not necessarily about universally shifting ideas of status or maleness, but rather a symptom of a broader shift to valuing specialisation and the retention of special, perhaps secret, bodies of knowledge.[61] Based on Kienlin's work,[62] and inspired by the literature discussed above which posits that innovation is part of an extended social process, I would suggest that there was no conscious choice to adopt copper. Rather, its production was part of a larger social structure, tied to mythology, personal relationships and the practice of quotidian activities. This larger social structure was characterised by social and economic spheres in which a complex, specialised skill set was both readily accepted and immediately of worth. In this context, it seems that daggers – a new form, closely associated with early metal by dint of being among the first metal objects many prehistoric Europeans would have seen – may have conceptually represented newness and innovation, two qualities which were becoming widely prized by people engaging in the increasingly intense and long-distance trade and communication networks which characterised fourth and third millennia BC Europe.[63]

4 Conclusions

In this paper, I have discussed the idea, well known in sociology and technology studies, that innovations are not taken up automatically or with great frequency. Instead, the adoption of a new idea, practice or technology is better understood as simply one outcome (and by no means the most common one) of a long process grounded entirely in social interaction between individuals and between communities. In this light, the slow and sometimes punctuated adoption of metal in prehistoric Europe makes great sense.[64] Metal objects, particularly in their earliest forms, were not necessarily more physically functional than lithic tools or tools made from organic materials, nor can we suggest that they were innately valuable. Value too is a socially defined category, and things are recognised as valuable because they fit into pre-existing categories of valued materials.[65] Instead, I have suggested that, in order to understand the adoption of metal and metallurgy, we need to look at underlying social value systems and the emergence of social and economic structures that would have made metal and metallurgy seem like worthwhile things to adopt. Specifically, I suggest that an increasing focus on special and circumscribed knowledge, visible archaeologically in the trend during the fourth and third millennia towards valuing specialisation and the products of specialised technologies, allowed metal to be valued and adopted. Daggers seem to have played a special role in this process. They are among the earliest metal forms to circulate widely in Europe; and flint daggers circulated widely as well during the fourth, third and second millennia BC. While traditionally archaeologists have described the flint daggers as imitations of metal, I argue that both flint and metal daggers are part of a broader dagger idea linked to the spread of specialist knowledge and specialised technologies. Knowing how to make daggers was a special thing;[66] possessing one indicated a person's engagement with the expanding networks of trade and communication by which special knowledge and valued materials travelled.

59 Frieman 2012b; Frieman 2012a.
60 Kienlin 2008, 101–103.
61 Frieman 2012b.
62 Kienlin 2008.
63 Frieman 2012a.
64 Roberts, Thornton, and Pigott 2009.
65 Taylor 1999; Graeber 2001.
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1 Adapted from Rogers 2003, fig 5.1 and Rogers and Shoemaker 1971, fig. 3.1. 2 Adapted from Rogers 2003, fig. 1.1. 3–4 C. J. Frieman.

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Metal Headbands in Southwestern Asia at the Turn of the 3rd Millennium BCE: A Social Innovation in Its Context

Summary

Ornate headgear made from metal is attested in ancient southwestern Asia since the 4th millennium BCE, and became a widespread phenomenon in grave inventories of the later 3rd and the 2nd millennium BCE. Variously called "headband", "diadem" or, more specifically, "crown", a variety of sheet metal bands adorned the heads of people buried in graves. These metal sheets sometimes consisted of unusual alloys or of precious metals, and are thought to have functioned within a system of status signaling as markers of rank and / or wealth, an important social innovation at that time.

Keywords: Southwest Asia; Early Bronze Age; headbands; innovation

Verzierte Stirnbänder aus Metall sind im alten Südwestasien seit dem 4. Jahrtausend v. Chr. bezeugt und wurden in Grabinventaren des späteren 3. und 2. Jts. v. Chr. zu einem weit verbreiteten Phänomen. Unterschiedlich als „Stirnband", „Diadem", oder genauer, als „Krone" bezeichnet, schmückten verschiedene Blechbänder die Köpfe der bestatteten Menschen. Diese Bleche waren manchmal aus ungewöhnlichen Legierungen oder aus Edelmetallen gefertigt. Sie haben vermutlich innerhalb eines Systems von Statussymbolen als Markierungen von Rang und/oder Reichtum funktioniert, was in dieser Zeit eine wichtige soziale Innovation darstellte.

Keywords: Südwestasien; Frühbronzezeit; Kopfbänder; Innovation

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1 Introduction

The following contribution pursuits to trace the appearance of one particular type of early metal headbands: narrow parallel-sided stripes of metal sheet, often with punctual embossed decoration, which appear in significant numbers in burials at the beginning of the 3rd millennium BCE. These headbands can be made from silver, gold, lead, copper or of alloys that combine copper with silver, which indicates a remarkable level of technical knowledge on the side of the metal smiths. In their finished and polished state, the headbands must have been remarkable for their unusual material and the aesthetics of the shiny surface.

It is my explicit aim to focus on the cultural and historical context of the first occurrence of these headbands. The headbands proper stand for an innovation that took root around 3000 BCE as part of a whole bundle of technical and social innovations that appeared at about the same time, and it would not have occurred in its specific way without these: hence, the headband innovation is intertwined with innovations in status construction and representation, which by themselves are again markers of a specific historical constellation, as will be argued below. A perspective focused onto this particular type of headband and onto a precise time range may thus contribute to dissect this innovation process into digestible steps and to approach the question "who wore these headgears?" more closely. The constricted perspective willingly adopted here will allow us to narrow ambiguities about the identity of the early diadem wearers, and will provide insights into the dynamics of the innovation process.

I will proceed by first laying out some general considerations on the study of prehistoric innovations and secondly introduce the state of research concerning the question of diadem wearers before a presentation of the archaeological evidence and a contextualized discussion of these findings. Ultimately, I intend to demonstrate that the appearance of parallel-sided metal headbands with embossed decoration at the turn of the 3rd millennium BCE precisely denominates a female element in close relation with high status (male) warrior burials. This later group forms the peak of a society that had, following the collapse of the first centralized state-like institutions of the late 4th millennium BCE Uruk period, established social ranking on the base of military merit in times of insecurity and 'chaos'. This chaotic context prevailed for about two centuries, before a renewed round of urbanization and state formation changed the setting again. In consequence, the original meaning of the headband disappeared. Later headbands, from the 28th century onwards, indicate a more loosely defined and more widespread, rather aesthetic use of headgear, with differing translations in individual regional traditions. Headbands at that later time could still signal high status and adorn male and female burials as well as children, but material, craftsmanship and sometimes also a lack of care in finishing bespeak of a different attitude towards the representation of the buried individual. Hence, studying the headbands opens a window onto the appearance and establishing of a new social signal in a specific historical context, and onto its subsequent transformation, under different historical circumstances, into a more loosely defined fashion accessory.

2 Studying innovations

The quest to understand innovations is one of the key issues driving research in the social sciences, archaeology included.[1] Other than sociology or ethnography who actively engage in dialogue with their study subject, archaeology focuses on the material remains of past societies whose members are no longer available for direct consultation. Furthermore, by the very nature of the material archaeological record, taphonomic processes have contributed to a patchy record available for study. While time distance and the sometimes poor state of preservation of the archaeological material may appear as a disadvantage of archaeological approaches, this is outbalanced by the opportunity offered by archaeology to gain a perspective in the *longue durée*. Although some important successions of detail development remain invisible, the *longue durée* perspective has the advantage to condense drawn-out rhythms and processes into observable sections and hence to establish long term cause-and-consequence relations that would go unnoticed in

1 Rogers and Shoemaker 1971, passim, see 48–53.

modern sociological or ethnographic documentation.[2] An archaeological enquiry into innovation thus offers insights that are otherwise not or barely achieved: the adoption of innovations can proceed rapidly or slowly, and often occur time lags between an original invention and the acceptance of an innovation that can be documented archaeologically beyond the boundaries of ethnographically observable time.

The archaeological study of prehistoric innovations has developed a toolbox of methodology that I briefly recall here. Accordingly, innovation is a complex process that unfolds over several subsequent steps: it begins with new insights and recognitions, continues by the integration of this new information into technical and social systems and the adoption of newly developed routines in production and consumption. If, how, and when these steps are taken depends on numerous factors: the geographical proximity of actors, the ways of transmission of knowledge, the availability of materials, the social embedding of the principal agents and many more. In consequence, the adoption processes often follow cycles that begin with isolated early cases of adoption before the majority of users follows (Fig. 1). Along the path, and in particular in its beginning, there is ample space to experiment or tamper with the novelty, leading possibly to a translation of the original invention to new technical or social systems (Fig. 1). Only when the new system has become mainstream can we really talk about innovation, and it is – by the very nature of the patchy preservation of archaeological materials – only this stage of an innovation process that becomes tangible in the archaeological record.[3] By its very nature, any successful innovation integrates a multitude of technical and social knowledge into a large package – and it co-occurs in relation to other changes, historical, social, or technical.

Archaeologists working on prehistoric innovations rely on various concepts to disentangle the individual steps that contribute to the innovation package: the approach adopted here follows a general approach of *chaîne opératoire*[4] to single out changes in individual decision making by producers and consumers. The strength of a *chaîne opératoire* lies in its concept that integrates 'hard factors' like properties of place and material with 'soft factors' like a consumer demand that is driven by social decision making into a consistent scheme. The model allows to more precisely locate the occurrence of an innovation within a complex interplay between production and utilization and to narrow the perspective onto case-specific logics and individual changes behind any innovation. It thus allocates space to consider changes in behavior within their particular social and historical circumstances. It is this latter aspect of socio-historical setting that I will return to throughout the following.

With regard to metallurgy, the specific nature of the material metal has to be taken into account: any metal can be recycled time and again, making it a virtually infinite resource. Instead of linear production chains, cyclical models have therefore been proposed[5] that acknowledge this particular property: the metallurgical circle sees a constant in- and outflux of material (Fig. 2). The re-use of old artifacts comes at the expense of the archaeological visibility of metal, and the archaeological record on metal is strongly biased by depositional practices. Therefore, studies on ancient metal require, probably more than those on any other archaeological material, to take sources into account that are independent of the material studied. In Greater Mesopotamia, we are in the fortunate position to have at our disposal not only sites and archaeological finds, but also texts and imagery that contribute to fill the lacunae (Fig. 2). In the following discussion on the appearance of metal headbands, I thus make use of only a small section of the metallurgical circle scheme, but will increase the level of analytical detail through the explicit consideration of additional and indirect sources to locate this innovation within a larger cultural and historical context.

3 Historical background

The 4th millennium BCE saw the emergence of urban settlement in the alluvial lowlands of southern and the fertile plains of northern Mesopotamia.[6] Centralized institutional control over staple goods and labor character-

2 Bintliff 1991; for an exemplary application of this concept, see Lamberg-Karlovsky 1985.

3 Renfrew 2009.

4 There have been numerous reprisals of the original approaches formulated by Marcel Mauss with regard to body skills, and furthered by André Leroi-Gourhan in applications to the lithic production chain and others, see e.g. Leroi-Gourhan 1964; Schlanger 2004.

5 Ottoway 2001; Hansen 2013a.

6 Liverani 2006; Pollock 1999; Ur, Karsgaard, and Oates 2007.

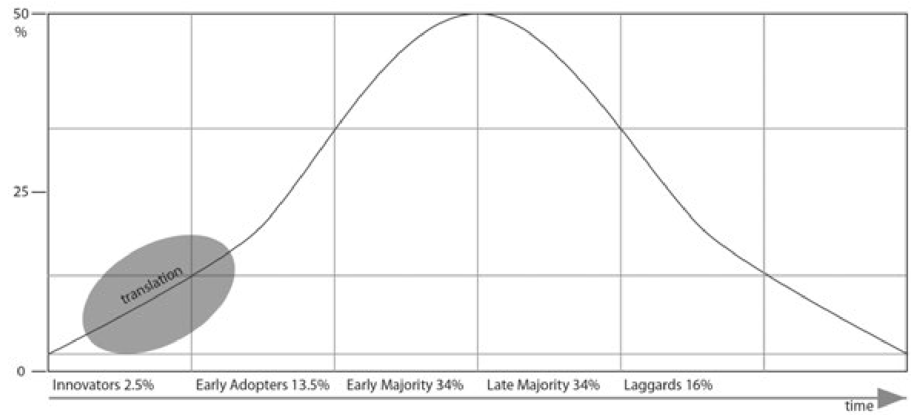

Fig. 1 Standard curve of innovations and possible period where translations can take place (Standard curve follows Rogers 2003).

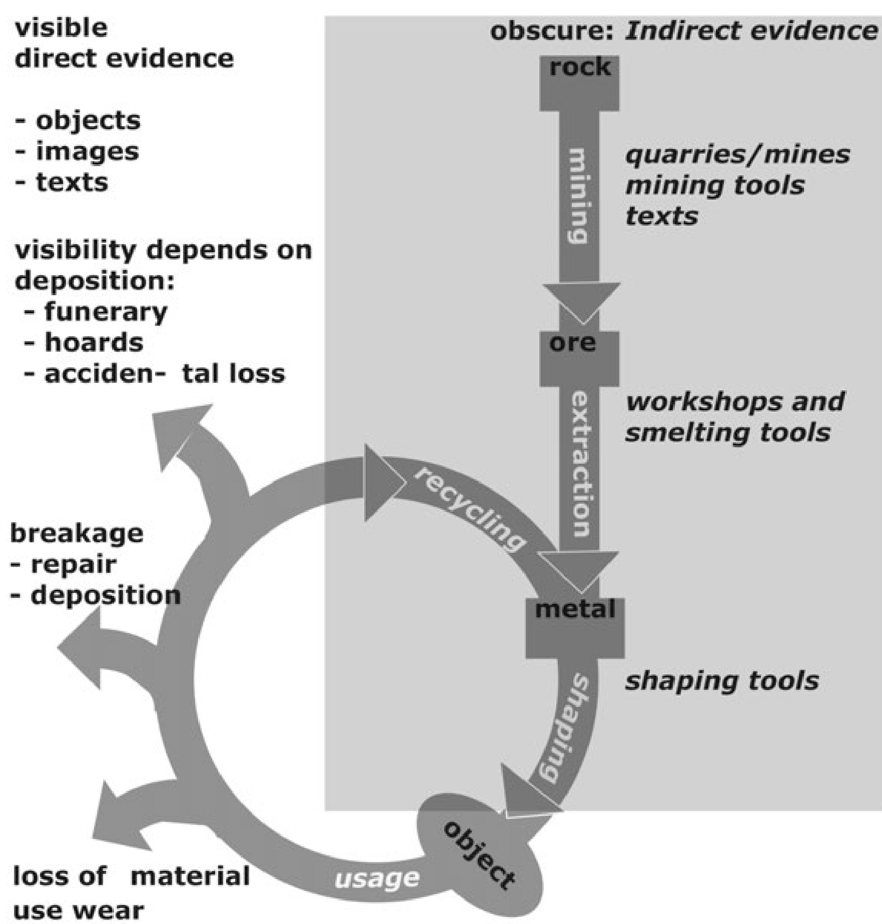

Fig. 2 Metallurgical cycle; grey rectangle indicates space where interpretation depends on indirect sources.

ized these urban centers, exemplified by the growth of the city of Uruk in what archaeologists call the Uruk period,[7] and by a material record of seals and written documents, monumental architecture and an imagery conveying strict hierarchical relations. Power was exerted by a paramount figure, the EN, as a ritual and military leader. The relative political stability and the security that the Uruk towns offered to its inhabitants came at the expense of organized warfare between the Uruk cities and their neighbors, during which enemies were either killed or captivated and pressed into the growing workforce of the urban industries (Fig. 3, 1–2).

From around 3350 BCE onwards, this new administrative model was adopted also in distant regions, including the Middle and Upper Euphrates, the Khuzestan plain and southern Iran, in central sites that often did not command a truly urban population. Although successful at the onset, in the North these transplanted centralized economies collapsed around 3000 BCE, possibly due to a lack of anchorage within the local traditions of economy and power.[8] They were replaced by a mosaic of small and fluid cultural units whose social and economic organizations seem to have been less complex than the preceding system. Security was an issue in these societies who had left the relative stability of the early states. Different from the preceding period, no imagery linked to organized warfare is known. Instead, mythological themes that focus on the role of heroes in combat with forces of chaos are a widespread motif and may be read as a metaphor of insecure times (Fig. 3, 3–4). To counter these, the new units were self-dependent and self-protective,[9] as can be deduced from the appearance of small fortified settlement sites[10] and of graves with weaponry[11] in a wide zone around the Mesopotamian alluvial plain.

Only in the Mesopotamian alluvium did cities rapidly transform into state units with a three-tier hierarchy centered around a central city with a city god temple and a palace in the so-called Early Dynastic period.[12] Economy there was in general organized around the institutional households of the temple and the palace, and around guilds of craftsmen that include, among others, also metal workers: the archaic texts from Ur mention the profession of smith. Within that hierarchical organization, organized warfare took place between individual city states under the leadership of political authority (Fig. 3, 5–6). It is usually assumed that political organization remained at the level of city states, but textual evidence from the city Kish may be read to indicate the early formation of a territorial state.[13] This text registers captives takes during numerous campaigns of warfare in a wide geographical sphere, including regions in the Zagros mountains.

During the later 3rd millennium BCE, the early city states formed a confederation, as is reported in the Fara texts; but this and subsequent historical developments already lie outside the chronological scope of this contribution: I focus here on the period of rapid transformation subsequent to the collapse of the first centralized states, c. 3000–2800 BCE, and only take an anecdotical look backwards into the 4th millennium BCE, when some of these novelties were prepared in the mountainous regions around lowland Mesopotamia.

4 Diadem wearers in southwestern Asia

Head adornments made from silver, gold, copper or unusual alloys are documented in ancient southwestern Asia from the 4th to the 2nd millennium BCE and beyond. Most researchers agree[14] that people buried with a such a metal head ornate most probably represent an elevated social class. This opinion is based on a number of observations: (1) within groups of graves, only a limited number is equipped with such exceptional headgear; (2) burials with head ornate often correlate with a high number of grave goods; (3) the headgear is often fabricated from exceptional metals that could represent wealth. However, the case is not always straightforward, and as Z. Wygnanska reminds us, not all diadems

7 Hans J. Nissen. „Das Uruk der Gemdet Nasr- und frühen Frühdynastischen Zeit.“ *Lecture delivered at the conference: 8. Internationales Colloquium der Deutschen Orient-Gesellschaft* (Berlin 2013).

8 Frangipane 2010.

9 Among others, see Finkbeiner et al. 2015, 431–432; Gerber 2005; Quenet 2008, 285.

10 There are different approaches towards the interpretation of these fortified sites, cf. Gibson 1981, 157–162; Forest 1996, 201–204; Renette 2009. There is however no doubt about the fortified character of these settlements.

11 Forest 1983; Helwing 2012a; Renette 2013.

12 Postgate 1992; Brisch 2013.

13 Steinkeller 2013.

14 Mindiashvili 2012; Panagiotopoulos 2012; Revello Peris 2003; Schuhmacher 2002; Wygnańska 2014.

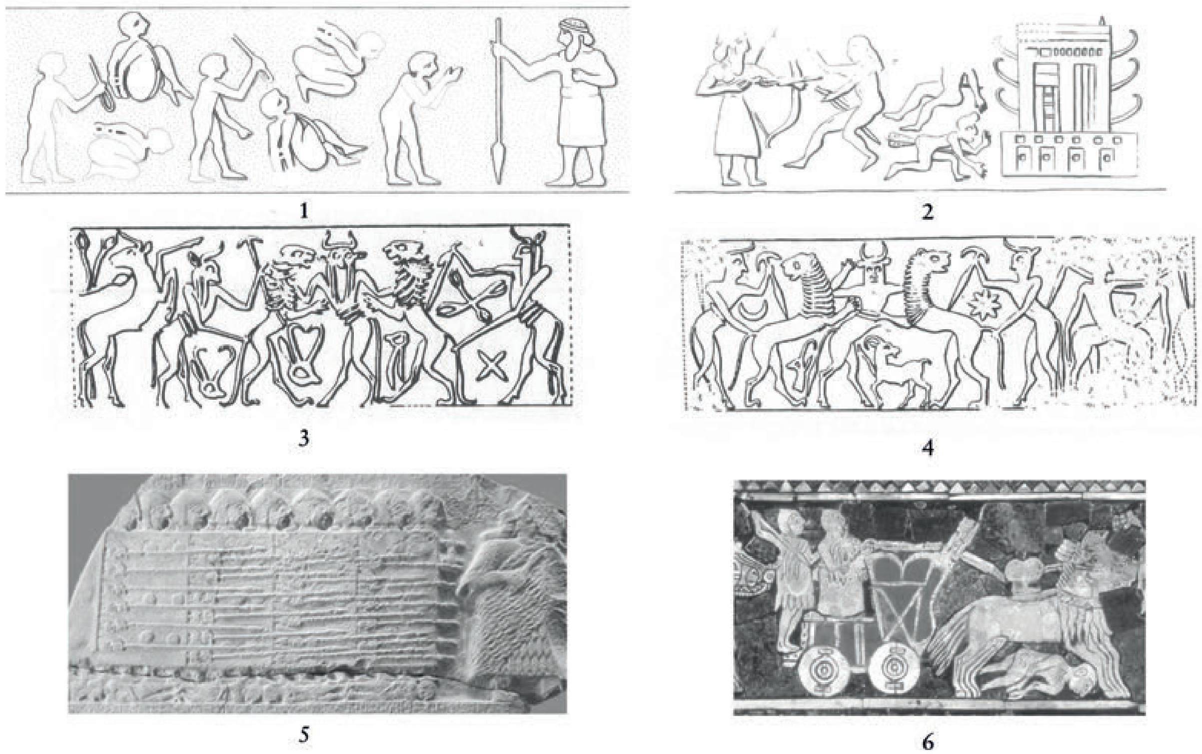

Fig. 3 Images of warfare (not to scale). 1–2 = Organized warfare under the leadership of the EN, Uruk period; 3–4 = Combat scenes with heroes and animals, ED I/II; 5–6 = Organized warfare in formation, ED III.

may have had the same uniform function,[15] some may have served to signal important official functions of their wearers, and there may be regional or local variations in diadem fashion adaptations.

How can we narrow down this interpretational range? I propose here to focus on a particular limited time range when metal diadems make their first major appearance in southwestern Asia around 3000 BCE: at that point, they mark the beginning of an innovation in the representation of the dead person that can only be understood in the context of the wider cultural and historical development in the region. There are a few predecessors for the new custom that provide a prelude to what follows: a few select finds of silver headbands date to the 4th millennium BCE and are to be understood within a different context.

4.1 The earliest headbands: the 4th millennium BCE

One of the most ancient metal headbands recorded was found in a female grave in Korucu Tepe in Eastern Anatolia: tomb K12 was a mudbrick cist excavated on the northwestern slope of the mound that held the body of a female equipped with silver jewelry.[16] Besides hair rings and a gorget, a silver headband was found in front of her head (Fig. 4, 1), with a series of bone beads close-by. At the time of excavation, the tomb was dated to around 3000 BCE, but ceramic parallels for the inventory allow to place it firmly into the LC 3-4 period of the first half of the 4th millennium BCE.

North of the Caucasus in the Kuban region, two golden headbands with applied rosettes (Fig. 4, 2 a–d) were found associated with the central male inhumation in the famous kurgan at Majkop, forming part of an extremely rich funerary equipment.[17] The Majkop kurgan

15 Wygnańska 2014, 117.

16 Loon 1973, pl. 5, 1; Fig. 3, for a plan of the grave, pl. 3, B for in situ position of the headband.

17 The original publication, Farmakovskij 1914 was not available at the time of writing; quoted after Govedarica 2002, 783–785.

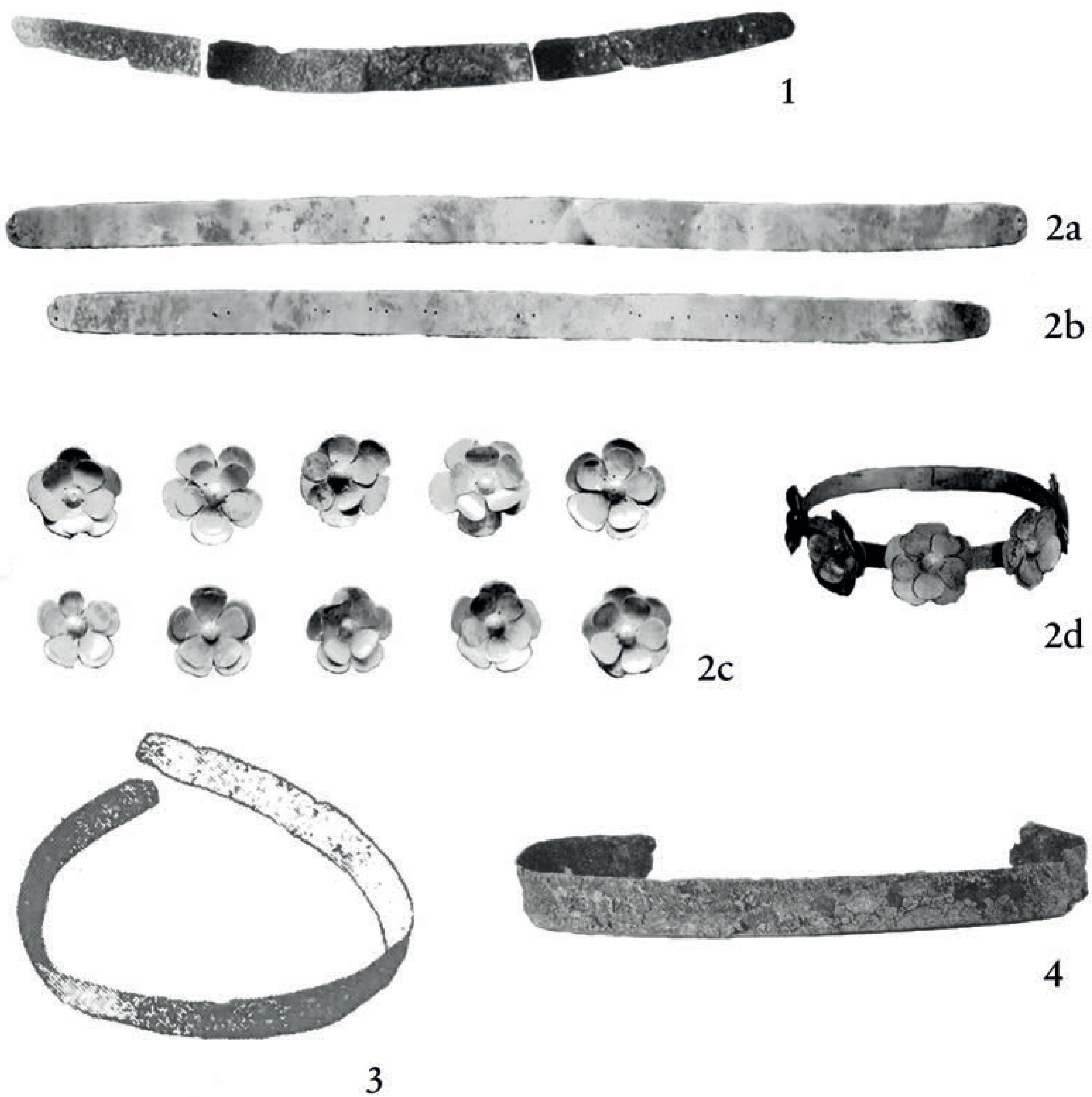

Fig. 4 Fourth millennium BCE headbands (not to scale), from silver (1, 3–4) and gold (2). 1 = Korucu Tepe, from woman's grave in K12; 2a– c = Majkop kurgan, two headbands, flower-shaped applications, and headband with applied flowers; 3 = Hesar II, headband; 4 = Byblos cemetery, headband.

is today dated to the early phase of Majkop, from 3700 to 3500 BCE.

Another parallel to the Korucu headband comes from the site of Tepe Gawra in northern Iraq: excavated in the first half of the 20th century, the site is known for its early tripartite monumental architecture as an alleged counterpart to the Uruk development of southern Mesopotamia. An infant burial under the floor of the temple of level IX is reported to have held a golden headband.[18] The grave was then assigned to level X[19] and in the X–VIII range during the restudy,[20] which would fall into the early 4th millennium BCE.

18 Tobler 1950, 99, 107, 116–117, 199; no figures.
19 Tobler 1950, 199.
20 Rothman 2002, 281, for an inventory list; contra; Forest 1983, 52.

Further east, Tappe Hesar II has also yielded silver headbands as part of grave inventories (Fig. 4, 3).[21] The site lies on a major overland route linking to Eastern Iran and the Oases cultures of Turkmenistan and is known for its involvement in the lapis lazuli trade along the northern edge of the Great Iranian Desert.

Byblos on the Libanese coast is well-known for its '*cimetière énéolithique*', an extensive graveyard with hundreds of pithos burials that yielded one of the largest collections of silver items dating to the 4th millennium BCE.[22] Seventeen graves held undecorated headbands made from silver (Fig. 4, 4), some of them more than one; graves 630 and 631 were child burials, each with a silver headband, visible on an *in situ* photograph of grave 630 on the skull of the child;[23] unfortunately, the generally poor state of documentation prohibits to extract meaningful details about the overall distribution and deposition of these headbands.

With the exception of Byblos, which in this particular position on the Mediterranean coast may belong into a different sphere of long-distance interaction, the other early headbands share some characteristics and represent related phenomena. Majkop and Korucu lay wide outside (Fig. 5) the influence sphere of the emerging centralized states in Mesopotamia. Tepe Gawra is closer, but seems to have been abandoned when Uruk influence became evident in northern Iraq. All three sites can hence be considered as outside of the wider Uruk sphere at the time when the inhumations equipped with diadems took place. Associated ceramics in the Korucu grave and in Gawra X belong to the Chaff Faced Ware tradition ubiquitous in the lands south of the Caucasus in the earlier 4th millennium BCE (LC 3–4).[24] Sites adhering to this CFW tradition share also burial customs with inhumations of bodies in various positions, often in cavities dug sideways at the base of the funerary shaft.[25] These burial customs left archaeologically visible traces, unlike the regions under the influence of the emerging early states where human burials were rarely recorded – a pattern clearly instigated by differing depositional practice, possibly outside of the settlements proper that so far have been at the center of research attention. The few known 4th millennium BCE diadems have hence been preserved through a bias in the burial record, and find no direct counterpart in Mesopotamia. While the find number is way too limited to draw further conclusions, it is significant that the 4th millennium BCE diadems seem not to follow a uniform distribution pattern: infant, male and female individuals are buried with headbands.

Contemporary Mesopotamian dressing customs can only be reconstructed on the basis of pictorial evidence and there, headbands are still rare. 4th millennium BCE cylinder seals with human depictions show bulk motives where humans are shown as silhouettes only and are either uniformly bald or wear their hair sleeked back or in a ponytail.[26] Only one figure stands out and occurs on seals and in large scale stone sculpture: a man whose hair is tied into a bun behind the neck and fixed by a band around the head. Although some scholars identify this band as a metal diadem,[27] it is shown as such a thick roll that this could rather signify a rolled-up scarf or the brim of a cap. This headgear correlates with a standardized dress of a plain or a netted skirt and identifies the person as the ruler or EN.[28] In this function, he pursues official duties: the conduct of seasonal ceremonies and the care for the well-being of the communal herds; but also the protection from forces of the wilderness as symbolized in the lion hunt stele; and from enemies: the man in the brimmed cap is shown repeatedly

21 Attributed by Schmidt 1933, 381, pl. CV, D to phase Hesar II (H.1185) the chronology of the Hesar graves is currently restudied, cf. Gürsan-Salzman 2016.

22 Prag 1978, 37, lists 22 (+) silver headbands from tombs 77, 145, 163, 222, 230, 247, 272, 630, 631, 1191, 1566, 1567, 1671, 1674, 1675; tombs 630 and 631 are described in detail in Chehab 1950, with pl. I; II; Dunand 1955, 22 describes a grave with three silver headbands; Dunand 1961, 78–79, talks about an exceptionally rich grave, ill. pl. IV, 2, where the corpse had one intact silver headband and fragments of a second, and the grave furthermore held 4 daggers and one ivory scepter; Dunand 1973, 320 fig. 192; for a recent re-evaluation of the graveyard evidence, see Artin 2009.

23 Chehab 1950, pl. I.

24 Marro 2010.

25 For example, at Helwing 2012b; Tobler 1950; Rothman 2002.

26 Amiet 1972, nos. 646, 663; Boehmer 1999, seals no. 1 (pl. 1–3); no. 2 (esp. pl. 7); Pittman 2013, Fig. 16.14, from Susa; 16.15, various sites.

27 Discussed in detail in Braun-Holzinger 2007, chapter 1, pp. 7–32 p. 10 "[...] breites Kopfband oder Diadem [...]"; but see the thick bulge e.g. in pl. 3 FS 2, and others in the catalogue of this chapter.

28 At least this being the traditional view, following Braun-Holzinger 2007; for a position contra this interpretation that sees a divine being in the figure of the man in the net skirt, see Marchesi and Marchetti 2011, 195 with fn. 46, who argue that the pieces date later and then represent a divine figure; if the late dating is correct, one could consider the possibility of a post-humous divination, as well-known for generations of Mesopotamian kings.

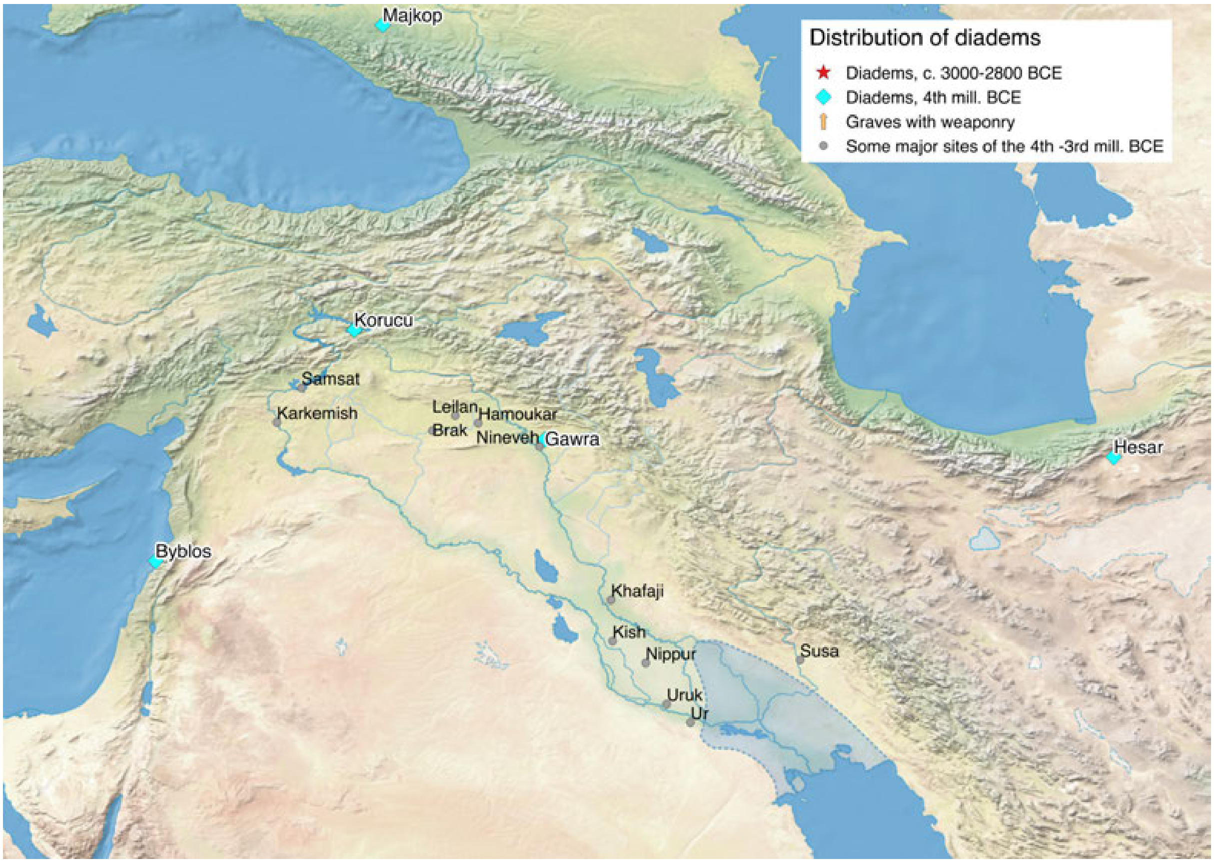

Fig. 5 Map presenting location of known 4th millennium BCE headbands.

with weapons, either as a warrior with bow and arrow, or overseeing scenes where prisoners are brought before him, whereby he is equipped with a fenestrated axes[29] or with a lance pointing downwards.[30] The prisoners are clubbed or cut with daggers (at least the items depicted can be interpreted as such). These images convey a canon of established power based on the maintenance of internal order and strength against outside intruders.

However, no single image of the EN indicates the use of a metal headband or else to fix his hairdo. Hence, the Uruk-influenced region seems not to have made use of metal headbands at the time when the physical objects occurred in graves in the mountain zones around the Mesopotamian Plain.

4.2 Headbands: 3000–2800 BCE

A number of metal headbands are known for this time period from burials spread out over a wide area, from Central and Eastern Anatolia and the Southern Caucasus to Iran. In order to look at the evidence one by one, I begin with the best documented case – a grave complex excavated in Arslantepe and attributed to period VIB1 in the local chronology, the century 3000–2900 BCE.

This exceptional burial monument (Fig. 6, 1)[31] consists of a large stone cist chamber that held the body of an adult man who was richly equipped with ceramic and metal vessels and sets of metal weapons. It is one of the oldest burials with a set of weaponry in the region: the equipment comprised 9 spearheads, 2 swords, 3 daggers and 4 axes.[32] This equipment is more than what a single person could handle, and may represent either a deposit made by minions or a case of over-abundance, as is

29 Boehmer 1999, Fig. 20, 10.
30 Boehmer 1999, seals nos. 3–4, pl. 8–16.
31 All description follows Frangipane et al. 2001 if not otherwise indicated.
32 Frangipane et al. 2001, 108.

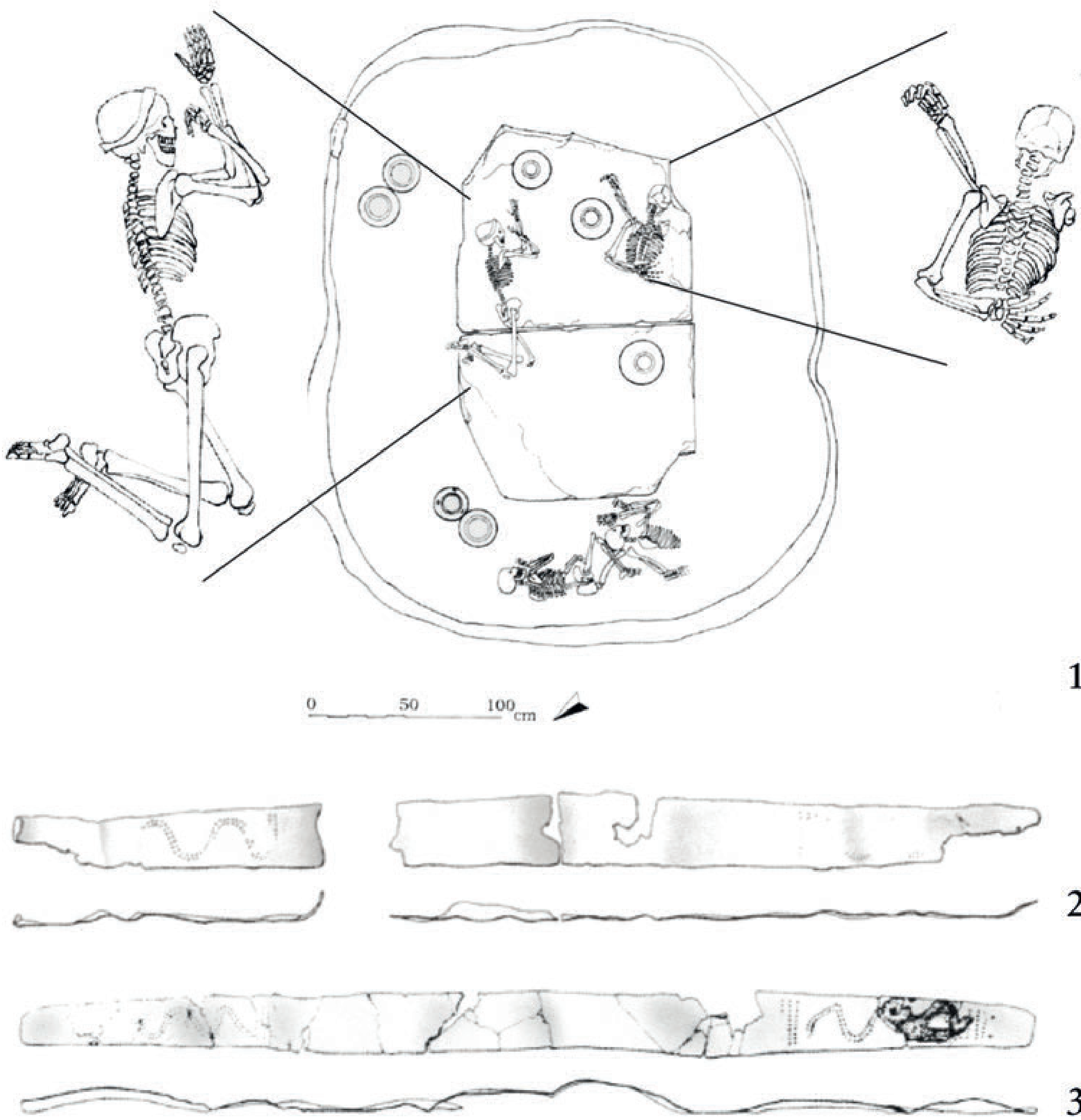

Fig. 6 Arslantepe VIB1 'Royal Tomb'. 1 = position of accompanying burials H-223 (right) and H-224 (left) with headbands, atop the burial chamber, and close-up view of these; 2–3 = headbands worn by the two individuals.

known also from other rich grave contexts in the Near East and Europe.[33] Evident is, however, the emphasis on weaponry that identifies the central inhumation as a personality with military leader qualities – in brief, a warrior.[34] The weapon sets represented in the Arslantepe grave are functional at short reach and can be used in direct man-to-man combat, as swords and daggers are only useful at short range; axes can potentially be thrown, but also be used at close distance. Only the spearheads may also function as long-range weapons. The personality buried in the Arslantepe grave seems hence to have gained his merit in combat.

33 Hansen 2002.

34 For a broader treatment of the issue of 'warrior burial', see Philip 1989; Rehm 2003; Helwing 2012a; Hansen 2013b; for the European discussion, see Kienlin 2015 for a critical assessment of the concept of a warrior elite.

If we compare these sets of weapons with evidence on violence known from the preceding Uruk sphere described above, we see fundamental differences: Uruk period warfare had been carried out at a distance, with bow and arrow,[35] and not in direct man-to-man confrontation. Imagery from the two centuries after the turn of the 3rd millennium BCE does little to contribute to a closer understanding of warfare after the collapse of the centralized institutions: ED I seal impressions revert to mythical topics, with a majority of scenes emphasizing combat between gods or demons and heroes. These combats were carried out in direct contact, and the only weapon visible is the dagger (Fig. 3, 3–4).[36] While these images do not convey any straightforward illustration of war scenes, they emphasize the notion of chaos that requires the strength of heroes to overcome and defeat. In this light, the appearance of warrior tombs and the emphasis on the military merits of the deceased bespeaks of a changed esteem for individual physical force and the capability to protect one's community from dangers lurking outside that became essential after the collapse of central institutions that could guarantee peace and security for the individual members of the group.

The Arslantepe warrior tomb held, besides the central personality inside the chamber, the corpses of four adolescents placed on top or next to the stone cist (Fig. 6, 1). On the tomb lid directly lay two corpses, one identified as a girl in the east and a second person in the west whose sex identification remains ambiguous, but possibly male. Both wore a metal headband from copper-silver alloy, with point-chased decoration (Fig. 6, 2–3). The two others were not equipped and lay on the northern edge of the tomb. Anthropological findings suggest that all four adolescents were killed at the side of the grave.[37] This demonstrates, together with the richness of the central burial, power over life and death of subalterns – an apogee of power demonstration that was earlier observed in the Majkop kurgan,[38] is also mentioned for Novosvobodnaja and Nalčik,[39] and that we encounter again much later in the Early Dynastic city state of Ur in the famous cemetery of the second half of the 3rd millennium BCE,[40] where it is exaggerated to a gigantic scale.

The Arslantepe headbands were hence adornments to one woman and one unidentified person who found their destiny to accompany a deceased high-ranking warrior. The monument is one of the earliest warrior tombs in the Euphrates valley and marks both the start and the apogee of this new custom that is attested in a number of other graves and graveyards in the Upper/Middle Euphrates and the Tigris region as well. To name but a few, we know more warrior graves from Hassek Höyük[41] and from a large graveyard at Birecik;[42] along the Tigris, the recently discovered graves from Bashur Höyük[43] are noteworthy for their weapons and luxury items as well, although no headbands were recorded there.

The characteristic headbands found with the two accompanying burials at Arslantepe are made from an unusual alloy of silver and copper. They are around 30 cm long and have parallel sides. The ends are pierced so that the pieces could be fixed on a textile. Zigzag lines of embossed dots decorate the metal sheets. The close resemblance between these two diadems and examples the southern Caucasus has been remarked on since their first publications, and they have variously been treated as evidence for a Kura Araxes affiliation of the personalities buried in the Arslantepe tomb. To put this evidence now into a wider context, I will thus proceed by reviewing these and other comparisons.

4.3 The Caucasian evidence, 3000–2800 BCE

Headbands from the southern Caucasian region of Shida Kartli in Georgia are regularly quoted as comparisons for the Arslantepe headbands. One example is from the Qvatskhela graveyard that yielded one headband of copper in grave No. 2 (Fig. 7, 1).[44] Shape and decoration technique resemble the Arslantepe diadems. The

35 Amiet 1972, Fig. 695.
36 E.g., Karg 1984, Pl. 5, 1–5.
37 See the part of M. Schultz and T. H. Schmidt-Schultz "Preliminary Report on the Results of the Anthropological and Paleopathological Investigation" in Frangipane et al. 2001, 123–129.
38 Govedarica 2002, 785.
39 Hansen 2014, 397.
40 For well-known examples in Ur, see Woolley 1934, 34–42, esp. 36; 97–107 for PG 1054; 62–73, esp. 63, 65 for PG 789; 73–91, esp. 74 for PG 800 preservation conditions are not always good enough to determine if additional burials are indeed accompanying burials.
41 Behm-Blancke 1981.
42 Sertok and Ergeç 2000.
43 Sağlamtimur and Ozan 2014.
44 Glonti, Ketshoveli, and Palumbi 2008, 157 pl. 5, 1; Glonti, in Jalabadze et al. 2012, 60–61, fig. 12, 4.

Qvatskhela diadem was decorated with dotted lines and schematic animal representations. It had been found on the head of the buried person, apparently with the zoomorphic images upside-down. The dating of this context falls around 3000 BCE: a recent re-dating overrules earlier radiocarbon dates for the layer following above the burial that had indicated a date around 2800 BCE.[45]

Two more diadems were found in Shida Kartli in the site of Gudabertka, reportedly from a settlement context (Fig. 7, 2–3).[46] The two specimens are made from copper alloy and display the same technique of decoration by embossed dot lines as the Qvatskhela one. The decoration with zoomorphic motifs is also closely comparable. As find observations for this site remain poor, no reliable dating or contextual evidence can be given.

This restriction applies even more to an unprovenanced hoard allegedly from the Irano-Turkish borderlands. This hoard was contained in a small vessel and consisted of sets of pins, tutuli and two headbands, one of gold and one of silver (Fig. 7, 4–5).[47] The two diadems have oval ends that turn into rolled-up eyelets. The decoration consists of embossed dotted animal motifs separated by sun discs. Around the edge of the sheets are lines of hanging triangles indicated. Among all items listed as examples for the Caucasian diadems, these two examples are by far the most elaborate ones. The almost exact replication of the motif on diadems of different material invites speculations about possible patterns underlying the assignment of gold and silver to different groups of users. Furthermore, these exceptional examples can provide a hint at how rich the Caucasian assemblages may originally have been, whereas the properly observed archaeological evidence is less complete. Within the logic of the metallurgical cycle, such objects would mostly not have survived and made it into the archaeological records, but served as raw material to be remelted or sold.

The close resemblance of the Arslantepe diadems with Caucasian examples has led to their inclusion in a wider sphere of influence of the Kura-Araxes world,[48] and there is furthermore ample evidence for Kura Araxes relations at Arslantepe. But while the close resemblance of the Arslantepe diadems with the Caucasian examples is intriguing, this connection is not the only one that can be traced in the archaeological record, and an assignment to the Kura Araxes sphere therefore would be misleading if used for all other diadems, as will become evident in the next section.

4.4 Other diadems, 3000–2800 BCE

Five headbands made from gold are reported from the famous tombs at Alaca Höyük. One diadem from grave A is formally close to the Caucasian examples: it consists of a narrow parallel-sided metal sheet bands and has a line of embossed dots along the edge.[49] Two others are slightly wider sheets with triangular openings that are at the end twisted together to close the circle; from this nod hang four long narrow bands of gold sheet that have no further decoration.[50] Triangular openings like those cut into the main band occur also on other golden head gears from the same site.

The Caucasian affinity of the Alaca Höyük graves has long been acknowledged.[51] The recent re-dating of some of the Alaca Höyük graves[52] makes this relation even more intriguing and allows to directly relate not only the well-known animal standards from Alaca but also the head ornate with the Caucasus in general and Majkop in particular.

A stone cist grave on the city mound of Kültepe has yielded another comparable headband: it is made from silver and has a simple embossed decoration of zigzags (Fig. 7, 6).[53] Although dated by the excavator to the late 3rd millennium BCE,[54] its close resemblance with the early headbands listed here could hint at an older dating of this specific piece.

Another interesting – and less known – relation of the Caucasian diadems are with Early Bronze Age tombs in the Iranian Zagros Mountains. A silver headband with embossed decoration has been found in a stone

45 For the dating, see Glonti, Ketshoveli, and Palumbi 2008, 155–156, the new date was measured in Rome (Rome 1619: 4465 +- 55 BP).

46 Gambashidze et al. 2010, pl. X, nos. 153; 154; For the re-finding of these objects, see description in Mindiashvili 2012.

47 Schauer 1980, Fig. 1, 16–17.

48 Carminati 2014, 171.

49 Koşay 1938, 103, 107, pl. LXXXII lower.

50 Koşay 1938, 103, 107, pl. LXXXII upper.

51 Hančar 1938.

52 Ü. Yalçın 2011, 143; Ü. Yalçın and H. G. Yalçın 2013.

53 Özgüç 1986, 24 fig. 23.

54 The grave context cannot be reconstructed from the published evidence, cf. Özgüç 1986, 24. Özgüç' dating to the late 3rd millennium BCE is largely based on comparisons with finds from Assur and not on intrinsic dating evidence.

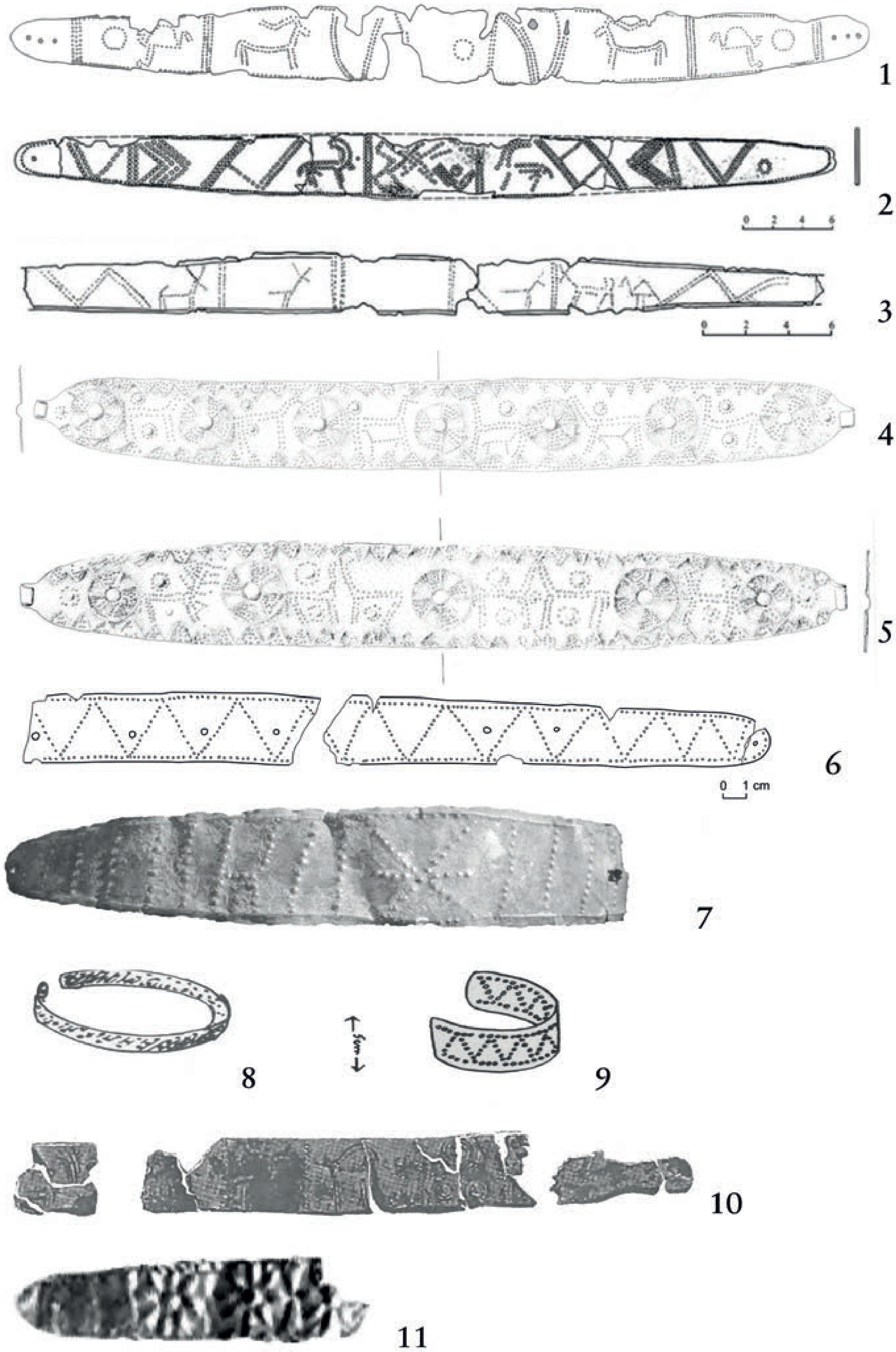

Fig. 7 Headbands, 3000–2800 BCE (not to scale), from copper (1–3, 8–9), silver (5, 6, 7, 10) and gold (4, 11). 1 = Qvatskhela grave 2; 2–3 = Gudabertka; 4–5 = unprovenanced hoard; 6 = Kültepe city mound; 7 = Gululal-i Galbi; 8 = Tappe Giyan burial 49; 9 = Tappe Giyan burial 104; 10 = Hesar III; 11 = Mari grave 300.

cairn at Gululal-i Galbi (Fig. 7, 7),[55] a burial site located in the Zagros piedmont in the modern province of Ilam. The grave is one of two that were documented during Louis Vanden Berghe's Lorestan missions; he reports that the silver band was found together with an axe head and a copper bowl atop one grave. In the final publication, it is speculated that the placement of these objects outside and atop of the grave may refer to a particular burial rite; however, as the grave has been reused in the late EBA, it is highly likely that at that occasion, materials belonging to predecessor burials were removed and deposited outside the original grave, a habit observed also in other EBA burial sites in the Zagros.

Copper bands with embossed decoration have also been found in Tappe Giyan, a large settlement mound in the Iranian Zagros. Grave 49 at Giyan held a skeleton whose head was adorned with a bronze diadem with embossed dotted decoration (Fig. 7, 8).[56] A string of beads and lime stone discs, two bronze bracelets and three ceramic vessels complete the assemblage. Another grave in the same place, grave 104, held an embossed bronze band (Fig. 7, 9),[57] two axes, a skewer and some stone balls. The early excavation with insufficient context observation makes the dating of the Giyan evidence notoriously unreliable. However, the formal resemblance of the diadem from grave 49 and its association with a female burial equipment, and the association of the second example of embossed band with a set of weapons in grave 104, match the evidence presented so far.

Tappe Hesar in Iran continued to yield few silver headbands in its phase III that extends from the early 3rd into the early 2nd mill. BCE. One (Fig. 7, 10),[58] from one of the most elaborate graves, had an embossed decoration of caprids, directly recalling the Caucasian examples.

In the Syrian city of Mari was a complex of three large stone-built tombs with false vaults uncovered under the courtyard of the Ishtar temple.[59] These stone tombs follow a funerary tradition that resembles the customs known from the Zagros EBA graveyards. While two graves were badly looted, grave 300 was less affected by later disturbances and still held remains of the original rich inventory with metal vessels, jewelry, and ceramics, among them two painted jars of the scarlet ware tradition,[60] one half of a golden headband with embossed rosettes (Fig. 7, 11)[61] and residues of silver sheet. The large grave was certainly planned and used for more than one inhumation, so a precise date of the inventory is not possible; but the two scarlet ware jars would match well with the early EBA traditions of the Zagros mountains,[62] and the headband would fit this overall picture.

4.5 Headbands and warriors: 3000–2800 BCE

The evidence just presented falls chronologically into the narrow time range after the collapse of the first centralized states and before the formation of new political units in the north of Mesopotamia. Geographically, it covers a wide range of highland habitats at considerable distance from each other (Fig. 8). Over this wide zone, a diversification of local styles, a dispersal of small settlements over wider areas and the construction of fortified round buildings in the piedmont zone are all indices of a period of instability. Mari falls outside this geographical zone, but the occurrence of scarlet ware there, outside of its major distribution region, indicates possible long-distance relations with the Zagros piedmont.

Little reliable observations are available on the find contexts; however, there are reasons to hypothesize that the headbands relate to a female sphere: best evident in Arslantepe where burial H-224 is female and H-223 not determined (which does not exclude a female gender); the main burial is male and does not wear a headband but a belt. In Mari grave 300 and Tappe Giyan tomb 49, the related jewelry rather supports an interpretation as female. Unfortunately, the Caucasian examples lack observation, and the Alaca graves also have not undergone any anthropological investigation.

The argument can further be extended on an evidence of absence: headbands occurred within the same geographical and chronological range as did warrior

55 Haerinck and Overlaet 2010, 50, 52–53; fig. 45; pl. 72; 74 lower in b/w; pl. 75, color plate XXV.

56 Contenau and Ghirshman 1935, 25 pl. 17, 4; from grave 49, at - 3.5 m.

57 Contenau and Ghirshman 1935, pl. 30, ;1 from grave 104, at -7.5 m.

58 Schmidt 1933, 401–407, pl. CXXII A (H.449). As with Hesar II, the chronological positioning of the grave may shift upon restudy, cf.; Gürsan-Salzman 2016, 167, the grave is assigned to late Hesar III, based on the typology of the seals found therein; however, the decoration of the silver headband may indicate an earlier date at least for this item.

59 Parrot 1938, 4–7.

60 Parrot 1938, 5 nos. 1436–1437; pl. II, 4 lower row.

61 Parrot 1938, 6 pl. II, 3.

62 As already pointed out by the excavator, see Parrot 1938, 6.

Fig. 8 Map showing distribution of known headbands, 3000–2800 BCE.

graves, but the warrior graves known for the period are never equipped with a headband. But there is a close relation between the wearers of diadems and warriors buried close-by, as stated for the Arslantepe grave, where the diadem wearers followed the main warrior personality in death. A relation of wearers of headbands to graves with weaponry is also visible in the case of the Tappe Giyan graves. The Gululal-i Galbi grave was used repeatedly, also for persons buried with weapons, and also the Hesar graveyards were grouped around tombs of warriors.

Finally, a look at graves with scarlet ware – of which two specimen were found in Mari in the burial with jewelry and a gold headband – reveals that warrior graves are a regular element in the early EBA graveyards of the scarlet ware tradition, as attested, for example, in Kheit Qasim[63] and to a much lesser extent at Ahmat al-Hattu[64] in the Hamrin, and probably also in the graves recorded long ago in the Deh Loran Plain of western Iran.[65] This observation brings the argument to a full circle: we observe at the beginning of the 3rd millennium BCE a larger and new currant to represent the military capability of elites to defend and protect their communities through the weaponry included in the warrior graves. As these military leaders do not wear headbands, while some women do, I conclude that the embossed head-

63 Forest 1980, Fig. 1 plan of the graveyard; Fig. 5 right column for the scarlet ware; Forest 1983, 138; Forest 1984a; Forest 1984b, 87: metal weapons were found preferably in the larger graves; Forest 1984c, 113, compares the custom to deposit metal work within the brickwork of the tomb is also reflected in the stone-built dolmens where weapons are hidden away between the stones.

64 Sürenhagen 1981; Eickhoff 1993, 75, mentions the comparative rareness of metal weapons.

65 At Tappe Musiyan, see Gautier and Lampre 1905; note that Forest 1984c, 113, already had remarked on similarities in the practice of deposition of metal weapons between the bricks of the tomb construction in Kheit Qasim with similar practices in the EBA stone cairns in Lorestan.

bands represent a female element in close relation with these central warriors.

Thus, I therefore propose to interpret this occurrence as a new custom of marking status in the female sphere that corresponds to the warrior graves, but not as a cultural or ethnic marker. Rather than a cultural affiliation with Kura Araxes, the headbands (as well as the warrior graves) testify to a new ideology of power that crosscuts cultural boundaries. This power is grounded for men in personal military success, which developed only after the necessity arouse to engage in man-to-man combat that became necessary due to the absence of a central state organization. Female status, as far as is visible from the funerary record, seems based on their affiliation with the successful warrior; if this affiliation is voluntary or was imposed on them forcefully, as one might assume on the basis of the human sacrifices in Arslantepe, remains an open question.

4.6 Headbands: post-2800 BCE

The focus of this study has been deliberately narrowed to the two centuries immediately following the collapse of the state authorities. The subsequent historical development brought about a consolidation of the South Mesopotamian city states and a renewed trend towards urbanization in the north. In Anatolia emerged long-distance trading networks that linked individual centers. In the southern Caucasus, Kura Araxes communities had spread over great distances. Before this geo-political mosaic, it is evident that individuals and individual regions pursued different trends. Headbands continued in use, but their meaning seems to have changed, from the original high status female to a more variable interpretation of the scheme. Forms changed as well, and besides the parallel-sided headbands appeared also leaf-shaped ones.

The West Anatolian community at Demircihöyük – Sarıket made ample use of headbands during EBA II (c. 2600–2500 BCE),[66] without any visible differentiation according to sex and age. A total of 29 graves here yielded headbands of various materials, copper, silver, gold and lead; the finish of the objects was crude, some of the embossed dots have pierced the sheet, and rough edges have not been smoothed. One can speculate if this careless treatment was applied to objects that possibly were worn only once, in the funeral.

In Mesopotamia, headbands occurred in various places and in larger numbers in the famous Ur cemetery of the ED IIIa period (c. 24th century BCE).[67] These could be plain, but one was decorated with an embossed relief scene[68] that replicates the motifs of an animal frieze similar to the temple decoration at Tell al-Ubaid. But most types of head ornate in Ur are either highly elaborate, like the floral design known from the Puabi tomb,[69] or are simple leaf-shaped frontlets. A. Gansell achieved a distinction of four standard jewelry sets within the Ur cemetery assemblages,[70] of which one was clearly female and one clearly male; but none of these sets contained headbands. However, the famous gold helmet of Meskalamdug that was excavated in Ur[71] shows a plain band around the head; a similar feature occurs on the copper head from Niniveh.[72] Headbands thus continued to form a regular component of later 3rd millennium BCE burials assemblages, but their distribution and function seem to have followed different rules than that of the earlier headbands, like a fashion attribute taken out of its original authentic context that subsequently lost its original connotation. Nevertheless, the re-formation of large-scale interaction spheres that connected the cities of Mesopotamia with Anatolia and the wider world contributed to an ever wider spread of this fashion as far as the Greek islands and Crete, where they stayed in use well into the 2nd millennium BCE.[73]

To sum up, the narrowly focused perspective on the headbands of the early 3rd millennium BCE has allowed to trace a historically meaningful change in funerary costume, be it for funerary purpose only or for wearing in lifetime as well. This shift can be contextualized within changed life circumstances of communities that arose after the collapse of a centralized authority that was at once demanding and protective. The necessity to secure self-defense and alliances of individual communities in the

66 Seeher 1991; Seeher 2000; a similar pattern is observed in Küçükhöyük, see Gürkan and Seeher 1991.

67 Compiled by Wygnańska 2014, Table 2.

68 Woolley 1934, pl. 139.

69 Woolley 1934, pl. 128.

70 Gansell 2007.

71 Woolley 1934, II, inner color plate, and pl. 150.

72 Strommenger 1962, color plates XXII, XXIII.

73 Panagiotopoulos 2012.

absence of a larger regulating institution correlated with the rise of new elites based on military merits and physical force, warriors or warlords. A female element in relation with these paramount warriors was distinguished by the specific headbands that were at the heart of this discussion.

After the reconstitution of centralized urban power, tactics of warfare changed once more: as the images on the Ur standard[74] or the stele of the vultures[75] indicate, the late Early Dynastic military was strictly organized in combat units. The individual warrior disappeared and was replaced by formations of faceless soldiers. In the funerary record, the distinction of the warriors ceased, except for military leaders of high status, such as the kings and princes of the city states. These were marked through weaponry in their graves, but to a large extent, these weapons were now merely symbolic and produced from precious materials that would have been of no use in combat.[76] The headband as the symbol of the female counterpart also lost its meaning and become a decorative item in a number of possible forms, worn mainly by women but also by men.[77]

5 Conclusion: back to a perspective on innovation

As the preceding presentation has shown, the appearance of metal headbands in burial inventories shortly after 3000 BCE is the archaeologically visible result of a complex interplay of factors. Reverting to the metallurgical circle, there are two crucial points in the circle where change applies. They fall both in the field of deposition, and none is technical in nature: new practices in burial deposition assure a transmission of fine objects as delicate as headbands – there must have been originally many more, and more elaborate ones, as is demonstrated by the two specimen from the unprovenanced hoard. Headbands had been produced before, and were then worn by women and men in high status burials in regions that remained marginal or distant to early experiments on institutional centralization that took root in the Taurus Mountains in late 4th millennium BCE. With the collapse of this system around 3000 BCE, the meaning of the headbands seemingly became more restricted – they now adorned (mainly) females associated with the new elite. Any further specification as to the status of these women – family members ? female slaves ? prisoners of war ? – is impossible at this moment. The elite in power was represented by male individuals marked by an equipment of close-combat metal weapons in warrior graves, and sometimes by an overabundance of weaponry. Changes here apply in general to the weaponry used – daggers or swords, axes and spearheads, as opposed to distance weapons such as bow-and-arrow that appear on the late 4th millennium BCE imagery – and to the deposition in ostentatious tombs, a new category of funerary representation. Hence, all innovations visible in this record are owed to an adjustment to a changed social environment in a post-collapse society. Subsequent developments in the later 3rd millennium BCE bring about the adaptation and transformation of the headband fashion, from its original meaning as a marker of females in relation with the warrior elite, to a piece of adornment for different and more varied categories of people. This transformation – which in the innovation standard graph would represent the mainstream adoption – correlates with a loss of the original meaning and a creative re-invention of a style in adornment.

74 Woolley 1934, esp. pl. 92 for the "war side."
75 Strommenger 1962, pl. 66; 68, for the combat formation.
76 Woolley 1934, pl. 151; 152.
77 Gansell 2007; Wygnańska 2014, Table 2.

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1 After Rogers 2003. **2** B. Helwing. **3** 1 – after Boehmer 1999, pl. 17, 4; 2 – after Amiet 1972, No. 695; 3–4 – after Karg 1984, pl. 5, 2–3; 5 – detail from "vulture stele", modified after http://www.louvre.fr/en/mediaimages/victory-stele-eannatum-king-lagash-called-vulture-stele-0 (last accessed 27/05/2020); 6 – detail of the Ur standart, after Aruz 2003, p. 98. **4** 1 – after Loon 1978, pl. 5, 1; 2a–d – after Korenevskij 2011, fig. 95, 1–3, 12; 3 – after Schmidt 1933, pl. 105D, H 1185; 4 – after Chehab 1950, pl. 2 lower left. **5** B. Helwing, made with Natural Earth and QGIS. **6** Frangipane et al. 2001. 1 – Montage of Figs. 13; 32; 31; 2 – from Fig. 19, 1; 3 – from Fig. 19, 10. **7** 1 – after Glonti, Ketshoveli, and Palumbi 2008, fig. 5, 1; 2–3 – after Mindiashvili 2012, fig. 1, 2–3; 4–5 – after Schauer 1980, fig. 1, 16–17; 6 – after Özgüç 1986, fig. 23; 7 – after Haerinck and Overlaet 2010, pl. 35 lower; 8–9 – after Contenau and Ghirshman 1935; 10 – after Schmidt 1933, pl. 122A; 11 – after Parrot 1938, pl. 2, 3 upper. **8** B. Helwing, made with Natural Earth and QGIS.

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Heidi Köpp-Junk

Wheeled Vehicles and Their Development in Ancient Egypt – Technical Innovations and Their (Non-) Acceptance in Pharaonic Times

Summary

The river Nile was the major transit route of ancient Egypt. Nevertheless, a complex and intense overland traffic system existed, supplementing the waterborne transport. The wheel appears in the 3rd millennium in Egypt, which is, compared to other regions of the world, where they are attested in the 4th millennium BC, rather late. Moreover, wagons only play an infinitesimal part of the Egyptian traffic system. In contrary to that, the introduction of horse and chariot was much faster; besides, a high frequency of utilization can be stated. The difference in the use of these innovations is not to regard as non-acceptance, but refers to climatic, geomorphological and practical reasons.

Keywords: chariot; wagon; cart; camel; donkey; inundation; travel; mobility; land traffic and transport

Der Nil war die Hauptverkehrsader im pharaonischen Ägypten. Dennoch existierte darüber hinaus ein komplexes Landverkehrssystem, das den Transport auf dem Wasserweg ergänzte. Das Rad ist in Ägypten erstmalig im 3. Jahrtausend v. Chr. vertreten, was im Vergleich zu anderen Regionen der Welt, wo es im 4. Jahrtausend v. Chr. bezeugt ist, verhältnismäßig spät ist. Zudem spielten Transportwagen im ägyptischen Verkehrssystem nur eine verschwindend geringe Rolle. Im Gegensatz dazu erfolgte die Einführung von Pferd und Streitwagen zum einen sehr schnell, zum anderen ist für beide eine hohe Nutzungsfrequenz feststellbar. Der Unterschied in der Annahme der Innovationen Wagen und Streitwagen ist nicht als Nichtakzeptanz zu betrachten, sondern durch klimatische und geomorphologische Aspekte sowie praktische Gründe bedingt.

Keywords: Streitwagen; Wagen; Karren; Esel; Kamel; Überschwemmung; Reisen; Mobilität; Landverkehr und -transport

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1 Introduction

Altogether, only a few Egyptian carts and about 60 wagons are known in Egypt from the Old Kingdom up to Graeco-Roman Times, a period of around 3000 years. This article presents some of them, the contexts in which they were used as well as their development. Moreover, their introduction to Egypt will be discussed. In the Near East[1] (Fig. 1), Caucasus[2] and in Europe[3], the oldest wheeled vehicles are already attested in the 4th millennium BC; in Egypt, however, the earliest wheel only appears in the 3rd millennium BC. Therefore the reasons for this delay as well as for their low use will be analyzed.[4]

1.1 Sources

In ancient Egypt, wheels are attached to objects as a scaling ladder, a siege tower or to vehicles as carts, wagons, and chariots. They appear beside textual evidence in polychrome paintings in tombs, on coffins, in vignettes in the Book of the Dead as well as single- or multicolored paintings on mummy wrappings or reliefs on temple walls and stelae. Moreover, the vehicles are attested as models, artifacts, or even children's toys, money boxes, and on coins in martial, civil, or religious context.[5]

1.2 Definitions and general aspects related to wheels and wheeled vehicles

Since the termini denoting wheels and vehicles as well as transport and locomotion are used differently in publications, several definitions how the various terms are used in this article will be given in the following. Moreover, general features associated to wheels and wheeled vehicles will be outlined.

Means of transport deals with how loads were transported, means of locomotion with the movement of people. Furthermore, different main categories of wheels are attested, namely disc wheels and spoked wheels. Disc wheels either consist of one element or are assembled from several components. Due to their solidity they are still used nowadays in order to move heavier loads for example on wheeled transport platforms. The earliest vehicles were equipped with one-piece or tripartite disc wheels, sometimes with a crescent shaped cavity in order to reduce the overall weight. In the 4th millennium BC they are attested from the Rhine to the Indus River.[6] The disc wheel is not designed for high speed. Because of the large weight, the inertia of masses hinders the movement, which means that more power is necessary to move and rotate this mass than in the case of the spoked wheel. Therefore, vehicles with disc wheels were usually drawn by oxen, which have a greater pulling power than horses.[7] With two oxen as draught animals, a speed of about 3.2 km/h for a four-wheeled wagon with disc wheels can be assumed.[8]

The spoked wheel is much lighter than the disc wheel, as it consists of less material. Thus a higher speed can be achieved; however, it only allows the carrying of smaller weights. Therefore, the advantage of the spoked wheels lies in the weight reduction of the wheel itself and the associated higher speed.

The termini wagons, carts and chariots should not to be confused. Considering the types of vehicles, there is a difference between carts and wagons. Carts have one axle and two wheels, whereas wagons have two to six axles and four to twelve wheels.[9] Due to the fact that carts are equipped with only one axle, they are in an unstable balance and rather used for the transport of smaller loads. Wagons are more stable because of their two or more axles and are, therefore, used for medium or higher loads.[10] For heavy duty transport overland,

1 See for example the steatite vessel from Wari or the pictograms of Uruk; Nagel 1966, 1, 2, fig. 3; Salonen 1951, 155, pl. 1, 1–2; Hayen 1989, 44; Burmeister 2004, 14, fig. 5. For the earliest vehicles from the Near East see Burmeister 2011, 211–215, and Köpp-Junk 2015, 135–138.

2 Burmeister 2010b, 223.

3 The earliest wheeled vehicle in Europe is represented by tracks of a cart, found in Flintbek (Zich 1992–1993, 25–26, fig. 8, 10). The vehicle was drawn by persons, not by draught animals (Burmeister 2010b, 224). For a listing of the earliest vehicles from Europe see Burmeister 2011, 215–223, and Köpp-Junk 2015, 134–135.

4 In detail on transport, movement, mobility and travel in ancient Egypt see Köpp-Junk 2015.

5 Köpp-Junk 2015, 132–160.

6 Piggott 1992, 18.

7 Concerning oxen, horses and transport vehicles in detail see Köpp-Junk 2015, 107–109, 117–160, 166–171. The draught capacity of horses only developed its full potential with the help of a horse collar, which was not used in early times.

8 Piggott 1992, 17–18.

9 Littauer and Crouwel 1979, 5, 7; Burmeister 2010a, 224.

10 Hayen 1989, 47.

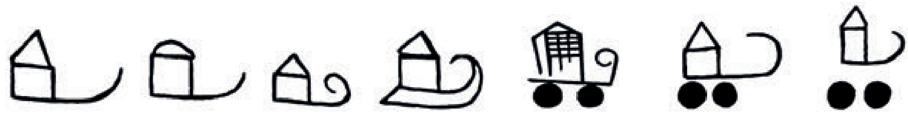

Fig. 1 Pictograms of the Uruk IV period in the 4th millennium BC show sledges, some of which are equipped with wheels.

the sledge was preferred in ancient Egypt.[11] The vehicles with only one axle are characterized by a better maneuverability and a smaller turning radius in comparison to those with two or more axles.[12]

Moreover, carts, wagons and chariots serve different purposes: wagons as well as carts were employed as a mode of transport in ancient Egypt, the chariot as a mode of locomotion with a highly prestigious character. Equipped with spoked wheels and drawn by equids, they were used for high-speed movement in sports, hunting, and military context. Besides, they served as a mundane mode of locomotion in the everyday life of the king, his family, and the elite.[13]

2 The wheel in Ancient Egypt

2.1 Objects on wheels

The very first depictions of wheels in Egypt appear in war scenes.[14] The wheels are not attached to conventional vehicles, but to war equipment.

These oldest wheels are attested in a scene in the tomb of Kaemheset in Saqqara, dating to Dynasty 5 (2504–2347 BC).[15] A scaling ladder on disc wheels is pictured, from which a city wall is attacked (Fig. 2).[16] Neither the link of wheel and axle nor the connection of wheel and ladder is visible due to the rough visualization. Besides that, both ends of the ladder are hidden behind the wheels; therefore, it is not recognizable how they were attached to the wooden axle in order to keep them rotating. Linchpins are not shown.

A similar scene is preserved in the Theban tomb of Intef from the late Dynasty 11 (2119–1976 BC). Here, a siege tower is depicted, equipped with a disc wheel. Again, the construction of wheel and axle is not recognizable (Fig. 3).[17]

2.2 Wheeled vehicles as a mode of transport: carts und wagons

Only a few carts and a bit more than 60 wagons are identified in ancient Egypt. The evidence is very heterogeneous, due to the different kind of sources, consisting of paintings on tomb walls, papyri, mummy wrappings, reliefs on temple walls or stelae, models and artifacts as mentioned below.[18] In the vast majority of cases the wagons and carts are unique. Whereas wagons are shown with one-piece disc wheels[19] as well as spoked wheels, Egyptian carts are equipped with spoked wheels only. According to the pictorial representations, the wagons are provided with two to three or maybe even four axles and four and six to presumably eight wheels. Some of the carts and wagons are presented in the following.[20]

The earliest Egyptian four-wheeled wagons combining a transport platform and wheels date to the Second Intermediate Period. One of them is depicted in a relief on the stela of Amenyseneb from Abydos, dating to the 13th Dynasty (1794/93–1648/45).[21] It is equipped with small disc wheels and drawn by oxen.

From the Second Intermediate Period as well, another wagon is shown in the tomb of Sobeknakht in Elkab[22] (1620–1550 BC) (Fig. 4). It has four disc wheels,

11 Köpp-Junk 2015, 160, 210.
12 Burmeister 2010b, 224–228.
13 Köpp-Junk 2015, 188–209.
14 Of course it has to be questioned whether the iconographical record reflects reality. Nevertheless, two- dimensional views on reliefs and in paintings showing wheeled vehicles presented in the following are taken as face value, since only facts known to a society or at least the artist can be portrayed.
15 Annual figures referring to Egypt here and in the following are in accordance with Beckerath 1997.
16 Quibell and Hayter 1927, frontispiece, 25; Kanawati and McFarlane 1993, 25; Köpp-Junk 2015, 137–138, fig. 49, pl. 8d.
17 Tomb of Intef, Thebes, Assassif, Dynasty 11; Arnold and Settgast 1965, 47–61, fig. 2; Jaroš-Deckert 1984, foulding map 1. Maybe the siege tower was originally provided with two disc wheels, but due to the degree of destruction of the scene only one is visible.
18 In detail see Köpp-Junk 2015, 132–160.
19 Tripartite disc wheels are not known from ancient Egypt so far.
20 In detail see Köpp-Junk 2015, 132–160.
21 During the reign of Khendjer; University of Liverpool Department of Egyptology, E. 30; Bourriau 1988, 60–63, figure on page 62.
22 Tylor and Clarke 1896, pl. 2.

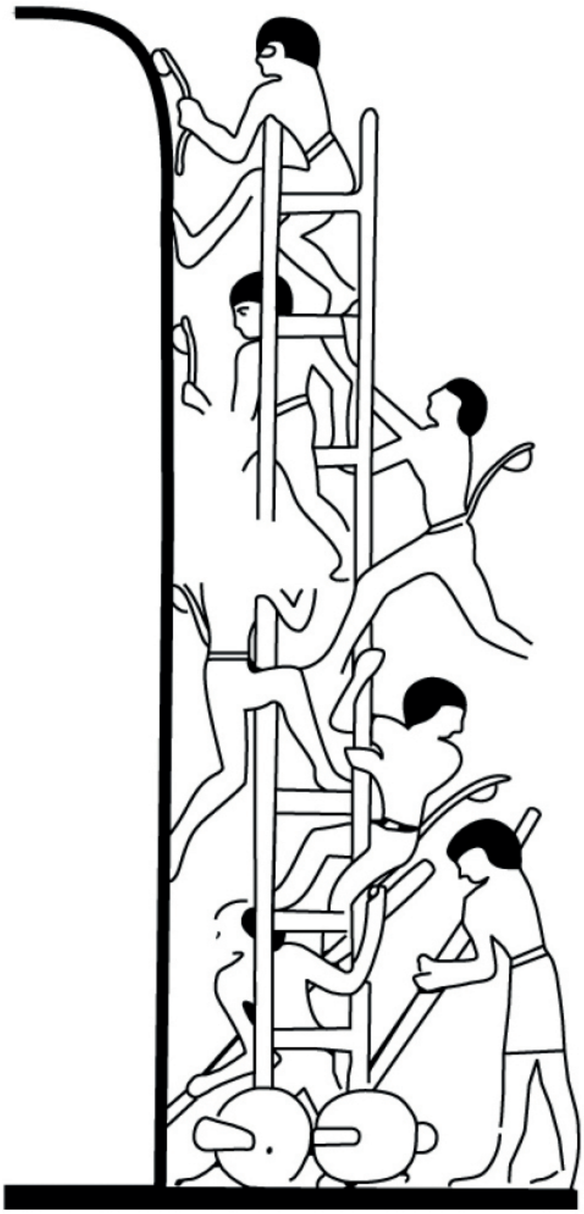

Fig. 2 In the tomb of Kaemheset at Saqqara from Dynasty 5 a scaling ladder with two disc wheels is shown.

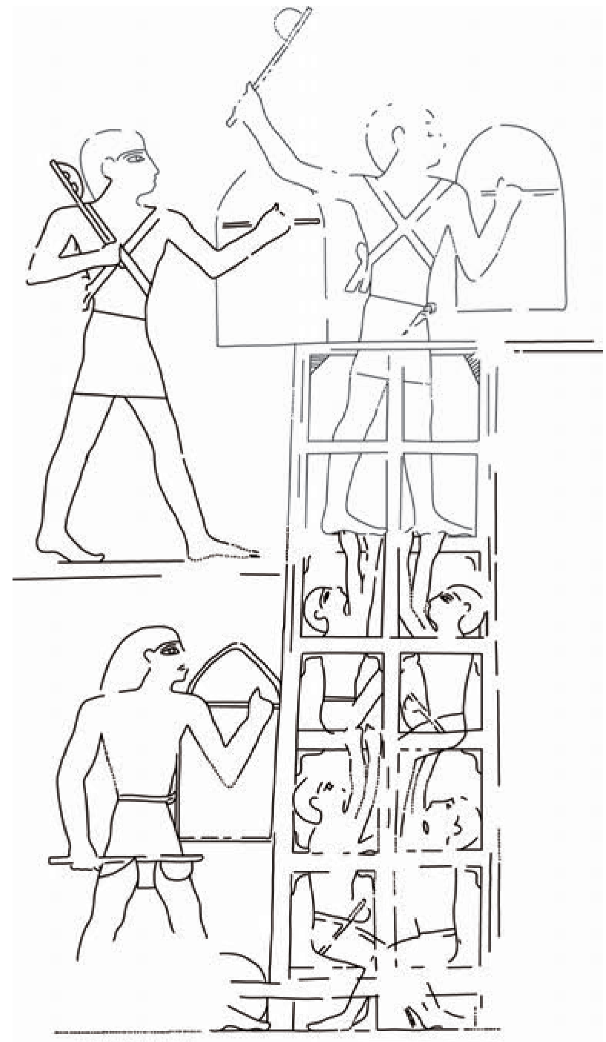

Fig. 3 A siege tower with disc wheel is depicted in the tomb of Intef, dating to Dynasty 11.

two axles and is dragged by two oxen.[23] The vehicle floor is very flat and designed like the runner of a sledge. The construction of axle, wheel, and wagon is unidentifiable. The towing rope seems to be fixed to the axle. The depiction suggests that around the axle a different kind of wood was used than on the outer rim of the wheels. The transport scene pictures the combination of sledge, barque, and wagon,[24] with the wagon being the actual means of transportation. The wagon is drawn

23 Egyptian wagons are very seldom drawn by horses, but mostly by teams of oxen or men.

24 In this grouping both bark and sledge share a religious connotation, whereas the wagon functions as a mundane mode of transportation overland (Köpp-Junk 2015, 123, 127–132; Köpp-Junk 2014, 122–124).

over a transport road with integrated wooden planks,[25] such as those found near the pyramids of the Middle Kingdom in Lisht and Illahun.[26] In modern trekking, sand boards and sand ladders are used to move on sand or snow. The ladder is positioned under the wheels preventing the vehicle's wheels to sink too deeply into the sand on a similar principle as in the scene in the tomb of Sobeknakht.

During the transition from the Second Intermediate Period to the beginning of the New Kingdom, the earliest wagon with spoked wheels is attested. It is a model of a wagon from the tomb of Queen Ahhotep[27] (ca. 1550 BC). The body of the wagon is a flat piece of wood, the wheels are made of bronze. Two small barques belong to the wagon, one is made of gold, one of silver and both have oarsmen sitting in it.

With carts a new type of vehicle appears in the New Kingdom. In the fragment of a harvest scene in the private tomb of Duaineheh at Thebes (Fig. 5), a cart with spoked wheels is depicted, dating to the reign of Queen Hatshepsut in Dynasty 18 (1479/1473–1458/57 BC).[28] The body of the cart consists of thin slats of wood and its two wheels have non-profiled spokes. The vehicle is drawn by two oxen. This type of vehicle, however, is not restricted to civil contexts. Several carts are depicted in the Ramesseum,[29] the mortuary temple of Pharaoh Ramesses II (Dynasty 19, 1279–1213 BC). The wheels have six spokes; therefore, they are no heavy-load transporters. The carts' bodies are high and box-shaped. They are part of the baggage claim in the scenes of the battle of Qadesh, [30] 870 km north of modern Cairo, and therefore obviously used for long distance travel.[31]

Apart from those carts and wagons with four wheels, six-wheeled wagons from Dynasty 17–19 and Dynasty 25 were found, the most of them are equipped with disc wheels, one with spoked wheels. One of them with six small disc wheels is depicted on a mummy wrapping which is now in the Dartmouth College Museum, dating to Dynasty 17 to 19 (about 1645–1186 BC). The transport platform has the shape of a sledge. Axles or linch pins are not traceable. The vehicle is drawn by two oxen.[32]

Reconstructed relief fragments of the so-called Talatat-blocks of the temple of Akhenaten from Dynasty 18 (1351–1334 BC) show four wagons with six-disc wheels (Fig. 6). They were drawn with ropes by 11–17 individuals.[33] The linch pins depicted at the axles prevent the wheels from sliding from the axle.

A wagon with six spoked wheels and a square shaped, high superstructure are shown in the reliefs of the Sanam temple from the time of Taharqa in Dynasty 25 (690–664 BC). Its wheels have six non-profiled spokes. Its draught animals are not clearly identifiable; it might be horses or donkeys.[34]

Of a much later date is the four-wheeled wagon[35] from the tomb of Siamun in the Siwa Oasis from the 1st century BC (Fig. 7).[36] Nowadays the depiction is severely damaged. The wheels are provided with eight spokes. They are decorated with floral ornaments.[37] The wagon is equipped with a flat platform and serves as a transport vehicle for a shrine on a barque. Again, the combination of barque, sledge, and wagon is apparent like in the scene of the wagon in the tomb of Sobeknakht, which is about 1500 years older. The wheels are provided with objects which are to be interpreted as big headed nails, attached to the outer rim of the wheel in order to minimize the wear of the tread.[38]

From the Graeco-Roman period a special type of wagon is attested, transporting an Apis bull. The wagons are pictured on about ten small relief fragments, showing a very similar scene in all examples.[39] The wagons are presented from the side, showing four disc wheels. In earlier times, in representations in wall paintings or

25 For transport roads, ways, path and routes and the vehicles which they can use in ancient Egypt in detail see Köpp-Junk 2015, 37–81.
26 Arnold 1991, fig. 3.44; Arnold 1992, 92, fig. 75, 102, 103 a–c; Petrie, Brunton, and Murray 1923, pl. 15.
27 Egyptian Museum Cairo, JE 4681 (golden barque), JE 4682 (silver barque) and JE 4669 (wagon); Saleh and Sourouzian 1986, no. 123.
28 Tomb of Duaineheh, Thebes, TT 125, Dynasty 18; Metropolitan Museum of Art New York, no. 55.92.1; Decker 1986, 54, fig. 3; Hayes 1959, fig. 90.
29 Hofmann 1989, fig. 88.
30 The fight took place between the Egyptian army under Ramesses II and the Hittites in the 13th century BC and resulted in the very first peace treaty in world history (see Klengel 2002).
31 For more details on carts in Egypt see Köpp-Junk 2015, 138–140.
32 Caminos 1970, 120, pl. 53; Köpp-Junk 2015, 148.
33 Redford 1988, pl. 31.t
34 Griffith 1921/1922, pl. 32; Köpp-Junk 2015, 148–149.
35 For other four wheeled wagons see Köpp-Junk 2015, 132–160.
36 Fakhry 1973, fig. 74; Lembke 2004, fig. 9a; Köpp-Junk 2015, fig. 61 (reconstruction combining the results of both).
37 For decorated spokes on a ptolemaic chariot see Woytowitsch 1995, fig. 726, and another one, driven by the goddess Astarte (fig. 725); see as well Köpp-Junk 2011, 209.
38 Köpp-Junk 2015, 135–36, 146.
39 Köpp-Junk 2015, 149–155.

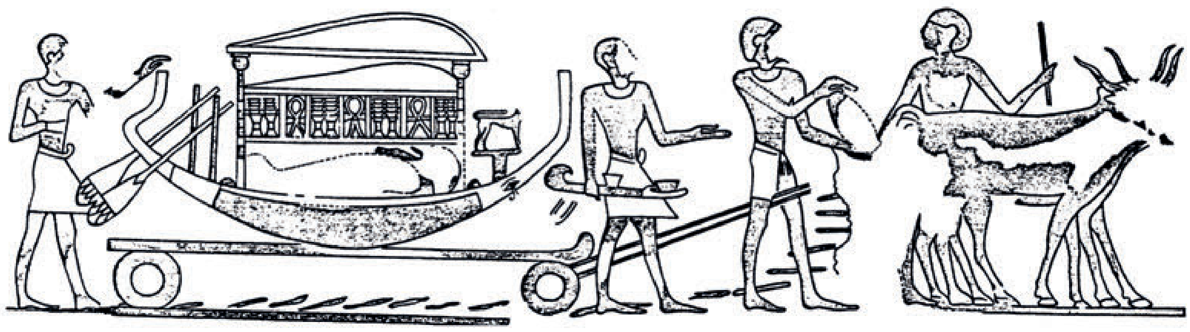

Fig. 4 In the tomb of Sobeknakht in Elkab from the Second Intermediate Period a wagon with four disc wheels is represented. The base of the body of the wagon has the shape of a runner.

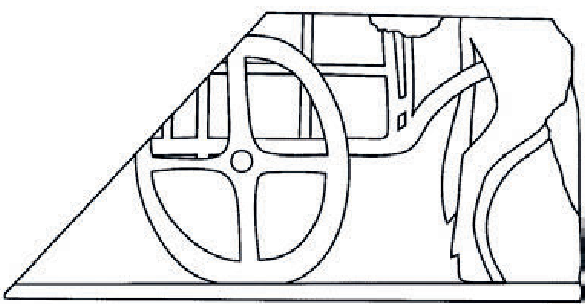

Fig. 5 A scene from the tomb Duaineheh of at Thebes from the reign of Hatshepsut shows a cart with two spoked wheels.

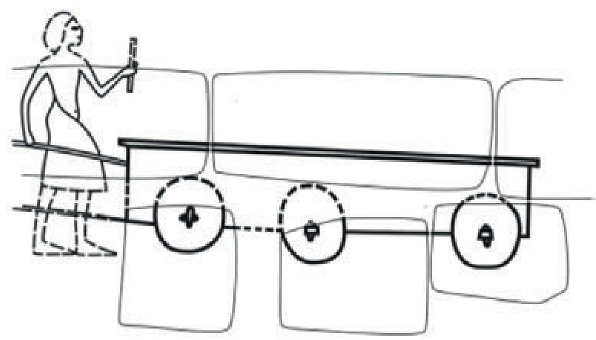

Fig. 6 One of the four wagons with six disc wheels from the reliefs of the Talatat-blocks of the temple of Akhenaten from Dynasty 18.

reliefs showing wagons from the side, the half of the total number of wheels are shown. In the Graeco-Roman period some of the wagons are pictured showing the total numbers of wheels in a representation in perspective, with two of the wheels being in an irregular distance from the two others and in different sizes; they are obviously displayed in the background.[40] However, since the scenes of the Apis wagons do not show these features, therefore they are not pictured in a representation in perspective. Moreover, the load is obviously very high, the vehicle massive on its own, and the body of the vehicle very long.[41] Together with the detail that in Graeco-Roman Times transport wagons equipped with even 12 wheels are known,[42] it seems justifiable to assume that the Apis wagons are provided with eight wheels.[43]

2.3 Wheeled vehicles as a mode of locomotion: chariots

Whereas carts and wagons were modes of transport, chariots were wholly inadequate for the transport of loads and were only used as a mode of locomotion. In contrast to carts and wagons, there is numerous evidence – be it iconographic, textual or even archaeological – that shows the different areas of usage of the Egyptian chariot. About 11 are even preserved in their entity; in the tomb of Tutankhamun six complete examples were discovered. Furthermore, a number of individual parts were found.[44] A kind of standard form is noticeable.[45] This makes the replacement of wearing parts easier, since they did not have to be individually designed for every chariot, but could be fabricated as pre-productions.

40 Köpp-Junk 2015, 142, 146–147.

41 The length of the body seems to imply as well that four axes were used. In case of only two axes the obviously heavy load would be distributed unfavorably and the floor of the vehicle might begin to sag.

42 Bülow-Jacobsen 1998, 64.

43 Köpp-Junk 2015, 142, 150.

44 Littauer and Crouwel 1979, 75; Littauer and Crouwel 1985; Herold 2006; Köpp-Junk 2015, 188–189.

45 Wente 1967, 66; Hofmann 1989, 119, 339.

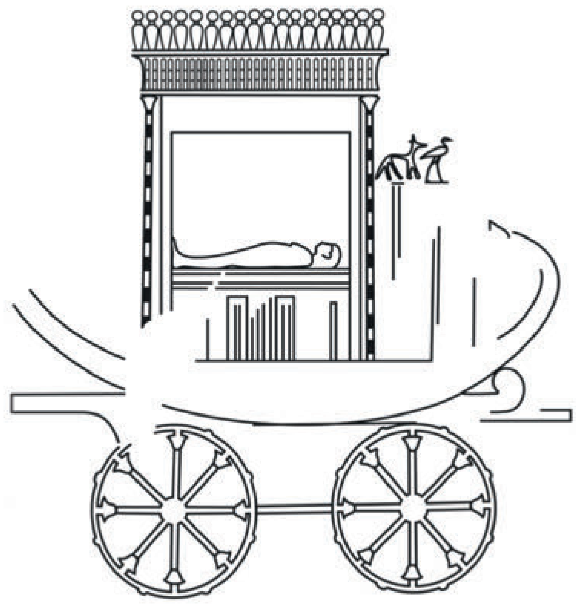

Fig. 7 Four-wheeled wagon from the tomb of Siamun in the Siwa Oasis from the 1st century BC (reconstruction combining the results of Fakhry 1973, Fig. 74 and Lembke 2004, Fig. 9a).

Therefore, the vehicle manufacturer could have typical parts subject to wear on stock.[46]

The first textual reference for chariots in Egypt occurs on the second stela of Kamose from Dynasty 17 (around 1550 BC) referring to chariots used by the Hyksos.[47] No archaeological finds from the very early stage of the chariot are known. More textual evidence is preserved from the beginning of Dynasty 18 in the biography of Ahmose, son of Abana, in his tomb in Elkab and referring to his fights together with king Ahmose I, the successor of Kamose, against the Hyksos.[48] The chariot mentioned in this text belongs to the Pharaoh. From the reign of the same king depictions of chariots in his temple in Abydos are attested.[49] Under his successor king Amenhotep I the picture of a chariot drawn by horses is shown in the tomb of Reneni in Elkab.[50] A four spoked chariot wheel appears in the wall scenes of the Theban tomb of User (TT 21), dating to the reign of Thutmose I, the third king of Dynasty 18.[51] A scarab shows the same Pharaoh on a chariot firing arrows.[52] In the course of Dynasty 18 the number of documentary evidences increases. Therefore, only some years after his introduction around 1550 BC the chariot appears frequently in the texts of the annals of Pharaoh Thutmose III[53] (1479–1425 BC), which are records referring to the military campaigns of the king to Syro-Palestine, as a very effective and obviously self-apparent military equipment.

The Egyptian chariot was used in warfare, hunting, sports, but also for travelling.[54] Its use in warfare is well attested.[55] Several hunting scenes depicting private individuals as well as Pharaohs on a chariot are documented (Fig. 8).[56] The sportive aspect plays a secondary role and is rarely shown, as for instance in a relief of Amenhotep II from Karnak.[57] Chariot races, known from ancient Rome, are not attested in Pharaonic Egypt.

Besides that, in its capacity as the status symbol par excellence, the chariot was the supreme mode of locomotion for the elite in the New Kingdom for private and public purposes. It was used by Pharaohs and high officials.[58] Both, men and women are shown in chariots (Fig. 9–10).[59]

The literary text 'Letter of Wermai,' preserved in Papyrus Pushkin from the Ramesside Period, gives an insight into its daily use as a mode of locomotion. The text describes the involuntary journey of a person called Wermai, a priest in the temple of Heliopolis. He travelled by ship and chariot since he was relieved of his duties and even chased away from his town. However, this was not the end of the protagonist's bad luck, as he reports: "I had to travel by foot, since my horses were taken away

46 Köpp-Junk 2015, 193.
47 Dynasty 17, second stela of Kamose line 13; Habachi 1972, 36; Decker 1986, 36. For another textual evidence for an early chariot see Urk. IV 3, 6 (inscription of Ahmose). For textual evidence for chariot and horse see below as well.
48 For another textual evidence for an early chariot see Urk. IV 3, 6 (inscription of Ahmose).
49 In the Ahmose temple in Abydos scenes of horses and chariots are shown. More early textual evidence, which is lost now, existed in a tomb in Saqqara (Köpp-Junk 2015, 167).
50 Tylor 1900, pl. 2; Hofmann 1989, 363, pl. 46; Raulwing 1993, 80.
51 Davies 1913, pl. 22; Nagel 1966, 37.
52 British Museum London, EA 17774.
53 Urk. IV 645–734.
54 Schulman 1980, 146, 148.
55 For the use of the different types of chariots in warfare see Köpp-Junk 2015, 199–214.
56 For example Hofmann 1989, 281; Saleh and Sourouzian 1986, no. 186.
57 Decker and Herb 1994, pl. 70, E 4–5.
58 Schulman 1980, 145; Decker 1984, 875, n. 16; Köpp-Junk 2013; Köpp-Junk 2015, 196–199.
59 Köpp 2008; Köpp-Junk 2015, 198–199.

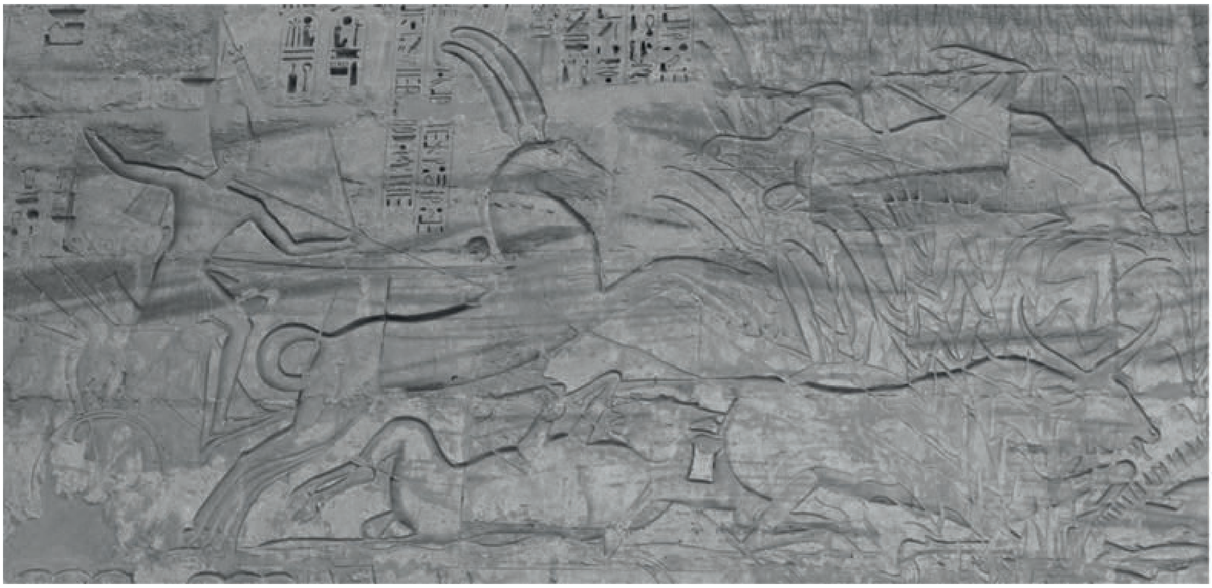

Fig. 8 A relief from the mortuary temple of Pharaoh Ramesses III at Medinet Habu from the 20th dynasty shows the king on his chariot, hunting desert game.

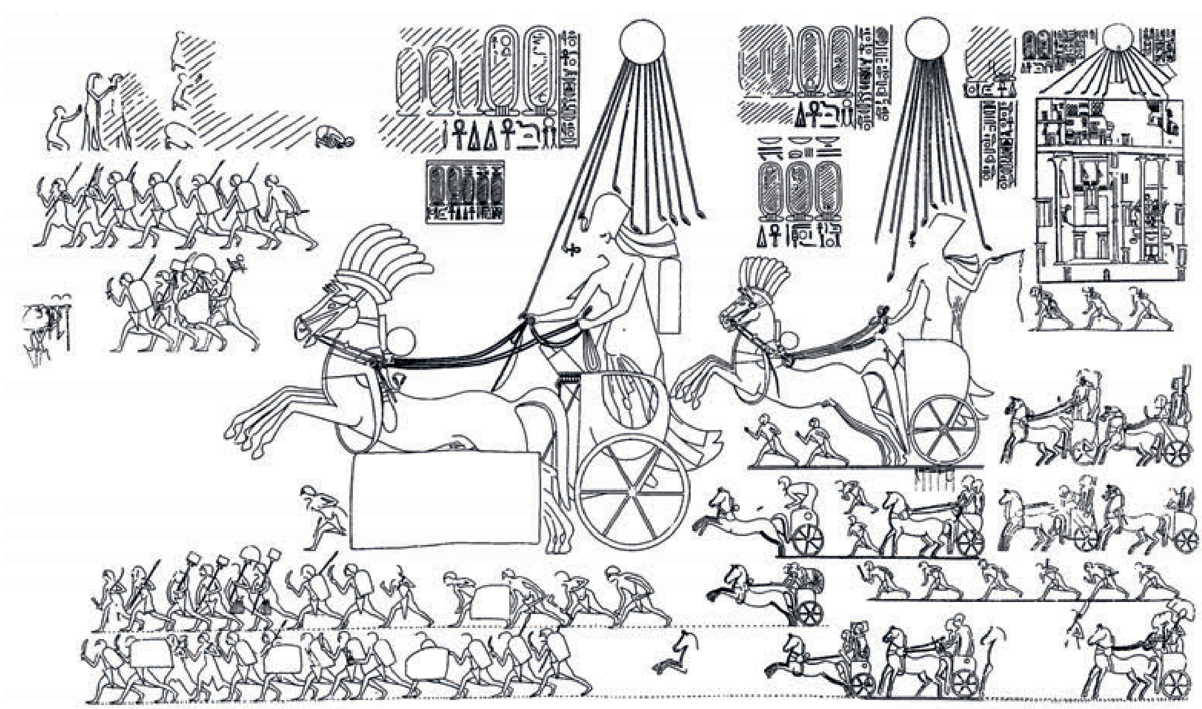

Fig. 9 Nefertiti, Akhenaten and their daughters on a family outing on chariots.

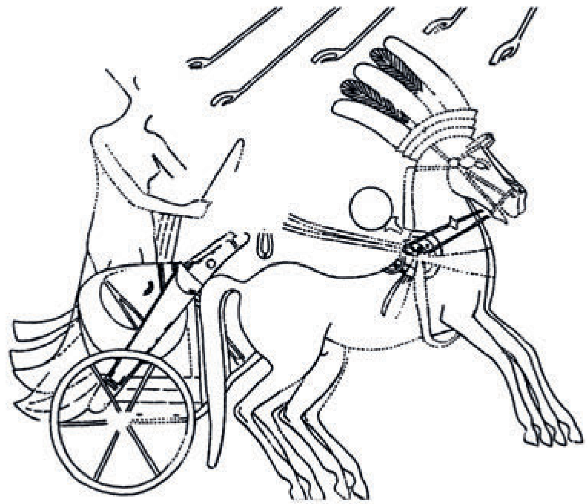

Fig. 10 Queen Nefertiti on her chariot.

and my chariot was stolen. Without them I was forced to walk".[60]

The chariot was, in comparison to all other means of locomotion, the fastest, but also the most expensive one. Besides the chariot, the owner needed to afford the horses as well as the personal staff for the maintenance and care of both. The advantage of the Egyptian chariot lies, thus, primarily, in its speed, which is about 40 km/h.[61] The open work construction of the frame was meant to make the vehicle as light as possible. The chariot found 1829 in Thebes and now in the Museum of Florence, dates to the beginning of Dynasty 18. It weighs only 24 kg, its tread being 2 cm wide.[62] In ancient Egyptian texts, the speed of the chariot and the horse team was described very illustratively. A stela from Memphis states the following about Pharaoh Amenhotep II from Dynasty 18: "He crosses the river Orontes on his chariot wildly charging like the power of the Theban god Montu".[63] In an inscription in the Luxor Temple the king on his chariot is described as "A star made of electrum".[64] The speed of the horses was, moreover, compared to that of animals like leopards, falcons, and bulls.[65] In Papyrus Anastasi, the speed of the horse team of a chariot is equated not only to a panther, but to a storm as well.[66] The dream stela of Thutmose IV from Dynasty 18 declares that the horses of his chariot were faster than the wind.[67] In an ancient Egyptian love song, preserved in Papyrus Chester Beatty I, a courier is requested to come as fast as possible to his beloved one. Therefore the messenger chose the chariot, the fastest way of locomotion besides riding in ancient Egypt:[68]

> "Please come to your beloved one quickly like
> the quickest messenger of the king.
> The heart of his master longs for the message of
> the messenger,
> his heart longs to hear the news.
> The stables are prepared for him, the horses are
> waiting at the stations
> and the chariot is already harnessed.
> He does not rest on the way.
> Having reached the house of his beloved one his
> heart will be truly happy".

The chariot was only limitedly suited for long-distance travelling because of its light construction; notably its spoked wheels required an even and compact soil in order to function properly. Therefore cross country driving was only possible in appropriate terrain, but not on very rough, rugged ground, interspersed strongly with big stones.[69] Still, various texts[70] suggest that chariots were even used for long distance travels in the desert, given that roads or ways existed or the ground itself was geologically solid enough or that they were prepared before to be usable for chariots. The text of the Ramesside

60 Papyrus Pushkin 127, column 3, line 4–7.
61 To travelling speed in ancient Egypt in detail see Köpp-Junk 2015, 289–302.
62 Museo Archeologico Nazionale di Firenze, no. 267; Horn 1995, 50.
63 Urk. IV 1311.
64 Urk. IV 1685, 1.
65 Papyrus Anastasi I 18, 5; Hofmann 1989, 66–67; Hölscher 1934, pl. 27, line 24.
66 Papyris Anastasi I 18, 5; Fischer-Elfert 1986, 159.
67 Urk. IV 1541, 8–13.
68 Papyrus Chester Beatty I, Ib; Gardiner 1931, pl. 29, G, 1–4.
69 Köpp-Junk 2015, 205–209.
70 Chariot drivers appear as members in some of the expeditions leading to the Eastern Desert. An inscription from Kanais dating to the reign of Sety I mentions His Majesty's charioteer (Hikade 2001, 217). A short Wadi Hammamat inscription from the time of Ramesses IV refers to the charioteer *Pn-jrj-Rʿw-ms-sw* (Hikade 2001, 204). Another expedition inscription dealing with the largest known mission of the New Kingdom to the Wadi Hammamat, consisting of 8,361 expedition members and occurring under the same Pharaoh, alludes one royal chariot driver, 20 stable masters as well as 50 charioteers (Hikade 2001, 40–41, 42–43, 207–208) and, according to Schulman's interpretation, the same number of chariots belonging to them (Schulman 1963, 83).

papyrus Anastasi I[71] describes the crossing of a mountain pass leading from the coastal plain to Megiddo with chariots being taken along.[72] The text as well as pictorial evidence reveals that chariots could be carried over uneven, rough or hilly terrain on the shoulders of one or two man.[73] Due to their little weight it was not necessary to dismantle them.

Egyptian chariots were drawn by male horses.[74] The earliest archaeological proofs of the horse in ancient Egypt were the bones and teeth found at Tell el-Daba[75], Buhen[76], and Tell el-Maskhuta[77], dating to Dynasty 13 (about 1650 BC).[78] It is, however, uncertain whether the horse was used as a riding or a draught animal in this early phase. Although the first four-wheeled wagons belong to the same period, they were never drawn by horses in Egypt, but by oxen or men. From Dynasty 13 to Dynasty 17 there is a hiatus, since the next textual and pictorial evidence for horse and chariot only appears a little bit later, namely at the end of Dynasty 17 (1550 BC) and the begin of Dynasty 18.[79] The earliest depiction of a rider on horseback in Egypt belongs to the reign of Thutmose III.[80] Therefore, in ancient Egypt the horse is attested for pulling chariots[81] before it was used as a riding animal, which is only rarely shown throughout Pharaonic times.[82] With the beginning of Dynasty 18, horses start to play a major role as draught animals for chariots. Although they have a high draught capacity of up to 1000 kg and a carrying capacity of 170 kg,[83] they were neither used as pack nor draught animals for wagons in ancient Egypt, but preferred when high speed locomotion was needed, such as for mount messengers or for pulling the chariot.[84] The animal was very prestigious and horse teams were very popular New Year gifts in the higher social classes.[85] Moreover, horses were in the most literal sense even royal gifts between sovereigns. Amenhotep III got some from Tushratta, ruler of Mitanni, Akhenaten got 10 horse teams from Burnaburiasch of Babylon and another one with white horses from Ašuruballit, king of the Middle Assyrian Empire.[86]

3 Development of wheeled vehicles in Ancient Egypt

On the basis of little evidence the following facts can be stated about carts and wagons. In Egypt, carts and wagons were only used for the transfer of freight, not for passengers. The first type of wheel attested in ancient Egypt is the disc wheel in Dynasty 5; spoked wheels are depicted much later in Dynasty 17.

The first objects on wheels are no vehicles, but a scaling ladder from Dynasty 5 and a siege tower from Dynasty 11. The oldest four-wheeled wagon dates to Dynasty 13, the earliest carts as well as the six wheeled wagons to the New Kingdom. Therefore, wagons were used in ancient Egypt before carts. But, of course, this order merely reflects the nowadays existing sources, it do not necessarily correspond to reality.

71 The satirical text of Papyrus Anastasi I illustrates the correspondence of two scribes named Hori and Amenemope. Hori is mocking Amenemope with queries concerning the calculation of the workers' supply and how many tiles were needed to build a ramp. By the way he gives geographical details of Palestine and Syria.

72 Papyrus Anastasi I 23, 1, 3 and 7, 24, 2.

73 Papyrus Anastasi I 18, 5–20, 6; 23, 1–24, 6; Hofmann 1989, 121, fig. 67, 99; TT 78, 18th Dynasty, Amenhotep II-III, funeral procession; Brack and Brack 1980, pl. 88.

74 For mules as draught animals for chariots see Hofmann 1989, 366.

75 Boessneck and Driesch 1992, 24–25.

76 Hofmann 1989, 21–26.

77 Wapnish 1997, 355.

78 For a review on these early evidences see Raulwing and Clutton-Brock 2009, 1–106.

79 On the Carnarvon-tablet, dating to Dynasty 17, the term *ḥtr.w* appears, written with a cow's skin as a determinative, not with a horse, as one would expect to avoid uncertainties. Nevertheless, Gardiner translates 'horses' (Gardiner 1916, 106–107), it is however possible that a team of oxen was meant. In the text of the second stela of Kamose (Dynasty 17, Habachi 1972, 36) the term *tꜣ-nt-ḥtr* is mentioned, again with a cow's skin as a determinative, but here the factor of uncertainty is smaller, since it is the usual word and writing in later texts for 'chariotry'. Nevertheless, already during the reign of the successor of Kamose, king Ahmose, there is clear evidence of horse and chariot. The biography of Ahmose, son of Abana, dating to the beginning of Dynasty 18 (see above, Urk. IV 3, 6), mentions a chariot with one of the usual terms for chariot *wrrj.t* written with a chariot as a determinative. In the temple of Ahmose in Abydos from the same time chariots and horses are depicted (Harvey 2003; O'Connor 2009, 108–109).

80 Metropolitan Museum of Art New York, no. 05.3.263.

81 See above the quoted evidences of Dynasty 17 and the beginning of Dynasty 18.

82 Köpp-Junk 2015, 166–171.

83 Ohler 1988, 35.

84 Köpp-Junk 2015, 166–171.

85 Decker 1986, 56, 367, note 103; TT 73 (tomb of Amenhotep), TT 93 (tomb of Kenamun), both Dynasty 18.

86 Knudtzon 1915, 83, 57. 91, 37. 129, 10 (Akhenaton), 133, 36 (Amenhotep III).

Very often the transport platform has the shape of a slim board, not seldom designed as a sledge runner. This is a reference to the classic transport vehicle 'sledge', which was used since Dynasty 1 (about 3000 BC)[87] for heavy transport in profane and ritual situations. In connection with the latter, they received a religious connotation;[88] therefore, the equipping of a wagon with those runners makes sense, referring to the fact that the wagons are often depicted while transporting the deceased to the tomb as well.

Concerning wagons, it should be stated that they are more often equipped with four wheels than with six or even more. Before the Second Intermediate Period, there is no evidence for wagons or carts at all. Wheels are attested only twice, namely on the scaling ladder in the Old Kingdom and the siege tower in the Middle Kingdom.[89] In the Second Intermediate Period two wagons are documented. The number increases in the New Kingdom, but declines again in the Third Intermediate Period. Whereas for the Late Period not a single example exists, the largest number[90] with four to probably eight wheels is attested in Graeco-Roman Times.

Considering the contexts in which objects on wheels, carts and wagons appear in ancient Egypt it is noteworthy that the first wheels attached to a scaling ladder and a siege tower were both used during military confrontations. Carts are depicted in combats as well, but, besides that, they are shown in harvesting and religious scenes. Regarding the wagons, the majority is portrayed in a religious context, but they were obviously not restricted to this area. A military context is for example known from the Gebel Barkal stela from Thutmose III.[91] This text from the New Kingdom mentions wagons which were used to transport disassembled ships during the campaign against the Mitanni. Furthermore, wagons with disc wheels as well as those with spoked wheels appear as a mundane transport vehicle in religious scenes; hence, it is impossible to argue that wagons with spoked wheels or those with disc wheels were limited to a specific context only.

The Egyptian carts and wagons are very heterogeneous and unique. Moreover, there is a large variety of types of the two dimensional representation of the carts and wagons, and they are often quite rough. Thus it is not possible to observe a development from a more massive vehicle to a more fragile one. Since the illustrations are neither detailed nor primarily designed to reveal technical features and construction elements, a technological development of spoke, wheel, and nave from the earliest to the latest wagon is not traceable. Altogether, technical details like the combination of spoke, wheel, and nave or the connection of vehicle body and axle or axle and wheel are, in the majority of cases, not recognizable. Only in case of the wagon from Medinet Madi statements are possible,[92] for example concerning the connection of wheel and axle. There are, in principle, two different options for making the wheels turn. One variant consists in attaching the wheel firmly to the axle with the axle rotating under the body of the vehicle. Another possibility is that the wheel rotates around the axle with the axle being fixed to the body of the vehicle.[93] This last variation is attested by the wagon from Medinet Madi, which shows four disc wheels of about 31 cm in diameter rotating on an axle fixed to the frame of the wagon. The wheels were prevented from sliding from the axle by linch pins.[94]

Two groups are distinguishable within these objects on wheels, carts and wagons. The first consists of objects with the wheels directly attached to them, such as the scaling ladder and the siege tower already mentioned with the wheels being an integral part of the objects, summed up to the formula

{(load + wheels)}.

The further development consists in adding wheels to a transportation platform, thus allowing the transport of a freely selectable load:

{load + (transport platform + wheels)}.

87 Köpp-Junk 2015, 219–127.

88 Köpp-Junk 2015, 127–132.

89 For a wagon found in Medinet Madi the dating is unclear, it might belong to the Middle Kingdom or to the Ptolemaic Period (Köpp-Junk 2015, 143–155).

90 10 of them belong to one type of wagon with presumably eight wheels, which were mentioned above.

91 Urk. IV 1232, 1–6.

92 Dittmann 1941; Köpp-Junk 2015, 141, 143–155.

93 Burmeister 2010b, 226.

94 Köpp-Junk 2015, 141, 143–155.

Therefore, it is not the invention of the wheel which is the pioneering innovation,[95] but the combination of wheels with a transport platform, offering the possibility to transport numerous products and loads.

In principle, the wagon in ancient Egypt originated from wheeled objects as the scaling ladder on wheels. Obviously, the development from the first use of the wheel combined with the scaling ladder to the complex system 'wagon' like the one in the tomb of Sobeknakht was a severe technical leap. Therefore, it can be suggested that predecessors of this wagon existed, but they are not documented yet. Nevertheless, some very important aspects necessary for the construction of wagons existed already before Dynasty 13 in Egypt; those are traction, draught animal, wheel and skilled craftsmanship.[96] The principle of traction was known before from the pulling of sledges or ploughs since the Old Kingdom at the latest. The hauling ropes were fixed directly to the horns of the oxen[97] or by means of a horizontal wooden slat.[98] Oxen, the typical draught animal for carts and wagons, or men were already used for pulling sledges as well. The principle of a wheel rotating around an axle was known from the scaling ladder. Egyptian artisans were very highly skilled.[99] Therefore, several features of the phenomenon 'wagon' were known before, but it is only now in Dynasty 13 that it was combined with the most important factor, the transportation platform.

There is no development from the cart to the wagon or from wagon to cart. Moreover, regarding the chariot, a common development line of cart, wagon and chariot is not traceable in ancient Egypt as well. The sequence of their appearance is, as shown above, the four wheeled wagon being the first vehicle, followed by the chariot and the cart finally. The reason why there is no such a development trend lies in their different areas of usage. The chariot was a mode of locomotion, very fast, agile, maneuverable, and, therefore, of very little weight. In contrast to the chariot, carts and wagons were used for the transport of loads; their construction focused, thus, on stability.[100] Unlike in the Near East, the chariot is attested in ancient Egypt without any preliminary stage like war cars[101] or battle wagons[102].

4 The Introduction of wheeled vehicles in Ancient Egypt

There is no explicit textual or archaeological evidence from Egypt itself, revealing where the idea of wagons and carts came from.[103] Both appear in the 4th millennium BC in several regions of the world as in the Near East, Europe and the Caucasus, with no coherent contact line being traceable.[104] There is no remarkably very much older evidence maybe even in a noticeable accumulation in one special area, indicating that the invention 'wheel' might have taken place there. Therefore, it is still in question whether the wheel was invented in only one spot or it evolved at different places coincidently.[105] Concerning the diffusion of the wagon in general, Burmeister argues that due to their lack of maneuverability and their high dependence on roads and ways, wagons and carts were not the medium of the diffusion of the wagon on their own.[106] He supposes that not a whole wagon was imported as an innovation, but only the knowledge of it – its blueprint as he puts it[107] – due to the limited usability of wheeled vehicles on routes without suiting subsoil or an existing road system. Therefore it is possible that somebody from one of these wagon using areas came to Egypt to bring an exemplar or at least the idea of a wheeled vehicle to Egypt, but no evidence of that scenery is handed down to us. Similarly, one might assume that the idea of a transport vehicle on wheels was observed by Egyptians travelling to foreign lands and brought back to Egypt. Again, there is no proof for that. But it is noteworthy to take into consideration that connections from Egypt to Syria, Palestine and the Near East as well as far

95 Hayen 1989, 36.
96 For a similar listing see Burmeister 2011, 233.
97 See for example Davies 1913, pl. 2.
98 Köpp-Junk 2015, 108.
99 This detail will be discussed below.
100 Köpp-Junk 2015, 188–209.
101 Powell 1963, 153.
102 Littauer and Crouwel 1979, 48.
103 Comparisons between Egyptian wagons and carts to those from the regions with earlier use of wheeled vehicles showed no result as well.
104 Burmeister 2011, 223, 226, with a concise summary of the evidences and a distribution map of wagons (fig. 25).
105 For more on this debate see e.g. Burmeister 2011, 226.
106 Burmeister 2010a, 225. He assumes that they were primarily used on short distances. But, referring to the text of the Gebel Barkal stela (Urk. IV 1232, 1-6), wagons were used on long distance travel in ancient Egypt indeed.
107 Burmeister 2011, 228.

into the south to Nubia and beyond are already attested in Predynastic times;[108] since that period, a high degree of mobility is documented in ancient Egypt.[109] Obviously, for this intensive travel rate no wheeled vehicles were necessary.[110] Referring to textual evidence, people were on the move in in connection with their profession and on official duty through the order of the pharaoh in the very most cases. In addition to the travels of the elite, the mobility of the middle and lower class is mentioned in the texts as well. Therefore, travelling was not a high class privilege. The mobility of craftsmen is often attested; travels of over 600 km for one way are no exception.[111] In the interaction with foreign countries and cultures, the traveler left his everyday radius of action behind and expanded his knowledge and his horizons.[112] The contact with foreign cultures and customs and especially the personal exchange between guest and host allows exchanges of ideas and inventions and therefore the diffusion of innovations.[113] Especially the impact of the mobility of craftsmen in terms of the diffusion of technical innovations should not to be undervalued. Moreover, since earliest times the technical skills in woodworking, metalworking and leather production, essential for the manufacturing process of carts and wagons were on a very high level in ancient Egypt. Therefore not only the technical skills were present, but the majority of the different materials needed as well.

All in all, from where and when the idea of carts and wagons came to Egypt, it is to state that referring to the high mobility of the Egyptian society, the places from where the idea of wheeled vehicles or even the hardware might have been imported are numerous; therefore, the source cannot be clarified, except for the fact that it must be in the north of Egypt as the Near East, since there are no wheeled vehicles attested in the south, i.e. in Nubia, before they were known in Egypt. Concerning the date it is to state that the depiction of the first wheel in Dynasty 5 or the wagon in Dynasty 13 is not necessarily identical with the arrival of the innovative idea 'wagon'. The idea was maybe not translated into action for a long time and might have come to Egypt long before Dynasty 13.

Concerning the chariot, there are neither previous models as war cars or battle wagons traceable nor did it develop from vehicles existing before in ancient Egypt. The chariot was not an Egyptian invention, since the fast, light, and equid-drawn chariot appears almost simultaneously in Mesopotamia[114], Europe[115] and Egypt[116] in the middle of the 2nd millennium BC. Referring to Moorey, the Hittites, the Hurrians as well as the Amorites used the light chariot in the 17th century BC as well.[117] Even earlier chariots are known from the Ural, dating to 2000 BC,[118] and from the Sintashta-Petrovka culture dating about 2100–1880 BC.[119] The question of the import of the chariot to Egypt as well as its origin at all is debated already for a long time. Several approaches to an interpretation were taken. Whereas some suggest a transfer to Egypt northern Syria[120], Syria-Palestine, or Mesopotamia[121], other researchers argue in favor of Indo-Aryan sources, often for linguistic reasons.[122] Actually the Near East is favored for several reasons,[123] for example the Egyptian word for 'horse' is a loan word from the Near East.[124] Often the Hyksos, who resided in the northern part of Egypt in the Delta in the Second Intermediate Period, are named as intermediaries.[125] But there is no explicit evidence that the

108 Köpp-Junk 2015, 262–263.
109 On Egyptian mobility within Egypt and beyond in detail see Köpp-Junk 2015.
110 Not only the earliest, but moreover the most important modes of transport and locomotion in ancient Egypt were boats, ships and other vessels (Köpp-Junk 2015, 29–37, 82–93); on Egyptian ships and boats see as well Landström 1974; Dürring 1995; Merriman 2011.
111 In other premodern societies such as Europe the radius of action is much smaller than in Egpyt (Jockenhövel 1991, 49–62; Burmeister 2011, 228).
112 Köpp-Junk 2015, 19.
113 See as well Burmeister 2011, 227–228.
114 Littauer and Crouwel 1979, 90.
115 Egg and Pare 1993, 209; Larsson 2004, 390–392, fig. 14.
116 Littauer and Crouwel 1985, 90.
117 Moorey 1986, 211.
118 Häusler 1986, 144; Burmeister 2004, 32.
119 Krause and Fornasier 2012, 32–36.
120 Hofmann 1989, 14.
121 Salonen 1951, 165; Wiesner 1939, 33.
122 Burmeister and Raulwing 2012, 93–113, summarizing the research status in detail. For linguistic aspects see Raulwing 1994, 71–79; Zeidler 2000, 97–111.
123 Crouwel 2013, 74, 84.
124 Hofmann 1989, 42, 44
125 See for example Yadin 1963, 86; Hoffmeier 1976, 43; Bibby 2003, 14. Their ethnic origin is unclear, but, due to similarities in the archaeological material of their capital Auaris, it can be suggested that they came from the northern Levante, more precisely the Libanon and northern Syria (Bietak 2010, 163). All in all there is not much textual or archaeological evidence for the Hyksos, the earliest dating to Dynasty 12 (Bietak 2010).

Egyptians had adopted the innovation 'chariot' from the Hyksos. Chariots are simply attested in the battles between the Egyptians and the Hyksos.[126] Furthermore, the archaeological finds of chariots in their capital Auaris are very restricted.[127] Therefore, the chariot might have been introduced into Egypt from another independent source, i.e. past the Hyksos in the Delta[128] and avoiding them, or maybe even through the Wadi Hammamat and across the Red or the Mediterranean Sea.

It is not apparent by the Egyptian sources how the knowledge came to Egypt, be it by travelling Egyptian craftsmen, by trade, as diplomatic gifts,[129] or as tributes or booty. The intensive mobility of Egyptian craftsmen was discussed above. Due to their highly skilled level there would also be the possibility that the chariot is an internal further development based on an idea that came from somewhere else, observed by a traveling artisan. Of course, foreign craftsmen as well as traders and other travellers came to Egypt as well; therefore it was a mutual exchange of knowledge, techniques, inventions, and innovations in both directions.[130] Egyptian traders have a high mobility as well, which is not only traceable within Egypt, but also beyond; in the New Kingdom they are even attested in Cyprus and Ugarit,[131] the last one being a distance of 930 km overland from modern Cairo. Long-distance trade even of prestigious objects was very common in ancient Egypt and is documented very early.[132] Insofar the transmission of chariots by trade is not to rule out, since they were prestigious status objects par excellence.

Moreover, gift exchange was a very important medium of communication between Egypt and foreign rulers. The horses for example, given to several Egyptian kings from the rulers of Babylon, the Mitanni and Assyria, were already mentioned above, therefore the transmission of the chariot via diplomatic gift exchange cannot be ruled out because of their high prestigious status.

In the tribute and booty lists in the annals of Pharaoh Thutmose III several chariots appear, with a distinction between simple chariots, those of gold and silver, and polychrome decorated ones.[133] Chariots coming to Egypt as tributes of foreign rulers are repeatedly depicted in private tombs of the New Kingdom. In the Theban tomb of Iamunedjeh (TT 84, Dynasty 18, under the reign of Thutmose III), for example, Syrian messengers are shown, offering a chariot as a tribute and pulling the vehicle with the help of its pole. In the tomb of Huja in Amarna (northern cemetery tomb 1, Dynasty 18, under the reign of Akhenaten) Libyans are depicted, presenting two chariots as tributes, each one transported by two persons.[134]

For the transfer of chariots by trade or by craftsmen no evidence is attested, the same applies to diplomatic gift exchange. The import as booty or tribute is obvious, since it was a usual offering in later times. The text of a stela from Dynasty 12 (about 1800 BC) mentions spoked wheels, axles, and poles as booty,[135] which is chronologically close to the first evidence of horses and wagons in Egypt in Dynasty 13.[136]

Therefore, for the possible area from where the chariot or the idea of it might have come to Egypt the Near East is to favor. As transmission channels trade, travelling artisans, diplomatic gift exchange, tribute, or booty come into question. Concerning the date it might be

126 Schulman 1980, 108.

127 Schulman 1980, 113; Bibby 2003, 15.

128 Shaw even suggests that the Hyksos blocked the access to chariots, body armor and composite bows (Shaw 2001, 69).

129 For diplomatic relations and the distribution of warfare technology see Shaw 2010, 82.

130 For the mobility of craftsmen in the Near East in detail see Zaccagnini 1983, 245–264. For the international und cultural relations demonstrated by the Minoan fresco in Tell el-Daba see Bietak 2008.

131 Köpp-Junk 2015, 243–245.

132 Just to mention some of the initial evidence: Already in Naqada I storage jars from Canaan as well as Lapis lazuli from Afghanistan are attested in Egypt. In Predynastic and Early dynastic tombs, objects made of obsidian from Ethiopia and Yemen were found (Hendrickx and Bavay 2002, 67–68, table 3.5 (Canaan), 61, table 3.3 (Afghanistan), 60 (Ethiopia, Yemen). In the tomb U-j, belonging to Scorpion I and dating to Dynasty 0, 4500 l of wine from Palestine were stored (Hartung 1994, 110). Travels to Punt through the eastern desert and the Red Sea already took place during the Old Kingdom.

133 Urk. IV 663, 12–664, 1: chariots decorated with gold and simple ones. Urk. IV 692, 2: decorated with silver. Urk. IV 699, 10–11, 704, 15, 706, 2: decorated with silver and gold. Urk. IV 712, 9–10: decorated with gold and gold and silver respectively. Urk. IV 659, 16–660, 1, 690, 9–10: decorated with silver and gold and those painted polychrome. In Urk. IV 691, 7 und 711, 13 only the determinative of the chariot is written without further information except for the acquired number of chariots.

134 For further tributes in the form of chariots and horses see Decker and Herb 1994, 5, 8, 13, 17, 21, 24, 26, 31, 44, 46, 52, 69, 76, 103; for tributes in the New Kingdom on the whole see Hallmann 2006.

135 Altenmüller and Moussa 1991, pl. 1, line 18. Since the word for chariot is not mentioned explicitly, the objects might belong to wagons instead of chariots as well.

136 See the bones and teeth of horses found in Buhen, Tell el-Daba and Tell el-Maskhuta and stated above.

suggested that their actual introduction to Egypt took place even earlier than Dynasty 17 and the Hyksos era,[137] also indicated by linguistic aspects.[138]

5 Widespread and fast use of the chariot versus infrequent and late use of carts and wagons

As mentioned above, wheeled vehicles are attested in the 4th millennium BC in Europe, Caucasus and the Near East. Nevertheless, the first wheel in Egypt dates to the 3rd millennium BC. And although the wheel is known since the Old Kingdom, there is only rare evidence for the use of carts and wagons as means of transport in comparison to the frequently proven chariot. Assuming that the low number of archaeological and textual documents reflects that they were used very seldom in ancient Egypt, the question rises how this phenomenon should be explained. It is not an issue of technical skills, since already in Predynastic times the Egyptian craftsmanship was on a very high standard. Moreover, is not the result of a lack of mobility as stated above, since a very high degree of travel activities throughout the entire Egyptian society is attested in ancient Egypt from the earliest times. Furthermore, it is not a problem of conservatism or even fear of change, since the adoption of the chariot and, moreover, the horse as well was forthcoming very quickly, as will be discussed in detail below.

Some reasons for the low use of wagons lay in the climatic and geomorphological conditions of Egypt, more precisely the desert and the annual Nile flood. In pharaonic times, the area of cultivated land consisting of the delta and a small strip beside the river Nile were considered as 'Egypt', bounded by the eastern and western desert. In the modern state of Egypt 96.5 % of the land is occupied by desert.[139] The cemeteries were usually located on the west bank of the river in the desert, but still within easy reach to the settlements. All in all, the desert was seen as hostile and unsafe. However, referring to the usability of wagons and carts, on sandy ground the friction increases; it is 30 times higher than on even terrain.[140] Especially fine soft sand benefitted that the wheel sinks into the ground.

A further limitation is the annual inundation, which flooded the whole fertile land every year before the new Aswan high dam was completed in 1970. Therefore, wheels were impractical, since they would sink into the wet soil just as into the sand. However, sledges benefited from the slippery ground, and, furthermore, they were able to transport heavier weights without the danger of broken axles. Therefore, they were preferred in ancient Egypt for the transport of massive loads on the land route[141] as proven, for example, by a relief from the quarries of Tura, dating to the New Kingdom (about 1550 BC) and showing the transport of stone blocks on a sledge.[142] An even more extreme example of heavy transport by sledge is the very vivid transport scene in the tomb of Djehutihetep (Fig. 11) from Dynasty 12 at el-Bersheh.[143] It depicts the transport of a huge statue on a sledge, drawn by 172 men.[144] The statue of 6.8 m with a weight of approximately 58 t[145] is attached with ropes to the sledge. The technique of pouring liquid in front of the runners in order to decrease friction is already known since the Old Kingdom.[146] Approximately 35 km in total had to be covered by sledge over land.

Furthermore, the annual flood also prevented the building of a coherent large-scale road network, which would have been necessary for an increased use of wheeled vehicles. Moreover, it has to be taken in consideration that the fertile land was intersected by irrigation canals and dykes,[147] again making the use of vehicles more difficult. Therefore, due to sand and inundation with the latter one preventing an expansion of a coherent road network, the area in which carts and wagons could be used in Egypt was not well suited for wheeled transport vehicles.

137 See also Herold 2004, 125.
138 Helck 1962, 55; Nagel 1966, 32.
139 Schamp 1977, 4, 7.
140 Horn1995, 55.
141 Köpp-Junk 2015, 119. Of course, the water way was used for heavy transport whenever possible as the transport of two obelisks of 323t each in the time of Queen Hatshepsut shows (Arnold 1991, 60, 62, table 3.1).
142 Arnold 1991, fig. 6.39
143 Newberry 1895, 18–19, pl. 12, 15.
144 In Ancient Egypt sledges were always drawn by men or oxen, but never by donkeys or horses. Moreover, they were not used for passengers, but they were the classical means of transport for huge loads such as quarry stones or sarcophagi (Köpp-Junk 2015, 117–132).
145 Arnold 1991, 61.
146 See for example the scenes in the tombs of Ti (Montet 1939, pl. 55) and Qar (Simpson 1976, fig. 35).
147 Bagnall 1985, 5.

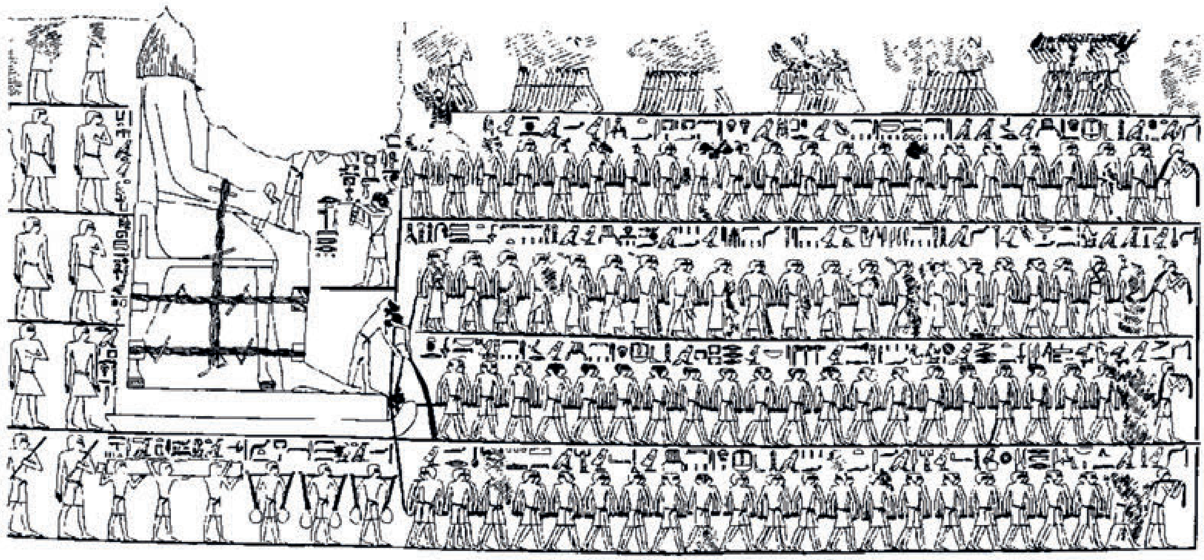

Fig. 11 In the tomb of Djehutihetep from Dynasty 12 at El Bersheh the transport of a huge statue on a wooden sledge is depicted. The sledge is drawn by 172 persons through the desert.

Besides the lack of a road network, another important factor impeding the use of wagons is their limited maneuverability. A change of direction was easier with carts than with vehicles with two or even more axes.[148] As far as the limited evidence from Egypt shows, only the wagon from Medinet Madi offers a kind of maneuverability, because its axles were to a certain degree revolvable.[149] Otherwise, a change of direction requires an enormous effort and produces high stress on the vehicle.[150]

Besides those practical aspects, the adoption or refusal of an innovation depends on several preconditions,[151] which in Egypt were perhaps not given for carts and wagons until Graeco-Roman Times.[152] The use of wagons increased in this late period, maybe due to the fact that the representatives of the Greek and Roman authorities coming to Egypt were accustomed to use carts and wagons, be it the ruling elite, the officials or the ever increasing population of Greek and Roman origin. It is even possible to find analogies for this phenomenon from the modern era in the canals of the Netherlands. In their own country, the Dutch used canals for the dewatering and as a main transport way.[153] During their colonization of Indonesia they likewise build canals as for example in Batavia.

But nevertheless, even in this later period wagons did not emerge to a major factor in the Egyptian traffic system,[154] since they were used next to camels or donkeys, the latter in a superior number; an efficient integration of wagons appears not to have taken place in Egypt. Burmeister notes, although not in respect to Egypt, that the use of wagons was seasonally restricted to the summer up to the Middle Ages and modern era,[155] only then in the latter mentioned period it was established as a common mode of transport, being an exception in the traffic system before.[156]

In Egypt, obviously there was no extensive requirement for wagons up to the end of the New Kingdom and even later. Though the elite seem to use the wagon for example in religious context such as for the transport of the sarcophagus as shown above, a widespread use would be to locate in the working area in the agriculture sector and therefore in the lower social class, but its members could not afford wagons and thus it was not of interest.

148 Burmeister 2010b, 224–228.
149 Köpp-Junk 2015, 143.
150 Burmeister 2010b, 228.
151 See for example Kaelin 2006, 17–39.
152 Köpp-Junk 2015, 157–159, 232.
153 Selberg 1846, 359.
154 Bagnall 1985, 4.
155 Burmeister 2011, 228.
156 Burmeister 2012, 81.

Traditionally the donkey was the classical transport animal in Egypt since Dynasty 1 (about 3000 BC)[157] and it still is today. It can be assumed that, despite the introduction of the wheel, donkeys were still preferred to carts and wagons, since they hold several benefits: Due to the form of their hooves, they have an excellent foothold on hilly, sandy ground, or moist surface.[158] They are independent from roads and paths in contrast to carts and wagons. With regard to fodder and water, donkeys have modest needs. They only have to be watered every second or third day.[159] A factor which should not be underestimated is that people were accustomed to suitably keep donkeys and how to work with them. Certainly, the high transport capacities of carts and wagons as well as their prestige value were recognized as very efficient and as a significant advantage. But it can be assumed that the 150 kg carrying capacity of a donkey was sufficient for everyday work.[160]

Therefore, the practical benefit of carts and wagons was maybe not considered as beneficial enough in relation to the multiple advantages of a donkey, regarding especially the enormous costs of purchase, maintenance and repairs of carts and wagons.[161]

The same applies for the camel in Egypt. The use of camels increased in Graeco-Roman Times as well, being only sporadically documented before.[162] Nevertheless, because of the rare evidence it can be suggested that they were at least known since the New Kingdom at the latest,[163] although their frequency of use is not to determine. But certainly they played no decisive role in the traffic system, being not the 'desert ships' they are famous for in later times.[164] Despite of their increasing number in Graeco-Roman Times, they did not displace donkeys; both coexisted, due to their different application fields.[165] Whereas camels unfold their advantages in the desert, donkeys were still the preferred working animal in cultivated land, maintaining their classic working area. In the Zenon archive, dating to the 3rd century BC, the camel appears as being 'well-established in Egypt'.[166] Bagnall assumes that the use of the camel was well-known in Egypt under Ptolemy II. He notes that as many documents refer to camels as to wagons in the Zenon archive, and stresses the fact, that not camel or wagon was the alternative transportation unit at that time, but camel or donkey, since the evidence for donkeys doubles the one for camels.[167] At the Mons Claudianus quarry, where granodiorite was mined between the 1st and 3rd century AD, seven times more donkey bones were found than those of camels.[168]

One aspect supporting the widely used application of the donkey was their low price, but compared to an average income they were still expensive. The costs of a donkey amount to approximately 25–40 deben in Ramesside Egypt. However, a team member of the tomb builders of Deir el-Medineh earned about 25–30 deben.[169] In the 3rd to 5th century AD the costs of a donkey are 5–10 times more expensive than an average monthly income.[170]

In the 2nd century BC the price of a male donkey is less than half as that of a male camel.[171] For wagons and carts no costs are attested in Egypt,[172] but an even higher price has to be assumed, to which the costs for the draught oxen have to be added. In the Ramesside period the price for an adult bovine animal is the fourfold of that for a donkey, ranging between 100 and 141 deben.[173] Therefore the pricing structure begins with

157 Köpp-Junk 2015, 110.
158 Ohler 1988, 35.
159 Peacock and Maxfield 2001, 296; Förster 2007, 5, n. 25.
160 Sledges are not attested in private ownership or everyday work scenes as well in ancient Egypt (Köpp-Junk 2015, 159).
161 The expense factor will be discussed below.
162 For the use of the camel in ancient Egypt for transport or riding animal see Köpp-Junk 2015, 112–116, 171–173.
163 Ripinski 1985, 140; Klein 1988, 53.
164 Having a closer look to evidences in the farer and closer surroundings of Egypt, it is to state that single discoveries from the 4th millennium BC are known as from Anau in Turkmenistan in central Asia. From the end of the 3rd and the beginning of the 2nd millennium BC camel bones were found in Mohenjo Daro in modern Pakistan. In Mesopotamia there is textual evidence about 1060 BC from the so-called *broken obelisk* (Herles 2010, 127, 131). Camel riders are attested from Tell Halaf in Syria about 900 BC and from Ninive dating to the 7th century BC (Boroffka 2004, fig. 12, 13). Nevertheless, an accumulation of evidence is to notice in the 1st millennium BC.
165 Köpp-Junk 2015, 112–117; 171–173.
166 Bagnall 1985, 3. Two papyri of the archive refer to large quantities of camels (P. Lond. VII 2179 (sixty camels), P. Cair. Zen. V 59835 (eighty camels)).
167 Bagnall 1985, 3–4.
168 Peacock and Maxfield 2001, Table 9.3.
169 Junge 1999, 315–316; Janssen 1975, 510–515.
170 Janssen 1975, 167–173, 175; Helck 1975, 272; Hofmann 1989, 52; Bagnall 1993, 38.
171 Bagnall 1985, 5–6.
172 Neither in the Graeco-Roman period (Bagnall 1985, 5) nor in earlier times.
173 Janssen 1975, 167–173.

wagons and carts as the modes of transport with the highest costs, followed by camels. The cheapest one is the donkey.[174]

Thus, the donkey was the most advantageous mode of transport, relatively inexpensive to buy and maintain as well as easily available, whereas it can be suggested that only a few carts and wagons existed in Egypt and that people had, therefore, a rather limited access to them.

For the chariot the situation is quite different. As stated above, it is attested quite frequently, although one might assume that the practical obstacles apply of course to all wheeled vehicles. Indeed it is the case, but on a very different scale. At high speed, narrow wheels do not sink as much into the sand. Moreover, in comparison to chariots, carts and wagons have a higher wheel load than chariots, which implies, that the load which operates on the wheel is higher and especially in soft sand the frictional resistance is higher as well. In case of a wagon the mass of the vehicle together with the transport load is transmitted by the four wheels to the subsoil, implying that every wheel has to carry one quarter of the total weight. Based on a total weight of 600 kg for the whole transport vehicle it means 150 kg for every wheel, but in case of a chariot, weighing only about 30 kg, it is only 15 kg per wheel. This means that much more power is necessary to move carts and wagons, especially on sandy or wet ground. Therefore the use of chariots is clearly less problematic on such subsoil than that of heavy carts and wagons.

The chariot was a very exclusive and luxurious prestige object and status symbol, identifying its possessor as a member of the elite.[175] Its adoption proceeded swiftly and it was established rapidly. Even though there was no need for wagons, there obviously was an urgent one for chariots. The quick adoption was not at least supported by the very high level of skills of Egyptian artisans in wood- and metalworking as well as leather production. Furthermore, other factors were the different areas of application of wagons and chariots as well as their disparities in weight and speed. Whereas wagons and carts were heavy, slow vehicles used for transport, chariots were very light and fast und functioned as a mode of locomotion in the leisure segment, sports, or warfare. After their relatively quick adoption, chariots were used in Egypt for about 1500 years. The last textual proof for chariots in Egypt dates to 41 BC.[176]

Concerning the circle of users it is to state that since the beginning the chariot was an elite vehicle, it was never a vehicle of people from the middle class. Therefore, the expense factor for purchase and maintenance was not relevant. The chariot cost a small fortune, namely eight deben of silver, with three deben for the pole and five for the body.[177]

Besides that, the chariot is the very first vehicle making a very high speed possible, which was never available before. Information regarding the speed of overland travel is seldom provided in ancient Egyptian material. By looking at similar means of transportation and locomotion known from the Middle Ages, the modern era, and from modern practical experiments, the ancient Egyptian travelling speed can be approximately calculated.[178] The speed of Egyptian carts, wagons, and sledges can generally be estimated to be about 3 km/h, of donkeys and carrying chairs 4–6 km/h. By foot, an average traveller achieves the same speed.[179] On horseback, up to 4–7 km/h could be reached at walking pace, and 45–52 km/h at full gallop.[180] A modern experiment with a replica of an Egyptian chariot gave a speed of 38 km/h over a distance of 1000 m.[181] It is, therefore, realistic to suppose a maximum speed of about 40 km/h for Egyptian chariots. It becomes apparent that with the introduction of the horse in Dynasty 13 and the chariot in Dynasty 17 a new dimension of speed became available. Before that, the speed of donkeys and travelling by foot was more or less equally slow. Considering a distance of 200 km, the differences are even clear: On foot, by donkey or by palanquin carried by persons or donkeys, about 5-13 days were required, whereas on horseback or by chariot only 4–6 days were needed. Of course

174 Bagnall 1985, 5, referring to the Graeco-Roman period, but probably transferable to earlier times as well.

175 As stated above, the wagon now and then appears as depictions in elite tombs as well, but it is not restricted to this social class, since it is mentioned as a mundane mode of transport on the Gebel Barkal stela as well. Carts were not shown in high class contexts at all in ancient Egypt, but this may well be due to the very few evidences.

176 Stela of Pasheryenptah, high priest of Ptah, Saqqara, 41 BC; British Museum London, inventory number EA 886.

177 Papyrus Anastasi III 6, 7-8; Janssen 1975, 329.

178 In detail Köpp-Junk 2015, 289–302.

179 Ohler 1988, 141.

180 Junkelmann 1990, 46.

181 Spruytte 1977, 39.

this speed advantage was another very important factor which makes the chariot so very attractive, next to allowing the owner a very new form of personal mobility. Moreover, the chariot was of indispensable necessity in the military context, since all war opponents were likewise equipped with chariots.

As shown above, the delay of the introduction of wagons and carts to Egypt as well as their low use before the Graeco-Roman period is due to the geomorphological conditions, leading to a preference of the donkey as means of transport in everyday live. The fast introduction of the chariot is due to the high attractiveness within the elite. Moreover, the adoption of the chariot was a pressing need, being a military necessity.

6 Summary

The first wheeled objects in ancient Egypt were no carts or wagons, but a scaling ladder and a siege tower; the earliest wheeled vehicles were wagons, followed by chariots, and then by carts. Carts and wagons were only seldom used; instead, donkeys were favored for daily work, sledges for heavy transport. The earliest evidence of wheels in Egypt is comparatively late, namely in the 3rd millennium BC, whereas in Europe, Caucasus and Mesopotamia they already occur in the 4th millennium BC. The late and restricted use of wheeled vehicles in ancient Egypt is not a non-acceptance of the innovation wagon, but owed to the climatic and geomorphological basic requirements of the country.

In contrary to wagons, the innovation chariot was rapidly widespread in Egypt, and they are attested until the 1st century BC. Beyond their use in war, they were an essential means of locomotion for the elite. The horse was quickly established as well, and it is attested for pulling the chariot before it appears as mount; all in all riding is very seldom in pharaonic times. As with wagons, there is not much evidence for camels up to the end of the Late Period. Again, it is not a deliberate non-acceptance, but based on their different areas of use and practical aspects, since camels unfold their advantages especially in the desert, whereas, again, the donkey keeps its dominant position as a transport animal in the agricultural sector. The use of camels and wagons increased in Graeco-Roman Times without substituting the classic modes of transport sledge and donkey, but they extend the Egyptian traffic system.

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Martin Furholt

Innovations and Social Heterogeneity in Late Neolithic Europe

Summary

The time period of the 4th and 3rd millennia BC in Europe is extraordinarily impacted by innovations like the wagon, the plough, the use of animal traction. In this paper, the concept of innovation will be discussed from a pragmatic perspective with regards to their social conditions and consequences. I will argue that the rate of innovation is linked to the degree of cultural heterogeneity, and that, due to a rising mobility of individuals and a widening of networks, the large-scale archaeological units of the 3rd millennium are to be seen as examples of both innovative and multicultural social units. During this period innovative practices increasingly permeated rising areas of social reality, starting from subsistence and transport, later reaching social relations and cosmology.

Keywords: innovation; technology; late Neolithic Europe; cultural diversity; transregional networks

Der Zeitraum des 4. und 3. Jahrtausends v. Chr. ist in Europa geprägt von Innovationen wie dem Wagen, dem Pflug und dem Einsatz von Zugtieren. In diesem Beitrag wird der Begriff der Innovation und ihre sozialen Konsequenzen aus pragmatischer Perspektive diskutiert und argumentiert, dass die Innovationsrate mit dem Grad der kulturellen Heterogenität zusammenhängt und dass aufgrund der steigenden Mobilität und der Ausweitung von Netzwerken die großen archäologischen Einheiten des 3. Jahrtausends als Beispiele für innovative und multikulturelle soziale Einheiten zu sehen sind. In diesem Zeitraum durchdrangen innovative Praktiken zunehmend aufstrebende Bereiche der sozialen Wirklichkeit, angefangen von der Subsistenz- und Verkehrswelt bis hin zu den sozialen Beziehungen und der Kosmologie.

Keywords: Innovation; Technologie; Europa im Spätneolithikum; kulturelle Vielfalt; transregionale Netzwerke

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1 Introduction

In the archaeological discussions surrounding the late 4th and early 3rd millennium in Europe, the concept of innovation is very broadly and extensively applied.[1] In Andrew Sherratts tradition, the 4th millennium is seen as a period of especially marked technological innovations, featuring the wheel, wagon and animal traction, the plough, and possibly the woolly sheep. [2] The early third millennium however could, by contrast, be seen as a period of social innovations,[3] namely new burial rites, the innovation of Europe-wide, trans-regional networks, as connected to the Yamnaya[4], Corded Ware[5] and Bell Beaker[6] phenomena, in the latter two cases connected to a set of distinct and emblemic ceramic vessel types.

At first sight it seems very tempting to go deeper into this chronological succession of two seemingly very different kinds of innovation complexes, as one could, again very much in Sherratts spirit, also argue for a causal link between the earlier 'technological' and the later 'social' innovations, by giving the former agency for fundamentally changing social relations. Certainly the temporal succession between Sherratts "Secondary Products Revolution" and the emergence of Corded Ware and Bell Beakers is an interesting point, but before going deeper into this discussion, some terminological issues have to be clarified. It actually seems very hard to pin down a real difference between these two supposed types of innovation. In fact, the distinction between 'technological innovations' and 'social innovations' is, I will argue, misleading. To clarify this point, I will discuss the concepts of technology and innovation.

2 Definitions: technology and innovation

2.1 The concept of technology

In this paper, I use a pragmatic starting point. In this tradition, Werner Rammert defines technology as any

> [...] artificially arranged device, that by virtue of their form, function and fixation to a carrier medium yields a desired effect in a reliable and enduring way.[7]

This is arguably a rather broad definition of technology, and it includes a broad array of phenomena. It describes, for instance, a machine, an instrument, or a tool, that can be used for a specific purpose. If we think, as one example, of a hammer that can be used to drive a nail into a piece of wood, this is clearly a technology in Rammerts sense. Thinking about this example, it does however become clear, that the hammer by itself is not a technology, but the hammering as a practical act. It follows from the pragmatic logic that a technology cannot be a material thing by itself. A material thing can only become part of a technology, if it is part of some kind of (clearly defined) practical happening, which is used by some actor to achieve the 'desired goal'. A technology thus is always a procedure, and in our example the technology is the hammering, which is connected to a material carrier medium, the hammer. What is more, within the hammering technology, the hammer is not the only material carrier medium, but it includes a person's arm holding it and performing a clearly defined movement, which is a crucial part of the technology. Thus this hammering technology is a combination of procedures and material carrier media. These procedures and carrier media show a specific arrangement, which together constitute the technology.

In the same way as with the hammering, Rammerts definition also includes phenomena, which would not always be designated as technologies in the colloquial use of the word. For example, the use of language is well described as an artificially arranged device, that is connected to material carrier media (vocal cords, mouth, tongue, sounds, gestures), yielding a desired effect in a reliable and enduring way. The same can be said for a religious ritual, that is normally in the same way directed towards a desired effect, or several effects. Norms of behaviour, standardized, social practices can also be

1 E.g. Bakker et al. 1999; Bakker 2004; Maran 2004; Johannsen and Laursen 2010.
2 Sherratt 1981.
3 Strahm 2002.
4 Harrison and Heyd 2007.
5 Furholt 2014.
6 Vander Linden 2006.
7 Rammert 2007, translation by author.

described as technologies facilitating, or even enabling social interaction and communication.

One could, I believe, try to argue to distinguish social technologies as a special type of technology separated from apparatus-based, or tool-based technologies. However, if one tries to clearly define this type, no real distinctive trait can be pinned down. Every technology is practically influenced by and part of social relations, and thus there cannot be something like a non-social technology. That is true for the hammering, which is a technology that has to be achieved by social learning, and for language-use, which may be performed in total solitude, but whose use must necessarily be enabled through social learning. In situations of social practice, both the hammering and talking are potentially part of social relations. To believe that hammering will not affect other actors than the hammerer and the nail, means to claim that in the same way a person 'speaking to himself' will not affect the people around the speaker.

Still, one might want to claim, hammering is clearly distinguished from speaking by the presence of a specialised solid, durable artefact, the hammer, which has a more enduring physical presence than a spoken word. This is surely a factor worth investigating. Is a more useful distinction that between apparatus-based and procedure-based technologies, the latter having a more direct social impact? However, the presence or absence of such a specific tool or apparatus does not tell us anything about the social base or impact of the technology. Using the dichotomy of social vs. apparatus-based technologies clearly makes no sense, as a telephone, the prototype social technology, would actually be classified as an apparatus-based technology. And also, why would the solidity of a tool or apparatus make such a fundamental difference? Is a spoken word not a physical thing? Where are the limits of its durability, or its solidity for that matter? Do the sound waves not materially alter the in-ear membrane the person hearing the word?

We can turn and twist the arguments as much as we want, but we will always come to the conclusion that all technologies are a combination of socially learned and arranged procedures, or practices, and artificially arranged material devices, whose use will potentially be determined by social factors, and will potentially have social consequences. The only useful distinction might be that for some technologies, solid, materially clearly bounded physical things are used, for others not. But the latter actually is very much reduced to speaking and the majority of gestures.

2.2 The concept of innovation

The concept of innovation is a comparably complex one. It is most widely used in economics, and following the classic definition by Joseph Schumpeter, an innovation is

> […] the doing of new things or the doing of things that are already being done in a new way.[8]

This is a perfectly pragmatic definition, but also a very broad one. So for such a concept to have any analytical value, it must be connected to an aspect of scale. Such a new doing or new way of doing must in a way have a notable effect, mostly, when we talk about innovations, we mean some more significant "changes of direction" of practices caused by this new way of doing things.[9] It is important to note that Schumpeters definition does not include a notion of 'optimising' of 'improving' something, as is often included in our colloquial use of the innovation term. The concept of improvement is very difficult to apply to social relations, as it would involve a number of normative judgements that are hard to justify. It is in this sense, that the original definition of Schumpeter omits such a notion and refers to 'a new thing,' not so much a 'better' or 'more efficient' thing.

To separate social innovations from technological innovations, as it is commonly done, brings with it the same conceptual turmoil as the definition of 'social technologies.' If an innovation is the 'doing' of a new thing, or of a known thing in a new way, there cannot be a distinction between 'immaterial innovations' and 'material innovations,' as often attempted.[10] 'Doing' something is per definition always a materially located phenomenon. Thus, as it is the case with technologies, an innovation is

8 Schumpeter 1947, 151.
9 Zapf 1989, 177.
10 As in the statement "[…] technological innovations are material, social innovations immaterial, or abstract", see Zapf 1989; also Gillwald 2000.

always a combination of something social, or 'immaterial' and something material (as reflected in Rammerts and Schumpeters definitions), but as it is always –per definition a combination of the two, this 'immaterial' is actually non-existant in isolation. This 'immaterial' component of a an innovation only exists when materialised in the course of such a 'combination' with something material, the social component of a technology or innovation is always a materialised phenomenon. A 'technological innovation' is always also a 'social innovation', and a 'social innovation' always involves technologies in the way they have been defined above.

3 Socio-technological innovations

So talking about innovations, they are by definition always 'socio-technological'. Trying to separate these two aspects of innovations is not in any way productive. Also the distinction between *product* innovations and *process* innovations does not capture the difference between those innovations appearing in the 4th millennium and those in the 3rd millennium. For example, though the wagon is clearly a *product*, its use, and thus its innovative nature can only be realised if combined with a number of *process* innovations, for example the use of animal traction, the training of those animals, etc. In the same way, changes in burial rituals in the 3rd millennium could be seen as a *process* innovation, but it is similarly represented by *product* innovations – burial mounds, wooden cists, etc. – as the use of a wagon is connected to the wheel, wagon, axel, and so on. There is no fundamental difference between innovations in the 4th millennium and those in the 3rd, all of them being both social and technological. I will thus rather apply a more schematic classification, speaking of two complexes of innovation, the first, innovation complex 1, dating in the second half of the 4th millennium BC, and the second, innovation complex 2, in the early 3rd millennium (see Fig. 1).

Thus, the difference between these two complexes is not to be looked for in the nature of innovations, because it is impossible to convincingly identify such differences, but in the context, the social sphere they actually affect. 4th millennium complex 1 innovations concentrate on the realm of subsistence, economy and transport, while 3rd millennium complex 2 innovations affected cosmology, social relations, social identities and interregional interaction. This surely is a significant differentiation, but as yet this assessment remains a purely descriptive one. In order to have any scientific value, we need to further explore the relation between innovations and their social contexts. Doing this, I will be interested both in the social conditions providing the possibilities to innovate, and the consequences such innovations might have had on these respective social spheres. Pragmatic theory will provide the basis for this investigation.

3.1 Innovation and social consequences: a pragmatic view

In the pragmatic tradition, innovations have been especially discussed in relation to their practical consequences for practices and beliefs. Already Ch. S. Peirce emphasised this point, more implicitly, when he described humans as enmeshed in a system of 'beliefs'.[11] Pragmatically, beliefs are held because they – being based on memorised practical experiences – provide guidelines for practice. A belief is found to hold true, as long as new practical experiences can be brought into accord with them, and the actions taken based on these beliefs have satisfying results, they 'work'.

Yet people, Peirce argues, tend to cling to their beliefs, even if new experiences start to challenge them, cast 'doubt' on their feasablility as guidelines of practice in the world. Only if the contradictions between these guidelines of action get too big, these 'beliefs' and their feasibility practically fail, or cause too much trouble, will people be forced to change these beliefs. This appears like a good way to define an innovation, namely as the point where old beliefs are changed after a period of growing 'doubts' introduced through changing realities, be it the introduction of a new thing, or machine, environmental change, changes in social relations etc.

In this tradition, it becomes more important to emphasise the social consequences of innovations as a disturbance of routines, rather than as a kind of improvement, as the colloquial use of the term implies. But how do such disturbances of routines occur in the first place?

11 Peirce 1877.

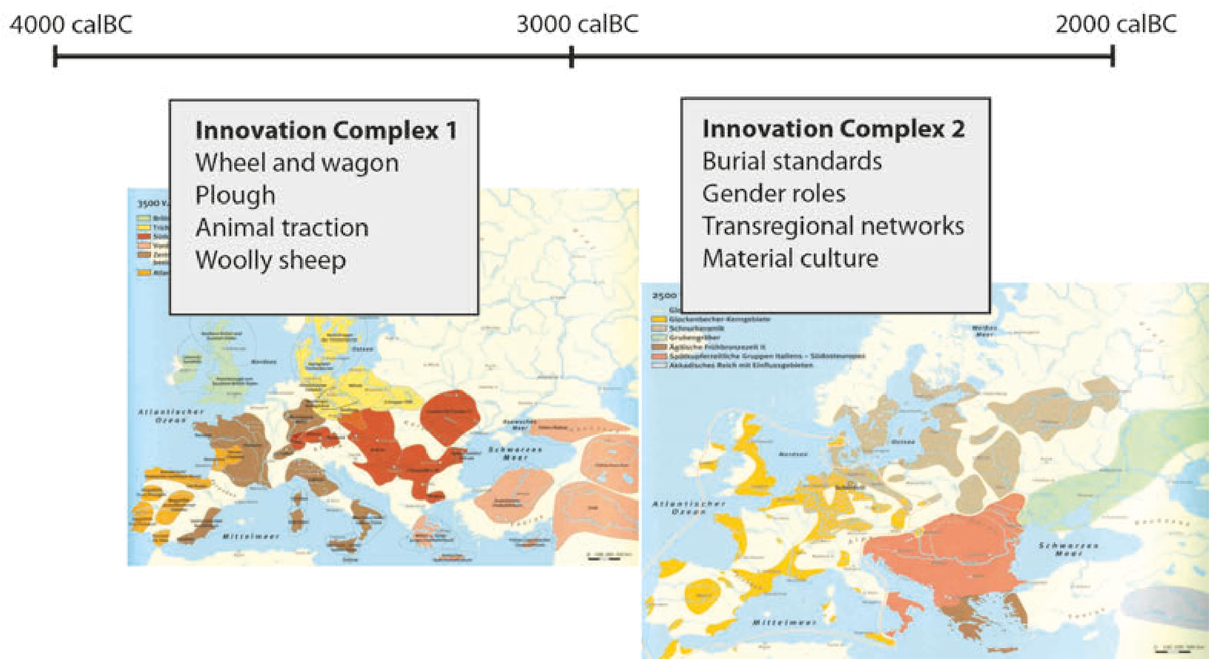

Fig. 1 Tentative classification of two innovation complexes dating in the mid 4th and early 3rd millennia BC, connected to archaeological classification units of different spatial reach.

By what factors are they furthered, or hindered? One important aspect that influences the likelihood of innovation is, I believe, to be found in the social configuration of a group, in the shape of the social relations.

More recently, the economist Bart Noteboom applied a pragmatic perspective on the conditions of innovation.[12] In his view, a pre-requisite for an innovation to be established is the existence of *cognitive distances* between interacting individuals. Culturally too homogenous people are not likely to innovate, or take up innovations, because they pertain rather similar ways of thinking. Thus the likelihood of new ideas is relatively small, whereas the presence of 'foreign' people, of individuals with different cultural backgrounds, different ways of acting and thinking creates conditions much more likely to break up the routines, to generate creativity and innovation. Thus, and that is a very important point for our archaeological inquiries, the rate of innovation is positively correlated to the degree of social or cultural diversity or heterogeneity within a group.

Following Noteboom, we should think of the relation of innovation and social/cultural diversity as a dialectic one. As I have argued, innovation requires social heterogeneity, but at the same time it also creates social heterogeneity, as it 'breaks the routines', as it disturbs and redefines existing social relations. It opens opportunities for new and deviating practices (i.e. innovations), it frees and mobilises the individual, which then again creates social, or cultural heterogeneity. It is in this sense possible to argue that innovation is both a trigger for and a result of social heterogeneity and mobility, when this is seen as a dialectic, self-enforcing process

3.2 Innovations and cultural heterogeneity

Speaking about social diversity and cultural heterogeneity as a pre-requisite for innovations, we have to discuss our view on the nature of Neolithic settlement communities. Saying heterogeneity means referring to social groups, for example settlement communities, of changing and unstable composition, where individuals, or small groups of people move in and out. This is by no means a problematic assumption, but strangely, dealing with the Neolithic period in Europe, there is a strong tendency to pre-suppose quite an opposite model. Without ever justifying this point, we mostly tend to think

12 Noteboom 2012.

of Neolithic communities as culturally and socially homogeneous, immobile groups of people, who for generations live together and intermarry with a few surrounding villages. This seems very much like our romantic ideas about a 'traditional' rural peasant life in premodern Europe.[13] This stereotype also includes the notion of these peasants as conservative and uncreative people, who very much cling to their traditional habits. Taking a self-critical position, it seems obvious, yet alarming, to what degree our ideas about Neolithic social organisation and everyday life is influenced by our perception of Late Medieval village life in a repressive feudal state system with institutionalised government, legal system and religion. It should be mentioned, that this very stereotype might be far from most Late Medieval realities.[14] Nevertheless, such a kind of society surely has existed at some point, and our view of it, as described, correspond very well to Notebooms notion of homogeneous and thus rather non-innovative people. It is however doubtful if such a model is the right premise, or baseline model, when thinking about Neolithic communities. In the anthropological literature, unsurprisingly, very different models of social organisation have been described. Here, I find it useful to refer to Hillier and Hansens[15] distinction between Correspondence and Non-Correspondence Systems of socio-spatial organisation.[16] Correspondence Systems are communities, which show a correspondence between residence and social contacts, that is communities where most social contacts are held with the direct neighbours or inhabitants of the same villages.[17] Thus, our 'traditional' – or let's say, late Medieval European peasant communities are classic examples of such a correspondence system. Non-correspondence systems, however, describe the opposite end of the spectrum, referring to communities where most social relations are held to nonlocal people. This system has been described for the anthropological examples of the Tallensi in Ghana, the Ndembu in Zambia and the Hopi in Arizona plus several modern examples.[18] It is also obvious that our postmodern towns are very much to be characterised as non-correspondence systems.

Non-correspondence systems, Ferguson argues, require

> [...] an openness in the interaction of both inhabitants and non-inhabitants coupled with a relatively weak and diffused local organisation.[19]

And he continues:

> Such societies tend to be globally strong, not so much locally, so at the settlement level, rules, social institutions are weaker, boundaries less defined.[20]

They require a higher degree of mobilities on the individual level, in order to uphold these non-local social bonds. As a result, these settlement groups are culturally heterogeneous, and empirically, often rather shortlived.[21] With the late Neolithic settlement material in mind, there is actually no reason to believe they should be seen as correspondence systems. Surely, there are gradual differences, but especially larger archaeological units are unthinkable in terms of a correspondence system.

To take this one step further, in a context like 4th and 3rd millennium Europe, it is very likely that the formation of larger regions with similar material culture, as it is for example represented by Yamnaya, Corded Ware or Bell Beakers, must be connected to increasing human mobility. As there is no evidence for a considerable craft specialisation, and especially pottery is produced at a household or settlement level[22], and as pottery production is based on social learning and training between individual potters, an alignment or homogenisation of pottery between different settlement communities or even regions can only be explained by an exchange of people, by people actually spending a considerable amount of time in a site in order to learn the new style or technology, or to put it differently, it requires

13 Ebersbach 2010, 205.
14 Bauer and Matis 1988; Vassberg 1996.
15 Hillier and Hanson 1984.
16 See also Ebersbach 2010.
17 Hillier and Hanson 1984, 251–256.
18 Hillier and Hanson 1984, 242–254.
19 Ferguson 1996, 22.
20 Ferguson 1996, 22.
21 Ebersbach 2010.
22 Larsson 2009.

the integration of people with different social and cultural backgrounds into local communities. This means that a rising spatial extent of similarity in material culture requires the presence of more heterogeneous settlement communities. Although this seems counter-intuitive at first, I would argue that widespread homogeneity or uniformity of material culture is clearly connected to or even correlated with a marked social, or cultural heterogeneity at the local level, the level of the settlement community.[23] There is, thus, a connection between the widening of material culture distribution and the strength of non-correspondence systems, and also the likelihood for innovations.

The only alternative to this view is, in my opinion, the traditional culture-historical model deriving from a Kossinna-like spirit, that would envisage whole, culturally uniform settlement communities or even groups thereof moving from one to the other site. The archaeological evidence clearly does not point in this direction, as despite the presence of trans-regional similarities, there is also marked regional variation, if mostly overlooked,[24] and also such a model cannot explain why this relatively high degree of similarity in material culture is upheld over centuries.

3.3 Against a totalitarian view on the past

In spite of these objections, Late Neolithic archaeological units, like the Corded Ware are mostly still seen and referred to as connected to the presence of one, likewise homogenous social group, or alternatively explained by one single factor or trigger, be it a new economic system, a new ideology, etc.[25] This way of thinking repeats the main flaw of the old Kossinna-style culture-historian tradition, namely to confuse the unit of classification for the archaeological material with real social entities[26] This is clearly a *reification* of our archaeological material, or a *totalitarian perspective* on prehistoric societies. This notion of totalitarianism is widespread in archaeology and, generally, in recent political and social debates. Communities, 'cultures', 'religions', are seen as homogeneous, clearly bounded entities, and it is them who we give agency, rather than the individual persons involved. In recent political debates, especially in these times of crisis, this totalitarian thinking is re-emerging, as ethnic or religious identities and connected stereotypes have re-gained their dominant position, supressing diversity and individual multiplicity of identities. It is clearly no coincidence, that such a kind of totalitarian thinking is powerfully re-emerging on the back of aDNA analyses focussing on the late Neolithic.[27] This research has been, unfortunately so, read as a support for single, large-scale migration events of "the Yamnaya People" out of the Russian steppes, thus creating the "Corded Ware People".[28] Although the actual authors of these studies clearly apply more differentiated models and very different agendas from a molecular biological point of view, the popular communication of their results is often a catastrophy, as it reinforces the totalitarian view just discussed. From an anthropological perspective, it is a major mistake to take archaeological cultures as representations of biological populations, whose sets of haplotypes are then compared. It reproduces this totalitarian view and supports it through the authority of exact science. From an anthropological perspective, but also considering the wider, political implications, this continuation of totalitarian models is to be criticised.[29]

4 Conclusion: multiculturalism and innovation

Very much in contrast to such narratives, I propose that the development of the late 4th and 3rd millennium, the formation of larger widening networks of practices and material culture and the implementation and spread of a complex of innovations in connection to these networks, should be seen, as a process of cultural heterogenisation, which, in a self-enforcing dialectic relationship, reinforces creativity and innovation. Instead of a period of clearly bounded cultural groups interacting, we deal with marked phenomena of multiculturalism, and it is important to emphasise the creative and innovative power of cultural heterogeneity, individual mobility and mixing of populations.

23 Furholt 2018.
24 Furholt 2014.
25 See Furholt 2014.
26 See Wotzka 1993; Furholt 2014.
27 Brandt et al. 2013; Haak et al. 2015.
28 Barras 2015.
29 Müller 2013; Hofmann 2015.

4.1 The innovation process

In this specific historical process, – Europe in the 4th and 3rd millennium – we can, as argued above, observe a temporal succession from innovation complex 1, mostly affecting the spheres of subsistence economy and transport to innovation complex 2, affecting social relations, social roles and cosmology. Without claiming this to be a general rule, one could argue that – in this case – the earlier subsistence based technological innovations are more easily integrated into social contexts, which were, in the 4th millennium BC relatively bounded and homogeneous, a proposition in line with the generally smaller spatial extent of archaeological cultures. These comparably bounded homogeneous social groups would, following Noteboom, be less susceptible to innovations, less likely to innovate. It is however conceivable that subsistence-based innovations might be more readily taken on, for example in times of environmental stress, failing harvests and so on. Thus it is possible to argue that the spread of subsistence-based innovations require a lower degree of mobility between and cultural heterogeneity within settlement communities. Innovations affecting social relations and cosmology are, one could argue, much more dependent on a degree of creativity and dynamics of thinking, as would be more likely to occur in a more heterogeneous cultural setting, where habits are challenged and routines broken up. Those later innovations (of complex 2) then, materialising in new types of burials and Europe-wide interaction networks represented by Corded Ware and Bell Beakers, can be seen as a consequence of the earlier complex of innovations affecting subsistence practices. According to the dialectic model laid out above, this first complex of innovations must have – by virtue of their ability to break routines and challenge habits – paved the way for the second complex (Fig. 1) that more directly and severely changed social relations and cosmological beliefs. The rapid and continuous spread of these latter innovations was in turn enabled through the very heterogenisation of local communities and the increase in mobility caused by these innovative disruptures in these non-correspondence systems.

The notion of a connection between local cultural heterogeneity and regional similarity of material culture is, arguably as yet a mostly theoretical statement, which might be judged by its general plausibility. Looking into the empirical material available however, isotope data and aDNA evidence does not contradict such a view. Evidence fit to compare individuals from the same settlement communities is methodologically complicated, as most individuals sampled derive from graves, but Elin Fornander analysed stable isotopes (C, N, S, Sr) from southern Swedish Battle Axe burials and showed a marked diversity both in nutrition and in mobility patterns.[30] For the Austrian Traisen valley, Daniela Kern and colleagues could demonstrate clear differences between mobility patterns (assessed by Sr-Isotopes) of distinct grave groups on the burial grounds of Franzhausen.[31] Price et al. found a remarkably high degree of mobile individuals (51 out of 81) in a sample of Bell Beaker Burials from south-eastern Central Europe.[32] Also, we could take the clear increase in mitrochondrial haplotypes in the archaeological sample towards the end of the 4th millennium BC[33] as evidence for a more visible mixing of different biological lineages, and thus ultimately as an indication for rising social heterogeneity, a higher degree of cultural mixing.

Still, clearly more empirical data needs to be assessed in order to justify this theoretical claim. But I still find it important to make the point that instead of using the molecular biological data to reproduce old prejudices of migrating peoples from the East, we could use this same data to discuss a more differentiated picture, where the individual is not subdued to totalitarian cultural entities, but may be seen as a dynamic actor with individual histories and multiple identities, and where innovation and change are seen in relation to social practices and social interaction, phenomena in their complicated, conflicting, often contradictive and dynamic realities. This discussion will be more difficult and complex than neat stories about mass migrations, but I believe we have the responsibility as scientists not to contribute to a renaissance of totalitarian myths.

30 Fornander 2013.
31 Kern 2012; Irrgeher et al. 2012.
32 Price et al. 2004
33 E.g. Brandt et al. 2013.

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1 This Figure was created on the basis of Müller 2010, figs. 75 and 79.

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Cross-Crafting and Its Meaning for Innovation in the Late Bronze Age Context of Tiryns, Greece

Summary

Studying single artefact classes can result in unsatisfactory past narratives. Investigating multiple materials stimulates a broader understanding about the nature of change and innovation. Combining *chaîne opératoire*, cross-craft interaction and agency approaches may reveal dynamic overlapping social networks of people that may adopt, adapt or reject the production and consumption of goods, and shows the embeddedness of different social groups in given communities through daily activities. Changes in acquisition, production and consumption processes affect the social biographies of items and people that were co-dependent. Case studies illustrate the context-specific diversity in technological changes and innovations influencing both outcome and cause for socio-political, economic and cultural changes.

Keywords: combined approaches; *chaîne opératoire*; cross-craft interaction; agency theory; workshop contexts; architectural energetics; Late Bronze Age Tiryns; Greece

Die Untersuchung einzelner Artefaktklassen kann zu unbefriedigenden Narrativen über die Vergangenheit führen. Die Untersuchung mehrerer Materialien regt ein breiteres Verständnis über die Natur von Veränderung und Innovation an. Die Kombination von *chaîne opératoire*, handwerksübergreifender Interaktion und *Agency*-Ansätzen kann dynamische, sich überschneidende soziale Netzwerke von Menschen aufdecken, die die Produktion und den Konsum von Gütern aneignen, anpassen oder ablehnen können, und zeigt die Einbettung verschiedener sozialer Gruppen in bestimmte Gemeinschaften durch tägliche Aktivitäten. Veränderungen in den Erwerbs-, Produktions- und Konsumprozessen wirken sich auf die sozialen Biografien von Gegenständen und Menschen aus, die voneinander abhängig waren. Fallstudien veranschaulichen die kontextspezifische Vielfalt an technologischen Veränderungen und Innovationen, die sowohl Ergebnis als auch Ursache für soziopolitische, wirtschaftliche und kulturelle Veränderungen sind.

Keywords: kombinierte Ansätze; *chaîne opératoire*; handwerksübergreifende Interaktion; *agency*-Theorie; Werkstatt-Kontexte; architektonische Energetik; spätbronzezeitliche Tiryns; Griechenland

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1 Introduction

Research in the last decades shows that the over-reliance on single classes of archaeological artefacts, such as pottery or metals or buildings, may result in reconstructions of the past that may be unsatisfactory.[1] While such analytical isolation has been addressed in many recent studies, there is potentially also a cost to pay in the form of less specialization. Seeing this more positively, however, a much broader understanding about the nature of change and innovation in certain contexts may be revealed instead as many papers showed throughout this conference. People shape materials which, in turn, shape people, and in doing so, it is a fundamental characteristic of people to communicate about their activities among each other, whether tacitly (e.g. apprentices observing experienced workers), or otherwise.[2] Thus sharing experiences, knowledge, skills and expertise is part and parcel of being, working and making things together.[3]

It has recently been suggested that not abundance but scarcity of goods may result in creativity because scarcity may force people to try out something new with the little resources available.[4] Change, and thus potentially innovation, may thus result from scarcity, people's resilience to such difficulties and people's creative reactions and adaptation to such situations. Scarcity may manifest itself in various forms: the decrease or lack of raw materials, changing access routes to these which are potentially influenced by socio-political changes,[5] lack of labour input to transform these raw materials into finished items, and the lack of knowledge and skills required to produce and consume. Therefore, changes in production processes that result from scarcity affect the social biographies of the items themselves and the associated biographies of people with whom these items were enmeshed or cemented together.[6] Equally, innovations or being creative seems to be "[…] a process of discovery and having ideas through the process of making".[7] For Gauntlett, the concept of 'social capital' is 'the community glue made up of friendly connections with others'[8] in a system where value is embedded in having social connections and collaborative projects in everyday life. As such, socio-technical changes and, in extension, innovations are connected to cultural, economic and socio-political changes which are very much context-specific, as my two case studies aim to illustrate.

Through these two case studies I aim to address the following questions:

1. What were the technical and possibly the socio-political mechanisms that were responsible for certain innovative production and consumption modes present in Late Bronze Age Tiryns?

2. To what degree does technical change and innovation influence society, or should we see it the other way around, or both? And what are the driving motors for these?

In attempting to answer these questions, the rest of the paper is divided in two parts: the first forms the basis of the work carried out under the Tracing Network project.[9] The second is based on the preliminary findings of the Tiryns-based architectural energetics project.[10]

In order, then, to study the complex technical and social patterns produced and lived by people in a 2nd millennium BC context, a combination of different approaches may allow us to reveal *multiple* activities and social practices that people were involved in throughout their lives with each other and their surroundings. Combining the *chaîne opératoire*[11] and cross-craft interaction[12] methods with an agency approach[13] has been found helpful[14] in trying to understand and grasp the

1 Nakou 2007, 224.
2 Lancy 2012, 114–119.
3 Sennet 2008, 7; Gauntlett 2011, 14–17.
4 Brysbaert 2017.
5 See Sherratt 2001 on changing access and trade routes in the Argolid during the last phase of the LBA; also Cline 2014 in more general terms for the whole East Mediterranean and its wider issues
6 Appadurai 1986; also Nakou 2007, 235.
7 Gauntlett 2011, 4.
8 Gauntlett 2011, 21.
9 https://www.universiteitleiden.nl/en/research/research-projects/archaeology/cross-craft-interaction-in-the-cross-cultural-context-of-the-late-bronze-age-east-mediterranean (last accessed 02/01/2021).
10 Its pilot study 'Architecture on the Move' was funded (2013–2014) by a Senior Marie-Curie – Gerda Henkel Research Fellowship. Built on this pilot study, the author's 'SetinSTONE' project on architectural energetics in the Argolid has received an ERC consolidator grant (2015–2020).
11 Leroi-Gourhan 1943–1945; Dobres 2000 among many others.
12 McGovern 1989.
13 E.g. Dobres 2000 among many others but specifically relating to technologies.
14 Combined: Brysbaert 2007, Brysbaert 2011.

socio-technical processes through which people engage with each other and with materials, and how such processes bring about changes, and innovative ideas, production and consumption practices. Several recent studies could illustrate that combining the *chaîne opératoire* and cross-craft interaction methods with agency theory may reveal the dynamic social networks of people that are at the basis of adopting, rejecting and abandoning the production and consumption of certain goods in specific contexts.[15] Such combined approaches also allow to interlink different social groups that build up the whole of any given community: skilled and unskilled workers, merchants, farmers, elites, and religious staff, just to name a few. Moreover, these approaches also bring to the foreground that such social groups are often our own singular understanding and categories of social, labour or craft divisions, which we may need to revaluate in light of new findings.

2 The Tracing Networks Project

The Tiryns project[16] of the Tracing Networks programme finished the study of four Late Bronze Age workshops (case studies I–IV) in 2014: three in the Lower Citadel and one in the Lower Town North East.

These were chosen on purpose because their overlapping occupations could reveal the continuity, introduction or disappearance of various crafts and their inherent social practices across both palatial and post-palatial periods,[17] each with their own socio-political circumstances. While studying the materials for this project, jointly conducted with Melissa Vetters, it was the recurrence of certain 'exotic' items in three of our four case studies that begged for specific attention. However, in order to understand the diachronic change in usage and possible meanings of these items, they needed to be discussed in relation to the other finds from the same stratigraphic contexts.[18] Two such studies have now been published so contextual details are, therefore, not repeated here.[19]

This paper focuses on the wall brackets as one such an exotic type of object found at Tiryns.[20] These typically hand-formed ceramic objects with cup and back plate were found in three of our Tirynthian case studies (I, III, IV) spanning both palatial and post-palatial phases.[21] Panitz-Cohen described the Cypriot and Levantine contexts in which these items were found, as domestic, while the objects themselves were likely employed for cultic practices rather than for other more mundane uses,[22] at least initially. They have been identified as incense burners and lamps; most of those investigated by her did not bare burning traces while Rahmstorf and Shlipphak both noted several examples with burning traces. All three authors noted ancient repairs or their reuse and understood these as signs of their intrinsic value or symbolic meaning.[23] Most recently, over 500 complete and fragmentary wall brackets dating from the LBA to early IA have been recorded and discussed by L. Rahmstorf. The majority were found on Cyprus, followed by plenty in the Levant. Based on excavated and published data, they have been considered a Cypriot, or possibly Levantine, object that travelled as cargo spacers or as a personal, likely ritual, object into the Aegean and the Levant. However, they were also locally produced and used in ritual practices in domestic, mortuary and sanctuary contexts.[24]

From the 13th c. BC workshop at Tiryns lower citadel South West, we examined every minute object that was found in two subsequent phases of the LH IIIB Middle building (case study I). Among these, we re-examined a wall bracket fragment (TN 708, see Fig. 2)[25] of which Rahmstorf suggested that it was of foreign, likely Cypriot, make together with two other fragments

15 Tsoraki 2011; Margomenou and Roumpou 2011; contributions in Rebay-Salisbury, Brysbaert, and Foxhall 2014.

16 https://www.universiteitleiden.nl/en/research/research-projects/archaeology/cross-craft-interaction-in-the-cross-cultural-context-of-the-late-bronze-age-east-mediterranean (last accessed 02.01.2021)

17 Details on context in Maran 2008; Maran 2006; Kilian 1988; on pottery studies of these areas see Stockhammer 2008 for Tiryns Unterstadt NW; Wirhova-in progress for the northern tip of the Lower Citadel.

18 Compare for a similar approach by Heymans and Van Wijngaarden 2011.

19 Brysbaert and Vetters 2010; Brysbaert and Vetters 2013; Brysbaert and Vetters 2015;

20 Rahmstorf 2008, 2014.

21 For comprehensive overviews of this type of object, both in clay and in metal, see Schlipphak 2001; Panitz-Cohen 2006; Rahmstorf 2014.

22 Panitz-Cohen 2006, 616.

23 Panitz-Cohen 2006, 616–617; Schlipphak 2001, 46; Rahmstorf 2014 193.

24 Most recent overview in Rahmstorf 2014.

25 TN refers to our Tracing Networks database entries in which each studied item has a unique TN number.

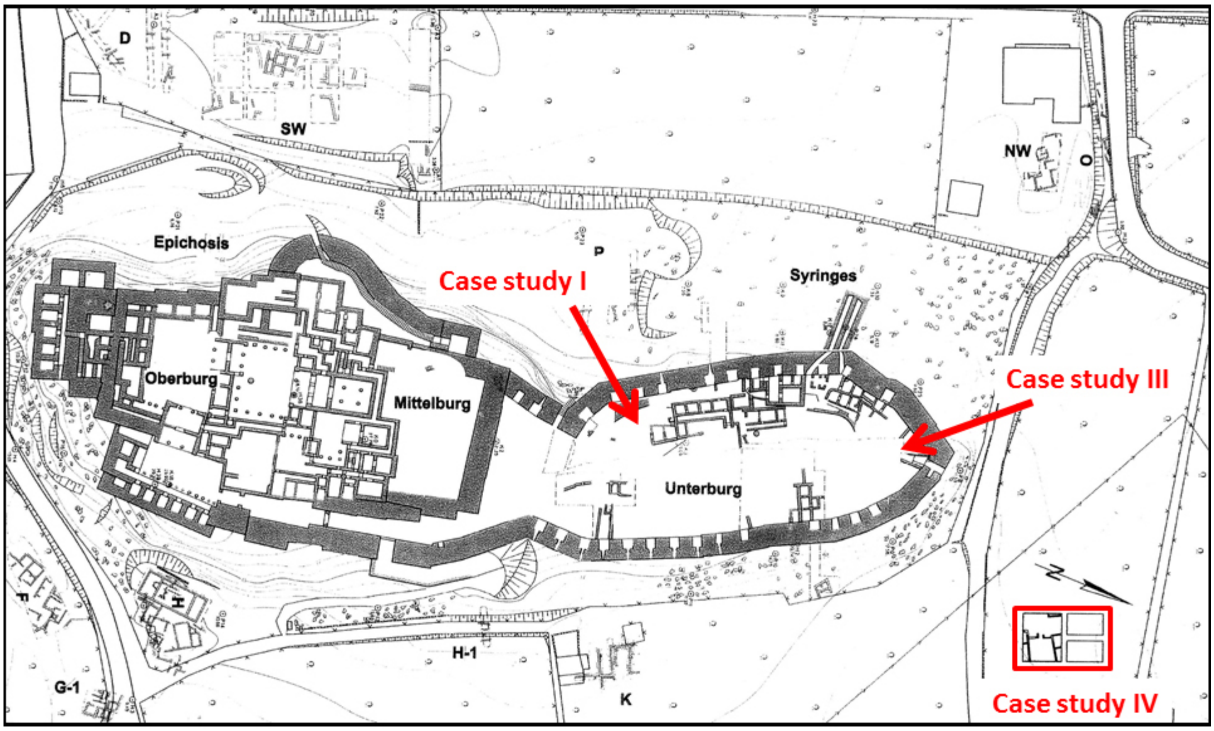

Fig. 1 Map of the Tiryns citadel, indicating case studies I, III, IV.

from the same general context (TN 643, TN 644) which clearly had a very different clay mixture and decorative patterns.[26] A hole was drilled in the back plate during the use-life of one such a wall bracket fragment (TN 643, see Fig. 3).

Contextually, these objects were found in association with several finds and features that suggest a metallurgical workshop where scrap bronze was likely remolten to be casted in weapons such as javelin points.[27] A mould fragment, a furnace, crucible fragments next to glass beads, burnt plaster fragments, Egyptian blue lumps and a pestle with Egyptian Blue traces all represent the workshop activities to which these wall brackets seemed to have belonged. Interesting are the *chaînes opératoires* and cross-overs in production between the metal items, the Egyptian blue pigment, and the calcined plaster fragments. The cup of one of the wall brackets was found heavily burnt with soot all over its surface (TN 644, see Fig. 4a–b). It could have been burnt through contact with a strong fire or through being reused as a scoop, possibly to remove hot ashes from a fire place or hearth in the general area of the workshop located in the LH IIIB Middle Building[28], likely a non-ritual usage of the item. However, the further association of miniature vessels, figurine fragments and glass beads in the LH IIIB Middle Building indicate that cultic activities took place within the workshop, possibly asking for a successful charge and casting session.[29] The use of figurines and glass beads in ritual practices has also been noted on contemporary sites in the Argolid and is considered a local practice.[30] The wall brackets, having been interpreted as ritual paraphernalia in Cypriot and Levantine contexts, are, together with the torch holders and other foreign elements, indicative of a different presence of both production and consumption practices noted in this workshop and its vicinity, even though several of these wall brackets were made in local clays and styles (TN 643, TN 644 versus TN 708, see Figs. 2–4).[31]

26 Rahmstorf 2008, Rahmstorf 2014, 193; Brysbaert and Vetters 2013, 186.
27 Kilian 1988; Brysbaert and Vetters 2013, 185.
28 The wall brackets were found in the area south of the LH IIIB Middle Building and thus not immediately associated with the actual furnace in its Room 210.
29 Brysbaert and Vetters 2013.
30 Tzonou-Herbst 2002, 206–218.
31 On the likely imported wall bracket from Tiryns: Rahmstorf 2008, pl. 91; Rahmstorf 2014, 193; Brysbaert and Vetters 2013, 186, 188, Table 4.

Fig. 2 Wall bracket TN 708. Scale: 5cm.

Fig. 3 Wall bracket TN 643. Scale: 5cm

The area of case study III in the northern tip of the Lower Citadel featured two well preserved wall brackets (TN 22, see Fig. 5, TN 29) dating to the LH IIIB Final occupation of Building XI.[32]

These seemed locally made and found again in association with other foreign elements such as the faience rhyton fragments,[33] and an ivory rod with cuneiform writing on.[34] The ivory rod may well have been employed in rhabdomantic practices[35] and this places the wall brackets again in ritual contexts although no furnace, only a fireplace, was found in Room 78a of this Final palatial workshop.[36] Canaanite amphorae with in-

32 Maran 2008; Brysbaert and Vetters 2010.

33 Kostoula and Maran 2012.

34 Cohen, Maran, and Melissa 2010.

35 E.g. Weippert 2011 among others.

36 Maran 2008.

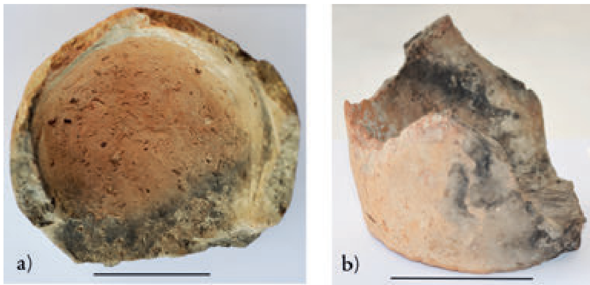

Fig. 4 Wall bracket TN 644. Scale: 5cm.

Fig. 5 Wall bracket TN 22. Scale: 5cm.

cised Cypro-Minoan writing[37] were found in the walkway outside Building XI. In the palatial workshop, gilding of several faience vessels made elsewhere may have taken place together with minor lead usage possibly relating to working with gold.[38] Lead working also took place in the post-palatial phase (LH IIIC Advanced) of this context,[39] but no wall brackets that belong undoubtedly to this phase were found here. None of the wall brackets found in Building XI show any trace of burning on the inside or the outside.

Finally, three fragments of one wall bracket (TN 957, see Fig. 6) were found in the post-palatial Lower Town North East,[40] our case study IV.

In the phase 2 occupation (LH IIIC Early) the burnt cup of the wall bracket was found near the hearth located in Room 8/00 while the two back plate fragments were found in the alley south of the room and were subsequently joined to the cup. This wall bracket probably broke during its use-life and once the useless back plate bits were tossed outside, the cup itself may have begun a second life as a scoop to clear out the hearth near which it was found, as scorching patterns on both in and outside seem to suggest.

Fig. 6 Wall bracket TN 957. Scale: 5cm.

3 The Architectural Energetics Project

While remaining in the Argolid, Greece, for the second case study, monumental architecture appears again in this region around the LH IIA period in the shape of tholos tombs, Mycenaean tombs built in dry stone work in the shape of a large beehive that are covered with an earth mound. The highest concentration and the largest ones known dotted the landscape around Mycenae from that time onwards.[41] The last two built in the region, the colossal so-called 'Treasury of Atreus' (see Fig. 7) and the

37 Hirschfeld 1996.
38 Mossman 2000, 91, on the use of lead in gold working.
39 Brysbaert and Vetters 2010.
40 Maran 2006.
41 Mylonas 1966.

'Tomb of Klytemnestra', were constructed during the era of the palatial administration of the 14th and 13th c. BC.

These tholos tombs have been studied extensively and especially their labour-intensive building was noted.[42] An abbreviated form of architectural energetics resulted in an idea of the scale of human input employed to construct these funerary monuments.[43] However, a full *chaîne opératoire* approach combined with data collection in the field is essential to obtain the most realistic human and animal labour cost figures. These may then lead to a more comprehensive understanding of the work *and* resources involved, and how these may have impacted on people's day-to-day activities and lives, especially in the last few decades of the 13th century BC where enormous building programmes took place in the Argolid region.[44]

Earlier on though, as was argued by Wright and Dabney in 1990,[45] it seems that around 1300 BC, the efforts that used to be employed in building the tholoi were diverted from 'an architecture for the dead' to 'an architecture for the living' whereby the emphasis moved from funerary monuments to palatial citadels and engineering works. It is that last half of the 13th century BC that thus witnessed an unseen building explosion in terms of the sheer amount of features and sizes of constructions such as the awe-evoking corbelled vaults at Tiryns's East and South Galleries (see Fig. 8), underground water facilities at Mycenae, Tiryns and Athens, citadel extensions with Cyclopean-style walls at Mycenae, Tiryns and Midea, a network of roads and bridges in the Argolid and beyond,[46] and engineering projects such as the still working Dam at Tiryns-Kofini.[47]

The architectural energetics project at Tiryns began in 2011, fieldwork tests were done in the autumn of 2013 and in the summer of 2014 the first fieldschool was held

Fig. 7 Wall bracket TN 957.

while collecting data around the section of the visitor's entrance, the Great Ramp and the Main Gate.[48] Without repeating data that is under publication elsewhere,[49] the important outcome of this test study demonstrated and confirmed the following factors:

1. Both local and non-local stones were employed in the construction of the various sections of the citadel complex at Tiryns over time.

The most local stone, the citadel outcrop itself, was used extensively but far from exclusively (see Fig. 9). This entails that transporting these often multi-tonne blocks[50] was economically reduced to anything from just getting it up in the wall (no transport, just hauling up) to potentially 50–100 m. The latter distances, even though short, do entail transport means of people, aided by oxen and wagons to bring anything above 100 kg to their precise location in the wall.

The non-local stone types came from various quarries,[51] most are located between 1 and 2 km distance

42 Mylonas 1966; Wright 1987; Cavanagh and Mee 1999.

43 E.g. Fitzsimons 2011.

44 E.g. Maran 2010. See now also Brysbaert 2020.

45 Dabney and Wright 1990.

46 Jansen 2002; Simpson and Hagel 2006.

47 Balcer 1974; Simpson and Hagel 2006; Maran 2010.

48 The fieldschool in the Spring of 2015 finished off what was started in 2014: area around the main Gate and Ramp, the East Galleries and the so-called 'Trigones' north of the Western Staircase on the west side of the citadel. These fieldschool campaigns provided, on the one hand, the Eforia of Nafplio the documentation which they can use for the ongoing anastylosis programme and provides us with data on the labour economics, one of the main goals of the SETinSTONE project.

49 Ann Brysbaert, Jari Pakkanen, Alkestis Papadimitriou, and Joseph Maran. "The 3D Documentation and Quantification of the Newly Excavated Area North of the Main Entrance and Great Ramp at Tiryns, Greece." In *Greek Building Projects. International Conference, Held at the Finnish Institute at Athens, May 22–24, 2014.* Ed. by J. Pakkanen. Helsinki: Foundation of the Finnish Institute in Athens (forthcoming).

50 Often well over 1 tonne, regularly up to 4–6 tonnes, and few weighed even more.

51 Varti-Matarangas, Matarangas, and Panagidis 2002: not all stones could be traced yet to their original extraction sources; see now also Brysbaert 2015b for a discussion on the stones themselves.

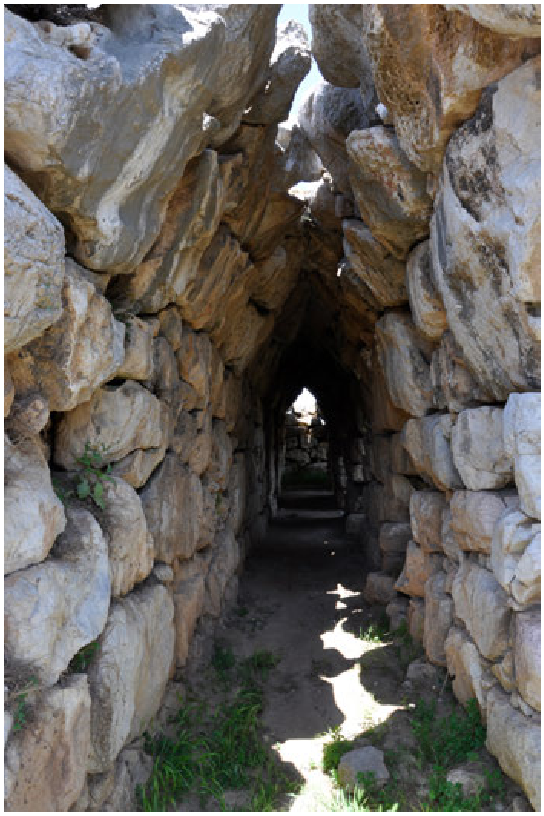

Fig. 8 Tiryns citadel's most iconic feature: East Galleries.

from the site while the conglomerate blocks and slabs sparingly used at Tiryns come from the region of Mycenae (c. 20 km away) (see Fig. 10). These stones, many of which weighing multiple tonnes, had to be transported to the site, costing human and animal labour time and efforts during which these resources could not be active elsewhere. Of interest is the fact that some of the stones from further afield, thus more costly to bring in, are not of the best quality so other factors in choosing these must have been decisive.[52]

2. While the common, but not only, understanding of the function of these citadels and their immense fortification walls has been in the direction of defense, it became quite clear from the initial calculations made, that the danger for which such walls were constructed, was not imminent since constructing even a very small section of the citadel took relatively long.

Fig. 9 Tiryns citadel outcrop with quarry bed cut lines.

Several parts of these citadels would have taken up several full years and during this time, the human and animal labour employed in these activities could not carry out simultaneously the much needed agricultural work to feed themselves and the overall population. If such construction activities took years to complete, other factors than enemy attack were motivators to construct at such a scale. Elements of status, power display and performance orchestrated by the palatial elites have been amply discussed for the Mycenaean contexts.[53] When Athens was trying to emphasize and therefore materialize their independence from Sparta in the aftermath of the second Persian War, Thucidides (1.90.3; 1.93.1–2) mentioned that the city wall of Athens, with a circumvention of c. 6 km, was erected in a matter of a few months by forcing everyone to contribute with any type of available stone for the socle, and mudbrick for the walls themselves. What is also important to take into account is not just the construction of the citadels, especially their expansions of the latter half of the 13th century BC, but also the fact that this went on in Mycenae, Tiryns and Midea more or less in the same few decades, and together with the construction of the two largest tholoi (see Fig. 7), the massive Dam, the road and bridge system and several other construction activities.[54] Some of these activities in fact contradict the purely defensive

52 Discussed in detail in Brysbaert 2015a.

53 E.g. Maran 2006; Maran 2012 in relation to Tiryns.

54 See now Brysbaert 2020 for details on how such building works could be combined with agricultural activities.

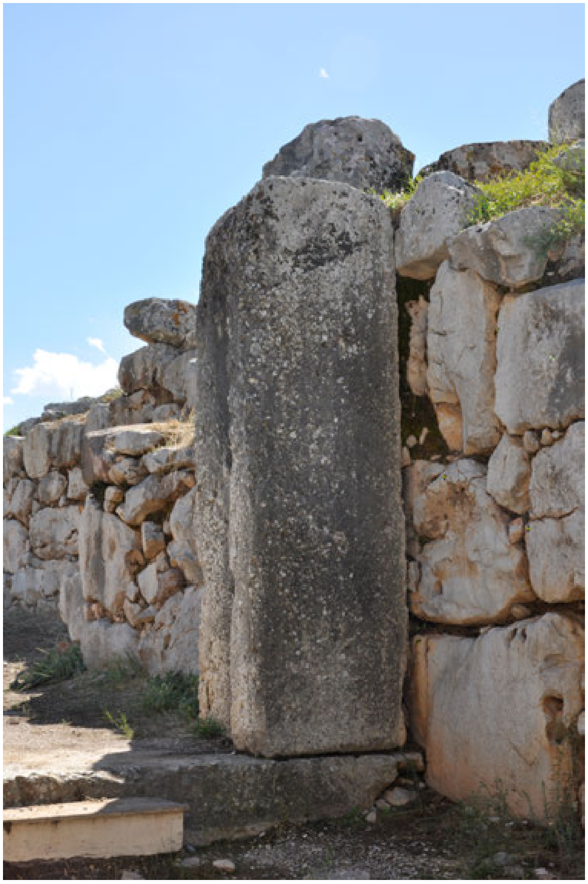

Fig. 10 Tiryns conglomerate block of the Main Entrance (9.6 tonnes). Discussed and calculated together with other conglomerate blocks from Tiryns in Brysbaert 2015a.

nature proclaimed of the citadel walls.[55]

3. One of the practical manifestations of these innovative approaches to resource management in this very specific Late Bronze Age palatial context in the Argolid is the cross-over usage of oxen.

The usage of cattle was attested since the Neolithic period in agricultural contexts,[56] oxen were depicted in clay figurine form in the EBA,[57] and they were likely used extensively in heavy agricultural work throughout the Bronze Age by those who could afford them, as can also be extracted from the Linear B tablets.[58] While the Linear B tablets are silent about oxen in building contexts – although cowherds are mentioned alongside wall builders on a major construction project[59] – it is only logical that once their strength was well understood, they would become the main choice of manageable energy power in transport activities to and from the quarries and on the building sites themselves. After all, the input of one yoke of oxen reduces human labour input by factor eight on average. That oxen were at least partially under palatial control is clear but they also crossed over in several non-palatial economic spheres for their grazing, guiding, maintenance, and feeding regimes.[60] The tablets mention oxen owned by the palaces of Pylos and Knossos, an oxherd at Tiryns, the fact that they are looked after by non-palatial staff (Pylos), and their hides are recorded too. Moreover, both iconographic and zoological evidence[61] points to the sacrifices of bulls at the palaces in feasting contexts. These animals were clearly of great importance and useful in various contexts[62] so it would only be a small leap to try them out on a building site. This was already suggested by Cavanagh and Mee[63] for the construction of the 'Treasury of Atreus' (Fig. 7) of which the blocks are of such size (its largest lintel block weighs 120 000 kg or 120 tonnes) that likely only oxen would be able to handle them.

4. A final, negative, manifestation of these construction programmes is that they are not mentioned in the tablets.[64]

As argued elsewhere, this may have two reasons. The first is that the building projects themselves were ordered by the palace itself and thus had no meaning to the palace bureaucracy that was mainly occupied with the economic transactions linked to their own interest (taxation, luxury goods production and the dispatching of materials to artisans, and the overseeing of military activities, of specific crop and animal rearing and

55 See arguments by Maran 2010 on the Dam construction in relation to the opening of the North Gate at Tiryns.
56 Isaakidou 2006.
57 Pullen 1992.
58 Palaima 2010, 367: "[…] Male bovids are allocated in teams as draught animals […]"; see also Halstead 1995; Brysbaert 2013 for detailed discussion on this set of topics. On cattle traction outside the Aegean: see Johannsen 2011.
59 Palaima 2010, 367.
60 Especially Nakassis 2013 for details and further references.
61 E.g.: Isaakidou and Halstead 2013.
62 Also attested in the Near East with more abundant textual evidence, see e.g. Heimpel 1995.
63 Cavanagh and Mee 1999.
64 But see Nakassis 2012 for building projects mentioned in the Pylos tablets.

of land tenure management[65]). Building their own vestiges, tombs and engineering projects seemingly did not fall under their immediate administrative interest spheres. Moreover, there may have been an additional level of palatial and elite household resource mobilization and management which was not recorded in the tablets but may not have represented large amounts of palatial mobilization.[66] A second reason may be that most of the work was possibly in the hands of sub-elites of the palace who employed the required labour forces through their own existing networks and connections, to plan and organize each activity, and to execute the entire building process from acquiring the materials to the final finishing of the constructions themselves. Linear B evidence points towards such phenomena.[67] What is of interest here is that the palatial administration thus seemed to have tapped into existing, possibly old traditional, social strategies of recruiting people and resources, but this time towards achieving a different type of outcome, their own massive and performative constructions. These existing social strategies may not be fully understood but certainly existed because the earlier tholoi were possibly constructed on the basis of such social structures of recruiting, managing and planning. Similar networking was likely tapped into for the more communal agricultural activities of harvesting when all available hands would be needed. The difference and the innovative aspect here are that the palatial bureaucracy, rather than implementing their building programmes through palatial-based structures, likely adopted existing structures to get things done, and adapted these to their needs. Providing labour or contributing one's oxen could have become a means of being taxed, for example. At the same time, while the palace tapped into large human and natural resources additional benefits for these people must have been advertised and apparent in order to legitimize their requests for this labour. We can only guess how this was done but the portrayal of defense and security, the provision of long-term income (while building) and serving, potentially, the ideological goal of belonging to a social group with a specific identity may have worked inclusively. Therefore, working together on a common project may have become a community bonding factor for all involved. As such, monumental constructions and the efforts needed can be understood as the physical manifestations of social order and, perhaps, collective will.[68]

After 1200 BC, building on such monumental scale ceased completely. In the post-palatial phase, some large buildings were constructed at Tiryns, such as Building T which was strategically located inside the Mycenaean Megaron and surrounded by the ruins of the destroyed Mycenaean palace. Maran suggested that an opportunistic elite group used that specific location to claim power and to legitimize this claim and its process through claiming their so-called ancestral lineage to the place.[69]

4 Discussion

In order, then, to understand, first, the socio-political and technical mechanisms that guided certain production and consumption modes that may be described as innovative, and second, to grasp the degree of influence that technical change and innovation may have had on society, it is useful to discuss the meaning and implications of the materials, processes, and practices in each study separately.

4.1 The wall brackets

In trying to tease out what these wall brackets mean, in their own context and diachronically, it is interesting that none of the workshops studied, apart from maybe case study IV in the Lower Town North East, can be determined as a clear domestic space in contrast to what Panitz-Cohen found on Cyprus.[70] Schlipphak, however, mentioned the finding of wall brackets on Cyprus in several domestic but equally in workshop contexts, more specifically metallurgical workshops, in sanctuaries, in graves, and on the Ulu Burun shipwreck.[71] In Tiryns, several craft activities took place in case studies I

65 E.g. Palaima 2010, 366–367; most recently Bennet and Halstead 2014 who stress the importance of the 'direct production' for the palace economy recorded in the tablets.

66 Bennet and Halstead 2014.

67 Nakassis 2012.

68 See Knapp 2009.

69 Maran 2012; see now also Brysbaert 2015b for a longer usage of this locale for ancestral claims.

70 Panitz-Cohen 2006, 616–617.

71 Schlipphak 2001, 15–21; see also Bass 1988 and Pulak 2010, 868, on the Ulu Burun examples.

and III at the same time, and both workshops produced items for the palatial economy for which Linear B, at least in part, provides further insights, such as casting bronze weaponry as attested for in case study I.[72] Both the production and consumption of these wall brackets continued into the post-palatial period at Tiryns, a phenomenon also noted, for instance, at Bet Shean, Sarepta and Megiddo where also earlier ones were found.[73] In several other Levantine port-towns, wall brackets were also present in the period preceding the Aegean palatial demise around 1200 BC.

Based on these finds, Panitz-Cohen argues strongly for the presence of Cypriot people themselves bringing these items along with them, because only they would know, at least initially, their use and value when introduced in an environment where they did not exist before. The so-called Cypriot wall bracket (TN 708, Fig. 2) found at Tiryns could fit this interpretation quite well. However, as mentioned above, most other objects from the Tiryns workshops associated with the wall brackets show a rather local tradition of metal working and related artisanal activities, some including local ritual practices (use of figurines, miniature vessels, possibly also glass beads).[74] Furthermore, the association of the locally made wall brackets (TN 643, TN 644, Figs. 3–4) with other foreign items may suggest that the artisans of this workshop may have had enough contact with Cypriot people (whether resident in Tiryns or not) in order to get to know these items, appreciate them and possibly adopt and adapt their production and their usage to their own needs. A similar case can be made for case study III.[75] Also Rahmstorf does not want to search for Cypriots behind each wall bracket, also not in Tiryns, despite the evidence of Cypriot, east Mediterranean and other foreign elements in the material remains of the site in this Late Bronze Age period.[76]

We cannot know how people at Tiryns would have used the wall brackets; it is only clear that they were involved in mostly cultic activities during their first use-life. However, during their second life, for example as scoops, they may have lost that ritual association. As such, both first and second use-lives were intricately connected to the lives of the wall bracket users. The appearance and usage of these initially foreign items in a local context may have been also accompanied by new gestures, ritual practices and belief systems, at least initially. The quick appearance, though, of the locally made wall brackets indicates an almost immediate acceptance and adoption of these foreign items in this local workshop context; and likely, the associated practices were either adopted and adapted too and integrated in existing social and cultic practices.

This stands in contrast to Panitz-Cohen's opinion who believes that these items could only have been made by people who knew their intrinsic use and value, i.e. Cypriot or Levantine people; she essentially sees these items as identity markers, Cypriot identity markers specifically. While we can suggest that wall bracket TN 708, made in yellowish gritty clay with a wavy line decoration on its back plate, may have been made (by a Cypriot) on Cyprus, all other wall brackets found in Tiryns showed a different style of decoration *and* were made in local clay, indicating local adoption and adaption, likely by local artisans, of the item and possibly too of its intrinsic value (see TN 643 with repair, Fig. 3; TN 644 possibly reused as scoop, Fig. 4).

Equally, the value ascribed to these items during both their first and second use-life must have been done locally since that likely shifted from ritual to non-ritual connotations. Part of such a shift is visible in the immediate adoption of the foreign element and their adaptation in local production and consumption practices, in their re-use as scoops or by drilling a repair hole in the back plate, and in their continuous use from palatial into post-palatial periods. Another example of value shift befits the examples found aboard the Ulu Burun shipwreck. Those were already used, visible in the burning traces, before they were packed on board,[77] either to be spacers in the packing of the ship or to be traded or exchanged upon arrival. Therefore, the locally made wall brackets and their secondary uses, noted at Tiryns and elsewhere, weakens, in my view, the argumentation that Panitz-Cohen provides for them to represent solely Cypriots and their inherent cultic practices.

72 Brysbaert and Vetters 2013; Smith 1992–1993 on Jn 829 which mentions javelin points as the end product against the handing out of a specific amount of copper or bronze to metal smiths.

73 Panitz-Cohen 2006; Schlipphak 2001; Rahmstorf 2014.

74 Brysbaert and Vetters 2013.

75 Brysbaert and Vetters 2010.

76 Rahmstorf 2014, 193; for case study I, see Brysbaert and Vetters 2013.

77 Rahmstorf 2014, 193.

Crucial for the wall brackets and their changing significance is that these newly but quickly adopted and adapted items became part and parcel of existing and local modes of practices, likely ritual ones, during this first use-life. Therefore, with the arrival of these new items also new practices came in and were amalgamated and crossed-over with the existing ones, forming altogether again new, hybrid, practices which were anchored in existing social strategies.[78] In an altogether different context, Nakou argues convincingly that distinctive foreign consumption patterns and accoutrements may have varied from region to region and that the difference in rhythm and nature of material culture changes because the response to the introduction of foreign items is the outcome of a deeper contrast between the different regions in terms of their relationships between power, value and material goods. To her, these deeper contrasts are historically embedded forces which we aim to recognize and these cannot be understood in looking at just one category of material.[79] While it would be incorrect to make analogies with Nakou's specific case study, the important implication of her conclusions for our case study lies in the realization that the Tiryns wall brackets had to be studied in relation to the other items found in the same contexts where they were found at Tiryns. This was crucial in order to understand the introduction of these wall brackets in a new setting, to grasp how (fast) they became adopted and adapted locally, how that affected the value shifts these items may have undergone (in their primary and subsequent use-lives) and how both their ascribed value(s) and usages may have affected existing social strategies within the existing local communities.

These realizations make that the innovative aspects of the wall brackets are much further and deeper embedded and anchored, socially-culturally and politically, than the mere clay and style differences between the one from Cyprus (TN 708) and all others found on the site. If, in following with Panitz-Cohen,[80] we could suggest that the original concept of a wall bracket and its specific cultic use was an identity marker (possibly even a Cypriot identity marker for TN 708), and thus had a very specific value, (i.e. identifying the person who had one as being knowledgeable about its correct cultic usage), then we can argue logically that a person or a social group, for example metal workers, from Tiryns who became acquainted with such an item and its associated practice may have wanted to incorporate the item, or item *and* associated cultic practice, in their lives. In order then to make a wall bracket and its associated practice their own, and not a mere Cypriot or Levantine imitation, it, therefore, *had* to be made in local clay and decorated with a local pattern, the Tiryns finger impression pattern (compare Fig. 2 with 5a).[81] Arguably, what could be more personal, and thus local, than one's own finger prints, impressed on a wall bracket made in local clay? The innovative process lies thus within the combination of adopting a new item, in adapting that item to local needs, an anchoring process, in fact,[82] and in making it, physically and mentally, one's own.

4.2 Building on a monumental scale

The amount and scale of the Late Bronze Age monuments in the Argolid clearly had a performative character befitting the elites' aspirations to affirm and maintain political and religious power over the region and their individual polities. Within this, it is crucial to understand, first, the human and other efforts and resources that were able to deliver on such a scale and, second, the impact these and associated activities may have had on the population of that region. In adopting the above mentioned combined approaches, it is possible to grasp several possible steps in such construction processes. As became clear in the recent pilot case study many activities vital to constructing on such a scale are embedded in other activities on which they build and depend on.[83] Such large-scale construction activities may also affect economic needs in terms of agricultural production as has been pointed out, for example, in rela-

78 After Nakou 2007, 239.
79 Nakou 2007, 240.
80 Panitz-Cohen 2006, 620, on Cypriot expatriates
81 In strong arguments in favour of their local production, Rahmstorf 2014, 192, mentions the existence of only two other wall brackets with finger impressions, from Kition, Cyprus (11th c BC), but they are distinctively different than the Tiryns ones and of different date.
82 See now Sluiter 2017, and https://www.ru.nl/oikos/anchoring-innovation/ (last accessed 02/01/2021).
83 Published as Brysbaert and Vetters 2013 and Brysbaert 2015a, the latter in part presented at the 'Fokus Fortification' Conference, held in Athens in December 2012.

tion to the site of Gla.[84] As such, clear cross-overs in the deployment of human and animal resources are to be noted between monumental building practices and simultaneously required food provisions to feed both these human and other resources, and people and animals beyond these intensive activities. These crossing activities required highly developed organization and planning strategies, good timing and resource management, and thus a structured understanding of socio-economic transactions. During these, material and immaterial aspects of any type of crafting blur entirely and so do the elite-labour dichotomies since all involved groups are interdependent during such activities while not ignoring that some are hierarchically stronger of course. While innovative approaches to the use of materials in monumental building seem to have been carved out in the actual stones, it is equally the level of planning and organization of both the individual construction as well as the overall 13th c BC building programme as a whole that was never seen before, and was not going to be repeated after c. 1200 BC until the Archaic period.

The 'simultaneousness' of all the above-mentioned constructions is, however, a matter of discussion. Were the elite rulers at the individual palaces coordinating their collective human and animal resources in such a way that there was no overlap between projects, and that there were always people left to stay active in the agricultural sector, or were people pooled between places for all of these activities together? Or, were they in competition with each other, instead, trying to get their 'programme' done first and best, at cost of other needed activities, thus overexploiting their resources? Or were there simply enough people for all activities? Of importance in the context of innovative processes are the organizational and managerial issues embedded in the material expressions of these elite rulers, marking their landscapes so intensively through its own resources, and at a level never seen before.[85]

Concerning the specific role of oxen, we also see changes in their relation to people over time. Early on, these costly animals may have belonged to elites only, initially to be used in collecting agricultural surpluses, thus providing basic needed provisions such as food. These elites may have been the ones that rose to power in the Mycenaean Shaft grave period. In the Late Bronze Age, oxen, owned by the palace were given in the hands of oxherds who were nevertheless allied to the palace and may have been the social group on which the palace relied for recruitment of people to build. Bulls were then also used for ritual sacrifice by palatial elites, i.e. as meat provision on specific occasions, possibly even to celebrate the outcome of the very activities in which oxen were involved: building and agriculture. As such, the elite may have shifted in their understanding of the use of oxen from providing solely primary needed commodities to providing these *and* 'non-needed' monumental constructions. It is clear then that the entangled relationships between oxen and people changed over time and more specifically after the demise of the palaces. Both oxen and skilled labourers, previously in function of palatial activities have to be seen as acting to structure relationships between people and things in these contexts. Once the socio-political and economic situation changed, their importance, thus value, will have changed too, thus having an impact on each other's day-to-day existence.

Around 1200 BC, people may have been socio-politically and economically strong or resilient enough to move on without the elites. Freed up of long-term construction under palatial rule, the section of the population directly involved in quarrying, transport and construction[86] likely went back, full-time, to their previous jobs in agriculture and crafting.

In the post-palatial era, oxen could have been re-integrated in agrarian activities by those who could continue to afford their fodder and maintenance, i.e. those who owned minimally 5–10 ha. The economic emphasis in LH IIIC may have been more on local production of food surpluses and competitive feasting, possibly materialized in Building T that was purposefully placed within the former Mycenaean Megaron of the LBA palace. It seems clear that the location where Building T was constructed was manipulated and used to claim a level continuity in power.[87] Feasting within that building which has been identified as a banqueting hall[88] was also a way of continuing pre-existing traditions by certain elites.

84 Dabney and Wright 1990. On similar economic impact factors relating to building Versailles: Lepetit 1978.

85 See Brysbaert 2020.

86 Brysbaert 2015a.

87 Maran 2009.

88 Mühlenbruch 2007.

What had changed was the surrounding monumental décor whose constructive labour was now reinvested in agricultural activities that did not result in reusable produce (such as bronze items) and thus needed constant attention. Possibly, one could see this halt of monumental building as going back to pre-existing traditions, known from the MH period whereby kin-based relations played the major role as organizational principle, rather than the later wealth and status-based system which needed ostentatious practices and display to legitimize their existence and dominant role in society.[89]

5 Conclusions

In the wall bracket case study different interconnected networks of artisans changed over time and allowed for certain specific artisanal activities, e.g. making and using wall brackets, to hybridize and continue. The local networks of knowledge sharing and enhancing were likely crossed-over by crafting the wall brackets which, in itself, may have come in as an indicator of a different or expanding artisanal network or node linked to it by a foreign element. The linking of different networks in this localized context happened through various forms of social sharing and communication and is a process, not an event. While within palatial confines, this liberty to share is possible in small but controlled workshop spaces, it seemed equally possible to run, in part, one's own business within palatial confines too. This is clear in the presence of a small obsidian industry in case study III which clearly did not fall under palatial control (not mentioned in the Linear B tablets) even though it took place within its confines.[90] This illustrates beautifully a local, very old traditional and existing non-palatial economy but carried out *within* the palace to help out someone who produces *for* the palace. Of importance in a discussion on innovation here is the realization that while the palaces controlled certain craft activities, personal or social group initiative was facilitated at the same time. The socio-political and economic structures in the shape of the palace bureaucracy thus affected local industries by facilitating interactions with foreigners if and where needed, via middlemen or independent merchants, in raw materials and semi-produced items, for finishing at or trading with the palace (e.g. ingots for casting weapons). These interactions were, therefore, also responsible for the necessary contacts between people, whether at Tiryns or elsewhere, that also brought the wall brackets to Tiryns. At the same time, while controlling specific crafts, other non-controlled ones were taking place too. It is thus the complexity of socio-technical interactions within the socio-political, economic and cultural dynamic sphere of the Late Bronze Age that affected processes leading to new phenomena which, in themselves, affected these very processes from which they emerged.

Also the monumental building case study witnesses configurational changes in several levels of overlapping economic systems in place at the same time: palatial, religious and non-palatial local economies. These shifted, after 1200 BC, in favour of local economies, likely still combined with religious economies while the palatial economy vanished, and with the latter, several material production and consumption practices. Linked to the disappearance of the palace economy disappeared these highly developed planning and organizational skills, needed in monumental building works on the scale we have seen. The effect of large-scale human and material resources expenditure during the final decades of the palatial period may have contributed in part to the socio-economic changes towards 1200 BC [91] but its economic extent is not determinant.[92]

The two studies illustrated a different nature, and different scales and rhythms of innovative appearances and disappearances, as responses to the introduction of different types of material culture expressions, and in the case of monumental building, its disappearance at the end of the palatial period. These different rhythms and scales can be understood as the result of local and socially stratified responses in terms of the relationships between power institutions, related value systems and associated material goods. The technical and material innovations and changes were initiated, adopted and adapted by the people in and around Tiryns in the 14th to 12th c. BC and cannot be explained by a monolithic understanding of the socio-political and economic environment whereby the palatial authorities were in

89 E.g. Voutsaki 2010 on clear arguments in favour of kin-based organisational principles during the MH period leading up to the shaft grave period.

90 Brysbaert and Vetters 2010.

91 Or 1177 BCE in Cline's terms, Cline 2014.

92 Brysbaert 2020.

charge of most, if not all, of the economy. It has been convincingly demonstrated that multiple economic layers were present alongside the LBA Mycenaean palatial economies.[93] Religious authorities and the local *damoi* had their own and partly interconnected economic systems to which people contributed in many ways and which went back to much earlier periods.[94] For example, Nakassis has shown that metal smiths working for the palace often owned large land plots and had other responsibilities such as looking after flocks of sheep.[95] Equally, simple oxherds may have been farmers during parts of the year while also taking part in transport activities relating to building during other parts of the year.[96] Some also owned substantial pieces of land. These examples blur both our labour divisions and the idea that artisans were simple skilled and unskilled workers. Building in the second half of the 13th century BC likely affected a percentage of the overall *active* population. Several groups were directly involved, such as the quarry men and builders and their families, others more indirectly such as farmers and various artisans who would provide food and fodder, tools and equipment.[97] A certain proportion of the local people were likely either directly or indirectly involved in the construction activities depending on the time of the year and the season.

Serious socio-political changes took place around 1200 BC with the demise of the Mycenaean palaces[98] as part of a much wider, pan-Mediterranean set of changes.[99] These caused the halt and disappearance of several materials such as the production of glass and faience, painted plaster decorative programmes in palaces and in elite buildings, Linear B script and the employment of seals cut from hard stones,[100] and monumental architecture. Some material expressions that disappeared as 'quickly' as they came up (e.g. monumental building) were those that seemed closest interwoven with the socio-political contexts of the upcoming and later vanishing palatial elites. It is of interest, however, to consider what precisely happened, for example, when glass and faience production was no longer needed in palatial and elite contexts. Artisans who developed related high levels of skills may have had several options: either to leave the area to regions where such demands would still exist, or abandon those specific skills and take up other activities which may require related skills, or change career completely into subsistence activities which produced primary commodities and for which the demand was possibly steady. It is very plausible that most such skilled artisans opted for the latter simply because most may have carried out their specific palatial-based craft activity on a part-time basis anyway as was likely the case for most metal workers, possibly also for glass and faience workers, and for people decorating walls in palaces and elite buildings. It is harder to understand what happened with the palatial scribes[101] but again, these people were likely also involved in the administration themselves[102] and could either take up more of management activities or resort to primary subsistence activities.

However, not all material culture phenomena and social practices were affected immediately, shown by the continuity, and even its initial intensification, of bronze and lead working, recycling, and metal circulation strategies via non-palatial middlemen, who were already present before 1200 BC.[103] Also ivory working, textile and pottery production, collecting and calcining old plaster fragments, obsidian blade usage alongside metal tool use,[104] and our wall brackets continued to be produced. The latter may have become very well integrated by the end of the palatial period in local production and consumption patterns. These patterns show a *shift of value* – from an original Cypriot or Levantine value

93 Most recently: Bennet and Halstead 2014; Pullen 2013.

94 Lupack 2008.

95 Nakassis 2013.

96 Brysbaert 2013.

97 Brysbaert 2013.

98 E.g. Maran 2010 for a good summary of the situation at Tiryns in context.

99 Cline 2014 with the latest reference updates and a thorough discussion on the overall topic of collapse in the East Mediterranean.

100 Younger 2010, 337: after the fall of Knossos c. 1300 BC Mycenaean seal stone use was reduced to employing heirlooms and the Mycenaean centres were not known, apart from maybe Vapheio, to make their own seal stones cut from hard stones as they were much better known from Crete. The seal use on the Mycenaean mainland was closely connected to the use of tablets, fell mainly in the administrative sphere, and must have disappeared together with the tablets.

101 E.g. Bennet 2008 on the disappearance of the Linear A script on Crete, while the disappearance of Linear B has been linked to the demise of the Mycenaean political economies around 1200 BC.

102 Bennet 2008.

103 Such middlemen were already seen in trade and exchange patterns during the LBA by Knapp and Cherry 1994; Knapp 2000; Brysbaert 2015b.

104 Clearly demonstrated in the post-palatial case studies III and IV at Tiryns; Brysbaert and Vetters 2010; Brysbaert and Vetters 2013.

ascription to a local Tirynthian one and from a ritual to a non-ritual one –, not a *loss of value*, because value is context-dependent and could have been ascribed by different social groups or even different individuals each time.

In sum, in asking how technical change influences society it is equally crucial to address how societies influenced change and innovation through the adoption and adaptation of new technologies or features, or rejecting them, or even harkening back to previous conditions, as a form of resistance,[105] once the palatial institutions folded. Gauntlett's definition of social capital as "the community glue made up of friendly connections with others"[106] in a system where value is embedded in having social connections and collaborative projects in everyday life, therefore, indicates the interactive role to be attributed to many social groups and even individuals since none were only at the receiver's end of the production or consumption chain. As such, inasmuch as people make things that make people, innovations influence societies that influence innovations, as part of wider and contextualized socio-technical processes at work.

105 Given 2004.

106 Gauntlett 2011, 21.

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Modes of Production in the ‘Copper Age’ of the Southern Levant. Techno-Social Innovations during the 5th–3rd Millenia BC

Summary

This paper will research the relation between technological innovations and the mode-of-production paradigm for late prehistoric societies in the southern Levant. We research the social relations of the societies of this region during the 5th to 3rd millennia BC, defined as belonging to the Chalcolithic and the Early Bronze Age I periods. We summarize the different ways to define modes of production in antiquity, taking in mind the debate that exists around this category. Furthermore we suggest some conclusions taking in mind that our laboratory is a small peripheral zone of the Near East and then the possibility of elaborate a model of technological innovations and social evolution could be restricted to this region, or the opposite, the social evolution and technological innovations in this region are the local expression of processes occurring in the Ancient Near East.

Keywords: technical innovation; social evolution; modes of production; southern Levant; Chalcolithic; Early Bronze Age

In dieser Arbeit wird die Beziehung zwischen technologischen Innovationen und dem Paradigma der Produktionsweise für spätprähistorische Gesellschaften der südlichen Levante untersucht. Es werden die sozialen Beziehungen der Gesellschaften dieser Region während des 5. bis 3. Jahrtausends v. Chr. erforscht, die als zur Zeit des Chalkolithikums und der Frühbronzezeit I gehörend definiert werden. Wir fassen die verschiedenen Definitionsmöglichkeiten von antiken Produktionsweisen zusammen und berücksichtigen dabei die um diese Kategorie geführte Debatte. Darüber hinaus werden Schlussfolgerungen unter Berücksichtigung der Tatsache vorgeschlagen, dass unser Untersuchungsgebiet eine kleine Randzone Vorderasiens ist und dadurch entweder das Modell der technologischen Innovationen und der sozialen Evolution auf diese Region beschränkt ist, oder, dass die soziale Evolution und die technologischen Innovationen in dieser Region der lokale Ausdruck von Prozessen sind, die in Vorderasien stattfanden.

Keywords: technische Innovation; soziale Evolution; Produktionsweisen; südliche Levante; Chalkolithikum; Frühbronzezeit

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1 Introduction

This paper will research the relation between technological innovations and social paradigms in late prehistoric societies of the southern Levant. It is clear that social and economic conditions must exist within these societies in order to innovations to be adopted and develop. However, could the mode-of- productions paradigm work for our analyses. For this paradigm we need to know the social relations on the societies we want to research. Do we know these relations for our study case in the southern Levant during the 5th to 3rd millennia BC?; we will try to present our understandings on this question.

Furthermore, there is a more difficult issue, is the paradigm presented by Karl Marx[1] some 150 years ago suitable today to be utilized as an instrument (not a dogma)?; do some of the modes of production presented by Marx fit our example? We are purposely not speaking about the deformation made by Joseph Stalin on this paradigm.[2] Of course there are several elaborations on these modes of production conducted in the 1960s and 1970s like Maurice Godelier[3], and Marshal Sahlins[4], which created some other modes of production, like the domestic one.

The last important question: is the southern Levant the appropriate 'laboratory' to test our subject, a small a peripheral zone in the Near East, a little bit separated during the 5th 3rd millennia BC from the so-called centers of civilization, can be taken as a model? In this case we are confident that the southern Levant is one of the most researched territories from the point of view of archaeological work, and we have a dense data base for the periods in question (Fig. 1).

2 Modes of production

We would like to refer some general lines in the definition of modes of production. In a general way is the method of producing all necessities of life. However, there are two elements interrelated that must be taken into account – one is the productive forces, meaning all the instruments and workers (including technology), and – the second is the relations of production (which are the result of the social development in a given society)[5], this last category is difficult to define, and of course to agree among scholars.

Then, when the forces of productions changed, when problems arise in the relations of production when economy changes and technology develops, a different kind of relations of production is needed.[6] If the change doesn't occur, there is the possibility of backward tendencies in society, even collapse. Nothing is linear, or 'pre-determinate'.

In general, however, what we have is a conflict and a potential revolutionary change (this does not mean everywhere the change is a political revolution, could be something like the industrial revolution). Here we have the opportunity at least to see how the changes in society are interrelated to the subject of technological innovations.

And, again, coming back to known models, here we can see the possible modes of production we can apply in the late prehistory of the southern Levant, and how they differ each to another. For instance, the so-called primitive form in which the individual has access to the herds and lands by belonging to a community (Fig. 2); here there could have been a lot of differences according to clan or kinship relation. I assume that there was not 'a' primitive form but several forms which fit with this mode of production. The second form which actually implies a hierarchic society is the so-called and so debated 'Asiatic mode of production'; here it will be called "tributary" mode of production.[7] In this mode the communities could have been supervised, controlled by higher units, paying tribute to utilize lands or for the products of the lands and animals, or giving labor to construct city walls or public buildings. In this mode, craft specialization begun to exist by attaching some groups of artisans to that higher units, but not only. In this paper we suggest that different forms of this mode of production existed in history, depending on the degree of

1 Marx 1993 [1939]. And see among others a discussion on this mode of production in Anderson 1974; Hindess and Hirst 1975; Godelier 1991.
2 E.g. Stalin 1940 [1938].
3 Godelier 1975; Godelier 1991.
4 Sahlins 1972.
5 Marx 1970 [1859].
6 Marx and Engels 1989 [1848].
7 In later periods Gottwald 1976 utilizes also this term; and see also Haldon 1993. Liverani 2005 utilizes a different term, palatial mode of production, for the societies of ancient Mesopotamia.

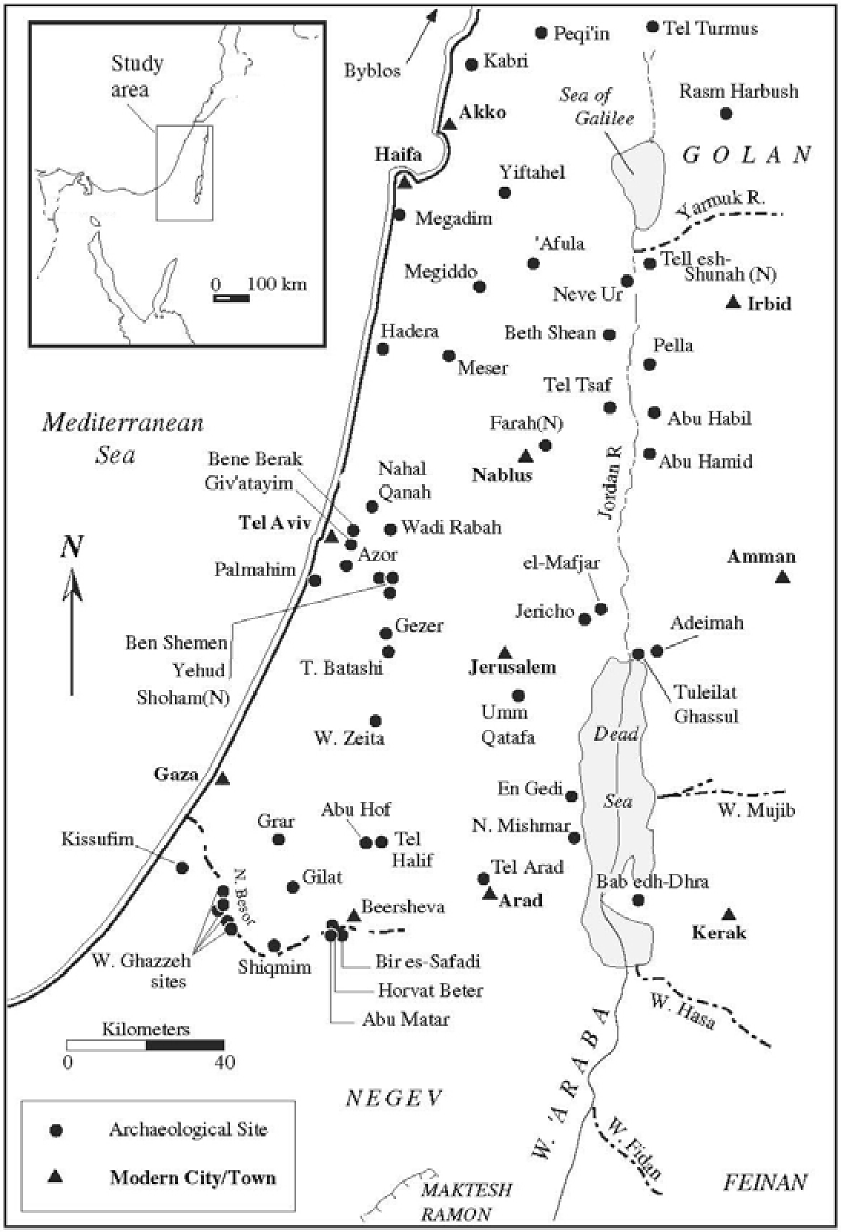


Fig. 1 Map of the southern Levant with the sites mentioned in the text.

attachment of the communities to the higher unity, the form of this unity, the degree of control, etc. Of course, it was also the 'ancient mode of production' based on slaves and private property, but we don't think that this applies to the Levant in the late prehistory.[8]

In a retrospective look at V. Gordon Childe's ideas on social evolution we can see where our 'Copper Age' is located. In the 1930s, Childe[9] suggested that urbanization and metallurgy were part of the same process, years later Childe[10] divided the question pointing out that copper metallurgy preceded the urban revolution, this raised the question of a 'Copper Age' (which he identified with the Halaf and Ubaid cultures in Mesopotamia) beginning before the urban Early Bronze Age. Although, afterwards here turned to some early thinking.[11]

8 And see Marx 1993 [1939].
9 Childe 1936.
10 Childe 1946. And see Hansen 2013, 137, and S. Hansen, this volume, on Childe and key innovations in the Ancient Near East.
11 Childe 1956.

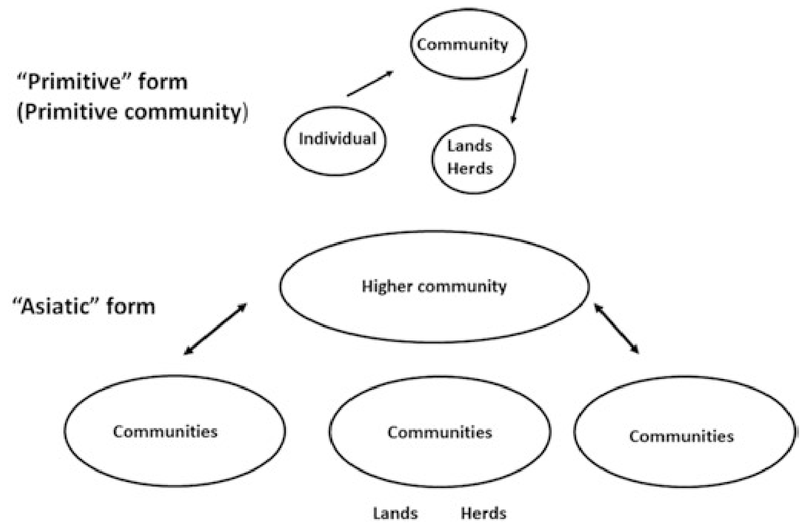


Fig. 2 The primitive and 'Asiatic' modes of production.

3 The 'Copper Age' in the southern Levant

Cultures	Periods	Years cal BC
Wadi Rabah	Late Pottery Neolithic/Early Chalcolithic	5800–4800
Qatif, Besorian, Jericho VIII, Tzafian		4800–4500
Early Ghassulian	Late Chalcolithic	4500–4300
Late Ghassulian		4300–3700
	Early Bronze I	3700–3100
	Early Bronze II–III	3100–2500

Tab. 1 Chronology of the 'Copper Age' in the southern Levant.

By going a little to our subject we will quickly explain the periodization of what we call 'Copper Age'. Actually, the reader will not find in general this expression in the literature of the southern Levant. The traditional division of three eras, stone, bronze and iron in ancient Palestine[12] was suddenly interrupted by the Chalcolithic label. But the Early Bronze Age is also a 'Copper Age'; there is no bronze till the Middle Bronze Age. Now from the point of view of the chronology we are in the middle of the 5th millennium, in the Ghassulian Chalcolithic or Late Chalcolithic for some scholars, with a pre-metal period of 200 years and then the beginning of copper metallurgy around 4300 BC (Tab. 1). Previous phases were called or Late Pottery Neolithic, or Early Chalcolithic, but we will not go to this in detail. Just it must be taken in mind that the Ghassulian is something parallel to the Late Ubaid-Early Uruk, and the EB I is a pre-urban and EB II-III is urban, from the half of the 4th millennium to the whole third millennium BC, these southern Levantine periods being parallel to Uruk, the Early Dynastic, and Akkad.

We have after the Chalcolithic a division of the Early Bronze Age in 3 phases, the first one EB I is mainly divided into A and B, with A represented by dispersed villages, and B, pre-urban, going almost to the end of the 4th millennium BC; then we have EB II and III which are urban in the sense that these sites are fortified with public buildings, and some internal urban organization.[13] But still, these Levantine settlements are neither the cities of Mesopotamia, neither those of the northern Levant.

When we study the settlements of the Ghassulian Chalcolithic we see villages with rectangular structures, houses, and some of them also with subterranean or semi-subterranean rooms as in the case of the Negev.[14] There are some sanctuaries (but this is a matter of discussion and there is no consensus on several cases); one of them is the sanctuary of Ein Gedi close to the Dead sea and some buildings in Teleilat Ghassul in Jordan.[15]

12 Albright 1949.
13 Greenberg 2011.
14 Levy 1987; Banning 2010.
15 Mallon, Koeppel, and Neuville 1934.

	Chalcolithic	EB I	EB II–III
Agriculture	Attached to wadis Wheat, barley	Developed Wheat, barley	Extended areas Wheat, barley
Horticulture	Incipient olives	Developed olives, grapes	Extended olives, grapes
Herding	Ovicaprines cattle pigs	Ovicaprines cattle pigs	Ovicaprines cattle pigs
Plough	Unknown	Probable	Probable
Transport	Unknown	Developed	Developed
Secondary products	Developed Milk Wool?	Developed Milk Wool?	Extended Milk Wool?

Tab. 2 A comparison between the Chalcolithic and Early Bronze agriculture, husbandry and probable management of lands.

These buildings are special in plan as Ein Gedi, located in an isolated area.[16] At Ghassul there are several buildings within the village, considered to be sanctuaries some of them with frescoes.[17]

When the first villages of the EB IA were constructed they had a different type of organization, meaning their architecture is oval, the "sausage" houses as Eliot Braun[18] call them, being almost disconnected one to another. This phenomenon occurs in almost all areas of the southern Levant, including the coastal plain of Lebanon.

When we pass to the EB IB, in the last quarter of the 4th millennium, we return to a rectangular architecture sometimes with round corners), but specifically more dense, a proto-urban plan becomes clear, as in Palmahim[19] where the EB IB rectangular architecture replaces the oval of the earlier level of EB IA. Some site of the EB IB have circumvolving walls, and some as Megiddo large sanctuaries (in the lower left), or public central buildings as Tel Erani (in the lower right).[20]

The EB II and III of the southern Levant see the rise of urban centers with external fortifications and public building, palaces or temples, as in Jericho, Tel el Farah, Arad and Bet Yerah (Khirbet Kerak). On the left you can see Palace B in Tel Yarmut dated to the EB III.[21]

Agriculture and husbandry are the main means of subsistence. It is difficult to follow the changes in agriculture of these periods, we can say that the main thing is the development and extension of what existed in the Chalcolithic into the EB, with the appearance of new species like grapes Same question in herding animals, some changes occur in the frequencies of animals, and the development of secondary products as milking (Tab. 2). The main change could be the appearance of the plough in the EB, probably done with oxen. On the domestication of donkeys we will refer later.

4 Burial modes

Worth mentioning are the burial customs, which could lead us to understand also social relations, this is what we call "burial modes" (Fig. 3).[22] In Pre-Pottery and Pottery Neolithic, there are burials under the houses, which mark clear 'household burials.' When we arrive to the Ghassulian or Late Chalcolithic, things changed, there are primary burials within the site, household burials, but then the bones were removed, located in containers and re-buried in cemeteries, in general burial caves, meaning 'community burials.' For the EB we have some examples, including Jericho, Bab edh Dhra and Assawir.

16 Ussishkin 1980.
17 Cameron 1981; Seaton 2008; Drabsch and Bourke 2014.
18 Braun 1989.
19 Braun 2000.
20 Yeivin 1961, Yeivin 1977; Kempinski and Gilhead 1991.
21 And see an extensive analysis on these buildings on a recent article by de de Miroschedji 2015.
22 And see Milevski 2019.

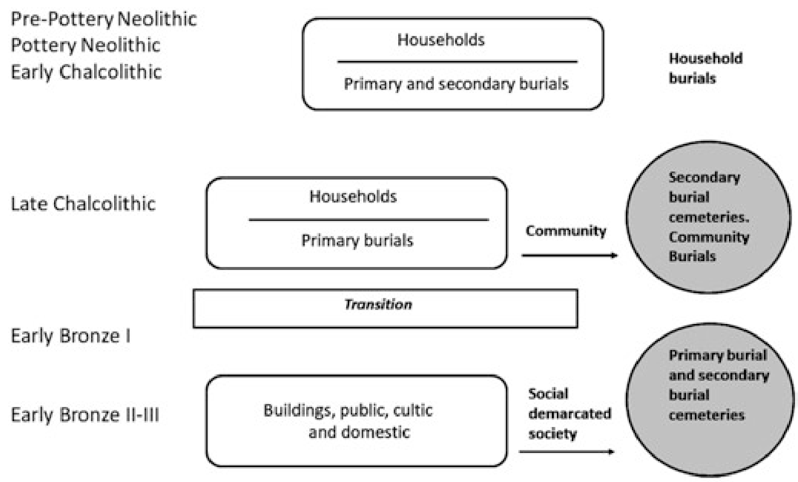


Fig. 3 Burial modes and social relations during the late prehistory of the southern Levant.

At Bab-edh Dhra in the east of the Dead sea, the EB IA tombs are still secondary. Articulated, primary, burials occurred first in the EB IB at the same site. In this case these charnel houses include a large number of individuals which were interpreted by Chesson as a broadening of kinship relations. This is also the case of some burials of EB IB in Assawir, in the Wadi Ara region, where hundreds of individuals were buried in caves near the settlement.

In EB II–III developed urbanism; we can find several differences in the burials indicating a sort of social hierarchy in the urban settlements.[23] For instance, the Lesser and Greater Charnel houses of Bab edh-Dhra, the late having gold, faience, mother of pearl shells, jewelry, stone palettes and other luxury items, they have also imported pottery vessels. They contain also metal weapons and mace-heads, probable mark of political and military powers.[24]

5 Pottery

In the following sections we will search for the distribution and exchange networks of some archaeological finds, exchanged goods of the Ghassulian Chalcolithic and EB in two cases. Starting with pottery groups we can see that Chalcolithic networks have restricted networks of 20–30 km maximum from the centers of production (based on petrographic studies of the clays and tempers) (Fig. 4).[25] However, Chalcolithic pottery is the first to be standardized in the southern Levant and produced in a certain amount; a totally different picture from the previous Neolithic cultures.[26]

EB I networks of pottery include many groups, probably 3 or 4 times those of the Chalcolithic;[27] they are distributed in places 100 km from the places of production (Fig. 5). In the urban EB II two main nodes of exchange existed: one in the north with the Metallic Ware pottery and one in the south with center in Arad dominating several lines of exchange.[28] It looks that two main political centers dominated also the economics of the southern Levant.[29] Perhaps, the utilization of potter's wheel, influenced in this process. In the Chalcolithic we don't have almost finds like this, just 5 (most

23 Kenyon 1965; Schaub and Rast 1989.

24 Chesson 1999.

25 Among the petrographic studies we can follow those undertaked in the northern Negev (e.g. Goren 1991; Goren 2006) and those in the site of Abu Hamid in the Jordan valley (Roux and Courty 1997). Few studies have been conducted in the Shephela (e.g. Milevski, Vardi, et al. 2013) and in the Galilee (Shalem et al. 2019). The petrography of cemeteries has been studied (e.g. Golding-Meir and Isserlis 2013; Cohen-Weinberger 2013, in press) but this is a different subject and do not include exchange of pottery between sites.

26 Milevski and Barzilai 2017.

27 Braun 1996.

28 Milevski 2011.

29 Amiran and Ilan 1993; Greenberg and Porat 1996.

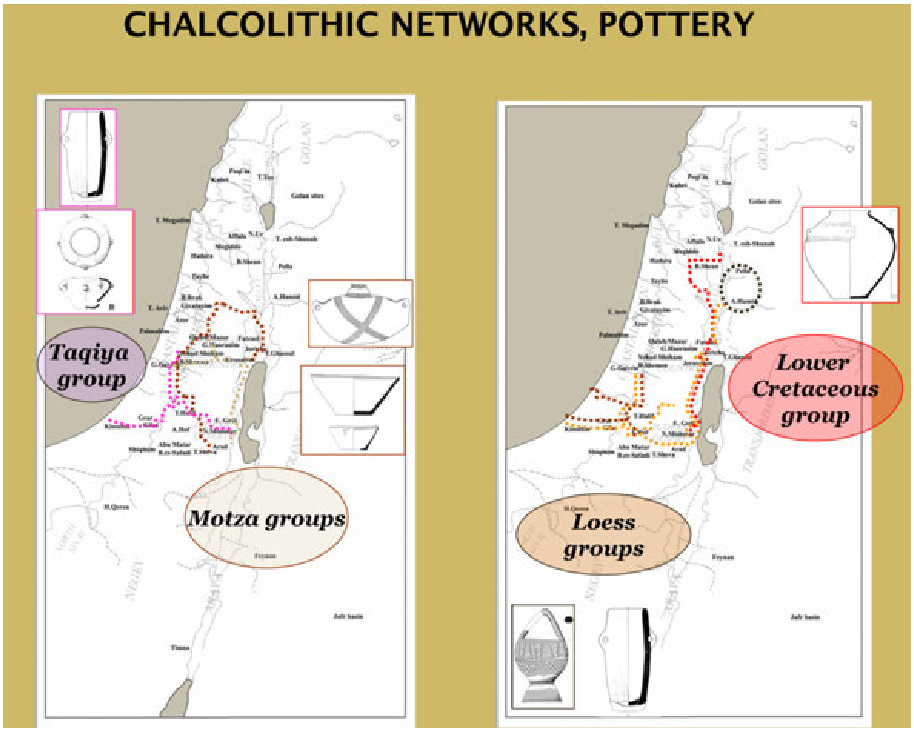


Fig. 4 Map with the distribution of main petrographic ceramic groups of the Chalcolithic. Color lines indicate distribution networks of the pottery groups.

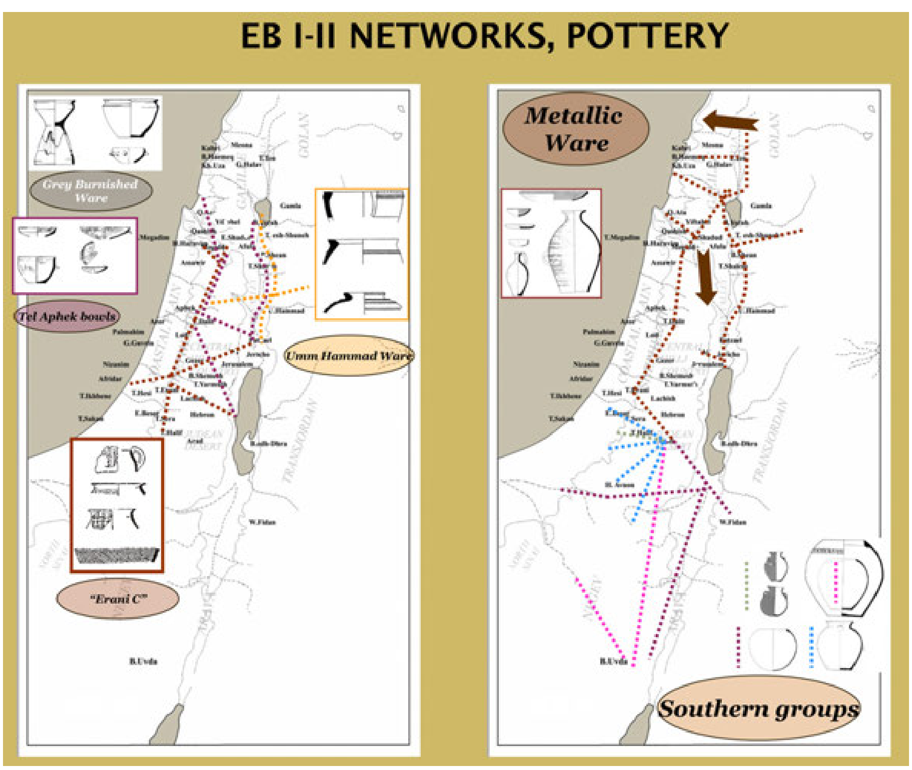


Fig. 5 Map with the distribution of main petrographic ceramic groups of the Early Bronze I and II. Color lines indicate distribution networks of the pottery groups.

of them non-published exemplars[30]), but there are 47 wheels from EB I–III sites, e.g. Ein Zippori, Bet Yerah, Megiddo, Meser, Hirbet Batrawy, Tel Yarmut, Horvat Ptora, and Ashkelon Barnea.[31] In the central Levant (Lebanon) several tournettes were found in the site of Tell el-Arqa but in EB IV contexts.[32] The low number of wheels in the Chalcolithic probably is due to a small number of potters doing the V-shaped bowls; according to Valentine Roux they could be itinerant specialists.[33]

6 Flint items

When we compare the flint production and exchange of tools also a striking difference could be seen from the Ghassulian Chalcolithic where local part-time workshops of sickle blades are found, utilizing local raw material, sometimes of low quality.[34] Unfortunately we know few of them, marked in red dots in the map of Figure 6. Tabular scrapers show a different story with long distribution lines from the south to the north.

These tabular scrapers continue to be produced in the EB, although with some changes in shape; some of them are decorated by incised lines.[35] However, the production of sickle blades totally changes. In the EB, the so-called Canaanean industry begun to operate with workshops located near the sources and networks distribution in medium distances.[36] The sickle blades were made of high-quality Eocene flint. The cores were prismatic and they have been found in few sites, while the blades were found everywhere. It is probably the work of full-time specialists and the distribution could be part of independent networks, or probably controlled by urban centers during the EB II-III.

7 Copper metallurgy

Another case is copper metallurgy, with the most striking example of different modes in the production and distribution between the Chalcolithic and the EB, even from the first stages of the EB I (Tab. 3).[37]

The main point to note is the fact that in the Chalcolithic the ores originated in the area of Wadi Feynan are transported to the area of Beersheva, where all the process of smelting and melting is done (Fig. 7).[38] In the EB there are sites near the sources in Feynan producing the so-called cakes, and the process of casting is done in other multiple sites in the southern Levant. Also, the EB types of tools and weapons are more variegated that in the previous Chalcolithic.[39]

Another important question is that during the Ghassulian Chalcolithic there is a lost wax industry producing luxury items as those of Nahal Mishmar, different from the simple cast mould production, and utilizing non-local antimony-arsenic alloys in few but important quantities. This industry disappears totally during the EB, putting a big question mark to our understanding.

During the Chalcolithic there are few production centers of the simple production in casting molds. The production centers of the lost wax technology were probably located in the Judean desert or the Shephela.

An intermediate phase could have been existed between 3650 and 3500 BC at sites located in the Araba gulf, like Hujayrat al Ghuzlan.[40] Exchange with ingots can be observed there, and bifacial flint tools (axes especially) were replaced by copper tools.

According to researchers of the site[41] these changes must be connected with social changes at the stie and the region. Copper production is connected with the construction of several structures such as channels and pools for irrigation and an enclosing wall.

30 The only published tournettes from the Chalcolithic are those from Lahav published by Jacobs and Borowski 1993, fig. 6; Dessel 2009, 20–23, figs. 7–8. One tournette was found recently at Motza, near Jerusalem in large salvage excavations conducted by Anna Eirikh-Rose and Uzi ʻAd, on behalf of the Israel Antiquities Authority (Lic. A-8661/2019).

31 Dothan 1959, fig. 8:16; Milevski and Baumgarten 2008, fig. 8.3; Roux and de Miroschedji 2009; Milevski, Liran, and Getzov 2014; Rosenberg and Golani 2012; Fiaccavento 2013 (with bibliography); Greenberg 2015.

32 Roux and Thalmann 2016, fig. 15.

33 Roux and Courty 1997.

34 Vardi 2011; Milevski, Vardi, et al. 2013, 107–128.

35 Rosen 1983b, 1997.

36 Rosen 1983a, 1997.

37 Shalev 1992; Shalev 1994; Golden 2010; Shugar and Gohm 2011.

38 Levy 2007.

39 Shalev 1994.

40 Khalil and Schmidt 2009.

41 Klimscha 2013.

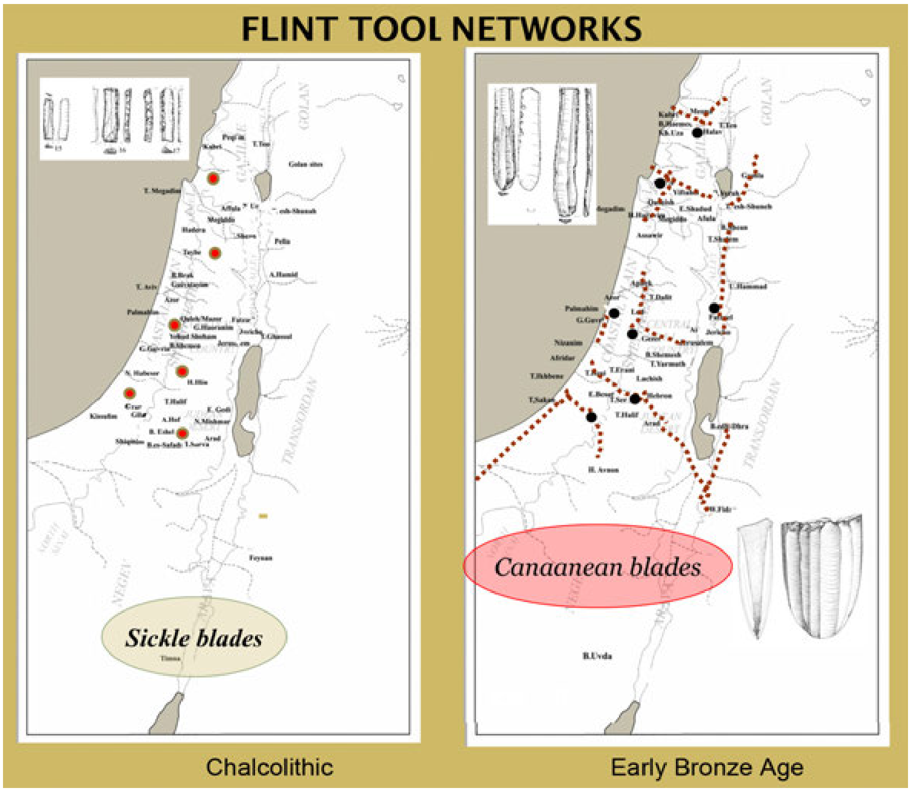


Fig. 6 Map with the distribution of flint blades from the Chalcolithic and Early Bronze I–III. Red dots indicate flint workshops in the Chalcolithic sites. Black dots indicated sites where Caananean blade cores were found and are thought to be workshops or centers from where the blades were distributed (doted brown lines).

Chalcolithic	Chalcolithic	Early Bronze I
1. Raw Material		
Mineral	Copper+	Copper+
Sources	Surface collection	Surface collection
Geological sources	Feynan (Timna?)	Feynan (Timna?)
2. Extraction		
Place	The ores are transported to Nahal Beer-sheva 150 km from the sources	Feynan, near the sources, copper blocks ('cakes')
Process	Ovens, crucibles	Ovens, clay blowers
3. Production		
Casting	Clay moulds/open installations, bifacials and awls	'Cakes' are transported to production sites, melting in crucibles, casting in close moulds/stone installations
Additional processes	Heating and hammering the blades	Heating and multiple hammering of blades

Tab. 3 Chart showing a comparison between the Chalcolithic and Early Bronze copper metallurgy of the southern Levant.

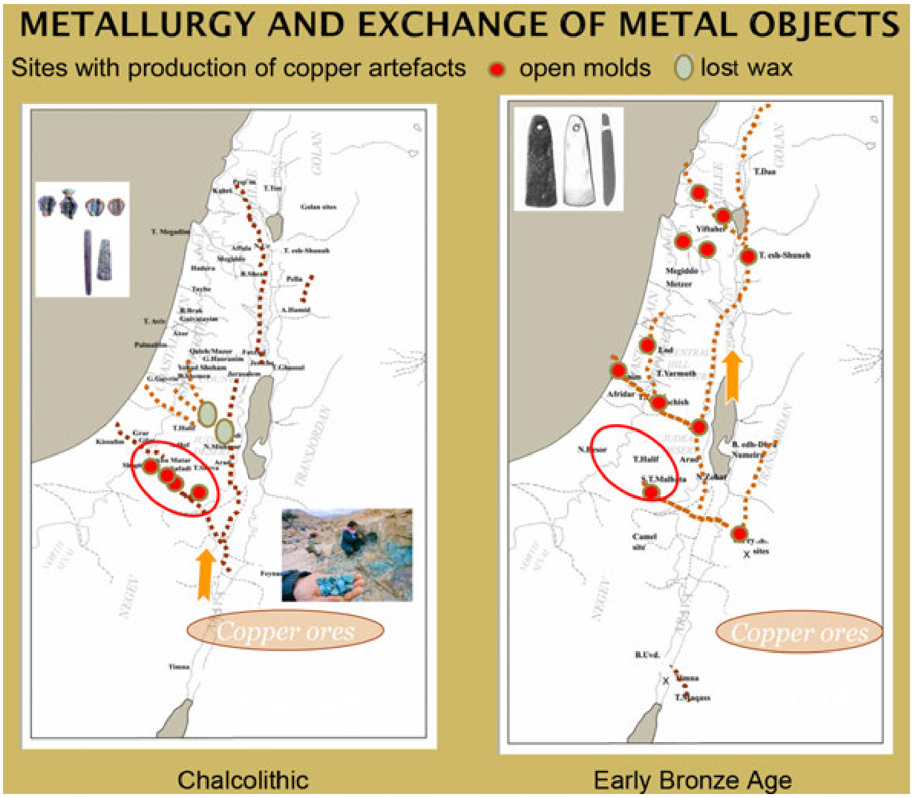


Fig. 7 Map with the distribution of copper artefacts during the Chalcolithic and Early Bronze I–III. Colour lines indicate Distribution networks of copper objects.

The great change became during the EB with numerous production centers in several regions of the southern Levant and the disappearance of the Beersheva valley sites.

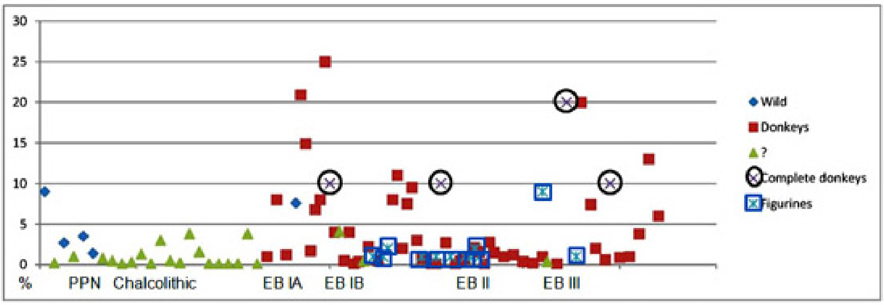
8 Domestication of donkeys

The domestication of the donkey, the *Equus asinus* is a fact of major consequences. Without going in detail, it looks that it has its ancestor in the African wild ass.[42] In the southern Levant, some colleagues[43] sustain that already in the Ghassulian Chalcolithic some domestication occurs. This is difficult to prove, but what is simpler to prove is that during the first stages of the EB I this domestication occurred (Fig. 8). For that we have the faunal remains of clear identified *Equus asinus* (mostly on the basis of the enamel pattern of teeth) and by the appearance during the EB IB of clay figurines representing donkeys with containers.[44] These figurines appear to show that during the EB II and III the donkey is also ridded as can be seen in the example of Khirbet Zeraqon in Jordan[45] but also with the examples of Mahruq and Lod[46] showing donkeys with saddles.

When we put together all the data we have on the equid remains of the Chalcolithic and the EB, and even before, it can be seen that only clear defined donkeys, *Equus asinus* appear in the EB, these are the red squares in Figure 8, wild identified species are blue rhombs, and the green triangles are equids which where not clearly identified.

That figure represents all the archaeozoological data with only complete skeletons appearing during the EB and not before; the donkey clay figurines appear in the EB IB. These figurines are part of a sort of a cult on these animals which were breaded and conducted by specialists, probably those also involved in exchange. The cult appears more or less some 300 years after the domestication. In sum the appearance of the donkey as a means

42 And see full discussion in Milevski and Horwitz 2019.
43 I.e. Grigson 2012.
44 Milevski 2011, 171–197.
45 Al-Ajlouny et al. 2013.
46 Hizmi 2004; Milevski 2011, fig. 10.4,3–4; Milevski and Horwitz 2019.



Note: Each spot represents a site in a certain period. Complete donkeys and donkey figurines represent units.

Fig. 8 Frequencies of equid remains in the southern Levant during late prehistory.

of transportation should have important effects in exchange which we have seen in the case of pottery, flints, and even in the transportation of copper.

9 Discussion

Techno-social innovations occurred during the ‘Copper Age’ in the southern Levant could be exposed in the chart of Figure 9. We try to set all the information presented before and see how the mode-of-production paradigm could be of utility.

We are going from the Chalcolithic village mode were in general all the settlements have a relatively equal standard, some of them perhaps with sanctuaries; agro-pastoral activities and crafts are imbedded into these settlements. The EB I, is pre-urban, the village community exists but a major circulation of goods is attested.

Craft specialization goes from part time in the Chalcolithic period to full time in some cases in the Early Bronze as the examples of the flint, pottery and copper production seem to show. The multiplication of exchange networks and extended lines of commodities movement in the EB implies a change in settlement patterns, and most important, a change in social organization which conducts to a pre-urban society in the EB I and an urban society in EB II–III.

Then the urban EB II–III shows the growing effect of these changes, they are converted in techno-social changes, with major units dominating small communities and making an advance in craft specialization. Perhaps small unites ‘paid’ some tributes to the superior institutions, i.e. palaces and temples; this could be also done directly in labor.

If we utilize the modes of production presented at the beginning of the paper, we can say that the Chalcolithic and EB IA show some kind of communal modes of productions more or less related to kinship relations within these communities; we do not know the exact forms of families or clans. At the end of the EB IB and the urban phases of the EB II and III we can suggest that we are on the tributary mode of production, probably one of the several forms this mode of production took.

Most interesting than these definitions, is that we can see that technological innovations came before, then the social changes; this is what we refer in the beginning of this paper as a time of changes because the production forces does not fit with the relations of productions.

10 Summary

The transition from the Chalcolithic to the Early Bronze Age in the Southern Levant represents a change in socio-economic systems that went from agro-pastoral communities in the Chalcolithic, with relatively developed secondary production branches, to an urban revolution towards the end of the EB I, developing in the EB II and EB III. The shape this transition took place is of course different in several aspects as those of other regions of the Near East, but the contents are probably the same conducted at different paces and deepness.[47]

The manufacture of pottery, flint tools, copper implements and others changed both in technology and

47 E.g. Frangipane 2012.

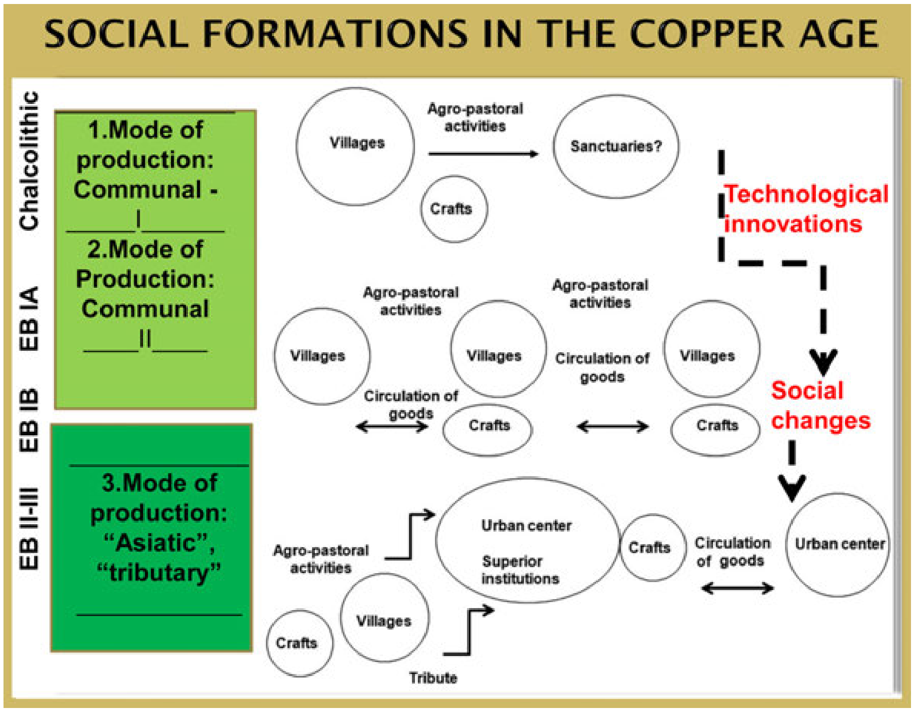


Fig. 9 Chart summarizing the modes of production during the 'Copper Age' of the southern Levant.

organization of production and distribution; a major division of labor occurred in this transition.

Means of transportation were deeply transformed with the domestication of the donkey; the circulation of commodities grew up from the Chalcolithic to the EB.

Architectural concepts changed from the very beginning of the EB I until the urbanization of the EB II–III. The same with the burial customs we presented here; they went from household, communitarian burials in the Chalcolithic to more socially differentiated cemeteries in the EB II–III.

In the final analysis, it is a question of the transformation of certain forms of social and economic relations into other forms, i.e. different modes of production. Of course, we need more research, in order to arrive to deeper conclusions. Technological innovations came before, then a new social organization appeared in the southern Levant.

Let us conclude that while it is difficult to define social relations in non-literate periods, and the old frameworks and definitions must be deepened, some of them may be changed, the materialistic-dialectic thinking is still a good instrument to understand techno-social innovations in prehistoric societies as Gordon Childe[48] did for the whole Near East. For us the southern Levant was a local expression of the social evolution, already presented by him, with all the new data accumulated and processed in the last decades.

48 Childe 1944; Childe 1956.

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Mapping Innovations during the European Iron Age. Introduction

Summary

During the Iron Age, between the 8th century and the 1th century BC, all the societies are clearly in a state of rapid evolution. This period of development is showing significative innovations which transform the social and economic way of life. By example, Celtic peoples have invented the scythe and adopted the Iberian Rotary mill. The coins are created by the Lydian's during the 6th century BC and they were introduced in Gaul, during the 3rd century BC. The agricultural tools' innovations didn't have any influence on the social organisation but they are progressively a real progress for the domestical way of life. Romans are more interesting by the production concentration for bread, ceramics, and metal for increasing production output.

Keywords: Iron Age; Celtic; rotary mill; scythes; coins

Während der Eisenzeit, zwischen dem 8. Jahrhundert und dem 1. Jahrhundert v. Chr., befinden sich alle Gesellschaften eindeutig in einem Zustand rascher Entwicklung. Diese Entwicklungsperiode weist bedeutsame Neuerungen auf, die die soziale und wirtschaftliche Lebensweise verändern. So haben beispielsweise die keltischen Völker die Sense erfunden und die Iberische Drehmühle übernommen. Die Münzen wurden im 6. Jahrhundert v. Chr. von den Lydern geschaffen und im 3. Jahrhundert v. Chr. in Gallien eingeführt. Die Neuerungen der landwirtschaftlichen Werkzeuge hatten keinen Einfluss auf die soziale Organisation, aber sie stellen nach und nach einen echten Fortschritt für die häusliche Lebensweise dar. Die Römer sind aufgrund ihrer Konzentration der Produktion auf Brot, Keramik und Metall zur Steigerung der Produktionsleistung interessanter.

Keywords: Eisenzeit; keltisch; Drehmühle; Sensen; Münzen

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Innovation is the act or process of introducing new ideas, devices, or methods. In principle and as a general rule, the society is resisting to novelties. In order to make it acceptable, it is fundamental to convince the community of its usefulness. To identify innovations and their adoption in a specific area, we need four parameters: a typological definition of the artefact, the dating of its introduction, archaeological contexts and geographical expansion. Accordingly, the BaseFer database which we created in order to obtain a general vision of the Iron Age in Gaul is quite useful for observing the cultural and technical evolution during this period.

The primary aim of the BaseFer database is to quickly visualize the knowledge on this period by establishing distribution maps at the scale of Europe. 15400 data have been collected on the Gallic Iron Age (750–15 BC) (Fig. 1). They are recorded and documented in GIS.[1] The purpose is to compare general data on settlements, burials, sanctuaries, deposits, etc., at the scale of the region or of the modern country. On this database, it is possible to develop statistical and spatial analyses: density maps, trend analyses, correspondence factor analysis, hierarchical clustering. The possibility to superimpose different maps allows the user to come back to the primary data at any time and to understand better the different contributions to the results of the spatial analysis.By example, we can select all the settlements in the database (Fig. 2) and then focus on those with post-buildings (Fig. 3).

After a short presentation of our treatment of the typo-chronology, we present three specific artefacts which transformed the economy of the Iron Age: the creation and the diffusion of the scythes – 400 B.C., the rotary querns – 500 B.C. in Iberia and the coins – 300 B.C. in Gallia.

The first step in order to analyse innovation is to define the chronology. For the Iron Age, we can obtain quiet good dates, by quarter of century. Here, we established the chronology by considering the end of the sites' occupation (Fig. 4). This corresponds to one period of our typo-chronology. Some sites could be in activity during a long time. The density of occupation is quite different from one region to another (Fig. 5). It is a real historic data which is not affected at this scale by the conditions of the sites conservation.

If this way of dating innovation has a real meaning, we must distinguish the settlements occupied during one period from the longer existing ones. This means to take away a lot of sites. The reference to the archaeological context of each discovery like settlement, necropolis, deposits etc. is useful in order to clarify the nature and type of the innovation and its using.

1 The development of the scythes in the Iron Age

The Scythe is a tool which was developed primarily in Europe, in the part of the world assigned by literary sources to the Celts and their neighbours. Gallic scythes have already characteristic features of this type of tool. But the scythes we know in modern times appear only during the 5th century AD. Olivier Nillesse assembled a corpus of 250 scythes for the Iron Age in Europe and created a typology.[2]

There are some scythes with socket, but most blades are connected to the handle by a tang and a ring (Fig. 6). This very original and old type of binding allows adjusting the opening of the blade against the handle, and correcting it if the blade undergoes a shock. The opening of the blade against the handle is characteristic. The 'celtic scythe', handled by one hand, have a very wide opening. Blades of scythes, handled with both hands, form an acute angle with handle. In addition, the blades cutting edge of the scythe handled with both hands is not in the plane formed by the neck and the back of the blade.[3] Thus the reaper can work with both hands and standing. These two tools have been used until the 19th century. But they were up there almost always reserved for the mowing of hay. Cereals were cut with a sickle until the 18th century. The distribution of the Iron Age scythes covers a large part of Celtic Europe. It is rare in the West, missing from Brittany, Scandinavian and Poland in the Iron Age, in the current state of the counting of the bibliography. A quantitative map accentuates the continental character of this distribution.

1 See Atlas of the Iron Age on http://www.chronocarto.eu/spip.php?article20&lang=en (last accessed 02/03/2021).

2 Nillesse and Buchsenschutz 2009.

3 Henning 1985.

The types distinguished by O. Nillesse form several geographical groups (Fig. 7): Scythe socket are distributed exclusively in the West of the France. It just found one near Chartres. The type 3 characterizes the region of the Alps. The dates are fairly coarse, because contexts are not favourable. Most of the Scythe blades are discovered on the surface, or in deposits that contain only iron objects, difficult to date. The oldest, however, are located north of the Alps. Many scythes have been found in deposits of iron objects. They are often associated with other agricultural tools. Moreover, deposits of iron objects are in this period very common, but according to the regions, they are deposited in different contexts. In Central Europe, they are isolated in the countryside, or gathered in hill forts, which are reserved for them (there are no associated settlement). In Gaul, the metal deposits are often in shrines, as in Gournay-sur-Aronde or Ribemont.

The long iron nails, which assemble beams in the *murus Gallicus* timber laced rampart, could also be assimilated to a specific form of iron deposit.[4] This innovation is extraordinary, insofar as it is very limited in time and space. Discoveries of *murus Gallicus* are confined to Celtic Gaul (Fig. 8).

We are confident about our conclusion because their distribution has not changed since the survey of A. Cotton in 1957, even if their number increased by two.[5] They are dated between 130 BC and the end of the previous era. *Murus Gallicus* is a fashion, a ritual more than a material protection. In fact the cost of manufacturing of the thousands of nails is exorbitant when compared to their effectiveness in strengthening the rampart.

2 Innovation in the Iron Age: grain mills

The evolution of the techniques of grinding of cereals in the Iron Age is a real revolution: it increases really the mill's productivity. This is the period where the rotating mill develops in Catalonia, then in Gaul and throughout the Celtic world. There are three main types among the mills used at this time (Fig. 9).

- The saddle quern includes a stone held in both hands that is rubbed on a flat stone. This technique is known since Neolithic.

- A more elaborate mill is called 'hopper grinders' or 'Olynthian mill' because it was first studied on the Greek site of Olynthos. The two elements are carefully pruned. The upper stone is pierced by a slot that allows a regular diet of grain. Training, which is still the subject of discussions, is operated by a handle or a wooden frame.

- The rotary mill represents a real revolution. It turns the upper stone (*catillus*) on the fixed lower stone (*meta*). The envelope of the grain is broken and flour flows on the edges. The manufacture of one kilogramme of flour is fifteen times faster than with a saddle quern.

A systematic study of these Mills was launched in France by the Team "Groupemeule".[6] It follows the precise typology and developments of these tools in space and time.

Mapping rocks used to highlight the origin and diffusion of the mills. From Neolithic until historical periods, the supply is sometimes limited to a short distance, other times best rocks are looked for over hundreds of kilometres. There are no regular chronological progressions of the distance of supply. Technical or morphological rotary quern variations characterize areas or periods. But the first rotating grinding tools are sometimes more elaborated than most recent mills. Some chronological developments, however, can still be observed. For example, the diameter of the mills increases regularly in Gaul during the second and first century BC.[7] This requires a more complex drive system, because the human arm has no longer enough force to rotate the heavy wheels. Stratified settlements that provide wheels are very rare. A fine example is the port of Lattes near Montpellier (Hérault) (Fig. 10).[8] It is occupied by a mixed population, Greek and native. M. Py showed that the saddle querns were used from the 4th to the 3rd s.; Olynthian mills appeared at the end of the 4th century, and were abandoned at the beginning of the second century BC.

4 Ralston and Buchsenschutz 2014.
5 Cotton, Wheeler, and Richardson 1957.
6 Buchsenschutz et al. 2011.
7 Jaccottey, Jodry, et al. 2011; Jaccottey, Defressigne, et al. 2012.
8 Py 1992.

The rotary querns are attested in the second century BC. A Pompeian quern fragment was discovered in levels of the first century AD. In Roman times, large traction animal or hydraulic mills were more and more frequent. The manufacture of flour left the domestic area and became professional. The spatial analysis of the penetration of the three major types of mills in Gaul during the Iron Age shows a gradual progression (Fig. 11).[9] The first rotary querns came from Catalonia and remained limited the South of France during the fifth century BC. Also, in the South of France, the Olynthian mills competed with the Iberian rotary querns (as we saw in Lattes). The Northern mills are always saddle querns. From the third century BC onwards, rotary querns spread in the North of Gaul, Olynthian mills resisted in Provence. During the first century BC, the rotary querns virtually occupied the whole territory.

Introducing this new mode of production does not involve the transformation of the Iron Age social organisation. Rotary querns remain in the household, but the productivity of this new instrument defeated traditions. We can say that the indigenous technology is, in this period, more effective than that of the Greek and Roman world. A more detailed study shows that regional or historical differences still exist in details.

Is there any explanation for the appearance of this revolutionary tool?

The use of the wheel in the production of objects and of the circle in their decoration, could promote the emergence of the rotary querns in the Celtic world. The appearance of the first rotary mills in Champagne was contemporary to the creation of *phalerae* decorated with intricate circular designs.[10] But the relationship between graphics, mathematics, and the use of the kinetic energy is not sure at all. It is possible to find distant heritage, with the wheel or the animal carousel. This does not explain the innovation represented by this new engine. It is clear that the technical possibilities to build were present from the fifty century BC onwards. But it is the idea of using the rotary movement to crush something that is at the heart of innovation. Its dissemination ran against tradition and other competing machines, as in the modern world.

3 Introduction of coinages in Celtic Europe

Coins have been created by the Lydians, during the 6th century BC;[11] in Gaul, coins were introduced during the third century BC probably by the mercenary warriors, employed by the Macedonian kings and by the Greek colonies on the northern Mediterranean coast (Emporium, Rhode, Massalia), and were copied throughout Gaul.[12] Gallic coins were especially influenced by the coinage of Philip II of Macedonia. Celtic coins often retained Greek subjects, such as the head of Apollo on the obverse and two-horse chariot on the reverse of the Philip II 's gold stater. The Celtic issues kept all the details as the legend ΦΙΛΙΠΠΟΥ (in Greek) and the mint marks (for example a Trident) but they also developed their own style on that basis, which brought to the development of a Greco-Celtic synthesis (Figs. 12, 13).[13]

During this first period, Celtic coins rather faithfully reproduced Greek types; it is possible to identify the model by the Greek mint mark. After, designs became more symbolic and generated all the iconographic variations of the Gallic coinages. If we look at the diffusion of the Greeks coins in Gaul through the collected data from BaseFer, we observe the difference of the distribution area for Massalia and for the other Greek cities. On a density map, the concentration of the Massalia issues in Southern Gaul contrasts with the Emporion coins near the Pyreneans and essentially with the Philip coins coming partly from the Danube and the Rhone River and partly from Massalia (Fig. 14).

The anamorphosis shows a Massalia coins' distribution map, in a distorted perspective; it gives us an image of the relations between Massalia and the Gallic hinterland; contacts are established only with the South by the rivers valleys, while the North remains unknown. It is quite interesting to compare this visual information to Strabo's mental mapping of Gaul, where all the mountains and the rivers have a South-North orientation (Fig. 15).[14]

Distribution and density maps of the gold coins show the choice of a gold standard in the North of Gaul and of a silver one in the Mediterranean area (Figs. 16,

9 Jaccottey, Defressigne, et al. 2012.
10 Flouest and Bacault 2003.
11 Picard 2009.
12 Gruel 1989; Hiriart et al. 2020.
13 Gruel 2006.
14 Thollard 2009.

17) The bronze coins maps compile several numismatic phenomena (Fig. 18): In the South, the diffusion of the bronze issues of Massalia and the bronze series of Languedoc. In the North-East, first the impact of the potins issues, then the stricken bronze coins are very important. In the West part of Gaul, the potin coins are not used. The particularity of the Celtic coinage is the creation of specific cast potin issues with the presence of supra – regional Gaulish potin coins from La Tène C2. The potin MA, copy of the charging bull bronze from Massalia, appear in the Parisii area in La Tène C2 archaeological context and around Massilia at the same period (Fig. 19).

Coins were gradually introduced in the Celtic economy, as a result of several factors and influences. The consequence was the production of local and diversified coinages by different issuing authorities. The gold Greek coins brought by the mercenary warriors were quickly imitated, hoarded and used for specific occasions, as wedding, heritage, largesse etc. The Greek colonies from Spain or from the Gallic Mediterranean coast produced silver and bronze coins that were disseminated in Gaul for commercial use (payments change, protection, taxes). They were quickly imitated; the Greek then Roman standard (drachma then denarius) were adopted. This reference to the Mediterranean system served as guarantee; it shows participation of the Gallic space to the Mediterranean commercial transactions. The potins, casted coins, issued by the aristocrats and the sanctuaries during the second and first centuries BC, were a specific answer of the Gallic societies. The metal value is not constant in these potins, its uses "modalities must be different and could be linked to the Celtic clientelism".[15] They could have been used like the medieval token.

4 Conclusion

Innovation is the result of individual initiatives, to create a more effective or attractive tool. The work becomes faster, more pleasant, less painful than the traditional way. The means, how the results are to be achieved, depending on the experience, ability to think, to imagine, to dream, to go beyond the traditional approach, by reconsidering the traditional ways of doing and by adapting the operating procedures of other fields of work.

In the discussions of the colloquium, we have already felt the temptation of reconstructing the myth of humanity's progress and the idea of a relation between the developments of techniques and the evolution of the social structures. For the Celtic, Roman and Greek worlds, from the 5th century BC to the 1st century AD, the technical evolutions and the social organisation backwards and forwards, with convergences and divergences; after this period, the Roman Empire blocked most of the particularities of the local area for several centuries.

Celtic peoples invented the scythe and adopted the Iberian Rotary mill when they were leaving their first cities for living the countryside, in scattered settlements.

These tools, as the first socks and the 'vallus', harvesters' ancestor, are introduced in households of rural context. At the same period, Romans and Greeks chose the urban way of life, leaving to the others the most significant innovations; they were more interested in the production of bread, ceramics, and metal, with an increased production output. Petronius relates how Tiberius would have put to death a worker who had invented a type of unbreakable glass (aluminium alloy?) because this innovation could have increased the unemployment in the glass craftsmen's corporation (*Satyricon* LI).

It appears that all these innovations are introduced quickly or more slowly, in a more or less large area. A same tool can be used in different ways. It depends on the resilience of the cultural or social resistance, of the works' practices, of the elite's implications.

The 'François Sigaut triangle' (Fig. 20) well highlights the three parameters which determine the success of an innovation: the individual who produces a new idea, the real, which allows concrete application of this idea, and the 'others', or the traditional society, that accepts this invention, which becomes an innovation, or refuses it, letting it in the field of games.

Network analysis and mapping provides theory and method for adding a lot of phenomena to the archaeological understanding, including innovation and diffusion. It is in fact rare that a single innovation can influence rapidly a society. It is one parameter among many others and its effect would be noticeable only on the long term.

15 Gruel 1995, 139.

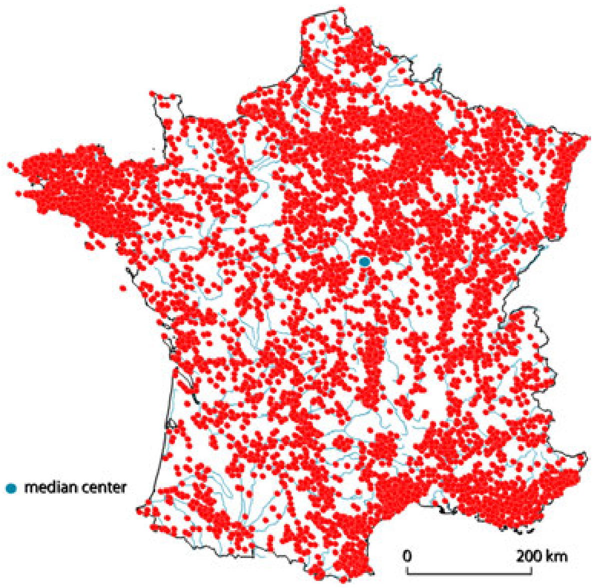

Fig. 1 Map of 15000 Iron Age Sites in France.

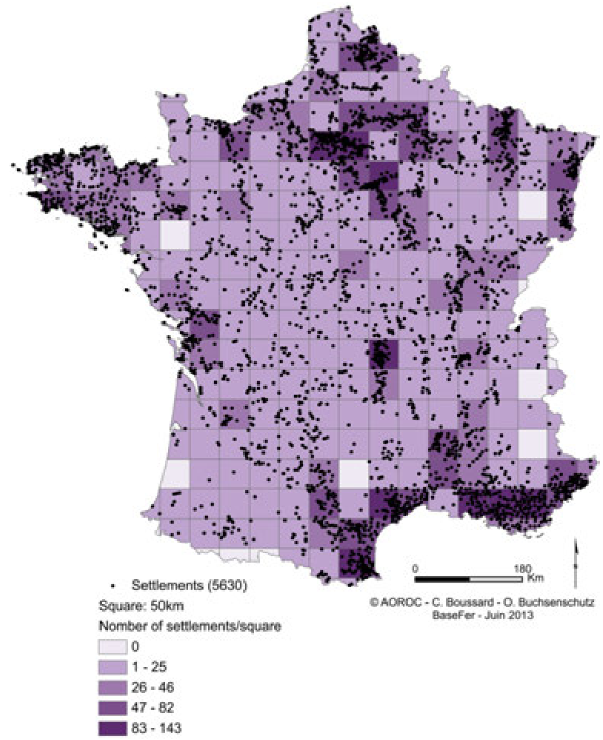

Fig. 2 Map of the Iron Age post-buildings in France.

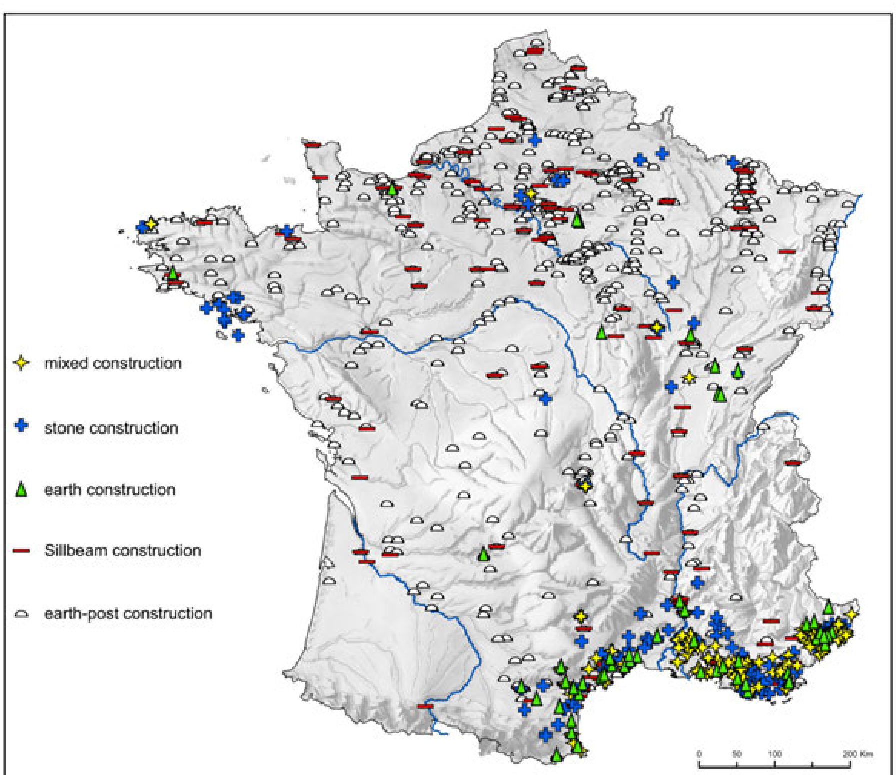

Fig. 3 Distribution of Iron Age Building Construction Techniques.

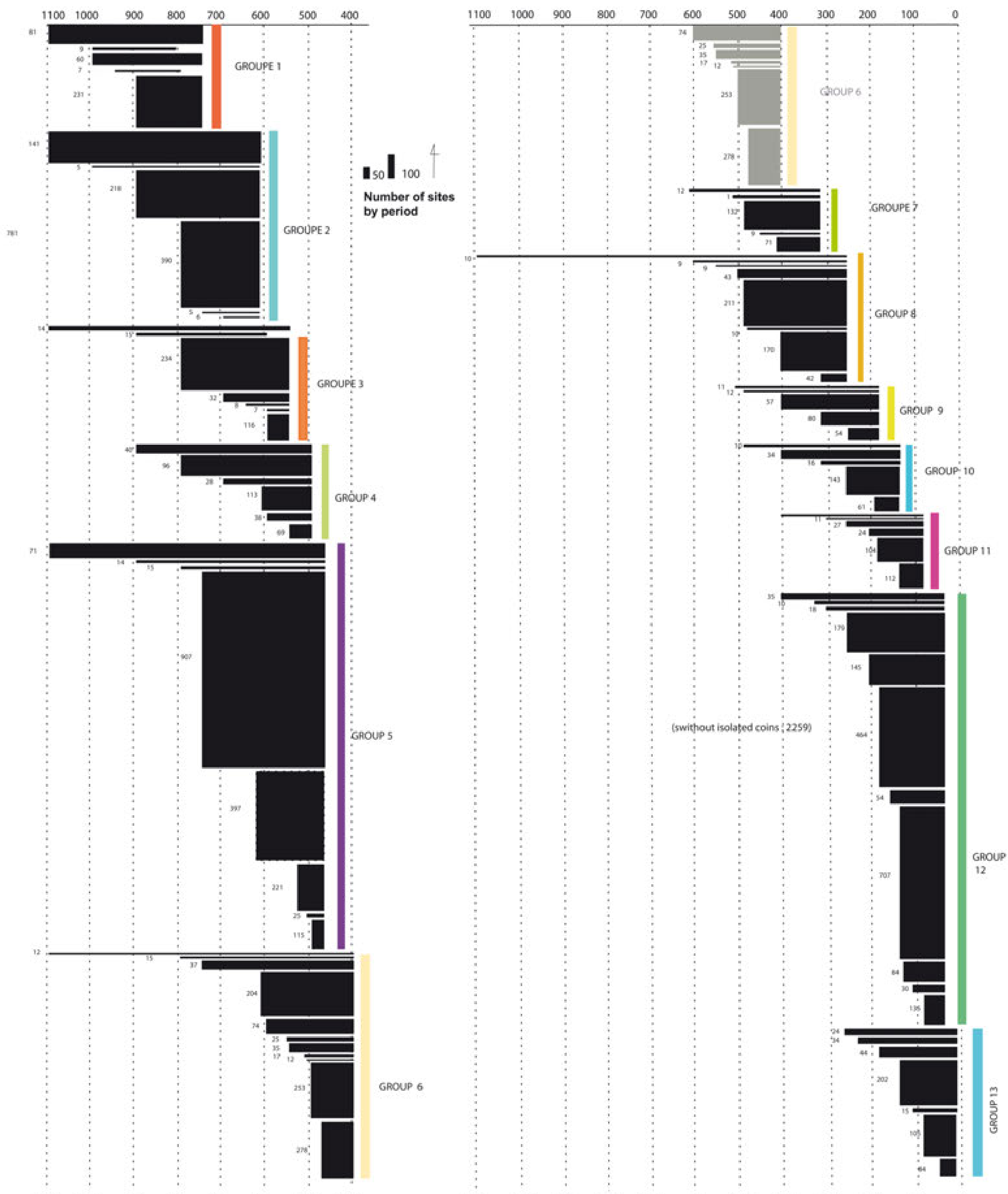

Fig. 4 Chronological distribution of the data.

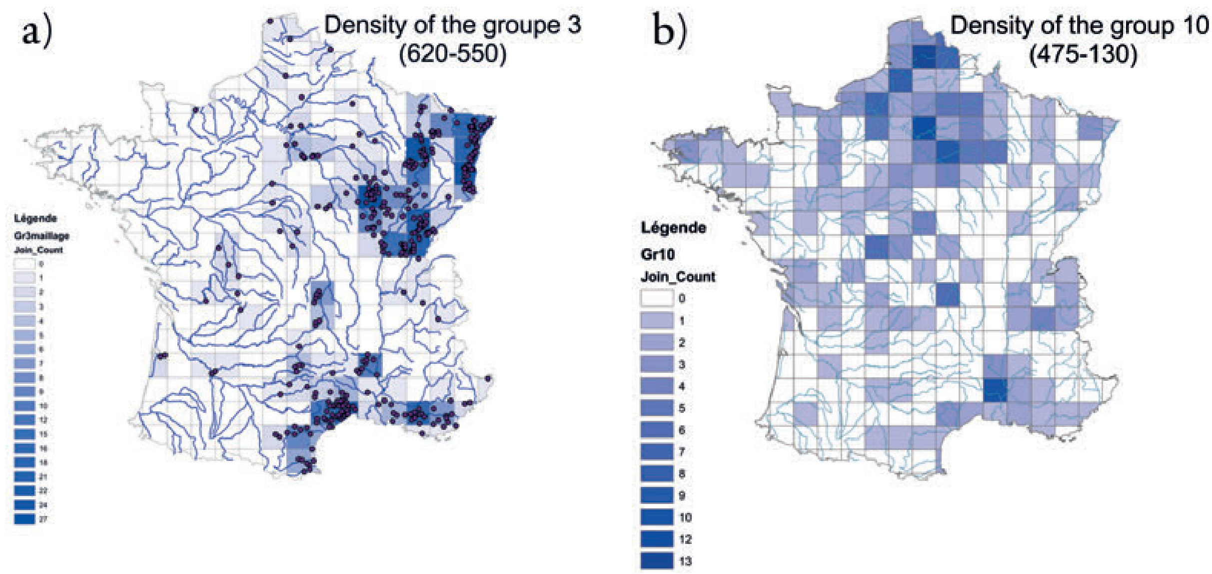

Fig. 5 Number of sites by department for various different periods.

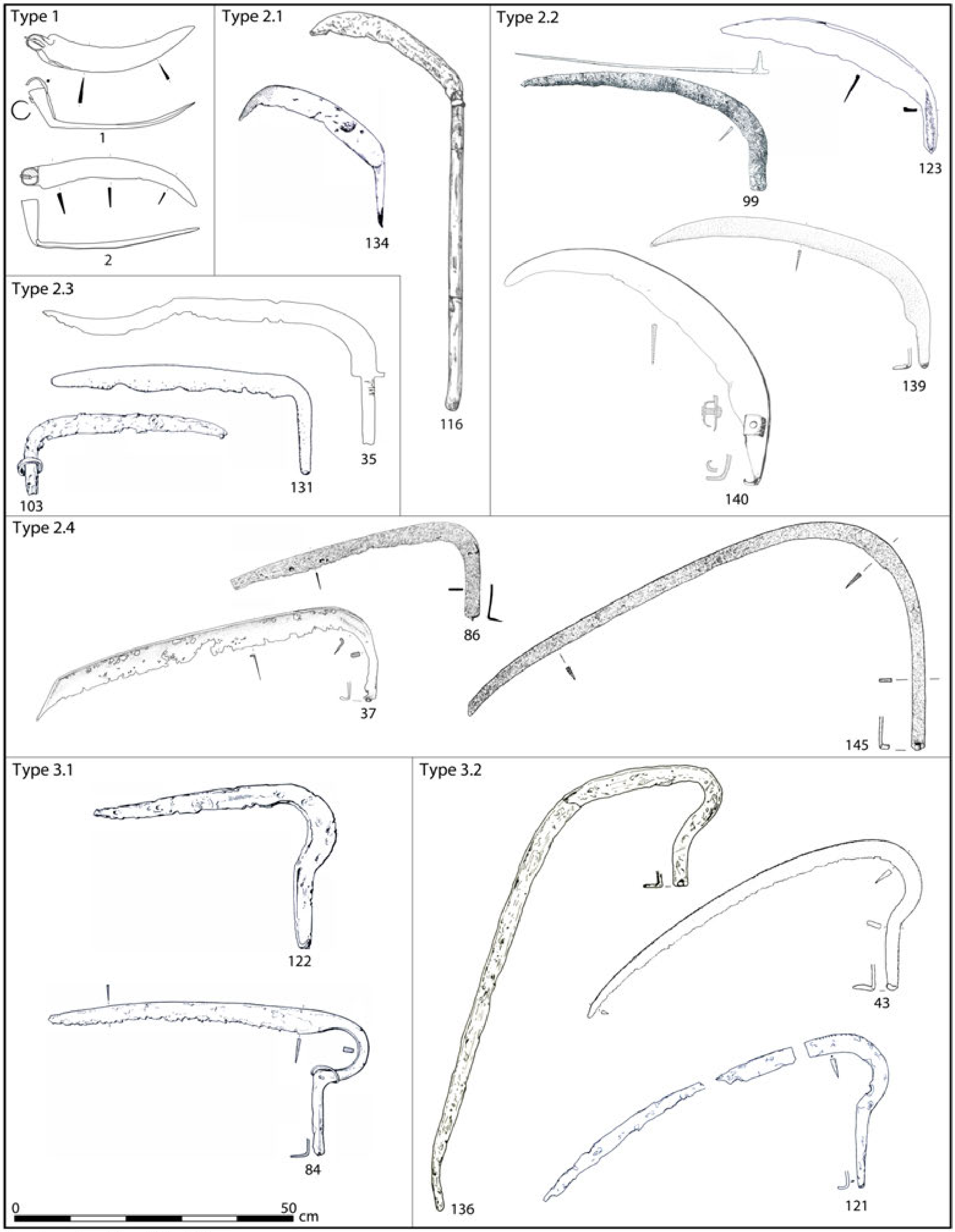

Fig. 6 Typology of ancient European scythes; 'celtic scythe' of La Tène site is the 116.

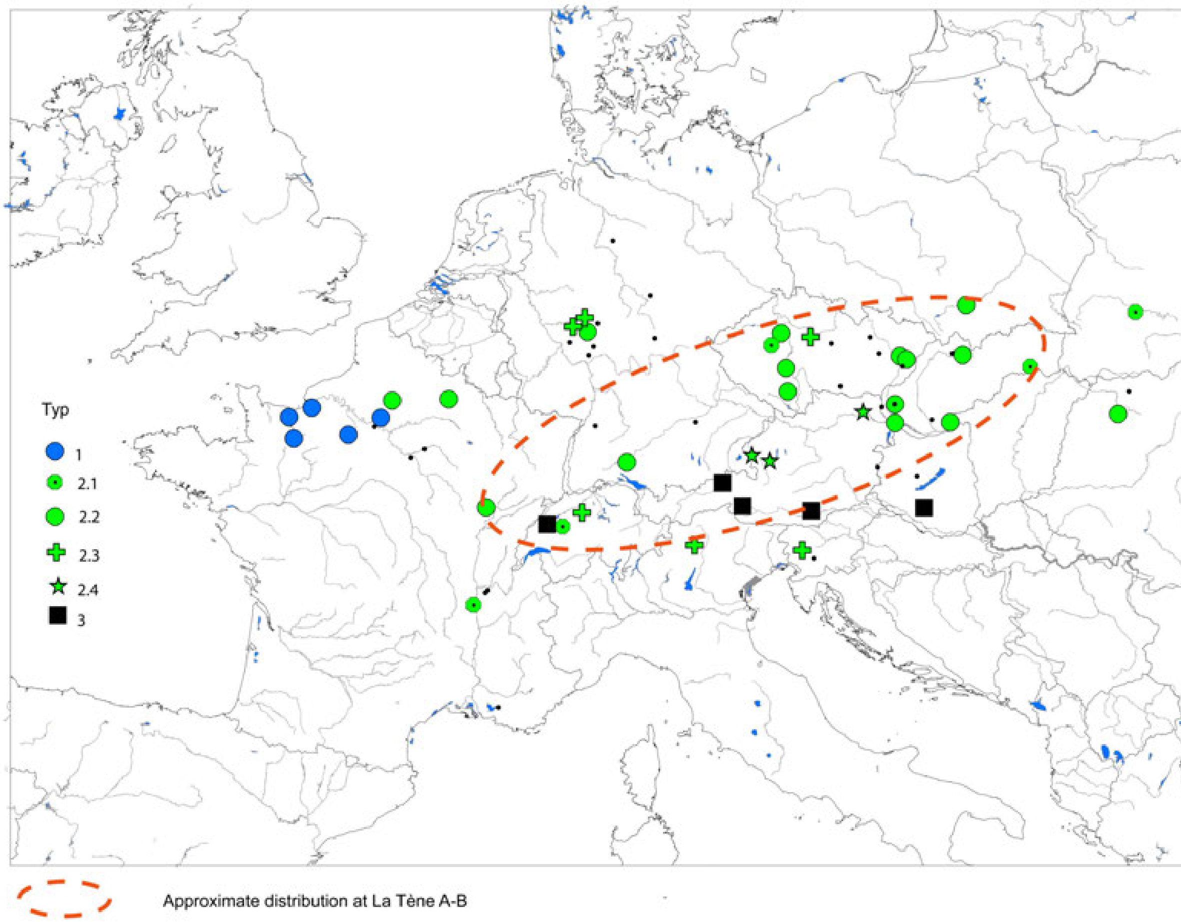

Fig. 7 Map of the typological groups of the scythes in Europe.

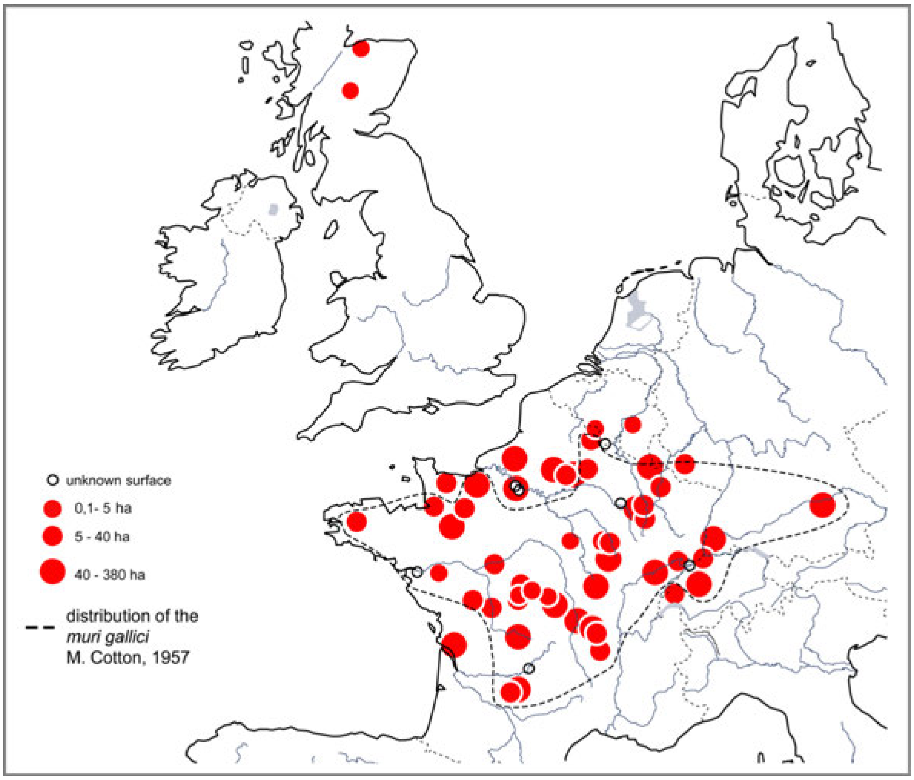

Fig. 8 Map of the 'murus gallicus' (nailed timber laced ramparts) in Europe.

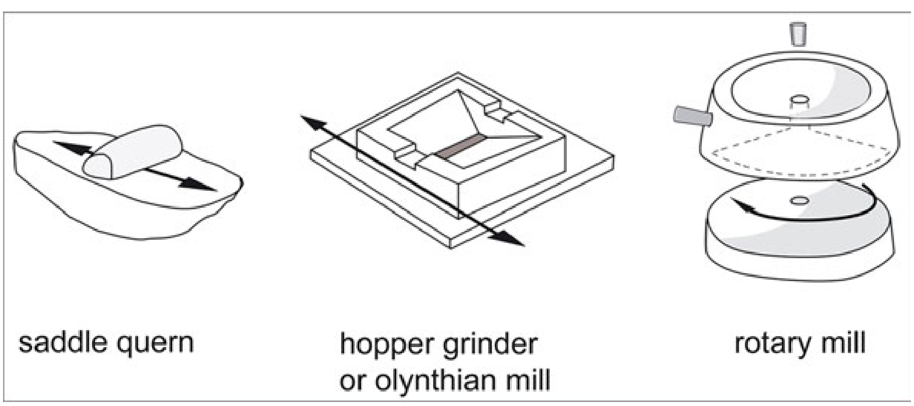

Fig. 9 Main types of Iron Age mills.

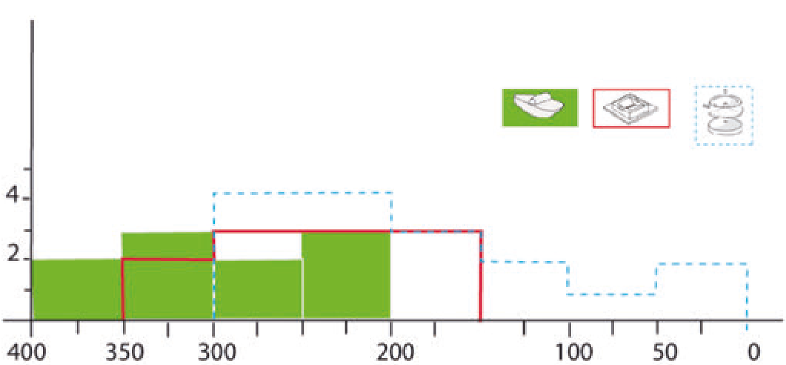

Fig. 10 Types of Iron Age mills in the port of Lattes (Hérault, France).

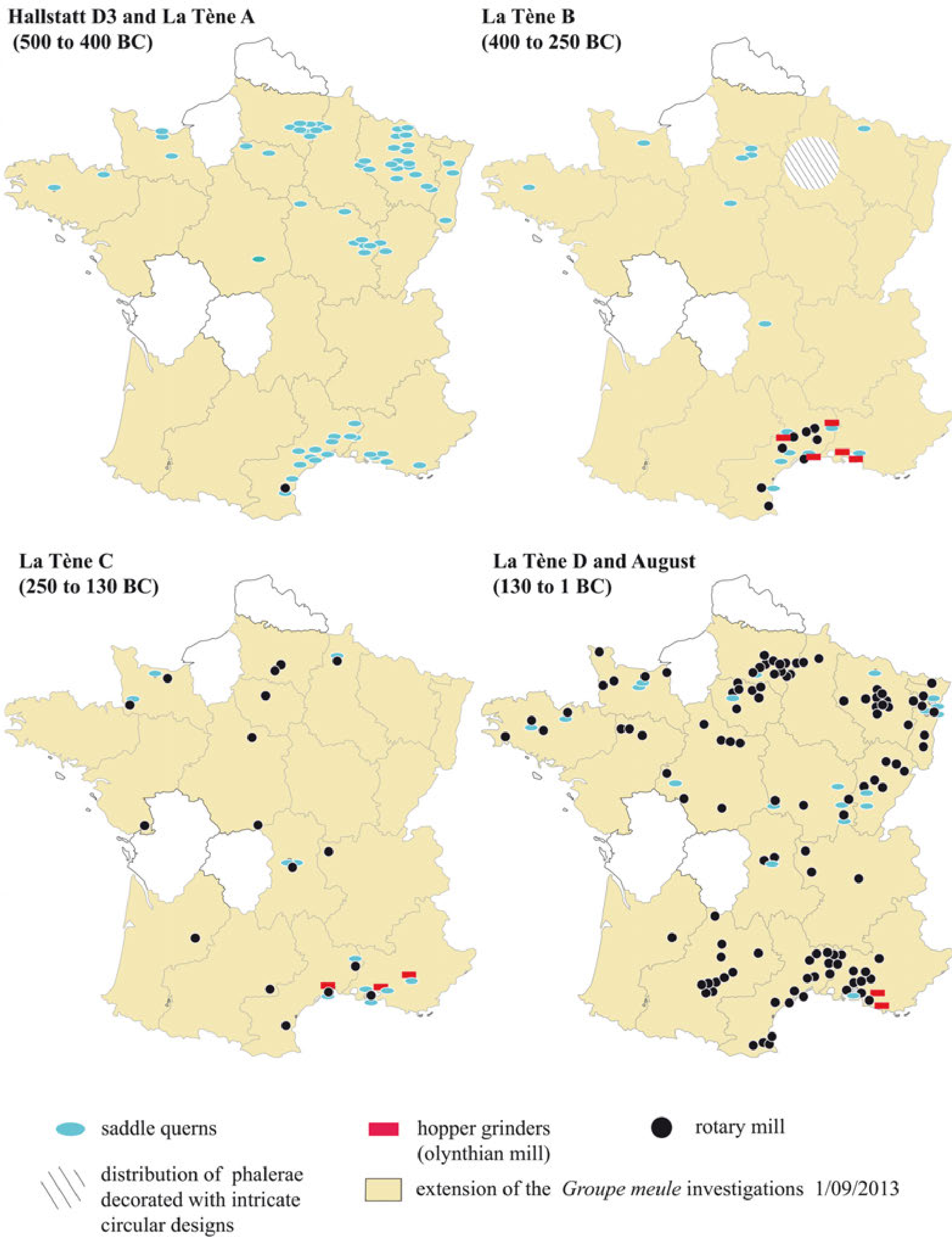

Fig. 11 Diffusion of the mills types in France in the Iron Age.

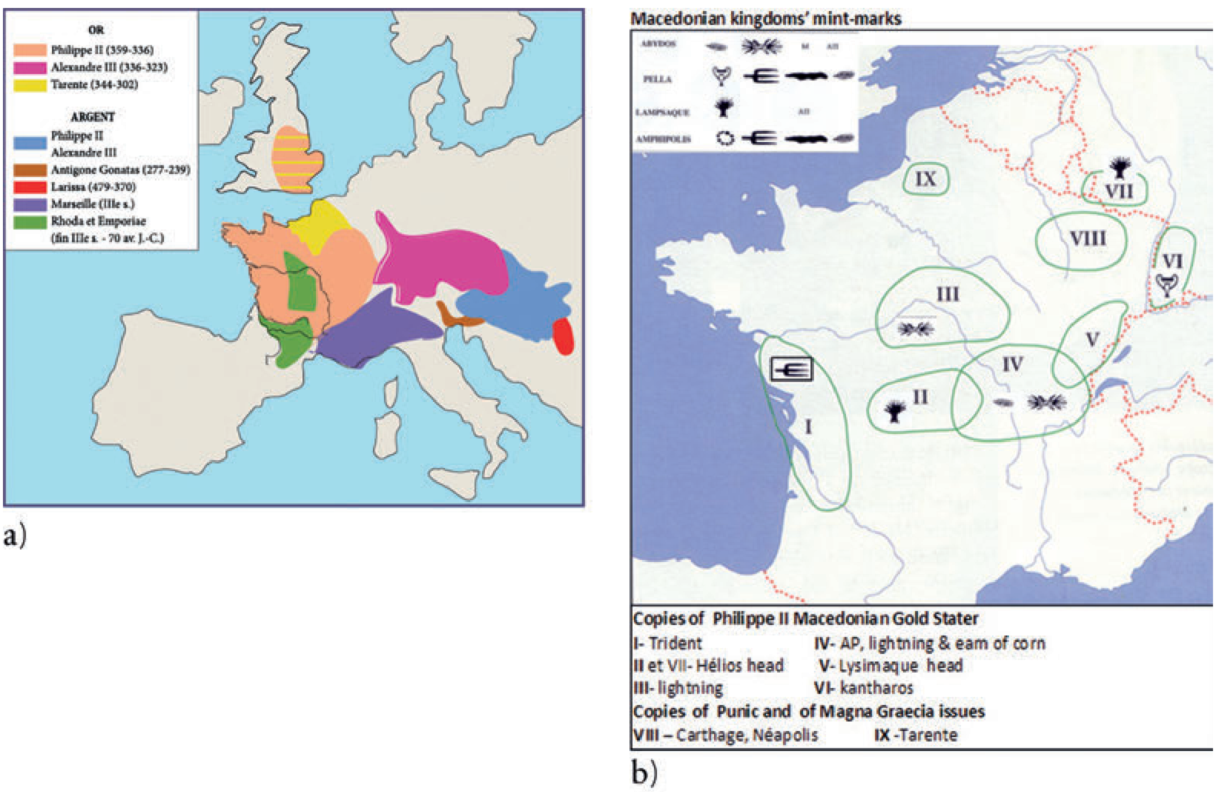

Fig. 12 Map of Greek prototypes copied in the Celtic area (a); Mints mark of Philip of Macedonia (b).

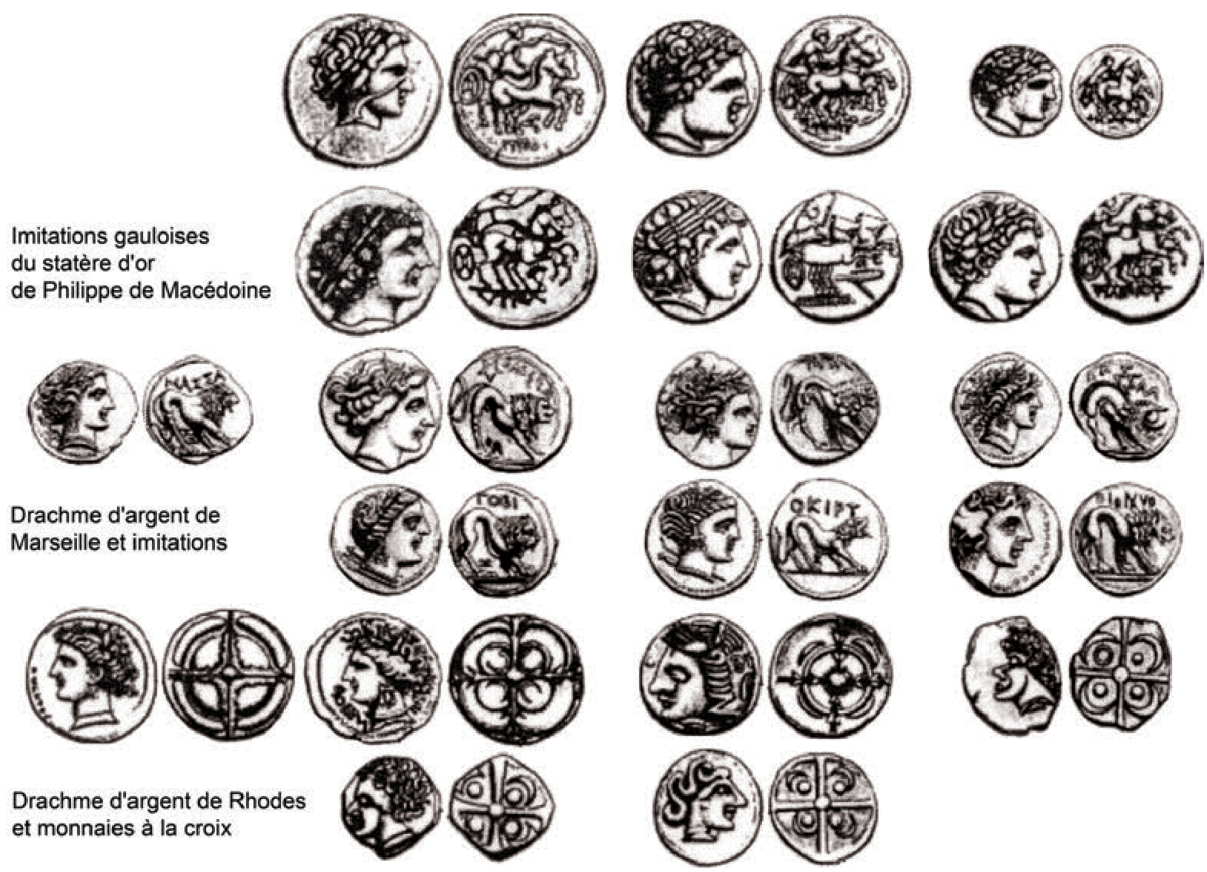

Fig. 13 Original Greek coins and their Gaulish imitations.

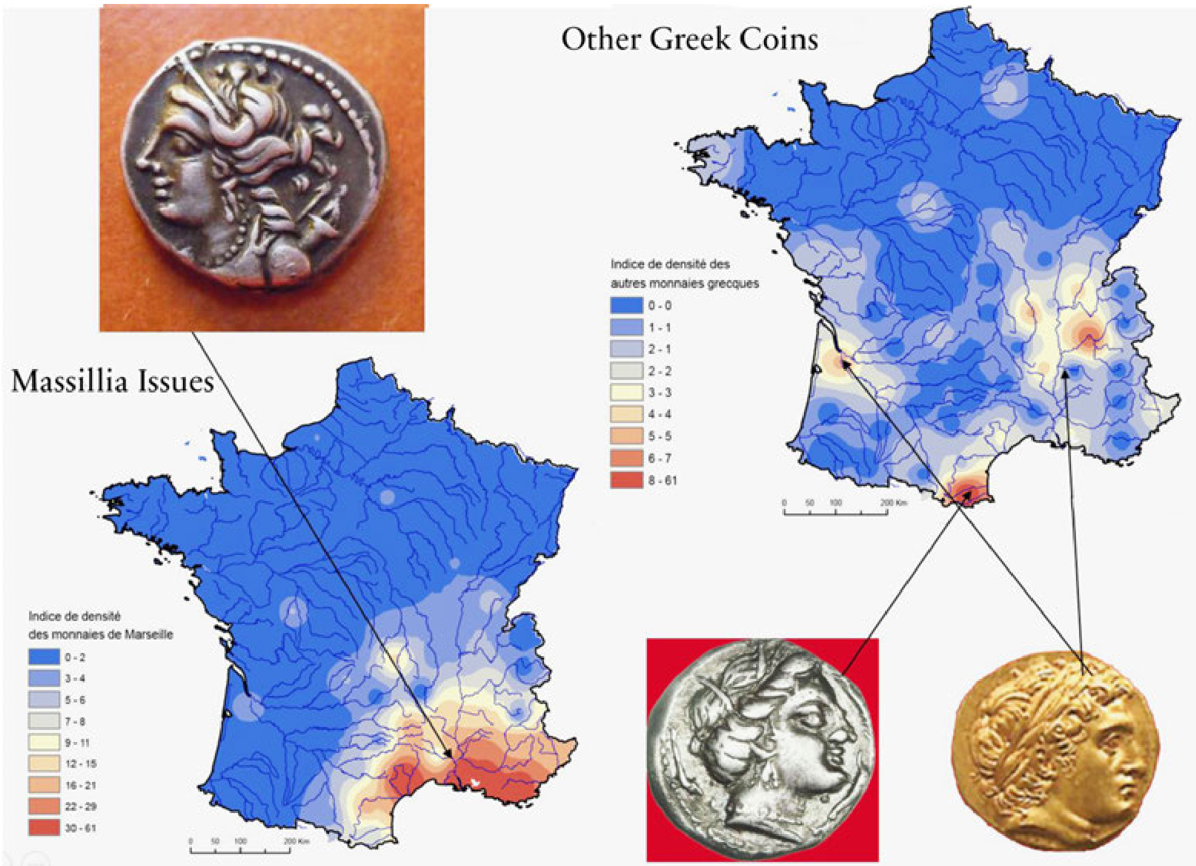

Fig. 14 Imitations of Greek coins, left – Massalia; right – Other Greek coins (Emporion and Macedonian stater).

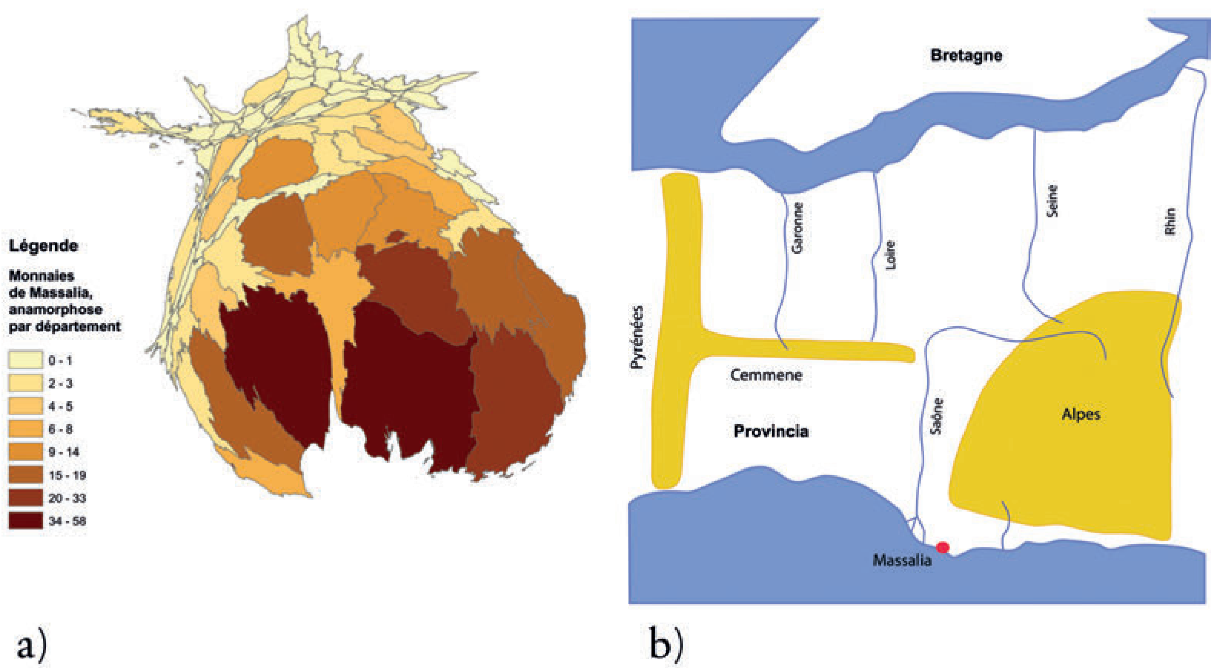

Fig. 15 Anamorphosis map of Massalia 's coins distribution (a); Strabon map of Gaul (b).

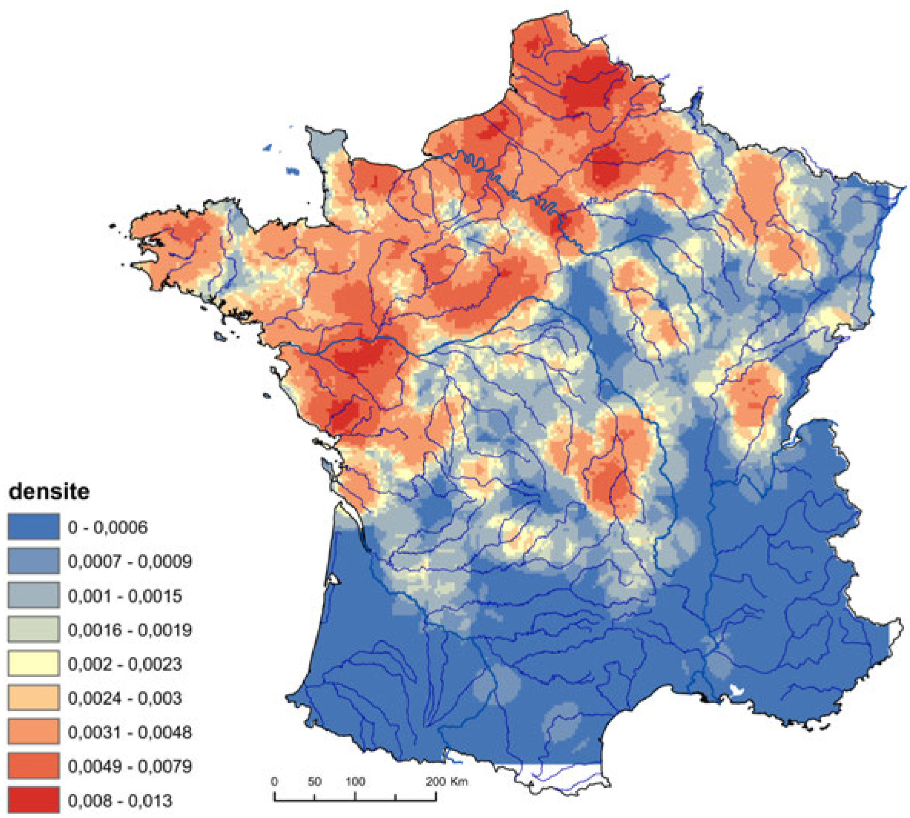

Fig. 16 Map of Gold Gaulish coins 'density.

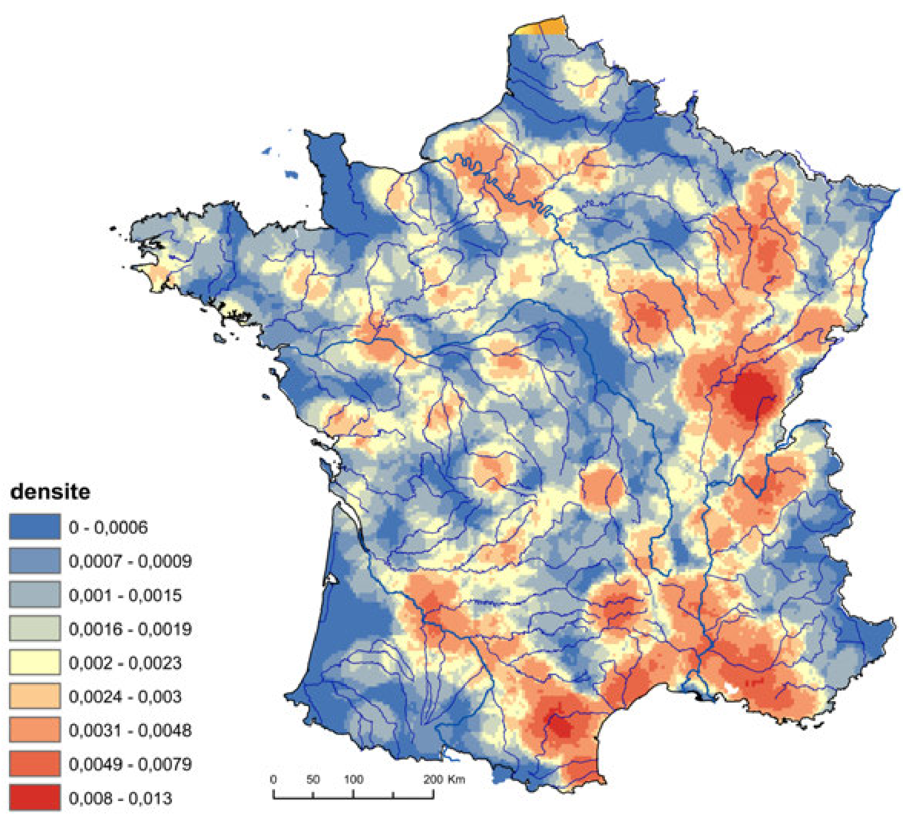

Fig. 17 Map of Silver Gaulish coins 'density.

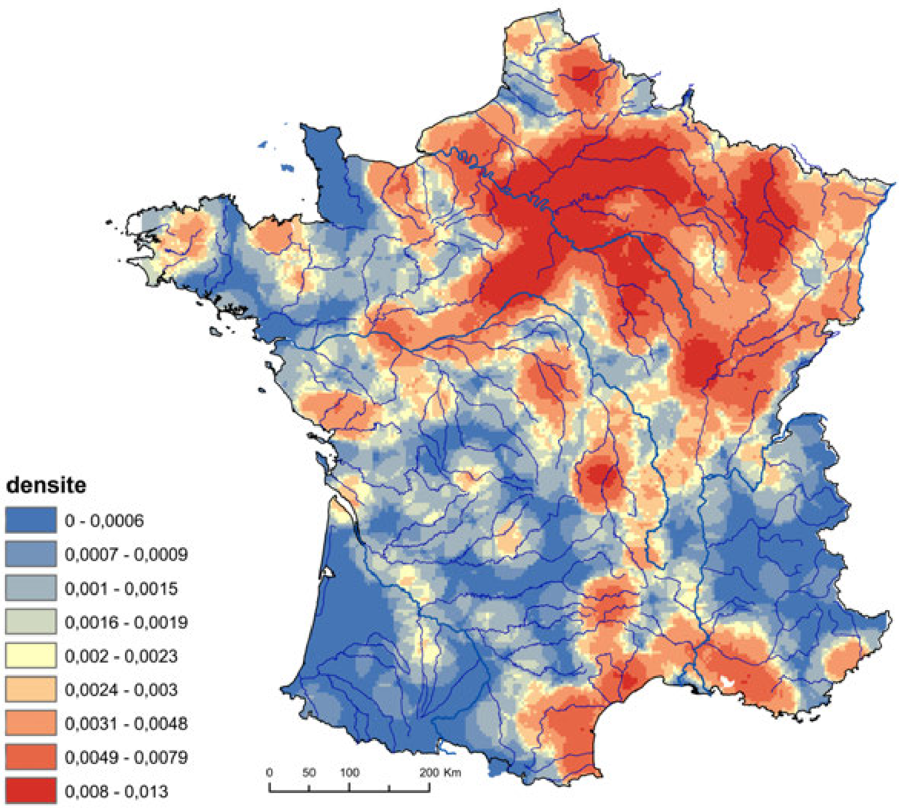

Fig. 18 Map of Bronze Gaulish coins 'density.

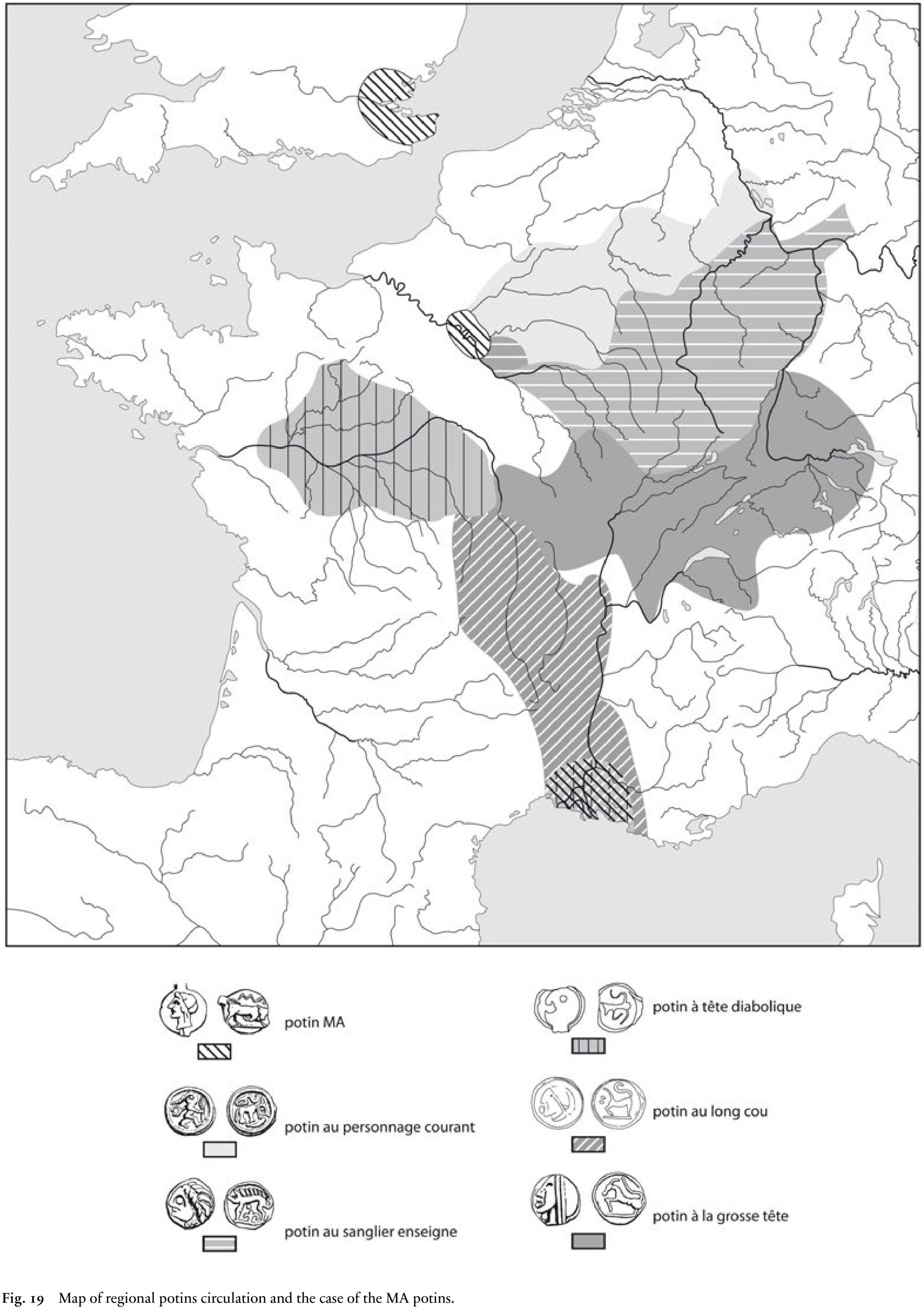

Fig. 19 Map of regional potins circulation and the case of the MA potins.

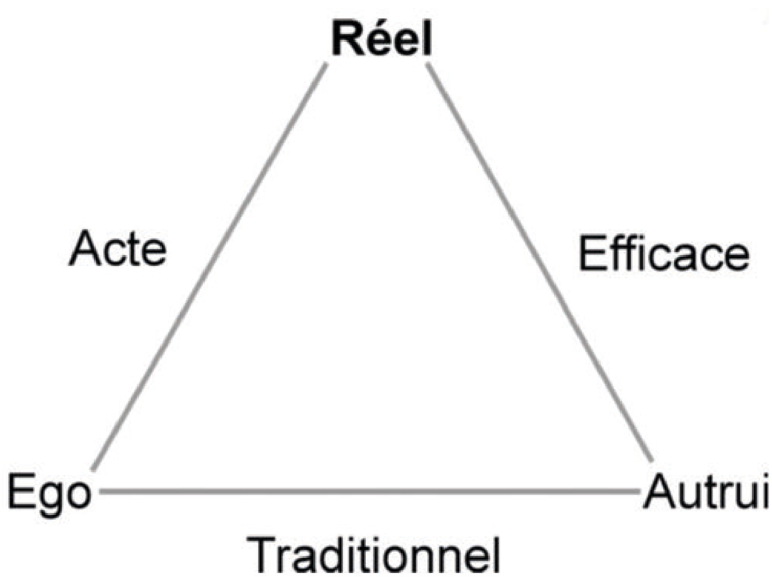

Fig. 20 Sigaut triangle.

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A Container Innovation in the Ice Age: The World's Oldest Pottery and its Dispersal among North Eurasian Hunter-Gatherers

Summary

The earliest ceramic vessels of the world have been produced in southern China by Late Glacial hunter-gatherers ca. 20 000 years ago. Over the following millennia, the new technology became known among forager communities in Japan, the Russian Far East, Transbaikalia and ultimately appeared in the Urals and in northern central Europe. Contrary to common views of pottery as part of the "Neolithic package", the Eurasian hunter-gatherer ceramic tradition has developed completely independent of other Neolithic traits such as agriculture, animal husbandry and sedentary lifestyle. The paper explores the chronological sequence of North Eurasian hunter-gatherer ceramic vessel production on the basis of radiocarbon dates and outlines methodological approaches that can further the knowledge on this crucial phenomenon.

Keywords: hunter-gatherer pottery; late Pleistocene; early Holocene; northern Eurasia; radiocarbon chronology; definition of the Neolithic

Die ältesten Keramikgefäße der Welt wurden in Südchina von spätglazialen Jägern und Sammlern vor ca. 20 000 Jahren hergestellt. In den folgenden Jahrtausenden wurde die neue Technologie unter Wildbeutergemeinschaften in Japan, im Fernen Osten Russlands und in Transbaikalien bekannt und erschien schließlich auch im Ural und im nördlichen Mitteleuropa. Entgegen der gängigen Auffassung von Keramik als Teil des "neolithischen Pakets" entstand die eurasische Jäger- und Sammler-Keramiktradition völlig unabhängig von anderen neolithischen Kulturerscheinungen wie Ackerbau, Viehzucht und sesshafter Lebensweise. Der Aufsatz untersucht die chronologische Abfolge der nordeurasischen Jäger-Sammler-Keramik auf der Grundlage von Radiokarbondaten und skizziert methodische Ansätze, die die Kenntnis dieses wichtigen Phänomens voranbringen.

Keywords: Jäger-Sammler-Keramik; Spätpleistozän; frühes Holozän; nördliches Eurasien; Radiokarbon-Chronologie; Definition des Neolithikums

The overview presented here on early Eurasian pottery would not have been possible without the cooperation with Russian colleagues. I would like to thank Dr. Nadezhda Nedomolkina, Vologda, and Natalya Tsydenova, Ulan-Ude, for the fruitful collaboration in our field projects on early hunter-gatherer pottery in Russia and Mongolia. The research was funded by the Deutsche Forschungsgemeinschaft (grant no. PI 1120/2-1) and the Gerda Henkel Stiftung (grant no. AZ 18/ZA/13). For interesting and stimulating discussions on the topic I thank Dr. Andrei Mazurkevich and Ekaterina Dolbunova, St. Petersburg, and Peter Hommel, Liverpool. A thank you also goes to the organizing team of TOPOI and the German Archaeological Institute of the conference "Contextualising Technical Innovations in Prehistory" in Berlin 2014 for the invitation to participate and to publish the study in the present volume. The manuscript was submitted in 2016, later publications have only been selectively incorporated.

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1 Introduction: The ceramic innovation

Vere Gordon Childe in 1936 described the major innovative property the invention of ceramic vessels had, in his opinion, in human cultural history as follows: „Pot-making is perhaps the earliest conscious utilization by man of a chemical change".[1]

However, this assumption is not entirely correct, as an intentional thermal modification of clay had already been employed by Upper Palaeolithic hunters millennia before the first ceramic pots were made. In the Pavlovian, a local variant of the eastern Gravettian in the Central European Plain, anthropomorphic and zoomorphic clay figurines as well as other 'structural ceramics' were produced in a complex technological process by hunters of the Late Glacial Maximum, around 29 000–25 000 cal BC. More than 10 000 artefacts made of fired clay are known from Moravian sites such as Dolní Vestonice, Pavlov I and II and Pžedmostí, among them the famous 'venus' statuettes. Further examples of Gravettian fired clay artefacts have come to light on French, Austrian and Ukrainian stations.[2] In Western Siberia, a human figurine of fired clay has been unearthed at the site of Maïninskaya, dating to around 18 000 cal BC.[3] A younger, independently invented tradition of fired clay figurative art has been suggested for the Croatian cave site of Vela Spila where 36 ceramic figurines and fragments dating to c. 15 500–13 000 cal BC were discovered.[4]

These early examples of figurative art bear witness to the – apparently repeated – discovery that by intentional shaping and firing of clay, artificial objects including representations of humans and animals can be made. Pottery vessels with their utilitarian, symbolic and social dimensions provide a differently focused array of information on numerous aspects of the communities and societies that produced them. As part of the material culture of ancient people, pottery is of particular importance in archaeological research because, firstly, it is one of the few materials that withstands decay under most depositional conditions, and secondly, because clay vessels are prone to continuous, comparatively rapid typological development. These two properties make pottery an extremely valuable source for the archaeologist. At the same time, there is a possibility that its importance within the socio-economic systems studied might be overestimated by archaeologists due to its prominence in the archaeological record.[5]

The emergence of pottery in the Old World is an intensely debated field in Stone Age archaeology.[6] From a 'western' perspective, the introduction of ceramic vessels has long been seen as an innovation connected to a presumed 'Neolithic package': Already Sir John Lubbock in his book „Pre-Historic Times" described the invention of pottery as a defining feature of the Neolithic, together with growing crops, taming animals and using polished stone tools.[7] In the first half of the 20th century, the supposed association of early pottery with the transition to a farming lifestyle was further promoted by Vere Gordon Childe in his concept of the Neolithic revolution, and subsequently, 'Neolithic packages' of various technological, economic, social and ideological aspects which as a baseline include domesticates and pottery were defined.[8] Although this standard definition of the Neolithic as a fixed 'package' of innovations has been discarded as a global concept over the last decades,[9] a disconnection of the history of pottery from agriculture and sedentism nonetheless remained difficult in (western) archaeological thought.[10] At the same time, a very different understanding of the concept of the Neolithic prevails in parts of Eastern Europe and in Russia: Here, the main feature distinguishing the Neolithic from the previous periods is the appearance of pottery vessels independent of any

1 Childe 1936.
2 Budja 2009; Hansen 2007, 41–42; Vandiver et al. 1989.
3 Bougard n.d., 32.
4 Farbstein et al. 2012.
5 See e.g. Oras et al. 2017, 112.
6 Gronenborn 2011; Hartz and Piezonka 2013; Hommel 2014; Hommel 2018; Jordan and Zvelebil 2009a; Kuzmin 2013a; Rice 1999.
7 Lubbock 1865.
8 For an overview and critical discussion see Çiliniroğlu 2005.
9 See for example Budja 2009; Gronenborn and Scharl 2015.
10 J. W. Hoopes and W. K. Barnett, for example, wrote in 1995 in their standard work on the emergence of pottery: "The archaeological record makes it clear that pottery was most commonly produced by sedentary, agricultural societies; most mobile, foraging societies did not have pottery […]. It is a mistake, however, to infer the existence of either sedentism or agriculture from the presence of pottery alone." Hoopes and Barnett 1995, 2. Beyond the narrow realms of archaeology, the knowledge that the ceramic container technology was a Pleistocene hunter-gatherer innovation is even less established in western cultural and social sciences: following the social anthropologist H. Popitz, pottery is subsumed as one variant of thermal modification of materials, setting in from c. 6000 cal BC as part of the "first technological revolution" which also involves agriculture and the founding of urban settlements even in recent publications such as Weyer 2008, 108–113; see also Popitz 1995.

food production, and over much of this region, pottery-producing hunter-gatherers make up the Neolithic communities.[11]

Various attempts have been made to solve this terminological discrepancy between western and eastern research traditions.[12] Especially in the regions between the two spheres such as Finland, Poland and the Baltic states, various compromise labels have been coined for pottery-producing hunter-gatherers, for example "Sub-Neolithic", "Paraneolithic", "Pottery Mesolithic", etc.[13] in Russian archaeology, there have been attempts to address the problem by equating the two different definitions of the Neolithic with two actual archaeological processes: „The Neolithic as a pan-European phenomenon resulted from at least two processes, one of which involved primarily farming, and another, pottery making. The two processes had apparently different centres of origins and were not simultaneous."[14] This way, a difference in definition of the terminus "Neolithic", as it developed in the separated western and eastern scientific *Denkkollektive,* is now in danger of becoming laden with actual archaeological significance by being interpreted as culture-historical patterns.

According to current knowledge, the earliest pottery vessels have been produced in the remote times of the Late Glacial Maximum, around 18 000 cal BC. Over the following millennia the new technology became known among forager communities in the Russian Amur region, in Japan, Korea, Transbaikalia and the northern parts of Indochina and ultimately appeared also in the Urals and in eastern and northern Central Europe. Outside Eurasia, early centres of hunter-gatherer pottery production also existed in northern Africa in the Sahara, the Sahel and the Nile valley from the 10th millennium cal BC onwards,[15] and on the American continent, where the earliest pottery vessels are associated with shell midden sites in the Amazonas basin in eastern Brazil, dating to around 6000 cal BC.[16] Thus, in several parts of the world ceramic containers were invented, produced and used entirely independent of other "Neolithic" traits such as agriculture and animal husbandry, monumental architecture, or a sedentary lifestyle, and they continued to exist as a genuine hunter-gatherer technology for many millennia.

In this study, the successive introduction of pottery vessel production among hunter-gatherer communities since the late Pleistocene is traced across northern Eurasia, and current research questions connected to the chronology of this technological innovation, its significance and functions are discussed.

2 Early hunter-gatherer pottery in Eurasia

In the 1960s at the Japanese cave site of Fukui, remains of ceramic vessels were for the first time associated with radiocarbon dates from the Late Glacial period. The scientific community at that time, however, had great difficulties accepting such an old age for pottery.[17] It was only since the 1990s that the idea of very ancient North Eurasian hunter-gatherer ceramics that developed entirely independent of the Near Eastern Neolithic began to become more widely acknowledged.[18] Today we can sketch a supra-regional picture of these early hunter-gatherer pottery traditions across the continent, although this picture still has a lot of blurred parts and even large gaps in some regions that are mainly due to the uneven research situation in various parts of northern Eurasia[19] (Figs. 1 and 2).

11 Chairkina and Kosinskaya 2009, 210; Ошибкина 2006.
12 Nordqvist 2018; Piezonka, Nedomolkina, et al. 2017; Yanshina 2017a.
13 See for example Werbart 1998.
14 Dolukhanov, Mazurkevich, and Shukurov 2009, 238; see also Kuzmin 2013b; Mazurkevich and Dolbunova 2015, 28–31.
15 Close 1995; Hommel 2014; Huysecom et al. 2009.
16 Roosevelt 1995.
17 Sagawa 2004, 127.
18 Van Berg 1997.
19 Gibbs and Jordan 2013; Hommel 2014; Hommel 2018; Jordan and Zvelebil 2009a; Jordan, Gibbs, et al. 2016; Kuzmin 2015; Piezonka, Kosinskaya, et al. 2020. The dating results referred to in this paper have been calibrated using OxCal v 4.2.4 (Bronk Ramsey 2009) and the IntCal13 (Reimer et al. 2013) calibration data, with date ranges corresponding to 95.4% probability and rounded to the nearest 10 years.

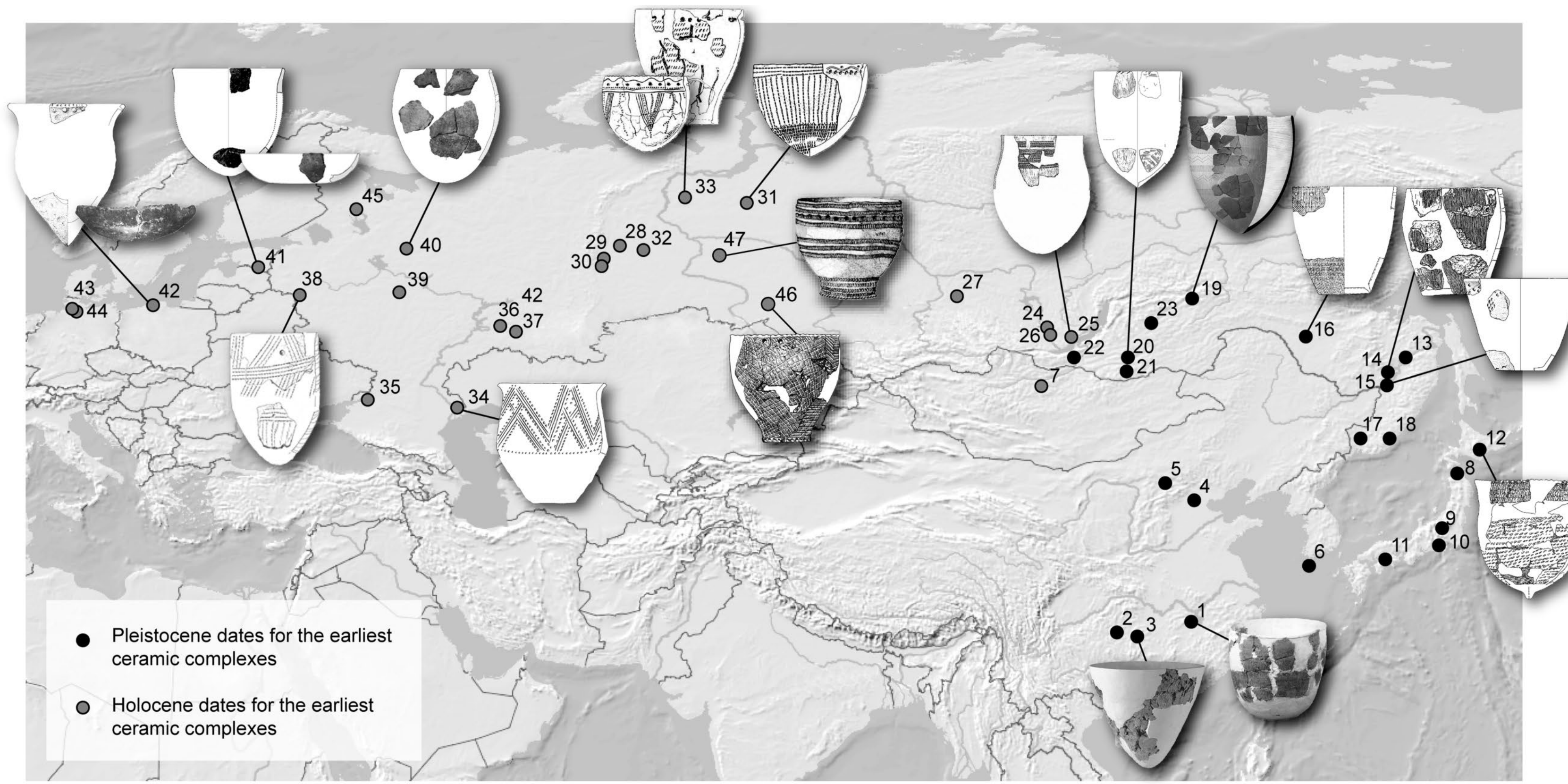

Fig. 1 Sites with early hunter-gatherer ceramic vessels in eastern and northern Eurasia mentioned in the text. 1 – Xianrendong, China; 2 – Miaoyan, China; 3 – Yuchanyan, China; 4 – Nanzhuangtou, China; 5 – Hutouliang, China; 6 – Gosanni, South Korea; 7 – Tolbor 15, Mongolei; 8 – Odai Yamamoto 1, Japan; 9 – Maeda Koji, Japan; 10 – Kitahara, Japan; 11 – Kamikuroiwa, Japan; 12 – Taisho 3, Japan; 13 – Khummi, Russia; 14 – Gasya, Russia; 15 – Goncharka, Russia; 16 – Gromatukha, Russia; 17 – Chernogovka, Russia; 18 – Ustinovka 3, Russia; 19 – Ust'-Karenga 12, Russia; 20 – Studenoe 1, Russia; 21 – Ust'-Menza 1, Russia; 22 – Ust'-Kyakhta 3, Russia; 23 – Krasnaya Gorka, Russia; 24 – Gorely Les, Russia; 25 – Sagan-Zaba 2, Russia; 26 – Ust'-Khayta, Russia; 27 – Ust'-Kazachka, Russia; 28 – Ust'-Vagilsky Kholm, Russia; 29 – Koksharovsky Kholm, Russia; 30 – Beregovaya 2, Russia; 31 – Et-to 1, Russia; 32 – Sumpanya 6, Russia; 33 – Amnya 1, Russia; 34 – Kairshak 3, Russia; 35 – Rakushechny Yar, Russia; 36 – Chekalino 4, Russia; 37 – Ivanovskaya, Russia; 38 – Serteya and Rudnya Serteyskaya, Russia; 39 – Sakhtysh 2a, Russia; 40 – Veksa 3, Russia; 41 – Kääpa, Estonia; 42 - Dąbki 9, Poland; 43 – Kayhude LA 8, Germany; 44 – Schlamersdorf LA 5, Germany; 45 – Pindushi 3, Russia ; 46 - Tartas 1, Russia; 47 - Kayukovo 2, Russia. References to sites, complexes and dates: see text.

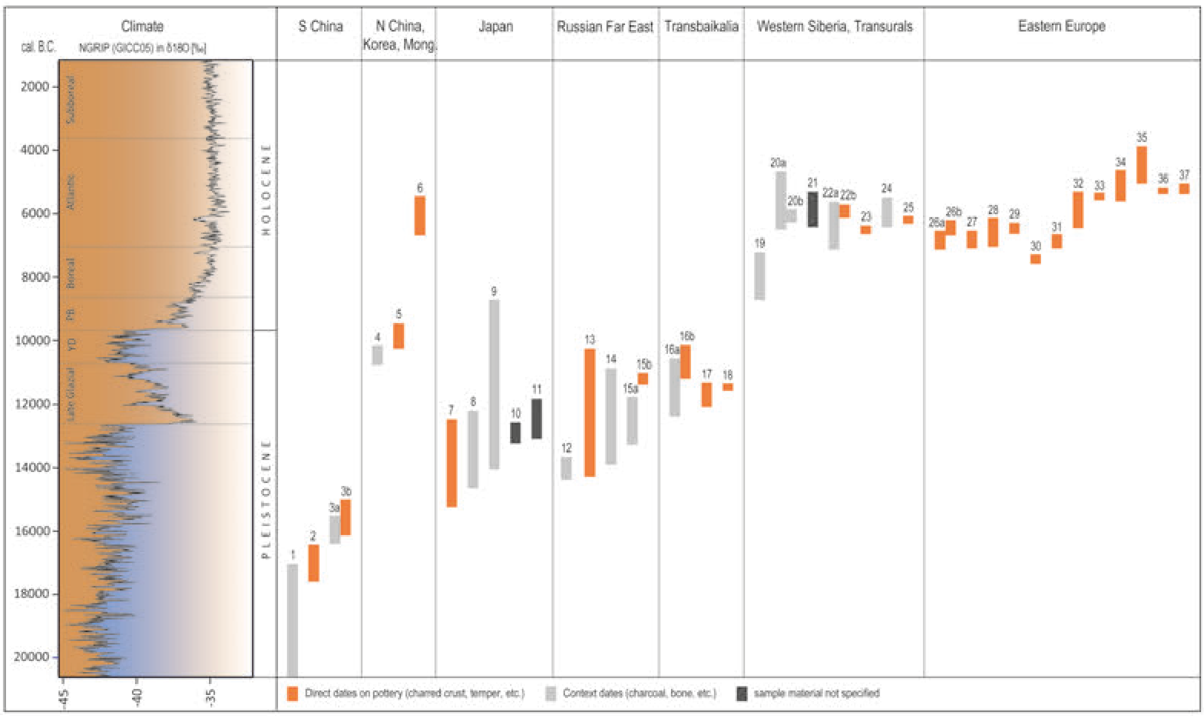

Fig. 2 Radiocarbon-dated complexes with early ceramic vessels in eastern and northern Eurasia. The age ranges refer to the earliest archaeological unit with pottery (layer, horizon etc.), respectively, if such information was available (for details: see text). 1 – Xianrendong, China; 2 – Miaoyan, China; 3a – Yuchanyan, China (dates on bone and charcoal); 3b – Yuchanyan, China (dates on pottery charred curst); 4 – Nanzhuangtou, China; 5 – Gosanni, South Korea; 6 – Tolbor 15, Mongolia; 7 – Odai Yamamoto, Japan; 8 – Maeda Koji, Japan; 9 – Kitahara, Japan; 10 – Kamikuroiwa, Japan; 11 – Taisho 3, Japan; 12 – Khummi, Russia; 13 – Gromatukha, Russia; 14 – Gasya, Russia; 15a – Goncharka, Russia (dates on charcoal); 15b – Goncharka, Russia (dates on pottery charred crust); 16a – Ust'-Karenga 12, Russia (dates on charcoal); 16b – Ust'-Karenga 12, Russia (dates on organics from pottery); 17 – Studenoe 1, Russia; 18 – Ust'-Menza 1, Russia; 19 – Gorely Les, Russia; 20a – Sagan-Zaba 2, Russia (dates on bone of terrestrial animals); 20b – Sagan-Zaba 2, Russia (dates on organic content of soil samples); 21 – Ust'-Khayta, Russia; 22a – Koksharovsky Kholm, Russia (dates on charcoal); 22b – Koksharovsky Kholm, Russia (dates on organics from pottery); 23 – Ust'-Vagilsky Kholm, Russia; 24 – Et-to 1, Russia; 25 – Beregovaya 2, Russia; 26a – Kairshak 3, Russia (dates on bulk organics from pottery fabric); 26b – Kairshak 3, Russia (dates on pottery charred crust); 27 – Rakushechny Yar, Russia; 28 – Chekalino 4, Russia; 29 – Ivanovskaya, Russia; 30 – Serteya 14, Russia (date on foodcrust that has probably been influenced by a substantial freshwater reservoir effect, see Mazurkevich and Dolbunova 2015, 26); 31 – Rudnya Serteyskaya, Russia; 32 – Sakhtysh 2a, Russia; 33 – Veksa 3, Russia; 34 – Kääpa, Estonia; 35 – Dąbki 9, Poland; 36 – Kayhude LA 8, Germany; 37 – Schlamersdorf LA 5, Germany. The results have been calibrated using OxCal v 4.2.4 (Bronk Ramsey 2009) and the IntCal13 (Reimer et al. 2013) calibration data, with date ranges corresponding to 95.4% probability and rounded to the nearest 10 years. References to sites, complexes and dates: see text.

2.1 Southern China

The earliest known evidence for ceramic containers in the world is associated with Paleolithic hunter-gatherers living in Southern China during the Last Glacial Maximum with a lithic technology belonging to the cobble tool and flake industries.[20] At the cave site of Xianrendong in the Yangtse basin, Jiangxi province, remains of ceramic vessels with rounded bases have been discovered in layers that yielded radiocarbon dates on bone and charcoal between 20 750 and 17 210 cal BC.[21] In the cave of Yuchanyan, Hunan province, also located in the Yangtse basin, bones and charcoal from the earliest layers with pottery have been radiocarbon dated between 16 350 and 15 660 cal BC. From this site stems also one of the oldest date directly associated with a ceramic vessel: organic crust adhering to a sherd yielded an age of 16 150–14 930 cal BC.[22] Further direct dates on pottery (on charred crust and on humic acid from the ceramic fabric) come from the cave site of Miaoyan, Guangxi province, covering a period between 17 620 and 16 450 cal BC.[23]

2.2 Northern China, Korea, Mongolia

In northern China and Korea, the earliest pottery complexes are several thousand years younger than the Southern Chinese finds, and they are associated with a different lithic tradition, the microblade industries. At Nanzhuangtou, Hebei province, on the northern Chinese plain, context data on wood and charcoal from the early ceramic layer are not older than 10 760–9460 cal BC[24], and on the site of Hutouliang, potsherds yielded a thermoluminiscence date of 11 870±1720 bp.[25] New discoveries of thick-walled, low-fired ceramic vessels at Houtaomuga, Jilin province, provide first information on the early pottery phase in northeast China. Charred pottery crust dates from the relevant phase I range between 10 570 and 9 260 cal BC, total organic content (TOC) dates between 10 990 and 10 180 cal BC and context data on human and dog bones between 9 810 and 9 195 cal BC.[26] The oldest dated pottery complex on the Korean peninsula is Gosanni on an island off the South Korean coast, yielding a direct date on pottery between 10 180 and 9470 cal BC; however, other dates of the same ceramic complex are substantially younger.[27] In Mongolia, information on the early ceramic horizon is still very sparse. So far the oldest direct dates on pottery stem from the site Tolbor-15 in the northern part of the country. In layer 1, pottery fragments decorated with horizontal impressed lines were associated with a microblade lithic industry. Radiocarbon dates on organic material preserved in the fabric of two pot sherds range between 6590 and 5570 cal BC.[28] Especially in eastern Mongolia, several sites are known with a Late Paleolithic industry that technologically resembles the inventories of early ceramic-bearing complexes further north and east, and further research is needed to clarify whether the late Pleistocene pottery traditions recorded in Transbaikalia and the Russian Far East extended south-west onto the Mongolian plateau.[29]

20 Cohen 2013; Cohen et al. 2017; Dikshit and Hazarika 2012; Lu 2010; Qu et al. 2013; Zhao and Wu 2000.

21 West section, layer 3C1B, east section, layers 2B1 and 2b; oldest date: UCR-3440: 18,520±140 bp, youngest date: BA-10263: 16,030±55 bp (Wu et al. 2012). While Y. Kuzmin (Kuzmin 2015, 2-4) regards the stratigraphic association of the radiocarbon dating samples and the early pottery at Xianrendong as not sufficiently proven, D. J. Cohen (Cohen 2013, 62) states that the series of data is consistent in itself and stems from stable stratigraphic contexts. According to him it can therefore be regarded as reliable.

22 Layer 3H, dates on bone and charcoal, oldest date: BA-06867: 14,975±60 bp, youngest date: BA-06863: 14,610±55 bp; date on pottery charred crust: BA-95057b: 14,390± 230 Boaretto et al. 2009.

23 Humic acid from potsherd: BA-94137a: 15,120± 500 bp; organic residue from potsherd: BA-94137b: 15,220± 260 bp (Zhao and Wu 2000).

24 Bottom of zone T1, BK-87088: 10,510± 140 bp, BK-87075: 10,210± 110 bp (Zhao and Wu 2000; Yang et al. 2012).

25 Lu 2010.

26 Charred crust on pottery: oldest date: 10430±50 bp (Tokyo university, no lab no. provided in reference), youngest date: 9900±50 (Tokyo university, no lab no. provided in reference); total organic content (TOC) of potsherd: oldest date 12940–12850 cal BP (Xi'an, no lab no., uncal. radiocarbon age nor reliability frame provided in reference), youngest date 10460±50 bp (Tokyo university, no lab no. provided in reference), context dates on human and dog bone: oldest date: 11,760–11,270 cal BP, youngest date: 1235–11,145 cal BP (both Xi'an, no lab no., uncal. radiocarbon age nor reliability frame provided in reference) Sebillaud and Wang 2019, table 1.

27 Cho and Ko 2009.

28 PLD-18654: 7685±30 bp, PLD-18655: 6725±30 bp (Гладышев, С. А. and Табарев, А. В. Раннеголоценная керамика северной Монголии (по материалам многослойного памятника Толбор-15). Материалы международного семинара «Вопросы изучения древнейшей керамики Северо-Восточной Азии (X-V тыс. д. н. э.) методами археологии и естественных наук». In print. http://www.archaeologysakhalin.ru/up/lib/0c252ae2dcc74018950975 1cbe72c664.pdf (last accessed 07/13/2020).

29 Piezonka, Tsydenova, and Tumen 2015; Tsydenova and Piezonka 2015.

2.3 Japan

In Japanese archaeology, the appearance of pottery vessels marks the beginning of the Incipient phase of the Jomon cultural complex. Contemporary aceramic sites with a microblade lithic industry are regarded as belonging to the final phase of the Upper Palaeolithic.[30] To date, more than 80 Incipient Jomon sites are known across Japan from Kyushu in the south to Hokkaido in the north, covering a period from the Late Glacial to the Pleistocene-Holocene transition around 9250 cal BC. The pottery of this phase has been subdivided on chronological and typological grounds into four subunits: 1) undecorated ware, 2) pottery decorated with linear relief or bulges, 3) ceramics ornamented with pits, dots and fingernail imprints and first cord-impressed wares, and 4) pottery with rolled cord marks and several other specific decoration elements.[31]

The earliest absolute dates of a ceramic complex in Japan come from the site of Odai Yamamoto 1, Aomori prefecture, at the northern tip of Honshu.[32] Fragments of undecorated, possibly flat-based vessels were found in association with a lithic industry of Mikoshiba-Chojakubo type, which is characterized by the absence of microblades. Radiocarbon dates on charred pottery crusts cover a period between 15 240 and 12 400 cal BC.[33] Other sites where undecorated ceramics have been found in association with Mikoshiba-Chojakubo lithic inventories include Maeda Koji in Tokio (radiocarbon dates on peat and wood: 14 660–12 250 cal BC)[34] and Kitahara in Kanagawa prefecture in central Honshu (radiocarbon dates on charcoal from cultural layer 1: 14 020–8580 cal BC).[35] Among the earliest sites with linear relief ware, the oldest decorated pottery in Japan, is the cave site of Kamikuroiwa in Ehime prefecture. The relevant layer 9 yielded a radiocarbon date of 13 150–11 520 cal BC.[36] Early decorated ceramics also came to light at Taisho 3 in the city of Obihiro on Hokkaido. Fragments of at least five pointed-based vessels decorated with imprints and bulges were found here together with a specific lithic industry without microblades that stands out among the cultural environment on Hokkaido and more closely resembles materials from Honshu.[37] Radiocarbon dates on charred pottery crusts cover a period between 13 060 and 11 840 cal BC.[38]

2.4 Russian Far East

Another focal point of Late Pleistocene pottery production is the Amur basin of the Russian Far East. Up until the Late Glacial period, the region was linked to the Japanese archipelago by a land bridge via Sakhalin.[39] The oldest pottery here is connected to the Osipovka culture, a late Pleistocene complex characterized by a lithic industry with microblade and bifacial technologies that continues Palaeolithic traditions. In contrast to the early, rounded- or pointed-based wares of neighboring regions, most of the ceramics in the Amur basin has flowerpot-like shapes with flat bases.[40] The oldest dates for pottery-bearing complexes come from sites at the lower Amur in Khabarovsk region. Most of them are charcoal dates while direct dates on pottery are rare. At Khummi, the most ancient relevant stratigraphic unit yielded a charcoal date between 14 300 and 13 700 cal BC;[41] three dates from Gasya range from 13 930 to 10 700 cal BC.[42] The well-investigated site of Goncharka has yielded a range of dates for the Osipovka cultural complex, starting around 13 120–12 350 cal BC.[43] Of special interest are four dates from a lens of burned material in trench 3: while the dates on charcoal cover a time frame of 10 440–9830 cal BC, the two dates on pottery charred crust are c. one thousand years older, ranging between

30 Cohen 2013.
31 Cohen 2013; Sato, Izuho, and Morisaki 2011.
32 Kaner 2009.
33 Oldest date: NUTA-6510: 13,780±170 bp, youngest date: NUTA-6506: 12,680±140 bp (Nakamura et al. 2001).
34 Cohen 2013.
35 Oldest date: Beta-105401: 13,060±100 bp, youngest date: Beta-105399: 9,480±80 bp (Nakamura et al. 2001).
36 12,530±40 bp (no laboratory number provided) (Sato, Izuho, and Morisaki 2011).
37 Sato, Izuho, and Morisaki 2011.
38 Oldest date: Beta-194629: 12,420±40 bp, youngest date: Beta-194631: 12, 100± 40 bp (Nakazawa et al. 2011; Шевкомуд 2006).
39 Sato, Izuho, and Morisaki 2011: 94.
40 Шевкомуд and Яншина 2012; Kuzmin 2015.
41 AA-13392: 13,260±100 bp (Buvit and Terry 2011, 384–386).
42 Oldest date: Le-1781: 12,960±120 bp, youngest date: AA-13391: 10,870±90 bp (Buvit and Terry 2011, 384–386).
43 Oldest date: 12,500±60 bp; dates from hearth no. 2, layer 3Б: dates on charcoal: AA-25438: 10,280±70 bp, AA-25439: 10,280±70 bp, dates on pottery charred crust: TKa-15004: 11,390±60 bp, TKa-15003: 11,110±60 bp (Шевкомуд and Яншина 2012, 54–56).

11 410 and 10 860 cal BC. A reservoir effect might be responsible for this offset.[44]

In Primorye region south of the lower Amur, pottery appears somewhat later, with the sites of Chernigovka 1 and Ustinovka 3 yielding direct dates on ceramic vessels between 10 830 and 6230 cal BC. Further west at the middle course of Amur River, the earliest ceramics are associated with the Gromatukha culture, connected to a stone industry with microblade and bifacial technologies which is regarded more archaic than the lithic complex of the Osipovka culture.[45] The site of Gromatukha has yielded dates on pottery temper from its lower layer between 14 240 and 10 160 cal BC.[46]

On Sakhalin island, early pottery sets in millennia after the ceramic innovation in Japan and the mainland Russian Far east. As recent studies have shown, it is only from the 8th millennium onwards that this container technology developed in connection with an intensification of the exploitation of aquatic resources.[47]

2.5 Transbaikalian Siberia

The region east of Lake Baikal provides some of the earliest pottery assemblages outside the initial ceramic-producing areas in the Far East.[48] Already since the middle of the 1970s, a group of archaeological complexes from the Pleistocene-Holocene transition have been uncovered in the upper Vitim basin, located close to the border of the Republic of Buryatia and Zabaykalsy Krai in the Russian Federation. Among them, the most important site with early pottery is Ust-Karenga 12.[49] More than 30 bag-shaped, pointed-based ceramic vessels decorated with comb stamps have been found in layer 7, which share typological characteristics with early pottery of the Amur region and southwestern Transbaikalia. This pottery is associated with an archaic lithic industry based on microblade technology that continues Palaeolithic traditions.[50] Radiocarbon dates on charcoal from layer 7 range between 12 300 and 10 630 cal BC, and dates on organic samples from the pottery itself cover a time frame from 11 130 and 10 200 cal BC.[51]

Comparatively early dates also exist for pottery-bearing complexes of the multi-layered sites of Studenoe 1 and Ust'-Menza 1 in southwestern Transbaikalia. An early age of the pointed-based, bag-shaped pottery was suggested on the basis of stratified context data and of the archaic character of the stone industry. Recently, a number of charred crust datings on the pottery itself have backed up this assumption: The five dates from Studenoe 1, layers 9G and 8, fall between 12 080 and 11 330 cal BC, and pottery from Ust' Menza, layer 8, yielded a date of 11 530-11 340 cal BC.[52]

Another early date of 11 600–11 190 cal BC is reported for the ceramic-bearing layer 1 of Ust'-Kyakhta 3 on the right bank of the Selenga River close to the Russian-Mongolian border. However, its stratigraphic association had been marked with an uncommented question mark in the publication by Kuzmin and Orlova.[53] Yaroslav Kuzmin himself later doubted the reliability of the association of the date with the early ceramic phase and in a recent publication ceased to mention it altogether.[54] The associated lithic assemblage cannot be reliably judged on the basis of the existing publications,[55] but ostrich egg shell in the tempering material in the pottery does point to an early chronological position, as ostrich remains are rarely found in contexts younger that the early Holocene in this region.[56]

Another site with pottery fragments in association with an archaic microblade industry is Krasnaya Gorka in the Eravnoe lake region in central Transbaikalia.[57] The ceramics in its most ancient cultural horizon, layer 2, lower part, are mostly undecorated; pointed bases are present. A first charred crust sample from one of the potsherds has produced a date of 7540–7190 cal BC,[58]

44 Шевкомуд and Яншина 2012, 53.
45 Шевкомуд and Яншина 2012, 228.
46 SNU02-002: 11,320± 150 bp, AA-38108: 10,450± 60 bp (Buvit and Terry 2011, 385).
47 Gibbs, Isaksson, et al. 2017.
48 Jordan and Zvelebil 2009b, 69; Kuzmin and Orlova 2000; Kuzmin 2015; Tsydenova and Piezonka 2015.
49 Hommel et al. 2019; Kuzmin and Vetrov 2007; Vetrov and Hommel 2018.
50 Tsydenova and Piezonka 2015, 106–107.
51 Dates on charcoal: oldest date: AA-60210: 12,180±60 bp, youngest date: GIN-8067: 10,750±60; dates on pottery temper: oldest date: AA-38101: 11,070 bp, youngest date: AA-21378: 10,600±110 bp (Buvit and Terry 2011, 384).
52 Studenoe 1: oldest date: TKa-15554: 11,960± 80 bp, youngest date MTS-16734: 11,570± 60 bp; Ust'-Menza 1: MTS-16738: 11,550±50 bp (Разгильдеева, Куникита, and Яншина 2013, 172).
53 Kuzmin and Orlova 2000, 359.
54 Kuzmin 2015; see also McKenzie 2009, 181, 183.
55 Tsydenova and Piezonka 2015, 107–108.
56 McKenzie 2009, 183.
57 Цыденова 2006; Tsydenova and Piezonka 2015.
58 KIA-42073: 8,345±66 bp (Hartz, Kostyleva, et al. 2012).

however, due to the very small carbon content in the sample the result must be rendered not reliable. The results of new excavations and AMS datings at this site in 2014 indicate that this ceramic complex takes up an equally early position as the oldest pottery in northern and southern Transbaikalia.[59] A charred crust sample from an undecorated pottery wall sherd produced an AMS-date of 11 169–10 905 cal BC, and animal bone and charcoal samples found only a few centimeters from the dated ceramic fragment yielded even older dates of 12 036–11 786 and 12 101–11 792 cal BC, respectively.[60]

2.6 Western Siberia and Transurals

On the map of early Eurasian pottery dispersals, Lake Baikal forms a 'fault line' that persisted for several millennia.[61] In contrast to the well-attested late Pleistocene pottery of Transbaikalia, the earliest reliably dated ceramic complexes to the west of the lake are much younger and, according to current knowledge, set in not earlier than the 7th millennium cal BC.[62] For the western Baikal region, the oldest radiocarbon dates for a pottery-bearing complex stem form Gorely Les by the River Angara. In layer 7a, 16 fragments of one vessel were found which was decorated with stamped and incised zigzag patterns and probably had a rounded base. The radiocarbon dates place this layer within a timeframe of 8780–7140 cal BC, however, these dates are not rendered reliable for dating this complex by all researchers.[63] Layer 6 following above contained later pottery, including cord-impressed ware of the Khajta type, and yielded dates between 7040 and 5300 cal BC.[64]

A key stratigraphy for this region has been investigated at the multi-layered site of Zagan-Saba 2 on the western bank of Lake Baikal. Here, pottery of the Khajta type associated with layer 6 represents the oldest ceramics.[65] Sixteen radiocarbon dates on animal bone and soil samples have been generated for this layer. Four of the five samples on terrestrial animal bones cover a very tight timeframe between 6200 and 5930 cal BC, while the bone samples of the Baikal seal are on average c. 700 year older, indicating a substantial fresh water reservoir effect in these aquatic animals.[66] The six soil samples are chronologically wider dispersed, ranging from 6470 to 4580 cal BC.[67] On the site of Ust'-Khajta in the lower Angara basin, layer 5 corresponds to the described complexes with Khajta type pottery. Two radiocarbon dates from this layer cover an extended period from 6430 to 5300 cal BC.[68]

Evidence for early Holocene pottery is almost completely absent in the extensive forest and steppe regions of southern Siberia. In Elenevka cave at the middle Enissei in Krasnoyarsk region, the oldest pottery-bearing layer with cord-impressed ware yielded two radiocarbon dates between 6010 and 5370 cal BC. On the site of Ust'-Kazachka in the same region, a *terminus post quem* (6200–5390 cal BC) and a *terminus ante quem* (5980–5230 cal BC) exist for the layer with the earliest, likewise cord-impressed pottery.[69]

Further west, in the Western Siberian Plain and the eastern foothills of the Urals mountains, the earliest pottery phase is characterized by a mosaic of different styles and types, with flat-based and conical vessel forms often existing side by side. Here, the early pottery horizon coincides with a unique set of innovations and intensification in the settlement system and the socio-economic sphere, including the appropriation of vast previously barely settled regions, the emergence of complex and even fortified settlements, and of ritual mounds (kholmy).[70] The oldest reliable dates for pottery in this region set in towards the end of the 7th millennium cal BC.[71] Very early dates published from sites

59 This work was conducted within the frames of the German-Mongolian-Russian project „Between China and the Urals: The emergence of the oldest ceramic traditions in Transbaikalia and Mongolia from the 12th millennium BC onwards", financed by the Gerda Henkel Foundation (project no. AZ 18/ZA/13).

60 Pottery charred crust: AAR-21437: 11,155±50 bp, bone fragments: Poz-68608: 12,010±60 bp, charcoal: Poz-68609: 12,020±60 bp (Tsydenova, Andreeva, and Zech 2017, see also Piezonka, Tsydenova, and Tumen 2015).

61 Hommel 2018, 7; Piezonka, Kosinskaya, et al. 2020, 12.

62 Piezonka, Kosinskaya, et al. 2020.

63 KRIL-234: 8,830±300 bp, Ri-51; 8444±144 bp (McKenzie 2009, 186–187).

64 (No laboratory number): 7,890±80 bp, To-4839: 6,510±100 bp (McKenzie 2009, 187).

65 Goriunova and Novikov 2015.

66 Oldest date: OxA-22357:7,203±37 bp, youngest date of the four: OxA-22374: 7,147±38 bp (Nomokonova et al. 2013).

67 Oldest date: SOAN-6597: 7,380±135 bp, youngest date: SOAN-7151: 5935±90 bp (Nomokonova et al. 2013, 114).

68 Новиков and Ольга 2011.

69 Elenevka: SOAN-3998: 6,900± 115 bp, SOAN-2907: 6,530± 60 bp (McKenzie 2009, 191–193).

70 Piezonka, Kosinskaya, et al. 2020.

71 Piezonka, Kosinskaya, et al. 2020.

such as Sumpanya IV (from c. 12 220 cal BC), Sumpanya VI (from c. 9750 cal BC) and Amnya 1 (from c. 8620 cal BC) have been repeatedly mentioned in the literature and have also been used in dispersal modellings.[72] However, their association with the early pottery phase at the respective sites is not reliable and they are now generally disregarded also by local scholars and supraregional accounts.[73] The earliest radiocarbon evidence securely associated with early pottery in this region now come from charred crusts from Ust'-Vagil'sky Kholm in the middle Trans-Urals (Satygino pottery type) and from Amnya 1 and Kirip-vis-Yugan 2 in the northern taiga (Amnya pottery type), dating between 6640–6390 cal BC cal BC (Ust'-Vagil'sky Kholm) and 6560–6390 cal BC (Amnya 1 and Kirip-vis-Yugan 2), respectively.[74] However, based on further context dates it has been demonstrated that for these dates, substantial reservoir effects of several hundred years either cannot be ruled out (Ust'-Vagil'sky Kholm) or are even very likely (Amnya 1 and Kirip-vis Yugan 2).[75] At Koksharovsky Kholm, charcoal dates from building 15 containing pottery of Koshkino type have provided a time span of 7020–5520 cal BC, and direct dating of the associated ceramics yielded a result of 6050–5730 cal BC.[76] Far to the north at the site of Et-to, charcoal samples from house 4 date the early pottery complex to 6360–5550 cal BC.[77] New evidence of early, partly flat-based pottery also comes from Tartas-1 in the Baraba forest steppe and from the enclosed settlement site of Kayukovo 2 in the middle Ob' region.[78] The latter provided a dating range of 5990–5640 cal BC, based on context data from house pit 4.[79] Most reliable in the entire region is the chronological information on early pottery from Mergen' 6, where the AMS dates of charred crust from Boborykino[80] and Koshkino type vessels cover the last quarter of the 7th millennium and the time around 6000 cal BC and are broadly in accordance with context data from this settlement site, therefore at best being slightly influenced by freshwater reservoir effects.[81] The crust dates on Koshkino type pottery from Beregovaya 2, ranging from 6330–6070 cal BC, back up these findings, as comparison dates on other sample materials show that they have not been affected by any detectable reservoir ages.[82] Summing up, the earliest reliable dates on pottery in the study area stem from the Middle Trans-Urals and the south of West Siberia, indicating an onset of pottery production towards the end of the 7th millennium cal BC.

2.7 Eastern Europe and Baltic region

Pottery has also been widely used over millennia by hunter-gatherer-fishers in the west of northern Eurasia, from the western Urals to the Baltic Sea and northern Central Europe (Fig. 3). In contrast to many of the above-described regions of northern and eastern Asia, our knowledge of the early pottery phase west of the Urals is much better due to a higher density of investigated sites, a fast-growing sequence of radiocarbon dates, numerous regional studies and also new supraregional summarizing works providing comprehensive documentation of the ceramic material itself.[83]

With the growing body of radiocarbon dates from the region over the past ten to fifteen years, the oldest pottery of eastern Europe appeared to commence in the first quarter of the 7th millennium cal BC in the northern Caspian region and by the lower Don, thus apparently predating the introduction of ceramics into mainland south-eastern Europe.[84] However, much of the

72 Gibbs and Jordan 2013; Hommel 2014; Hommel 2018, 5; Jordan, Gibbs, et al. 2016.

73 Kuzmin 2014; Piezonka, Kosinskaya, et al. 2020.

74 Ust'-Vagil'sky Kholm, pottery charred crust: oldest date: AAR-14840: 7,735±40 bp, youngest date: AAR-14838; 7583±38 bp (Panina 2014); Amnya 1, pottery charred crust: Poz-97648: 7,590±40 bp; Kirip-vis-Yugan 2, pottery charred crust: Poz-97649: 7,600±40 bp (Piezonka, Kosinskaya, et al. 2020).

75 Dubovtseva et al. 2020; Piezonka, Kosinskaya, et al. 2020.

76 Charcoal: oldest date: Le-7880: 7,560±200 bp, youngest date: Le-7887: 6,900±160 bp; organics from pottery: Ki-15915: 7010±90 bp (Шорин and Шорина 2011, 249–254).

77 Oldest date: Le-6595: 7200± 120 bp, youngest date: Le-6594: 6740± 65 bp (Косинская 2005, 20).

78 Kardash et al. in press; Molodin, Rajnkhol'd, et al. 2018; Molodin, Hansen, et al. 2021.

79 AMS dates on charcoal from house pit 4: oldest date: Poz–110379: 7010±40 bp, youngest date: Poz–110383: 6820±40 bp Kardash et al. in press, see also discussion of further dates.

80 *Sensu* Zakh and Yen'shin, see Zakh and Yen'shin 2015.

81 Charred pottery crust, oldest date: Poz-98999: 7410±40 bp, youngest date: Poz-98998: 7010±40 bp (Piezonka, Kosinskaya, et al. 2020).

82 KIA-42074: 7320±40 bp, AAR-14833: 7,320±38 bp; Piezonka, Kosinskaya, et al. 2020; Zaretskaya et al. 2014).

83 Mazurkevich and Dolbunova 2015; Piezonka 2015a; current research conducted by ERC Advanced Grant project INDUCE (PI: Carl Heron, London).

84 Dolukhanov, Mazurkevich, and Shukurov 2009, 239–240; Mazurkevich and Dolbunova 2015; Выборнов 2008; Vybornov et al. 2012.

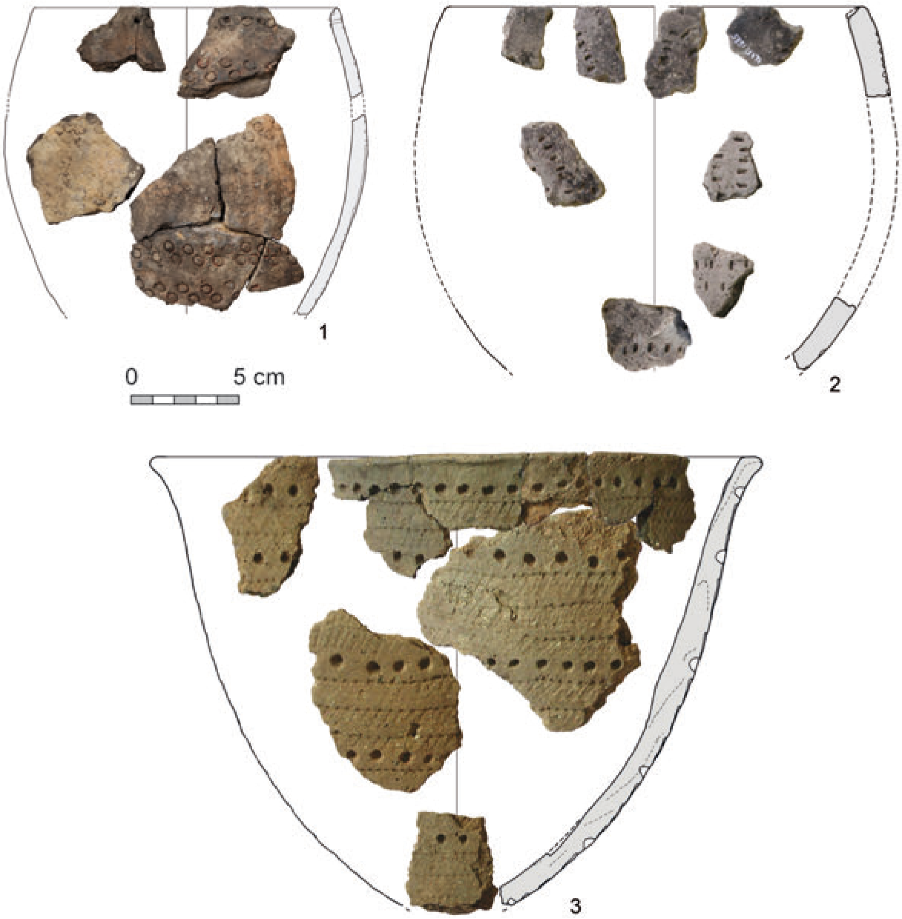

Fig. 3 Examples of Stone Age hunter-gatherer pottery in northeastern Europe. 1 – Early Upper Volga culture ware, Veksa 3, Russia; Narva culture ware, Kääpa, Estonia; Sperrings ware, Pindushi 3, Russia.

dates either were based on total organic content (TOC) of pottery or on charred crust dates and cannot be regarded as reliable due to the unclear origin of the dated carbon (TOC dates) or likely aquatic reservoir effects (crust dates).[85]

The earliest dates stem from round- or flat-based pottery decorated with incised geometric patterns found in the steppes and semi-deserts north of the Caspian Sea. TOC samples of ceramic fabric from Kairshak 3 provided ten radiocarbon dates between 7080 and 5770 cal BC.[86]More reliable as to the actual association of the sampled carbon with the time of use of the pot is a date on organic crust from pottery, providing an age of 6680–6500 cal BC although there is a possibility of an aquatic reservoir effect causing too old ages here.[87] Animal bone and charcoal from the complex yielded younger dates between 6080 and 5330 cal BC, they provide the most reliable age range for the compex.[88] At the multi-layered site of Rakushechny Yar, a key site for the prehistory of the northern Black Sea region, four samples of organic crust on undecorated pottery from layer 20 yielded dates between 7030 and 6050 cal BC.[89] Here, too, a reservoir effect is likely affecting the dates.[90] Undecorated, pointed-based ceramic ware also appears on the early sites of the Elshan culture by the middle Don. Two of the oldest dates include the result for a pottery TOC sample from

85 E.g., Dolbunova et al. 2020; Piezonka, Meadows, et al. 2016; Piezonka, Nedomolkina, et al. 2017.

86 Oldest sample: Ki-14133: 7950±90 bp, youngest sample: Ki-16400: 7290±180 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

87 Ua-41359: 7775±42 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

88 Animal bone: SPb-316: 7030±100 bp, Ki-14634: 7010±80 bp; charcoal: GIN-5905: 6950±190 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

89 Ki-6476: 7930±40 bp, Ki-6477: 7860±130 bp, Ki-6475: 7690±110 bp, Ua-37097: 7290±50 bp (Mazurkevich and Dolbunova 2015, Fig. 4).

90 Dolbunova et al. 2020.

Chekalino 4 of 7050–6100 cal BC, and the dating result for pottery from Ivanovskaya of 6570–6250 cal BC,[91] both now regarded as not reliable due to the dated material. A fourth region with very early dates for pottery-bearing complexes is located many hundred kilometres further north-west in the Dvina-Lovat' region of western Russia. Here, undecorated and sparsely decorated wares with incised patterns have been grouped into several typological phases, with the phases "a-1" and "a" being the oldest.[92] While one extremely ancient date of organic crust from a phase "a-1" vessel from Serteya 14 is regarded not reliable due to a likely distortion by a freshwater reservoir effect,[93] a phase "a" vessel from Rudnya Serteyskaya provided an organic crust date of 7050–6510 cal BC.[94] From the same site, wood associated with phase "a" material was dated to 6500–5810 cal BC.[95]

During the second half of the 7th millennium early pottery often decorated with small notches and flat as well as pointed bases spread along the rivers towards the west and north-west, reaching the Kama and upper Volga regions and the Sukhona region around 6000 cal BC. One of the oldest series of dates for the Upper Volga culture, the earliest pottery-producing culture central Russia, stems from layer IIg of the site Sakhtysh 2a. Seven charred residue samples and one uncharred plant sample attached to a sherd cover the period between 6350 and 5310 cal BC.[96] It is suspected, however, that freshwater reservoir effects have distorted at least some of these dates, resulting in too old ages.[97] Further north, the oldest date on pottery charred crust from the multi-layered site of Veksa 3 in the Sukhona basin stems from a sparsely decorated vessel found in layer 9, it ranges between 5640 and 5550 cal BC and has likely also been effected by a freshwater reservoir effect (Fig. 3, 1).[98]

Younger developments encompass the spreading of comb-decorated styles from the east which became established in the second half of the 6th millennium in the forest zone up to northern Fennoscandia, and the development of the Narva culture with a specific coarse organically tempered pointed-based pots and oval lamps in the eastern Baltic region.[99] Some of the earliest direct dates on pottery come from the Estonian site of Kääpa, six dates on charred crust from Narva vessels range between 5620 and 4580 cal BC (see Fig. 3, 2).[100] However, it is not clear to what extend these dates might have been distorted by a reservoir effect.[101]

At the southern Baltic coast, a comprehensive series of radiocarbon dates on organic crusts from pointed-based hunter-gatherer pottery and oval clay lamps has been conducted for the Polish site of Dąbki 9, encompassing a time frame between 5050 and 3970 cal BC.[102] Here, too, reservoir effects distort the absolute dating results, as is suggested organic residue analysis pointing towards the processing of aquatic resources in the pots, and it is more likely that the ceramic phase at this site sets in around the middle of the 5th millennium cal BC.[103] In the western Baltic and southern Scandinavia, hunter-gather pottery is associated with the younger phase of the Ertebølle culture.[104] The oldest absolute dates for this forager ceramics which also include pointed-based vessels and oval lamps come from inland sites in Schleswig-Holstein, northern Germany: a charred crust sample from Kayhude LA 8 has produced an age of 5480-5340 cal BC, and three charred crust dates from Schlamersdorf LA 5 range between 5480 and 4940 cal BC. Ertebølle sites at the coast have produced younger dates for the onset of pottery use, starting around 4700 cal BC. It is suspected that the absolute dates from the mentioned inland sites have been affected by a freshwater reservoir effect and thus appear too old, and that an onset of pottery production around the middle of the 5th millennium cal BC also at the inland sites is more likely.[105] Thus, pottery technology became established among hunter-gatherer-fisher groups of the circum-Baltic region in the late 6th

91 Chekalino 4: SPb-424: 7660±200 bp; Ivanovskaya; SPb-587: 7560±70 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

92 Mazurkevich and Dolbunova 2015, 25–28, Pl. 6.

93 Ua-37099: 8380±55 bp, the δ^{13}C value of the sample was with -33.8 ‰ extremely low, indicating a high content of freshwater aquatic material in the sample; Mazurkevich and Dolbunova 2015, 26.

94 Le-5260: 7300±180 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

95 Ua-37100: 7870±100 bp (Mazurkevich and Dolbunova 2015, Fig. 5).

96 Oldest sample: KIA-39310: 7356±30 bp, youngest sample: KIA-39313: 6371±30 bp (Hartz, Kostyleva, et al. 2012, Table 1).

97 Hartz, Kostyleva, et al. 2012;

98 MAMS-25493: 6677±25 bp Nedomolkina and Piezonka 2016; Piezonka, Nedomolkina, et al. 2017.

99 Piezonka 2015a, 244–253.

100 Oldest sample: KIA-35897: 6540±40 bp, youngest sample: KIA-49792: 5798±21 bp (Piezonka, Meadows, et al. 2016).

101 Piezonka, Meadows, et al. 2016.

102 Kotula et al. 2015, 118–123, Tab. 1.

103 Courel et al. 2020.

104 Hartz 2008.

105 Philippsen and Meadows 2014; Philippsen 2015b.

and early 5th millennium cal BC. Based on the current evidence it is very likely that the new container technology reached the Baltic from the east as part of the wider Eurasian forager pottery tradition described above.[106]

3 Approaches to understanding the adoption, dispersals, social functions and economic significance of hunter-gatherer pottery

3.1 State-of-the-art and open questions

The overview given in the previous chapters has shown how heterogeneous the current state of knowledge on early North Eurasian hunter-gatherer pottery is. For some regions (i.e. Japan, north-eastern Europe), a growing corpus of data and analytical results helps to draw an increasingly detailed picture of the early ceramic period, while in other areas, large gaps still remain due to the lack of relevant sites (i.e. southern Siberia).

Against the background of this heterogenous state of the evidence, a central question connected to North Eurasian hunter-gatherer pottery concerns the problem whether (a) the knowledge of pottery technology was dispersed continuously from the oldest core centres on China, Japan and the Amur region towards the west across Siberia and ultimately to the Urals and further into Europe,[107] or whether (b) pottery was independently invented several times by different hunter-gatherer communities in this vast region.[108]

Currently, no clear-cut global answer to this problem can be provided, and it seems more appropriate and promising to combine supra-regional assessments with detailed regional and local studies, also regarding other evidence such as lithic technologies, mobility patterns and economic strategies to disentangle the multi-faceted connectivities inherent in this both spatially and chronologically extensive phenomenon.[109]

In order to gain a better understanding of this problem, research on the early hunter-gatherer ceramic traditions of Northern Eurasia currently centers on the following complexes: (1) When was the innovation of ceramic vessels introduced in the various parts of Northern Eurasia? (2) How was the innovation introduced? Was it invented independently in a given region, or did the knowledge come from elsewhere? How was the knowledge transferred (through neighbours, wider cultural contacts, migrations, etc.)? (3) Why was the innovation of ceramic containers adopted? What functions and roles did the early pottery play in the social and economic spheres, what benefits did the integration of pottery into a groups' spectrum of material culture yield?

3.2 When? – Approaching chronology

To address the question *when* the ceramic innovation first reached a certain region, reliable intra-site and regional chronologies on the basis of well-documented stratigraphies and absolute dates (radiocarbon, thermoluminiscence etc.) must be built. Currently, the absolute chronology of the appearance and evolution of early hunter-gatherer pottery is for large parts of the regarded area still based on just a few radiometric C14 measurements, often with large uncertainties, from samples such as charcoal, wood, and organic sediment, found in more or less reliable association with the pottery concerned, or from TOC samples of potsherds that are unsuitable as indicators of absolute ages. Critical methodological reviews are addressing this problem, and for some regions, targeted dating programmes have been initiated and now start to feed into the building of more reliable scenarios.[110]

An important field of discussion in this respect concerns so-called reservoir effects in radiocarbon dates on charred crusts.[111] Charred residue adhering to the surface of ancient potsherds in most cases stems from burnt foods that were prepared in the vessels (hence the alternative terminus 'foodcrusts'), although other mechanisms, for example the use as grease lamps and the effects of cooking fires, can also produce charred surface residues.[112] These charred organic remains provide

106 Hartz 2008, 241; Piezonka 2015a, 254–256; Povlsen 2013.
107 E.g., Gibbs and Jordan 2013.
108 Kuzmin, Jull, and Burr 2009; see also Hartz, Kostyleva, et al. 2012; Kuzmin 2013b; Hartz and Piezonka 2013.
109 See also Hommel 2018, 6–12.
110 E.g., Fernandes, Meadows, and Dreves (eds.) 2015; Piezonka, Nedomolkina, et al. 2017; Piezonka, Kosinskaya, et al. 2020; Seitsonen et al. 2012.
111 E.g., Philippsen and Meadows 2014; Philippsen 2015a; Philippsen 2015b; Piezonka, Meadows, et al. 2016.
112 Teetaert et al. 2017.

valuable dating samples due to their unquestionable association with the time of use of the ceramics. There is, however, a danger of the radiocarbon dates from such crusts being too old. This can be the case when aquatic food stuffs (e.g. fish, mollusks) were cooked in the vessels, as aquatic resources tend to be depleted in radiocarbon. In freshwater systems, this is caused by the dissolution of ancient carbonate minerals from the bedrock. Aquatic plants introduce this ancient carbon into the food chain, leading to reservoir effects in fish, mollusks and aquatic mammals. In marine systems, the old carbon stems from deep sea water which gets intermixed with surface water containing more atmospheric carbon. In pottery foodcrusts, the age offsets caused by aquatic reservoir effects can account to several hundred years. Current research aims to systematically estimate reservoir ages in foodcrust dates by way of various archaeological and archaeometric methods (paired dates, bulk isotopic measurements of carbon and nitrogen, lipid biomarker analysis, single-compound carbon isotope determinations).[113] Especially promising in this respect are studies of experimentally made foodcrusts because here, both the components and the formation of the samples are known.[114]

A current line of research aiming to trace and visualize the chronology of early pottery dispersals is the application of mathematical modelling to radiocarbon data sets. Since the late 2000s, this approach has been further developed for early Eurasian and African pottery in order to identify early centres of pottery production in Eurasia and northern Africa and deduce information on the timing, pace and direction of further diffusion of the ceramic technology.[115] On the basis of the modelling results it is suggested that an East Asian hunter-gatherer and an African/circum-Mediterranean farmer ceramic tradition eventually converged from the 7th millennium cal BC onwards along a line from northern central Europe via the Black Sea, the Caucasus and across the Caspian Sea into southern Asia and that the adoption of pottery in the Near Eastern Neolithic might have arrived from northern Africa.[116] These novel, cross-continent scenarios need further analysis and verification, and methodical problems resulting for the model itself and from the varying reliability of the radiocarbon dates and their context in the database must be addressed in the future in order to further develop this promising approach. A first, amended scenario for Western Siberia within this wider scheme was developed on the basis of new dates and the critical assessment of the existing ones.[117] Irrespective of the uneven distribution of the evidence, it is possible on the basis of the current knowledge to identify a number of 'fault lines' or boundaries in the spatio-temporal continuum of North Eurasian hunter-gatherer pottery.[118] One of these 'fault lines' separates the Ice Age ceramic-producing centers of southern China, Japan and the Russian Far East from the Inner Asian expanses of northern China and Mongolia and the Korean peninsula that apparently remained aceramic for several millennia. A second, very distinct border is formed by Lake Baikal: to the east of it, pottery is already well-established in the Late Glacial period, while to the west of the lake, ceramic vessels start to appear millennia later in the early Holocene. Recent dating programmes have shown that in the vast plains to the East and West of the Urals Mountains, pottery technology became rapidly and more or less simultaneously known around 6000 cal BC, partly concurrently with other major socio-cultural changes.[119] Further, multidisciplinary research must follow up a possible connection with the 8.2 ka BP climatic event.

3.3 How? – Assessing mechanisms of transmission

The question *how* the introduction of ceramic vessels took place in a given region and what mechanisms were at play in this process can be followed up by way of systematic typological studies of the pottery itself. Based on technological, morphological and stylistic similarities and differences, continuities and breaks/frontiers in the distribution and dispersal of early pottery traditions can be identified. The origin of a certain ware

113 E.g., Philippsen and Meadows 2014; Heron and Craig 2015; Philippsen 2015b; Bondetti et al. 2020.
114 Philippsen 2013.
115 Jordan and Zvelebil 2009a; Gibbs and Jordan 2013; Jordan, Gibbs, et al. 2016; Silva et al. 2014.
116 Jordan, Gibbs, et al. 2016.
117 Piezonka, Kosinskaya, et al. 2020, 16.
118 Hommel 2018; see also Kuzmin 2015, Fig. 14.
119 Dubovtseva et al. 2020; Piezonka, Kosinskaya, et al. 2020, 17.

(local production vs. import) can be traced, for example, by petrographic and/or geochemical analysis of the fabric. For the investigation of technological and morphological traits, various physical and chemical methods can be employed (i.e. x-rays, thermic methods, XRF scans).[120] Experimental approaches have proven useful to better understand different decoration techniques used on hunter-gatherer pottery.[121]

A promising line of research involves the application of multivariate statistics such as correspondence analysis.[122] This approach is suited to overcome the problem that often, single criteria such as raw material and tempering or particularities of the decoration are being used to draw far-reaching conclusions on cultural connections and even migrations of populations. An advantage of multivariate analysis in pottery studies is the possibility to investigate the complex interrelation of a multitude of characteristics for a large set of specimen (i.e. vessel units). It thus enables the mathematical identification of organizing principles within the data set that cannot be recognized by a mere impressionist consideration or by uni- or bivariate statistical analyses of selected characteristics. The variables to be analyzed include technological traits such as temper, molding technique and surface treatment, formal criteria such as mouth diameter, wall thickness and rim shape, and particularities in the execution and design of decoration. As a result, structuring factors in the data set such as regional stylistic and technological traditions as well as temporal dynamics can be identified. The method therefore can be used to detect continuities and breaks in the dispersal of the early ceramics as well as information on chronological trends. A case study on early hunter-gatherer pottery complexes to the North and East of the Baltic Sea has led to the identification of two large typological entities and their sub-division into smaller groups, to the re-evaluation of the attribution of the ceramics from several sites to various traditions, and to the recognition of previously unknown spatio-temporal continuities, partly over large distances.[123]

Further approaches to the question of how early pottery was invented, dispersed and adopted include studies of the cultural environment in which ceramics first appeared. Such studies can show whether the new technology was adopted within an otherwise stable cultural continuum, or whether pottery came as part of a larger set of novelties and was associated with substantial cultural change, as has been shown, e.g., for the Russian Far East and for the Transurals and Western Siberia.[124] In this respect, detailed integrative studies connecting ceramic and lithic technological traditions are seen as a promising approach that need to be more thoroughly followed up in the future.[125] Through the application of cultural transmission theory and network analysis, regional and supra-regional trajectories and connectivities, but also breaks in the continuum, can be deduced.

3.4 Why? – Understanding roles and functions

The question *why* the ceramic innovation was incorporated into new cultural environments touches on the fields of pottery use and function, and, on a more general level, on the social and cultural dimensions of early pottery as a specific technological innovation.

That much of the early hunter-gatherer pottery was used for the preparation of foodstuffs and/or for the thermic transformation of other materials is deductible from the charred crusts frequently covering the inside of the pots and from soot adhesions on the outside. There are two major hypotheses on the function of the vessels: (a) Early pottery was utilized as a means to detoxify foods, to make them more palatable and to open up new resources (i.e. to cook mollusks, produce fish oil, prepare weaning foods);[126] and (b) Early pottery was used as a prestige good (i.e. to express one's position and abilities at reciprocal feasts either with the pots themselves or with special foods prepared in them).[127]

Bioarchaeological approaches are employed to address these questions: Measurements of carbon and nitrogen isotope ratios in the charred crusts and the analysis of organic residue within the pottery fabric can yield information on foodstuffs and other materials processed

120 Молодин and Мыльникова 2015.
121 Дубовцева et al. 2011.
122 See for example Spatz 1996; Schneeweiß 2007; Piezonka 2015a; Piezonka 2015b.
123 Piezonka 2012; Piezonka 2015a; Piezonka 2015b.
124 Piezonka, Kosinskaya, et al. 2020; Yanshina 2017b.
125 Hommel 2018, 9; see also Gronenborn 2017.
126 Lu 2010; Craig et al. 2013.
127 Hayden 2009; Hayden 2014, 654–658.

in the pots.[128] In various regions of eastern and northern Eurasia, among them Japan, the central part of European Russia and the eastern Baltic, results are in accordance with the observation that the appearance of early ceramic vessels seems to broadly coincide with an intensification of the exploitation of aquatic resources.[129] Furthermore, excavations at stratified sites with good organic preservation yield material for palaeobotanical and zooarchaelogical investigations of the associated complexes in order to understand the early pottery in its economic and environmental context.

An interesting observation concerns the fact that early hunter-gatherer pottery often shares a specific set of typological traits, including a conical, bag-like shape with the widest diameter at the mouth, a rounded or pointed base, and a structuring or roughening of the surface, i.e. by dense impressed ornaments, cord rollings, or brush marks (see Fig. 1). These features characterize not only much of the early Eurasian pottery described here but can for example also be found on Woodland period hunter-fisher pottery in north-eastern North America,[130] and on early wares of the sub-Saharan region.[131] One common assumption holds that pottery containers were first developed on the basis of pre-existing organic container technologies, namely basketry, woven or net bags.[132] But it is also possible that functional requirements inherent to the mobile foraging Stone Age lifestyle have led to the repeated development of this specific set of traits. In this respect it is interesting that in some regions of Northern Eurasia such as the Amur region, the Western Siberian forest steppe and taiga, and the Volga region to the West of the Urals, the earliest pottery phase actually included flat-based pottery, partly appearing alongside conical shapes. Later, the flat-based shapes generally disappeared from the assemblages, possibly indicating the settling for the most convenient with respect for the mobile hunter-gatherer lifestyles. The open shape and conical base could e.g. be useful for storage (hanging?) and transport (stacked? in nets?), and the rough surface possibly helped to more easily handle the pots when packing and moving. These open questions require more targeted archaeological, anthropological and experimental research.

3.5 Innovation reversed: The abolition of pottery container technology

Fired clay containers were not made by the Upper Paleolithic communities of central Europe mentioned at the beginning of this paper, although these people were able to shape fresh clay into desired forms and transform it into "artificial stone" by baking. We know today from hunter-gatherer communities in later times that high mobility and unfavorable climatic conditions would not necessarily have hindered the adoption and use of pottery vessels, so traits of life style and climatic conditions cannot be taken as the (only) explanation for the lack of pottery vessel technology among these Ice Age big game hunters.[133]

On the other hand, there is various archaeological and ethnohistorical evidence for the actual abolition of pottery technology in contexts where it had been previously well-established. In northern Finland, for example, the earliest local pottery type Säräisniemi 1, a regional, high quality variant of comb-pitted ware, disappeared at the end of the 5th millennium cal BC after having been produced for over one millennium. In the following ca. one thousand years, this region in the far north of Europe was basically aceramic, and it was only around 3000 cal BC that pottery technology reached the area again from the neighboring regions.[134]

An interesting ethnohistorical example from the North American northeast coast has been recorded by Frank Speck in the first half of the twentieth century.[135] The Penobscot, a Native American group in central Maine, did not use pottery vessels but traditionally cooked in birch bark vessels before they increasingly began to adopt European cooking pots. To cook in the birch bark vessels, both heating with hot stones and direct heating over the fire was employed. However, archaeological sites in the area are abundant with pottery sherds, showing that ceramic vessels have

128 Heron and Craig 2015; Philippsen 2015b.
129 Craig et al. 2013; Piezonka, Tsydenova, and Tumen 2015; see also Hommel 2014, 682.
130 See for example Mason 1981.
131 Huysecom et al. 2009; see also Hommel 2018, 12–14.
132 Hommel 2014, 666–669.
133 Hommel 2014, 668–669; see also Jordan and Gibbs 2019.
134 Pesonen and Leskinen 2009.
135 Speck 1997, 100–103.

been known and widely used in the region in the pre-European contact period. The Penobscot informants that were asked by Speck had no memory of any tradition of pottery making, but their term *se'ski·dju* which was used for the bark vessels and dishes literally means "earthen container". Even though Speck himself was not sure whether this linguistic observation really reflected a long-forgotten use of pottery vessels, the Penobscot example shows that ceramics can under certain circumstances be given up in favour of easily-made but not so durable organic containers. A similar ceasing of indigenious pottery traditions also took place in Siberia, here it was connected to the influx of metal cauldrons in the wake of Russian imperial expansion.

These brief examples illustrate instances of abolition of the ceramic technology in hunter-gatherer societies under certain conditions, a possibility that should also be borne in mind when investigating the dynamics of early pottery traditions of Eurasia.

4 Conclusions

Research results of the last decades have confirmed the Pleistocene age of the world's oldest pottery in eastern Asia. Ceramic vessels were subsequently made by mobile hunter-gatherer-fishers of northern Eurasia over many millennia completely independent of a 'Neolithic' based on agriculture and animal husbandry. The density and quality of currently available archaeological information in the vast space between the Pacific and the Baltic still remains very heterogeneous, and new research is needed to close gaps in the record and complete the picture in order to better understand the mechanisms behind the adoption and dispersal of this prominent technological innovation.

In addition to the development of a reliable archaeological data base, a better contextual understanding of early hunter-gatherer ceramic traditions is necessary that also considers aspects of the integration of ceramics into the existing hunter-gatherer ways of life, of its interrelation with socio-economic developments and transformations and with dynamics in the human-environment relations. Methodically, multidisciplinary approaches involving various scientific disciplines open new opportunities to receive more detailed results on these issues. New field research especially on multi-layered sites is necessary to collect material from well-stratified contexts. A central task is the generation of further absolute dates from samples securely associated with the early pottery phase. Connected to this, further research is needed on the problem of reservoir effects in charred crust dates, their identification and quantification. Biomolecular analyses including isotope studies and analyses of organic residues in charred crusts and the pottery fabric itself offer more detailed information on vessel contents and uses, and multi-variate statistics as well as computer modelling are being increasingly employed for the regional and inter-regional integration of the data.

Irrespective of the pending answer to the problem whether North Eurasian hunter-gatherer pottery was one single tradition dispersing over many millennia across the continent, or whether it represents the result of several independent inventions and regional dispersals of ceramic vessels, it is clear that this technology forms part of a set of large-scale, long-term processes and connectivities shaping the cultural developments on the Eurasian continent in the late Pleistocene and early Holocene. Due to its good archaeological visibility, pottery is especially well suited to investigate these processes in space and time, and the chances are good that the increasing interest in this topic among eastern and western archaeologists and especially their collaboration will lead to new insights on the genesis and further development of hunter-gatherer innovations in northern Eurasia and beyond.

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Florian Klimscha

Towards a Social Theory of Ancient Innovations

Summary

This paper summarises the results of the conference and offers a view on the ancient innovation-process. It is argued that the specifications of ancient societies hinder the application of modern innovation theories, and it is suggested that key elements of ancient innovation-processes can be deduced and need to be integrated in theorising ancient innovations.

Keywords: innovation; innovation process; diffusion of innovations; emergence of innovations; invention; ancient innovations; ancient innovation process

Der Beitrag fast die Ergebnisse der Konferenz zusammen und versucht darauf aufbauend den antiken Innovationsprozess zu skizzieren. Die Besonderheiten antiker Gesellschaften erschweren die Anwendung moderner Innovationstheorien, und stattdessen werden Schlüsselelemente des antiken Innovationsprozesses herausgestellt, die eine zukünftige Theorie beachten muss.

Keywords: Innovation; Innovationsprozess; Diffusion von Innovationen; Emergenz von Innovationen; Erfindung; antike Innovationen; antiker Innovationsprozess

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1 Introduction

V. Gordon Childe saw cultural evolution as the successive inclusion of key technologies. These technologies first appeared in a central region, Mesopotamia or Egypt, and were then diffused over several overlapping networks, into the European periphery.[1] Childe's model – while very elegant and elaborate – conflicted with the archaeological reality when calibrated radiocarbon data became available *en masse* in the 1980s and 1990s. It was now that scholars rediscovered Colin Renfrew and wrote local narratives of autochthonous inventions.[2] The wheel was invented several times and Germanic art styles did not necessarily imitate Roman ornaments any more. Prehistory did not need diffusion as a basic condition for dating and as a consequence grew more self-confident. Nevertheless many scholars stress that the diffusionistic approach is still possible, however, under a completely new chronological framework.

It is still scientific common sense, that during various time-periods the social systems in large parts of Europe, southwestern Asia and Northern Africa are drastically changed. Not only do we see the long-term effects of the Neolithic Revolution, but also the appearance of large-scale communication networks as the Baden-style in the 4th millennium or the Corded Ware culture in the 3rd millennium, but also the transformation of concentrations of power into the first city states in Egypt and Mesopotamia, and finally several European states in the Iron Age.

The introduction of technical innovations and their economic exploitation is one way to understand these changes, and it necessitates diffusion, but in contrast to the days of Childe, we are nowadays left clueless where and why these innovations originate and spread. Many key-technologies like writing, weighing and sealing or later money were considerably developed and pushed by state societies, while other innovations like specialised weapons or wheeled vehicles had a much wider distribution and often emerged in regions thought to be the periphery.

Can we, therefore, go back from local traditions to a modified diffusionistic view in the tradition of V. Gordon Childe, Sophus Müller and Oscar Montelius? Or has archaeology moved far beyond both diffusion and localised histories of technique and do we have to use completely new approaches to grasp the past?

2 Why study ancient innovations?

Modern studies mostly focus on the economic consequences of innovations, but innovations also have far-reaching consequences for social life and future technical developments: Locomotives did not only change the pace of overland travel, which had remained constant since the domestication of horses in the 4th millennium BC, but they were responsible for the introduction of wage-labour ("*Lohnarbeit*") in rural societies, the re-organisation of established landscapes, the expulsion of native people, a new perception of 'speed' as well as the beginnings of industrialized warfare.[3] Steam-powered looms not only sped up cloth production for the first time since the spinning wheel in the Middle Ages, but were also responsible for the pauperization of large population-groups, which resulted in massive social unrest in Britain and the weaver-uprisings in 19th century Germany.[4]

Yet, research on innovations and their socio-technical consequences is hindered by the short-term perspectives of modern studies. These rarely rely on data from more than 30 years in the past and often do not grasp the significantly deeper roots of innovations. In fact, short-term perspectives can even lead to grossly wrong conclusions:[5] Albert Einstein's direction of the Kaiser-Wilhelm-Institut in 1913–1914, for instance, did not result in the translation of theoretical knowledge into technological application, which was envisioned by Max Planck and others, but instead in the formulation of the general theory of relativity. Thus, an apparent failure led to ground-breaking new insights, which, in turn, were the basis for a large number of technical innovations. Would it be possible to fully grasp the impact of Einstein, if the investigation stopped around the middle of the 20th century?

1 Childe 1949; Childe 1951.
2 Renfrew 1969; Renfrew 1973.
3 Schivelbusch 2000.
4 Von Hodenberg 1997.
5 Goenner 2008.

Archaeological sources allow us to move beyond short-term perspectives. Within the archaeological record, innovation processes can be investigated over centuries or sometimes even millennia while they diffuse over whole continents. This allows understanding innovations not as self-contained events, but as part of a *continuous and undetermined* process with constant *anticipated* and *unanticipated* socio-technical change.

Research on ancient innovations has only very recently been made possible by two scientific developments: Science-based dating methods, like calibrated C14-dating in the 1980s, have achieved a considerable precision that permits us to separate, for the first time, the age of artefacts from assumed innovation processes. Prior to that, archaeology had to rely on diffusion theory and thus necessarily explained social change by the transfer of technical innovations from the urban centres of Egypt and Mesopotamia to the European periphery. The systematic application of C14-dating has shown many errors in this concept; and, today, it is widely accepted that key techniques like extractive metallurgy or wheeled vehicles are significantly older in the periphery than in the assumed core.

While Marx simply claimed that the shift from querns to water- and windmills created feudalism, we now have the possibility to tackle the relationship between technique and society the other way round, and to formulate a theory of innovations based on an empirical foundation.

The papers in this volume bring together theoretical and empirical points of views discussing the ancient innovation process. We think, they can also be read as a discussion of the famous S-curve and the underlying model of innovation-diffusion going back to Everett Rogers.[6]

3 Conceptualising the innovation-process in antiquity

Neither archaeologists nor researchers of technology have a well-founded assumption how ancient innovation-processes proceeded. Popular science and reports all too often simply claim that it was either similar like today, but slower, or that antiquity was a time of technological stasis.

In any way, we face the difficulty to explain how technologies that are even today essential for our society were developed in times without means to efficiently store information and without detailed knowledge of physical laws.

In this volume Gerd Graßhoff starts the discussion by deducing a long-term model of the innovation-process from modern data[7]. Innovation-research has a long history and was successively treated and understood differently. From the economic perspectives of Schumpeter to modern models of path-dependency and most recently the New Growth-Theory. Graßhoff acknowledges that any theory trying to grasp innovation must identify the 'causally relevant factors'. Since these are possibly Legion, it is crucial to be aware of the implicit selection of determinants in models of innovation-diffusion. While Everett Rogers' book on innovation-diffusion is widely used and quoted,[8] it is mainly the assumption that innovation is the result of a communication-process. Graßhoff criticises the focus on innovations that are not market-relevant with Roger's treatise. He thereby stresses that ancient innovations cannot be understood by just analysing communication-processes, but on the contrary the diffusion of objects and the necessary know-how for their production should be examined. Therefore the underlying modes of exchange could have been completely different from the innovation-diffusions described by Rogers. In Graßhoff's view innovation is determined by success on markets. There are, however, no necessities or coercive factors pushing innovations, though these may favour or hinder an innovation. Humans always have alternatives to adopting an innovation. Graßhoff establishes his own 3-phase innovation model, which elaborates on Rogers by adding three different diffusions. He proposes that an innovation has to pass three different diffusion-processes: 1. Discovery of the underlying principles, 2. Application of the knowledge and 3. Production. Graßhoff proposes that not always the most innovative technology succeeds, but that often those technologies fail at the market. Yet, it is only through their failure that new input is given to the process of innovation.

6 Rogers 2003.
7 Paper by G. Graßhoff in this volume.
8 Rogers 2003.

For Graßhoff, innovation is a process that may change while still going on. There is no clear aim and end product. Even the technological object that is produced may change during the innovation-process: It is therefore impossible to distinguish between the actual invention and any later parts. Every single change contributes to the development of a technological object during the innovation process. The process itself, drawing parallels from natural evolution, is only successful if in the end technical objects are produced. Thus it is impossible to single out the 'decisive' changes within both invention and innovation. Innovations *sensu* Graßhoff are "nonlocal"; they are the result of diffused knowledge emanating into applications of theory and finally the production of (technical) objects. Innovations are neither an event, nor do they have creators. They do not simply 'begin' and do not happen at a specific place. Innovation is in Graßhoff's words a "long-term, globally distributed synthesis of collaborative contributions".[9]

A contrary position is taken by David Warburton, who builds his argument from actual finds of ancient innovations and his understanding of their improvements[10]. Warburton stresses that there are often very long time spans in which innovations did not change at all, but were kept static. He claims that in most cases this is due to the lack of understanding in the underlying principles: philosophers were not interested (or had no deeper knowledge) of the scientific laws responsible for an innovation and the producers had no interest in improving a working machine or tool.

According to Warburton, ancient innovations took place only in the small urbanised centres, but the dominant agrarian world was largely devoid of innovations and remained unchanged since the Neolithic. Innovations did not change society, but only the lives of a 'select few'.

In contrast to modern innovations, philosophers (i.e. scientists) were largely not involved in the process of innovations, even though innovations were tailored to the needs of groups outside production. Bronze Age weapons, for instance, are the result of the collaboration of warriors and craftsmen.[11] The cost, on the other hand, seems to be a decisive factor for innovation-diffusion and falling prices for new technology are singled out as major stimuli.

In Warburton's view there is a dramatically difference between ancient and modern innovations: In antiquity innovations were changed according to social needs and boundaries, but innovations did not change society. Warburton sees the structural shift between antiquity and modern times in the existence of institutions; without the successive establishment of social institutions like fiat money or patent laws, technology had no infrastructure from where it could be developed in a way that changed society.

Svend Hansen approaches the topic from yet another angle.[12] Although he acknowledges that on first glance innovation research in ancient times seems to be doomed from the beginning, he claims that this is mainly due to wrong premises like that ancient times were technophobic or that all progress came from urban centres in the Near East and then diffused to the peripheries. In his view, the systematic application of science-based dating, as well as the fall of the Iron Curtain changed exactly these basic obstacles. Since the 1970 we are aware that not all innovations need to come from the Near East,[13] and new research has confirmed this: The earliest pots were made in Eastern Asia millennia before this was part of the daily life in the Fertile Crescent,[14] while metallurgical innovations started around the Black Sea or even the Ural. This completely changes the picture that was painted in overviews of prehistory (and which is still perpetuated outside the academic discipline). New approaches on archaeological innovations need to take this in account and now have the possibility to research the actual diffusion, reinvention and wearing off of innovations. Archaeological sources might not have the details of historical ones, but they do allow to see the dynamics of innovations and the multitude of consequences these bring over centuries and even millennia. With reference to the work of Max Weber and Jacques Cauvin,[15] Hansen is very positive that a similar view can also be useful to understand social innovations in a long term perspective: Archaeology is able to trace the spreading, changing and substitution of ideological systems over extremely long time-periods. This has been

9 Graßhoff in this volume.
10 Paper by D. Warburton in this volume.
11 Mödlinger 2011, 153.
12 Paper by S. Hansen in this volume.
13 Renfrew 1969; Renfrew 1973.
14 Cf. the paper by H. Piezonka in this volume.
15 Weber 1920; Cauvin 1994.

done from the very beginnings and was part of the political theories of Marx, Childe and others. Yet, early writers had to cope with a wrong chronology, a limited view on the distribution of phenomena and a flawed theoretical understanding of technology. Progress was a historical possibility but not a necessity and by far an unstoppable process. The successive adoption but also ignorance of innovations, technical and social alike, shaped societies and had consequences that could be felt even in modern times. Archaeologists now have the unique possibilities of not only starting this new and exciting field of research, but also to re-shape our understanding of many classical texts relying (often implicitly) on archaeological sources.

4 Emergence: How are inventions developed into innovations?

The difference between inventions and innovations can be shown already at the very beginning of human technology, where evidence of artificially created plastic depictions has been uncovered in Lower Palaeolithic layers in Israel. The 'figurine' from Berekhat Ram is, in fact, a pebble with the rough shape of a human being.[16] It resembles younger figurines of females that are well known in the archaeological and also popular literature and usually referred to as "Venus" figurines. The Berekhat Ram find is in many ways special: First of all it is not a real figurine. The shape of the rock was natural and not created by humans. It has, however, been verified that the contours of the stone have been modified by humans using a cutting object. The second peculiarity is the age of the find, which brings us to the time *homo sapiens* evolved, namely 250 000–280 000 years ago. The object was created by early hominins, probably descendants of *homo heidelbergensis*,[17] for which most researchers do not assume abstract thinking and the ability to create art.

Currently, the Berekhat Ram figurine remains rather isolated, and could also represent an individual performance that is not transferred to the rest of the group.[18] This would mean, there was no historical consequence of this exceptional case, and the object would be a perfect case for a failed innovation. If one accepts this interpretation, then the find can be read as a much-needed warning that the archaeological record does indeed sometimes preserve singular moments without larger socio-technical consequences. And these moments, events in the sense of Fernand Braudel, should be carefully considered, but not confused with those finds which are the result of the *longue durée*, namely those that were parts of repeated processes.[19]

Christian Jeunesse tackles the field of archaeological innovations from a unique point of view by arguing that the essential innovation in prehistory was the establishment of a system of mixing and firing substance, which he calls the MCTS ("mixing-and-combustion-technical-system").[20] The identification and application of the basic elements of this system help him to argue for unforeseen traditions in the development of prehistoric technology. That is essential, because archaeologists often have difficulties seeing the early stages of innovation processes and usually can study innovations only at a relatively advanced stage, when as Barbara Helwing demonstrates[21], the original meaning might already have been changed. Jeunesse, nevertheless, claims that the identification of the MCTS allows to trace the evolution of technology over large spaces and time. His paper takes ceramic as an end point of the development of manufacturing artificial materials.[22] Ceramic is a material unknown in nature and the shapes humans created from it also do not have natural archetypes. The main steps of the production involve grinding, alloying of different substances (i.e. mixing clay and temper), modelling and heating. These basic steps can be sketched also with metallurgy and glass – even though Jeunesse does not explicitly refer to those later technologies. Pottery (or the MCTS) is often thought to have derived from birch tar or compound adhesives, but in the view of Jeunesse both techniques lack heating and are therefore only vaguely related. The MCTS is a revolution in human technology and spawns (or is related to) other technologies, for

16 Goren-Inbar 1986.
17 Rightmire 2013.
18 This position was taken by M. Haidle in her lecture at the conference that was not turned into a paper.
19 Braudel 1977.
20 Paper by Ch. Jeunesse in this volume.
21 Cf. the paper by B. Helwing in this volume.
22 In the sense of Léroi-Gourhan 1993.

instance lime plaster and daub in the Near East and in later parts of the Neolithic also bread.

Why did humans invent ceramics and thus the MCTS? Certainly there was no need for it: The development of pottery figurines in the Near East, for instance, pre-dates the production of ceramic vessels by more than two millennia, and the invention of pots cannot be explained by shortages or pressure. While Jeunesse cannot answer this question satisfactory, he deduces brilliantly that developing an invention into an innovation cannot have been "a mere question of opportunity".[23] The time span between invention and innovations in prehistory is for him the time necessary for symbolic domestication. The Neolithic is then consequentially the process of turning Palaeolithic inventions into innovations, or in his own words the "accomplishment of the dreams made by anonymous inventors from the Palaeolithic".[24]

Jochen Büttner presents in his paper some considerations about how a complex technology like weighing might have emerged.[25] His initial thought is also valid for other technologies: Weight measurement was not a problem-driven innovation. The concept of weight as an attribute of objects seems to be the consequence of balances and weighing, and thus cannot have been a necessity before such machines were developed. In other words: Balances could not have been invented *ex nihilo* and then solved the problem to measure weight, because this problem did not exist before balances were invented, Büttner argues. Weighing starts relatively early in Egypt, in the reign of king Narmer around 3100 BC, but has its breakthrough only in the 2nd half of the 3rd millennium in the Urban state systems of the Eastern Mediterranean and Mesopotamia. Büttner compiles data from various fields of research and deduces that "perceiving weight measurement as a problem presupposes an understanding of weight as a[n …] physical quality".[26] This, however, cannot be assumed as a general concept shared by all human societies. In fact, Büttner points out that there is evidence that societies without a concept of weight did and do exist and that members of such societies, even when raised in modern Western societies, easily misjudge weight because they rather focus on other object qualities.[27] Büttner boldly interprets such studies as a general inability of humans to develop an idea of weight in relation to an object and its parts.

He explores two lines of argumentation instead: First the counting and measuring of objects and secondly the *comparison* (not measuring!) of the weights of two objects. With all other physical qualities counting can result in an understanding how the dimension relates to parts of a whole. With length, for instance, Büttner argues, that a wall made up of bricks of equal size can be understood as being the result from building it with bricks equal to a certain length. By simple counting such an amount of bricks could be calculated and stored. This does not work with weight. While a simple stick, to make bricks of equal lengths is sufficient for building a wall and measuring its partitions, a balance for weighing objects is a very complex machine that needs abstract knowledge. Whether the material is exhausted, or how it is reduced, is visible when measuring lengths (or volumes), but invisible with weights. Even small parts can weigh more than larger parts depending on their material, density etc. The weight of an object cannot be perceived as being twice or three times as high as that of another object. In this respect the size of an object fools our natural senses.[28]

It is essential to understand that the oldest balances in the archaeological record are equal-armed balances, and these do not measure weights, but simply compare it. Two objects can be placed one on each side and the balance allows to determine whether one is heavier or if both are of the same weight. Establishing the relative weight of two objects, however, is a "meaningful practice outside and before weight measurement".[29]

Weight comparison starts already when using a shoulder pole to carry two objects, and Büttner's argument could easily be extended to the situation where a person regularly needs to carry two heavy objects at the same time, one in each hand. In this case it is much easier to carry two objects of roughly equal weight. Büttner reconstructs the emergence of weighing therefore as the result of repeatedly comparing two objects of the same kind and the necessity to be able to compare them at different places. This, however, necessitates a third object

23 Jeunesse in this volume.

24 Jeunesse in this volume.

25 Paper by J. Büttner in this volume.

26 Büttner in this volume.

27 Bödeker 2006.

28 Cf. Murray et al. 1999.

29 Büttner in this volume.

of a similar quality that can be compared with both via a balance. Büttner sees an impulse in such a task in the rationing of substances. The symbolical recording of such procedures might have been the impulse to standardise such counts and establish 'official' weight units. All this was, nevertheless, still possible with weight *comparison*. Even with the advent of standardised weights, these only added a guarantee to the technology, but not a new way of measuring weight without comparison.

The comparison of the weights of two objects might, however, also have other purposes, which Büttner in his paper does not refer to. From the archaeological record two examples come to mind, which might have necessitated a precise equality of two or more objects in a quality that could not simply be perceived by the eye. While this is not the place to elaborate on such thoughts, the recipes of alloyed metals come to mind. These could not simply be recorded by taking two chunks of ore of roughly the same size. It might be worth to further examine the precision of early alloys. Furthermore, within prehistoric religion we regularly face the deposition of two or more objects of similar size, shape and type. Is it unthinkable that a prehistoric group of religious specialists ('priests') wanted to have a way to establish in how far these objects were equal or whether one large axe had indeed the same quality as several small axes?

Gary Feinman studies also metallurgy but compares it with writing and the non-development of 1960s visions of flying cars in a comparative perspective.[30] Feinman strongly turns against technological determinisms, which are in his words "simple, direct and free of human agency"[31] and re-appear like the living dead of modern post-apocalyptic horror visions. The example of state systems using stone-age technologies from Mesoamerica[32] is indeed a strong argument that cannot be dismissed. Yet, finding an alternative to understand technological change is not an easy task. Feinman approaches his topic from several angles. His first attack is based on the pseudo-Darwinian notion that the generation of inventions is arbitrary and undirected. On the contrary he claims that economically speaking there are conditions in which it is less cost intensive to experiment than in others and therefore such situations could yield higher pay-offs. This is a valuable thought reminiscent of Schumpeter's[33] concept of prices and innovations being the result of economic cycles. Feinman thus argues that invention frequency is not random but can be stimulated. The second fundamental factor for technological change is seen in the role of institutions, which are generally defined as "set(s) of rules that structure [...] interactions and relations between individuals".[34] The existence or non-existence of institutions dramatically shifts a society's attitude towards innovations and may enable or disable the adoption, spread and modification of technology. Power-differentials and the way these are affecting networks are therefore decisive factors, but top-down diffusion also has explanatory limits.

The way in which networks spread technology is further scrutinized. Networks, Feinman confines, however, are neither purely functionalist with all participants acting in the interest of a group's well being nor are they steered strictly top-down. Going back to his case-studies, Feinman subsumes that for early metal use the "institutional bases of power" as well as the "socioeconomic relations between rulers and ruled" were as important as the different metals themselves;[35] Feinman sees an important impulse in the adaption of metal tools in incentives to agricultural intensification.

The way, in which incentives for capital investment are perceived, is then his approach to go back to the problem of the non-development of flying cars.[36] Even though there are indeed issues, which would hinder the use of such vehicles, Feinman argues from a point of view of capital flow and contrasts the time when such visions were developed in science fiction with the economic development of the last few years. While the 1950s and 1960 were dominated by investment into U.S. infrastructure, this has successively shifted into financialization, personalised communication, surveillance and life extending. "If an innovation does not aim at leadership [...], it is unlikely to be innovative enough", he quotes technological expert Peter Drucker.[37] Thus, flying cars and other visions of the post war United States

30 Paper by G. Feinman in this volume.
31 Feinman in this volume.
32 Carneiro 1974, 180–181.
33 Schumpeter 1947.
34 Feinman in this volume.
35 Feinman in this volume.
36 Graeber 2012.
37 Drucker 1998.

are today even more unlikely to be invested in than in the past decades. Relationships of inequality and power influence the emergence and development of innovations also in modern times. Speed and direction of economic growth and therefore also the emergence of innovations are strongly influenced by the way wealth and power is divided within a society, as well as the structure and potency of social networks.

5 Diffusion: Why do innovations spread and why are there limits to the diffusion?

Once innovation-processes have started, they diffuse. The spreading of technology is essential as a stimulus for change in human society. Yet, little is known about why innovations moved over vast regions, but stopped at seemingly random borders. Florian Klimscha and Jürgen Renn comment in their paper on the long-term diffusion of metallurgy into Europe.[38] In its initial diffusion, metallurgy is limited to the Balkans and slightly later the Carpathian Basin and the Alps. While copper is used from the beginning for a variety of small tools, the most impressive remains are the heavy copper shaft-hole axes and adze-axes, which were also used as prestigious items and status symbols.[39] Copper axes (and comparable prestigious items) do travel large distances and reach distant places like Brittany or Southern Scandinavia.[40] Yet, the technology to produce such objects remains isolated in the core zone for nearly two millennia. Metal items are perceived as exotic and are imitated in stone in the following centuries,[41] but they cannot be reproduced. The initial diffusion of metallurgy, which in *communis opinio* is rather dysfunctional and mostly prestigious builds the socio-technical foundation for the adaption of further innovations. When in the 4th millennium new innovations like alloying or specific wood working tools emerge around the Black Sea, these can only diffuse into the areas which already have established the necessary know-how and infrastructure in previous times. This dramatically influences the technical development of large regions and the way these can innovate. Not only is metallurgy started significantly later, but also in the meantime the exchange of goods, information and marriage partners is hindered by allowing certain groups to monopolize on prestigious items by keeping their manufacture secret.

Catherine Frieman discusses the diffusion of metallurgy from the perspective of regions which resisted it but instead copied metal artefacts in traditional materials.[42] Frieman points out that this scenario is, however, simplistic and needs clarification. She studies flint daggers which appear in the North European Plain, Scandinavia and Western Europe roughly at the time when metallurgy is diffused into the Alps. Frieman argues, these societies were able to create a complex technical system in response to metallurgy. The flint raw material was carefully chosen and often from exotic sources. The objects themselves often show very high knapping proficiency. Frieman offers a very abstract and indirect view on innovations. In her words there was "no conscious choice to adopt copper",[43] but technologies were part of relationship-based units ('kin-groups').[44] Thus, the choice whether a dagger was metal or flint was not one that prehistoric users were able to make, but rather the dagger itself (and its new shape) was the innovation. Thereby, Frieman sees a trend towards specialisation in weapon production during the 4th and 3rd millennium in which bladed weapons, and especially daggers, have a prominent role. In her view, it is more or less a historical coincidence, that some of the groups, which start to begin producing daggers, already are proficient in casting metals and thereby further develop metallurgy by introducing alloys and finally begin to produce thin, bladed objects.

Barbara Helwing points out yet another specific of innovations: They can change during the diffusion. Helwing examines a specific set of metal headbands under the aspect of innovation-diffusion and meaning.[45] Metal headbands signify a social elite in the burial customs (and assumedly also in real life) during the 4th and 3rd

38 Paper by F. Klimscha & J. Renn in this volume.
39 Most recently treated by: Boroffka 2009.
40 Klassen 2000; Klassen 2004.
41 Cf. Also the paper by C. Frieman in this volume.
42 E.g.: Klassen 2000; Klassen 2004; Roberts, Thornton, and Pigott 2009; Roberts and Frieman 2015.
43 Frieman in this volume.
44 Kienlin 2008.
45 Helwing in this volume.

millennia BC in Western Asia. While the earliest examples from the 4th millennium are used in richly furnished graves of males and females there is a change visible in the first centuries of the 3rd millennium BC (ca. 3000–2800 BC). During this time span, copper-alloy headbands are known in a large area from Anatolia to the Caucasus into Iran[46] They are regularly known from females associated with male warriors. Thereafter, headbands are still in use until the 2nd millennium BC, but are now used simply as an adornment for both males and females. Headbands thus transform their meaning, when they become mainstream, to use Barbara Helwing's words.[47] Reflecting this on Rogers' diffusion model[48] would mean that the innovation would be reinvented during the adoption of the majority.

Heidi Köpp-Junk finally describes the case of a region that resists key innovations for a long time, yet never was considered peripheral or unimportant in narratives of antiquity: Egypt. Köpp-Junk chooses the wheel as her study object.[49] While the wheel is quickly diffused and is adopted nearly all over Eurasia within a few centuries after its invention,[50] the inhabitants of Egypt ignored wheels for a long time and even when they finally used them they were not part of wagons, but of siege equipment. Wheeled vehicles only appear in the 2nd millennium BC more than 1500 years later than in Europe and Mesopotamia. A different scenario takes place with the horse-drawn light chariot on spoked wheels. Even though this is no Egyptian invention, either, the horse drawn chariot is in use by the middle of the 2nd millennium, when it is frequently driven around the Eastern Mediterranean. Finds of horse bones hint at a slightly earlier date for the initial diffusion in the early 2nd millennium BC.

Many details are still missing in this discussion and need to be addressed in the future, but the record makes it clear that the essential point of the paper is a question: Why were the Egyptians so stubborn when it comes to adopting an innovation that is regarded as one of the most important by large parts of the modern world? Köpp-Junk puts forward practical reasons by pointing out that wheels were simply not the best way to move objects on sand. This does conflict nevertheless with the later adoption of chariots for which roads through the desert were built. Apart from a lack of understanding of the craft traditions involved in the construction of early wheeled objects, and the way that the wheel took into Egypt, there are issues concerning the quality of the archaeological data, which only derives from pictorial sources and funeral equipment. It might therefore be still possible that systematic excavation will reveal new data.

At the current state of research, it seems most plausible to argue from several angles, why the innovation of the early wagon was not adopted in Egypt. First of all the dispersed settlement structure of western Eurasia, where wagons are assumed to be a great assistance in moving heavy loads between the village and the fields, was missing in Egypt. Secondly, Köpp-Junk certainly has to be followed in pointing out that sledges were simply superior to wagons in the local environment and, not surprisingly, used from 3000 BC for the transport of heavy goods. Also the limited amounts of wood for the construction of disc wheels might have been of relevance here. Yet, this argument fails to convince when a slightly larger picture is seen. Already in the Levant and Mesopotamia, wagons are used considerably earlier – even though they are by far the best way to transport heavy objects. Therefore, a third alternative should be considered, too, namely that early wagons did not befit the rank of Egyptian elites, who instead used palanquins and were carried. Thus, a tripartite argument, namely the professional conduct of elites, the disadvantage to other technologies and environmental shortcomings can be brought forward as an explanation why the diffusion is blocked. It is only when the elites agree on the 'coolness' of driving, that the desert is transformed and wheeled vehicles in the form of chariots become *en vogue*. Since horse-drawn chariots can run nearly ten times as fast as cattle-drawn wagons with disc wheels, the factor which changed this attitude seems to be obvious. The introduction of the wheel is a classic example for innovation processes steered by social power as Gary Feinman has elaborated on.[51]

46 Wygnańska 2014.
47 Helwing in this volume.
48 Rogers 2003.
49 Paper by H. Köpp-Junk in this volume.
50 Burmeister 2004; Klimscha 2017.
51 Cf. Feinman in this volume.

6 Consequences: How do innovations change society?

Since the time of Childe we assume that innovation-processes bring social change and therefore are the foundation of cultural evolution. This has even led to a subdiscipline which compares historical change with Darwinian evolution.[52] The factual reality, however, is often more complicated and presented by several authors in this volume.

Martin Furholt scrutinizes the relationship between technical and social innovations by drawing a panorama over Central and Northern Europe in the 4th and 3rd millennium BC.[53] He concludes that the division is artificial and not leading to a deeper understanding of the innovation process. Yet, he acknowledges that there are indeed differences and proposes a division between *social technologies* on the one hand and *tool-based* or *apparatus-based technologies* on the other hand. Plainly put: Some technologies need solid, material things and other do not. Nevertheless, innovations are in Furholt's opinion (following Rammert[54] and Schumpeter[55]) always a combination of something social ('immaterial') and something material. Thus, all innovations are socio-technical, but he expands that perspective by stating that the immaterial part of a technology only works in collaboration with a material component.

This is the start for Furholt's reflection on the innovation-process. In his view the innovation starts when old beliefs are changed after a period of conflict, in which resistance, Furholt uses the Piercian term "doubt", grows stronger.[56] This finally leads to the introduction of something new and changes social realities. Routines are disturbed and many people will not see any improvement at all. This perspective is rather pessimistic and leads to a question: How can innovations then start at all? Furholt argues that cognitive differences within a group are necessary. There must be people who do not see the 'new' as something disturbing, but actually embrace it and speak and act in favour of it in the following cultural discourse. Thus, *cultural heterogeneity* raises the chance for successful innovations.

To understand how cultural heterogeneity (or homogeneity for that case) can be measured in the archaeological record, he analyses Neolithic communities as correspondence and non-correspondence systems.[57] Correspondence systems are communities where correspondence is limited to direct neighbours or within the village while non-correspondence systems uphold social relations mostly to people outside the village. Non-correspondance systems are characterised by weaker social institutions but higher individual mobility. Furholt uses this understanding of the innovation-process to reconstruct village societies of the European Late Neolithic. In his view, the 4th and 3rd millennium social units are the result of increased human mobility and this resulted in the creation of correspondence systems. The widespread archaeological homogeneity therefore correlates with social or cultural heterogeneity within the settlements. This, in turn, resulted in the diffusion of a first complex of tool-based innovations, which slowly broke routines and challenged society in such a way that it allowed the diffusion of social technologies in the second complex.

Ianir Milevski explores an empirical perspective by demonstrating how a sequence of innovations can transform a region.[58] His area of study is the southern Levant during the 5th to 3rd millennium. It is striking how different this picture is to that of Furholt, who analyses roughly the same time span in a region further north. Milevski's more restricted perspective allows to go into detail, and he discusses copper metallurgy, pottery production, burial modes, flint industries as well as the domestication of donkeys. While there are, of course, changes in all of these areas, these are usually seen as chronological markers. Milevski sketches a scenario in which the organization of crafts, the distribution of goods and the division of labour change, while societies begin to live in urban settlements. Technological change within basic crafts a well as new modes of transportation are seen as giving the prime impetus, while architectural designs and burial customs can be read as representing a successively more differentiated society. The impact of trade systems regarding flint tools

52 Mesoudi 2011. St. Shennan gave a presentation based on this methodology during the conference but was not able to publish it in this volume.
53 Paper by M. Furholt in this volume.
54 Rammert 2007.
55 Schumpeter 1947.
56 Cf. Peirce 1877.
57 Hillier and Hanson 1984, 242–256.
58 Paper by I. Milevski in this volume.

and metal is pushed by the domestication of donkeys as a new and more efficient means to transport goods over land.[59] Milevksi suggests the shift from household-based to community-based production, i.e. a shift in the relations of production, was corresponding to innovations in the modes of production. Technological change causes social change, but for Milevski this is rather not a revolution, but the result of several small scale changes over longer time periods.

The overreliance on single classes of artefacts or technologies is the topic of Ann Brysbaert's contribution.[60] Brysbaert discusses the contexts of crafts in Bronze Age Tiryns and demonstrates the high complexity of the underlying social processes. She starts her study with wall brackets and then draws a wider circle into the palatial and non-palatial economies of Tiryns. Wall-brackets are thought to have been brought by people from Cyprus and were primarily involved in mostly cultic activities,[61] but thereafter often lost any ritual meaning. In Tiryns wall-brackets are quickly adopted by local artisans, who might even have thereby taken over the original Cypriote value. Wall brackets were integrated into local modes of practice and thereby formed new hybridizations of foreign and local ritual and practice.[62] According to Brysbaert metal workers from Tiryns might even have wanted to incorporate not only the item but also the associated ritual.

Different networks exist and overlap already in the local sphere and are connected through social sharing. Brysbaert stresses that regular sharing structures the daily life and activities in a Bronze Age palatial community. The demonstration of how non-palatial crafts are carried out within the palace to assist palatial production is impressive in this regard[63] and suggests a caleidoscope of different crafts interacting with each other. Creativity within these contacts of different crafts are regularly overlooked for innovation theory. The palace may have controlled certain crafts, but personal contact was nevertheless possible and assisted by the palatial umbrella. Local personal resources were used for certain tasks, but also specialists from outside came into the palatial system and the personal contacts allowed small-scale innovations or components of technical systems to be communicated, experimented with and transferred.

Around 1200 BC this complex system ends with the demise of the Mycenean palaces. The production of glass, faience, linear B-script and other materials stopped. Brysbaert is able to plausibly explain the different pace in which these crafts disappear from the archaeological record with her set of tools. Those, which were interwoven with the socio-political sphere, ended first, but the specialised craftsmen needed to either move away to places, which still had demand for their tasks, or shift to subsistence activity and a part-time production of their craft. Brysbaert suggests the latter, but points out that there was also continuity in ivory working or pottery production and many other crafts, among them the production of wall-brackets. What is striking here, is that there is not necessarily a loss of value with the end of the market, but a shift of value and an integration into local, non-palatial contexts.

It is therefore not necessary to simply examine the way technology changes society, but, as Brysbaert makes clear, how social systems influenced the way in which technology is adopted, modified, and rejected. Yet, instead of simply reversing the technodeterminist mantra, she opts for a cyclic view on technology, in which innovations and societies continually modify and affect each other.

Katherine Gruel, Olivier Büchsenschütz and Olivier Nillesse present results from a large-scale mapping project on the Celtic Iron Age.[64] Apart from a spatial approach to innovation-research this paper demonstrates that antiquity was not devoid of innovations after the Neolithic Revolution and the 4th millennium. In fact, several innovations like iron scythes, coins or the rotary mill are comparable in their impact to the prehistoric innovations. Here, too new, research makes clear that innovations do not always appear in the Mediterranean centres and diffuse into the barbarian periphery. Innovation diffusion in the Iron Ages is a complex process with many places adopting and reinventing new technologies. Higher dating precision also allows more detailed models to be drawn and Gruel, Büchsenschütz and Nillesse explicitly see "individual initiatives"[65] as decisive for the creation of innovations. A

59 Klimscha 2013; Rosen 1997.
60 Paper by A. Brysbaert in this volume.
61 Panitz-Cohen 2006.
62 Nakou 2007, 239–240.
63 Brysbaert and Vetters 2010.
64 Paper by K. Gruel et al. in this volume.
65 Gruel et al. in this volume.

higher efficiency, an easier handling and a higher speed are their main criteria for successful Iron Age innovations. They also state a warning, that the "myth of humanity's progress"[66] should not re-enter the discourse on archaeological techniques. During the 2nd half of the 1st century BC technology and social organisation are very dynamic and show no clear evolution towards anything like higher complexity. On the contrary the agrarian innovations are developed in regions outside the Roman and Greek urban centres, like the rotary mill, which is invented in Iberia. Gruel and her colleagues see the reasons for the success of innovations in a complex dialogue between the individual producers, the possible applications of the 'new' and traditional society often resisting. Innovations do not succeed because of a single reason, but modern mapping tools and network analysis will help us to understand the complex histories underlying the diffusion.

7 Conclusion: The ancient innovation-process

Ancient innovations are a complex and vast topic. This short volume is far from explaining them in totality and exhaustively. Yet, the papers offered original, sometimes controversial, approaches towards understanding innovations in antiquity. Several broad lines can be summed up as a result.

The greatest consensus was achieved regarding methodology. The ancient innovation-process cannot be understood from the artefacts as static objects, but necessitates the thinking in *chaînes opératoires.*[67] Yet, the dynamic nature of innovations forces us to think also in another dimension namely that of networks:[68] Unless we understand how different crafts of the production process interact with each other and how these are related to agents inside and outside of a community, the answers to many crucial questions are simply inaccessible.

The products resulting from innovation-processes competed with other artefacts. In some cases, a market can be assumed as a mechanism of selection. However, while economic models have their place also in ancient innovation research, it must be kept in mind, that matter-of-fact tone, functionalist assumptions on the actions of individual agents and the problem-oriented practicality of modern handbooks barely reflect the reality in antiquity and prehistory.

Production was often closely related with other social spheres, which are not obvious to the modern observer. Cultic activities taking place in a workshop in Late Helladic Tiryns should not surprise us,[69] but motivate us to explore such options also for other technologies. Further above, I have already suggested that the practice of hoarding very similar objects since the Neolithic might be worthwhile to research under the aspect of forerunners of weight comparison.

Yet, this does not mean, that there is no means to understand the logic of ancient innovations. These do not simply appear randomly and create unanticipated effects with no consequences until the scientific spirit awakens in the Early Modern Age. On the contrary, ancient innovations can be understood from a theoretical perspective.

7.1 Emergence of Ancient Innovations

Innovations in antiquity did not appear at random and at arbitrary places. They are the result of available knowledge – often verbalised in rituals and owned by craftsmen and artisans. There is no good evidence that innovations are the result of problems encountered and systematically solved, either. Innovations resulted from long-term experimentation as well as an ideological domestication process and emerged at places where the necessary technical prerequisites were available during time periods and social constellations favouring experimentation. The frequency of innovation-emergence could be stimulated, the best known, yet most under-researched factor is certainly the price. Technological artefacts are not necessarily the result of theoretical knowledge, but might also be the result from the application of perceived physical consequences. In contrast to modern technology-development, ancient innovators tried to create technology with a different set of rules explaining the cosmos. Thereby religious beliefs and other parts of ideologies might blur the methods. Yet,

66 Gruel et al. in this volume.

67 Cf. The papers of Ann Brysbaert, Barbara Helwing, Christian Jeunesse, Florian Klimscha & Jürgen Renn and Catherin Frieman in this volume.

68 E.g.: Tsoraki 2011; Margomenou and Roumpou 2011.

69 Tzonou-Herbst 2002, 206–218.

technology-production was not just coincidence, but the result of controlled application of know-how.

People rarely developed innovations in the interests of society, but personal advantages or ideologies motivated creating novelties. Necessities did stimulate innovations, however, in practical tasks, like house building, tool making or weapon production. Nevertheless, the reinvention of such innovations was often hindered when the technology fitted the needs, i.e. a tool or weapon was thought sufficient. Such innovations emerged in workshops, during communal building activities or as the result of the communication of warriors and craftsmen.[70] There is no real evidence that philosophical problems were handed to craftsmen with the task to solve the problem. Antiquity is in large parts the age of the tinkerer, not the engineer. The skill of ancient craftsmen astonishes modern observers with regard to their precision and meticulousness. These craftsmen were able to replicate workable instruments and machines without necessarily understanding the underlying principles. What might have been unclear was, which parts of the *chaîne opératoire* were essential, and which were added to keep the production secret or conform to systems of belief. The improvement of technology was still impeded when it was written down, and also the limitation of know-how to craftsmen, often perpetuated in kin-groups, made it difficult to innovate technology. This allowed the wide distribution of complex machinery like the Antikythera mechanism,[71] but made its improvement impossible until during the Middle Ages new concepts were developed and practically applied. This is possibly a reason, why the movement of technical specialists or even people often resulted in technology-diffusion.[72] It was not a new set of genes, that enabled technological progress but the application of new ways of thinking deeply rooted in the culture of migrants.

7.2 Diffusion

Archaeological sources rarely allow to pinpoint the exact place where an innovation started. This is mostly caused by a certain chronological blurriness and the filter mechanisms of the archaeological record. In most cases it is impossible to clearly differentiate the various stages of modern innovations (discovery, application of know-how and production). Markets were limited. In many times and regions we actually have no evidence for the existence of markets, and therefore the 'best' technology did not necessarily survive a battle of fitness. Technologies were diffused in all kinds of stages and often they were successful although they were far from being suited for practical tasks because ancient users were fascinated by their esoteric qualities. Even in state societies and with the help of writing, systems, which, from a modern point of view, were clearly imperfect, did survive for long periods of time. The diffusion of innovations did not necessarily change society, but in most cases the innovation was appropriated by the adopting society; innovations were made to fit into society and not vice versa. The diffusion of complex technologies was limited by the availability of technical know-how; when this know-how was not available, elements of the innovation might still diffuse and were appropriated in local technologies which then could even evolve into unprecedented levels of specialisation.

Individual initiative (on the level of persons or small groups) seems to be the prime means by which inventions were developed into innovations and also diffused. Yet, for the diffusion and reinvention of innovations social institutions were also decisive and were able to boost the diffusion of new technologies, both on the local and on the supra-regional level. State-systems did not necessarily generate all innovations, but they could stimulate higher frequencies of innovations and transform technologies to their needs, which, as a consequence, could result in a much quicker diffusion. The production of technology was embedded in ritual, and this ritual was one visible and perceived attribute of the technology. Innovations did also spread because it was the ideology that fascinated people and not the technology. In some cases this caused the adoption of seemingly arbitrary (at least to the modern observer) elements of an innovation.

Innovations diffused not arbitrarily, however, but within networks, and the power differentials of ancient societies allowed elites to monopolize innovations by limiting their circulation into ruler-centric networks. Even such networks did have contacts, nevertheless, and

70 Mödlinger 2011, 153.
71 Marchant 2009, 288–299.
72 Haak et al. 2015; Petraglia et al. 2009.

this allowed the transition of elements or the hybridization with local technologies. The institutional bases of power, as well as the socioeconomic relations between rulers and ruled strongly influenced when and how new technology was first exploited.[73]

7.3 Innovation-Waves

Technology in antiquity is innovated on two scales. First there is small scale improvement on practical technology that was tested on an everyday schedule. Weapons, tools, houses are just some examples which fall into this category. However, once ancient producers/users perceived such a technological object as sufficient, it was usually not innovated any more. Sometimes also underprivileged groups were not given the chance to adopt innovations or did not have people interested in stimulating technology research. Querns and thus food production might be one such example, which after their Late Paleolithic invention only were really improved in the Iron Age with the rotation mill. Was a low status of women in prehistoric societies responsible for the lack of interest to improve this system? Suitable know-how existed at least since the invention of the wagon and the potter's wheel, and the reasons for its non-application to food production remains enigmatic. In the case of complex societies, craftsmen experimenting with tools might also have looked for market advantages and hoped to achieve a monopoly that way. Technology was developed, but not with the help of science as Warburton has put it.[74]

The second level of innovations are those which fundamentally change society and the relations of production. It is completely unknown, yet worth researching, whether Schumpeter's interpretation of the correlation of technical innovations and Kondratjew-waves can be demonstrated also for ancient societies. Such innovations do not appear sequentially, but can be limited to time-periods of different lengths. The innovation-processes are not necessarily forgotten, but their culmination into a new socioeconomical or environmental context or the conjuncture of several innovations or the individual exploitation of these innovations can mark 'revolutionary' changes. The Neolithization is the first such period where several Palaeolithic innovations are bundled, supplemented with animal husbandry and experimented with in the Fertile Crescent.[75] Other such 'horizons' of innovations can be identified in the 4th millennium, in Hellenistic times or during the Renaissance.

What is typical is that these events were not universally shared but took place in specific, geographically limited areas. It might help to imagine them as ancient laboratories, which under certain conditions were extremely productive. Yet, the stimulus for this productivity is still discussed. While previously climate change was often claimed to have pushed the Neolithization, Klaus Schmidt's exciting discoveries at Göbekli Tepe recently gave again credibility to Jacques Cauvin's[76] idea of symbolical revolutions preceding the economic change. In this volume, Christian Jeunesse has brought our attention again to the very large distance between the first application of technologies in the Palaeolithic and their development into innovations during the Neolithic,[77] while Svend Hansen[78] linked Cauvin's idea of the Neolithization with Max Weber's famous narrative on the protestant ethics and capitalism.[79]

There is no evidence of progress in the archaeological record. Progress might have been an option, but it is usually only perceived as such from a modern point of view. Groups or individuals responsible for developing innovations, were not aware of what they would create in the long run. Their initiative might have been selfish and completely different from what modern, rational models would like to make them think. However, neither prehistory nor antiquity were millennia of technological stasis. Change is visible in nearly every period and region. Maybe one thing that the study of ancient innovations can teach us already, is that we ourselves (the 'Western World' as it was created after the Industrial Revolution) are not the norm, but a historical accident that has created a system, which we do not understand. Thus it is probably not the best option trying to understand the human past from this perspective!

73 Cf. Feinman in this volume.
74 Warburton in this volume.
75 A conference to this topic was held in Berlin, 9.–11.12.2015 and is currently prepared for publication. https://www.topoi.org/event/31052/ (last accessed 03/06/2020).
76 Schmidt 1996; Cauvin 1994.
77 Jeunesse in this volume.
78 Hansen in this volume.
79 Weber 1920.

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