Maja Gori, Constance von Rüden
& Thomas Stöllner (eds)

Resources in Premodern Societies

New Approaches to Lifeworlds, Skills and Complexity

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ReSoc- Resources in Societies. Introduction

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In today's political debate, raw materials and resources play an increasingly important role. It is a mostly highly economized debate that is conducted with regard to the accessibility and safeguarding of raw materials as well as the shareholder value of deposit assessments. This debate obscures the view that raw materials and resources deeply are rooted in world-perceptions, in individual and communal life worlds and all-day-practices of people. Their "use" results from needs and technical knowledge that people have acquired in dealing with their environment. Resources are therefore much more than useful raw materials; they reflect the social and cultural practice of people and are thus an expression of a multi-layered process of appropriation, which as such is embedded in various changes. These changes in the handling of resources and the changes that this handling has triggered in societies is an essential part of the "Resources in Societies" (ReSoc) project.

This volume originates from the presentations delivered at the conference *Resources and Transformation in Pre-Modern Societies*, which took place online from November 19 to 21, 2020, on December 11, 2020, and on January 15, 2021. This event served as the concluding symposium of the postdoctoral school *ReSoc – Resources in Societies* and convened scholars to critically discuss the transformative potential of resources in premodern contexts from diverse perspectives, employing a range of methodological approaches. Three thematic sections constitute this volume, each reflecting the research lines established during the ReSoc conference: 1. Life-Worlds in Resource-Scapes, introduced by T. Stöllner; 2. Skill, embodiment and the growth of knowledge, introduced by C. von Rüden and M. Gori; 3. Resources and complex systems, introduced by M. Roos.

The majority of the theoretical and methodological frameworks discussed during the conference were developed within the scope of the *ReSoc Resources in Societies* postdoctoral

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school, generously funded by the Leibniz Association from 2016 to 2020. *ReSoc* was based on a collaboration between the German Mining Museum (DBM – Deutsches Bergbau-Museum Bochum), the Ruhr University Bochum (RUB – Ruhr-Universität Bochum) and the University of Hagen (FUH FernUniversität in Hagen).

ReSoc functioned as an interdisciplinary consortium of scholars, including Principal Investigators Prof. Thomas Stöllner, apl.- Prof. Sabine Klein, Prof. Michael Roos, and Prof. Constance von Rüden. They were supported by a team of five postdoctoral researchers: Dr. Maja Gori, Dr. Yiu-Kang Hsu, Dr. Frederik Schaff, Dr. Peter Thomas, and Dr. Arne Windler, with Dr. Matteo Cantisani joining during the final phase of the project. The *ReSoc* program was hosted by the Ruhr University of Bochum in partnership with the German Mining Museum Bochum. The program's Advisory Board comprised distinguished scholars: Prof. Roland Hardenberg (Frankfurt), Prof. Frank Hillebrandt (Hagen), Prof. Mark Pearce (Nottingham), and Prof. Susan Pollock (Berlin).

The *ReSoc* cluster has established three distinct research fields aimed at investigating questions related to resources and societies, both theoretically and empirically. These research areas are closely aligned with the primary themes and empirical studies conducted at the *Deutsches Bergbau Museum*: 1. Appropriating (raw) materials – Converting to things: Resources and materials in practice; 2. Spacing, making knowledge, and innovation through resources and as resources; 3. Transforming societies: Actors in materialized asymmetries.

The *ReSoc* initiative is set to continue into a second phase within the framework of the *Leibniz ScienceCampus "Resources in Transformation"*, supported by the Leibniz Association. Additionally, a Collaborative Research Center (CRC) project titled *"Georesource-Interwovenness and World Appropriation"* has been proposed to the German Research Foundation (DFG) for long-term investigation.

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Introduction. Life-Worlds in Resource-Scapes

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The life world of a miner is different from those of a doctor or a child. This trivial observation can be dissected on closer inspection: What *a priori* influences played a role in the individual and interdiscursive perceptions of the three people? In their relationship to their environment for instance? How is their reality constructed and remembered in narrative practice? If we look at the complexes of knowledge embedded in everyday practices, it becomes clear that the interwoven amalgam of perceptions and mental constructs is initially hardly static, but rather fluid and changeable. Miners, doctors and children perceive their environments in constantly changing contexts and thus continuously shape their life worlds as individuals and as part of their social space (*sensu* Bourdieu).

Following its first uses in the 19th century, the term life world underwent its first systematic examination primarily in the phenomenology of Edmund Husserl. Husserl (e.g. 1913) already assumed a double meaning of the term, in the sense of the "self-evident" in the definition of the relationship between humans and the world, as well as in the individual and everyday practical experience of each person. This discourse in the humanities and social sciences does continue to this day (see, among others, Schütz and Luckmann 1988; Habermas 1981; Kraus 2019). Archaeology, anthropology and cultural studies understand the term 'lifeworld' more in the practical, everyday sense, following the Alfred Schütz concept (for example, in the application by Giordano 2015) and less in the sense of communicative acting (such as the concepts of Jürgen Habermas) or in the sense of systemic relationism (as, for example, in the analyses by Björn Kraus) (Habermas 1981; Kraus 2019).

As an archaeologist, I could therefore ask in this chapter which experiences of individuals or groups in their respective living environments were relevant for the production of knowledge. What facilitated the formation of relevant bundles of practices, e.g. for the extraction of raw materials? What conditions governed the formation of a Resource-Scape as a social space? Which fundamentally shared ideas within a community were effective in decisions and the implementation of communal goals? What dispositifs

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(*sensu* Foucault) are inscribed in these discourses? It seems to me that these questions are also relevant for cultural studies and the bridge discipline of archaeology. When we look at resource complexes (for the term, see Hardenberg et al., 2017), this section must therefore focus primarily on the everyday discursive relationship between the individuals and the material world around them.

Mines are a good example for this especially when looking on daily practices and sensual perceptions in them. They create a certain environment that influences specifically the lifeworld of the miner as a raw material supplying person. How do we now understand his world of experience and perception for instance by our historical sources and objects? Let us start first with his/her daily practice in work processes and all the social interactions that are combined with it. In many cases it is the embeddedness of routines to the social and physical that allows the successful adaptation within a given amalgam of daily routines (daily routines for establishing identity and memory was particularly discussed by Michel de Certeau according to urban popular culture of the 20th century: De Certeau 1988). The analysis of daily practices (reconstructive or by observation) should give us access to his/her narratives and worldviews – also for times of temporally or culturally distant human communities. Such an approach certainly spans wider than the more usual concept of the 'chaîne opératoire' that archaeologists like to use explanatorily for their production and manufacturing debris. What seems important for resource complexes such as mining is that such is established with small working gangs as well as large organized and structured groups. It therefore is mirrored in materialized features of daily practices features (for instance in an archaeological context). Taphonomic investigation is therefore an important scientific approach to understand routines as such (see for mining the arguments in Stöllner 2022).

We can call these routines spheres of habitualized doing to a special (underground) work environment. Thousands of repetitions (e.g. of pick-hammer blows to a mining wall observed in an ancient mine) opens up the setting of practices once adopted to a specific setting. They are also representations of mental approaches to appropriate (sensually and culturally) things: Rocks, mined raw sources, already adopted tools and spaces can be described in a complex settings of life and work practices. It is clear that knowledge transfer is part of such appropriation processes that require some sort of knowledge sharing between the daily routines of different people involved. With other words: Techniques and practices can only be successfully adopted if cooperating people are willing to share, easier when they already are acquainted to similar practices and mental constructs.

It is this materialized reality of a resource complex that gave the frame for habitualized doings and experiences. The mine (as any other resource complex) provides access to a specific sensual world, in a mine this is darkness, moisture and temperature and smell. It also produces distinctive sensual experiences for instance by smelling, seeing, hearing and touching in an underground. Individualized perceptions are therefore particularly a worthy category for such specific sensual worlds, such as the "dark" underground working spaces show. Maurice Merleau-Ponty's ground-breaking foundation of the body-subject brings the mental and body experience to one interwoven embodiment, especially apparent when handling the specific conditions of a "dark" underground (Merleau-Ponty 1945/1974).

If looking at to contributions it is worth exploring their specific perspectives: Timothy Le Cains's contribution advocates for a new perspective on material life-worlds as materials more than ever enter into our physiological and cognitive nature. Tim's contribution outlines the embodied quality of materials and how it does shape thinking, life-worlds and our cognitive abilities (in the sense of the extended mind concept). His insights are supported by the recent development of neo-materialist theories through which we can begin to recognize how sociocultural phenomena themselves emerge from the ways human interacts with non-human things, including the mineral resources they extract from the earth. He argues that the human mind is not confined to our brains, or even our bodies, but is rather extensive with its surrounding environment. In this aspect LeCain's contribution shows us that life-worlds are not only determined by everyday practices alone but also by the cognitive influxes of the material properties of things so important to us. This is something that sets new qualities to the discussion about the different individual and intersocial "*a priori*" levels of the life-world.

Ultimately, LeCain's text also serves as a perfect introduction to two further contributions by Th. Stöllner and M. Pearce. Both deal with prehistoric communities in their role as 'resource providers.' My contribution focuses more on the social and ecological interrelationships of mining practices. This interrelationship corresponds to my understanding of a resource landscape. The article attempts to find arguments to understand the underlying narratives of resource complexes and the way in which mineral extraction has led to specific narrativisations. In prehistory, there may have been strong interrelationships with discursive practices of appropriation and deviations from them. The commodification of things is therefore understood as a kind of alienation from original discourse and material practices. I argue that different bundles of social and cosmological practices can help to understand such dimensions in prehistoric times as well. Mark Pearce examines the connection between mining and livestock farming, i.e. interrelated resources that, in his opinion, play an important role especially in early metal extraction. Mark thus also touches on the old (much-loved but also criticised) concept of 'secondary products,' which was first proposed by Andrew Sherratt (1981; 1983). His case study is based on the Southern Alps and the Italian peninsula, where cheese production (at least since the 2nd millennium BCE) was probably an important part of the context.

In our section we consider practices, which left their mark in an environment, as a decisive factor for approaching past life-words. Rafaella da Vela's contribution follows such by two resource-complexes, pastoral transhumance and agricultural networks in Irpinia, an inland part of Campania on the crossroads to the Adriatic coast. In her approach she follows consequently the Tübingen concept of resource assemblages (Hardenberg et al., 2017) in their contingency and joining to a single dynamic network that enabled a progression in rural development and population growths from the mid-1st millennium to the Augustan period. To understand the land-use pattern by these networks brought forward a better insight in various condensations of rural practices from the communities involved.

Although prehistoric and ancient mining research was not performed on large scale in China, Yiu-Kang "Gary" Hsu and Haichao Li from Sichuan University give a good overview on the current state of mining archaeological results from various parts of the Yangtze-river valley and its relation to boom of copper and bronze metallurgy since the Shang period. They also make clear that metallurgical and mining processes (even during phase or control by the Bronze Age states) can be regarded as two separated networks that certainly performed exchange but were specialized in their specific knowledge bundles. Pottery wares and mining timbering techniques provide arguments for knowledge transfer and mobility within the various local mining communities as a community of practice.

This changed when state control emerged around the mid of the 1st mill. BCE also over production steps in metallurgy and mining and led to seemingly dramatic change of the "resource-providers" life-worlds.

The last article in this section dealt with another aspect of resource management, especially the managing of garbage in the large late Iron Age settlement 'Gasfabrik' in the Basel region. Detailed of this waste management were made by Milena Müller-Kissing who argues for another resource complex often overseen in large scale prehistoric settlements. Most of the arguments are about the taphonomy of things and pit features that were analysed in a very detailed manner by the author and larger team or researchers within the frame of an evaluation process. Managing garbage can therefore rightly understood as a resource and practice bundle shared by most of the inhabitants of the settlement. It was a kind of "urban mining" nowadays again familiar to us.

Life-worlds can never be completely reconstructed in a temporally far-distant societal setting. Much remains only in outline and, especially for archaeologists only on a thin material legacy. But it is worth approaching to historically distant fragments of practice, experience and knowledge to frame past life-worlds at least in an outline. I believe that it opens perspectives to look behind the complexity of interwovenness in past resource-complexes and their more or less distant life-worlds.

References

De Certeau, M., 1988. *Invention du Quotidien. Vol. 1, Arts de Faire.* Paris 1980. Deutsche Ausgabe: Kunst des Handelns. Aus dem Französischen übersetzt von Ronald Voullié. Merve, Berlin 1988.

Giordano, Ch., 2015. Alltägliche Lebenswelt: Zur Archäologie, Karriere und Bedeutung einer phänomenologisch-hermeneutischen Grundkategorie. In: K. Roth, W. Höpken, G. Schubert, eds., *Europäisierung – Globalisierung – Tradition: Herrschaft und Alltag in Südosteuropa* (50. Internationale Hochschulwoche der Südosteuropa-Gesellschaft, 4.-7. Oktober 2011), München, Berlin, Leipzig, Washington, D.C., Verlag Otto Sagner, pp.33-54.

Habermas, J., 1981. *Theorie des kommunikativen Handelns, Band 2: Zur Kritik der funktionalistischen Vernunft*, Frankfurt am Main: Suhrkamp.

Hardenberg, R., M. Bartelheim and J. Staecker, 2017. The 'Resource Turn. A Sociocultural Perspective on Resources. In: A. Scholz, M. Bartelheim, R. Hardenberg, J. Stecker, eds., *ResourceCultures: Sociocultural Dynamics and the Use of Resources – Theories, Methods, Perspectives*, RessourcenKulturen 5, pp.13-23. Tübingen: Universität Tübingen.

Husserl, E., 1913. Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie: Allgemeine Einführung in die reine Phänomenologie. *Jahrbuch für Philosophie und phänomenologische Forschung,* Halle, vol. 1(1), pp.1-323.

Kraus, B., 2019. *Relationaler Konstruktivismus – Relationale Soziale Arbeit. Von der systemisch-konstruktivistischen Lebensweltorientierung zu einer relationalen Theorie der Sozialen Arbeit.* Weinheim: Beltz/Juventa.

Merleau-Ponty, M., 1945/1974. *Phénoménologie de la perception.* Paris: Gallimard (Phänomenologie der Wahrnehmung. Translated and with introduction by Rudolf Boehm. Berlin: de Gruyter 1974).

Schütz, A., and T. Luckmann, 1988. *Strukturen der Lebenswelt,* Bd.1, 3. Auflage. Frankfurt am Main: Suhrkamp.

Sherratt, A., 1981. Plough and pastoralism: aspects of the secondary products revolution. In: I. Hodder, G. Isaac, N. Hammond, eds., *Pattern of the Past: studies in honour of David Clarke*. Cambridge: Cambridge University Press, pp.261-305.

Sherratt, A., 1983. The secondary exploitation of animals in the Old World. *World Archaeology*, 15(1), pp.90-104.

Stöllner, T., 2022. Entangled Connections: Materialized Practices of Knowledge-Networks of Mining. From the Theoretical Level to Its Empirical Consequences in Mining Archaeology. In: M. Farrenkopf and S. Siemer, eds., *Materielle Kulturen des Bergbaus | Material Cultures of Mining. Zugänge, Aspekte und Beispiele | Approaches, Aspects and Examples*, Veröffentlichungen Deutsches Bergbau-Museum 243, pp.317-44. Berlin, Boston: De Gruyter. DOI:10.1515/9783110729955-014.

Resources as Life Worlds: How Do Material Resources Shape Cognition and Culture?

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In this chapter, LeCain argues that the ways in which societies and individuals can think and act emerge in significant part from the materiality of resources in at least two ways. First, as a material resource like copper or bronze sparks new ways of thinking and acting in the world. And second, as these new ways of thinking and acting become materially embedded in the society so that the environment itself carries the weight of their influence forward. In this neo-materialist approach, humans are understood to be entirely material creatures emerging from a material world, and even our seemingly most abstracted thoughts and beliefs rarely stray far beyond this world. Further, as we think and act within a particular environment of material resources, these patterns become ever more deeply engrained into who we are and how we understand the world. In sum, life ways become inextricably embedded in the material resources from which they emerged and were sustained. The material thus becomes the cultural, and the cultural the material.

Neo-materialism, cognition, culture, Bronze Age, environment

As I write this chapter, sitting in my office on a chilly Northern Rockies evening, I pause to think about what constitutes my "life world" at this moment. Looking about the room, there seems to be little or nothing, other than myself, that is "alive," at least in the conventional meaning of that term. To be sure, I know intellectually that at a microscopic level I am surrounded by, and indeed colonized by, vast numbers of bacteria, viruses, and other invisible organisms that I cannot see with my naked eye. There are also many things around me that are the product of once living creatures. The wooden desk I am sitting at and the paper pages on my overpacked bookshelves had their origins with living trees, and the leather on my big reading chair was once the living skin of a cow. Even the black plastic of my stapler and reading glasses and the brown paint on the walls come from oil, coal, or other hydrocarbons which were in turn the product of ancient life forms long vanished.

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Yet among these denizens of my life world, perhaps the least seemingly alive of them all are the metals around me. What could be more stolid and static than a metal object or part? Unlike the paper pages of books or the leather in my chair, these metals were not derived from living things which had clearly once enjoyed some measure of agency. And yet, the range and variety of metals even here in this small room are so extraordinary as to challenge my initial impulse to see them as entirely passive. The computer with which I write these words is made of aluminum, perhaps first gouged from the earth in a destructive open pit bauxite mine in Suriname or Jamaica. Inside the computer's smoothly machined shell are copper and small amounts of gold, as well as various rare earth minerals gleaned from mines in China and around the world. The black filing cabinets just to my right are constructed of iron, alloyed perhaps with manganese, phosphorous, and silicon. The portable electric heater that keeps away the night chill has radiating panels made from mica that might well have had their origins in the often-brutal mines of India or Madagascar. And of course, if I were to strip away the gypsum boards covering the walls and ceiling of the room itself, I would see the meters and meters of stout copper wires that surround me like the web of some mysterious metallic spider that pulsates with electricity.

Environmental historians have long understood that the extraction and processing of these inorganic and abiotic metals have powerful effects on living ecosystems. In many cases, metals are clearly implicated in the lives and deaths of countless other organisms around the world, though these connections often take some effort to recognize (LeCain, 2009). In an influential 1995 essay, the environmental historian Richard White sought to bridge the gap between the seemingly artificial and technological artifacts in his own office and the natural world from whence they had come. "There are clearly better and worse technologies," White rightly argued, "but there are no technologies that remove us from nature (White, 1996, 182)." Even metal-based machines like his own computer were part of a larger organic world of life, he suggested. However, White, like most environmental historians, stopped short of taking this powerful insight to its full logical conclusion. When he discussed the nature of his computer, he thought primarily of the electricity generated by distant hydropower dams that powered its circuits, observing that this distancing removed him from the actual lived experience of the electricity, the water, and the dam that coursed through his computer. The computer was in this sense not unnatural, but it did have the tendency to remove and alienate him from a different natural place or ecology.

White is surely correct about this – the invisible nature of electricity may be especially conducive to hiding our dependence on the places where power is generated. Yet in focusing primarily on the way in which an electrically powered computer distances us from the natural world, White also replicates the very dichotomies that he seeks to transcend by ignoring his embodied experience of the computer and other material artifacts in his office. True, simply using his computer does not grant him an affective engagement with far-off hydropower dams or other generating facilities. Yet, it does provide him with a means of experiencing a very different nature: the nature to be found in his computer's plastic shell and keyboard or with the copper in its circuits and in his office walls. In this, White's analysis reflects the tendency of environmental historians and others to downplay the importance of the built material environment as an important subject of analysis. Even as they recognize that all of the technologies, artifacts, and structures of a building come from nature, they often still tend to downplay the importance of analyzing the effects of this built environment on human beings.

To be sure, in the twenty-five years since White published that essay, environmental historians have begun to treat the built environment more seriously, providing thoughtful analyses of the pollutants found in modern office buildings (Murphy, 2006) or the effects of coal burning stoves in early twentieth-century homes (Andrews, 2008). But while there has been some progress on analyzing urban and interior environments, historians have been a good deal less successful in examining how the physical and cognitive effects of these built environments – where natural things are used rather than extracted, processed, or recycled – may affect human thinking and culture. The idea that the anthropogenic environment is built from naturally occurring materials is generally accepted, yet precisely how this material environment shapes history and individuals remains strikingly under-examined.

This neglect of the formative power of the built environment, I argue, reflects at least in part the difficulty we face in thinking of humans and their diverse cultures and societies as inextricably embedded in a material world, which in turn is inextricable from what we consider to be nature. Indeed, it remains common place today to believe that we humans have become ever less natural through our increasingly technological way of life. Yet seen from a more material and artifactually grounded perspective, the opposite might well be true. We moderns have surrounded ourselves with such a diverse array of metals and other materials that we are arguably more intimately connected to and embedded within a wider range of natural resources than at any time before. If engagement with material nature in all its astounding diversity is what defines being natural, humans today are in some sense the most natural creatures ever to occupy the planet.

In this sense, the diverse array of metallic artifacts that surround me in my office on this evening might usefully be understood not as *distancing* me from nature, but rather as a material environment that generates an embodied *engagement* with nature at a level that would have been unimaginable even a few centuries ago. Yet having recognized this material reality, how are we to understand and analyze the effects of such a strange and diverse metallic environment, which of course, is even richer outside the walls of my office? How can we as historians, archaeologists, anthropologists, and other thinkers incorporate the dynamic nature of these metallic worlds we occupy into our theories and methods? How are our human lives, both individual and collectively, physical and cognitively, both created and sustained by our intimate engagement with abiotic metals and minerals?

In this chapter, I want to make the case that the novel theories and methods associated with the New Materialism offer a powerful approach for understanding what I here term material "life worlds." As the political ecologist Jane Bennett has argued, the "vibrant matter" around us is not passive, but rather conspires with humans to produce new ways of existing (Bennett, 2010). My own preferred term for this approach is "neo-materialism," which is meant to capture approaches that emphasize the many synergies between new scientific and humanistic theories. At base, I argue that we need to understand humans and their diverse cultures and societies as emerging in significant part (just how significant a part remains to be determined!) from their interactions with the material environment, which could be everything from the copper wires in our walls to the trees in a forest to the cows grazing in a distant pasture. In this emergent sense, the cultural is always material, and the material is always cultural. Borrowing from a concept suggested by the historian Daniel Lord Smail, this can be usefully termed a "deep culture." That is to say, a concept that emphasizes the material roots of cultural phenomena that we have previously seen as primarily or solely abstract, symbolic, or linguistic in nature. Smail's "deep culture" focused on the human biological and cognitive nature of culture (Smail, 2007). Here I attempt to expand this to include the non-human and abiotic. With these new tools it becomes possible to understand the deep materiality of every aspect of human existence, thus offering a novel way of approach the central theme of this volume: the role of resources in creating, sustaining, and transforming societies.

The Age of Material Ages

For an earlier generation of thinkers, the idea that material resources like copper or iron could fundamentally shape individuals and societies had seemed compelling. Of course, they did not think of the results in terms of anything like the concept of "life worlds" I will explore here. Nonetheless, archaeologists had often periodized the past in terms of the material things that they believed generated and sustained a certain type of society. Nineteenth century archaeologists took it as largely self-evident that the ability to smelt copper and make bronze tools marked a significant shift in the nature of a civilization, establishing the pre-conditions for the rise of more complex cultures and societies. The Danish archaeologist Christian Jürgensen Thomsen formalized these ideas into the so-called three-age system of European antiquity in the 1830s: The Stone Age, he argued, gave way to the Bronze Age which in turn led to the Iron Age (Gräslund, 1987). In retrospect, such a material periodization clearly seems overly simplistic and deterministic. Consider, for example, that the use of wood persisted throughout all of these ages, yet it rarely was accorded a central role equivalent to metals, in part simply because wooden artifacts are prone to rotting and were thus less likely to be uncovered centuries later by archaeologists. Further, copper and iron artifacts no doubt seemed to offer clearer evidence of the human creativity and dominance of the natural world that Thomsen and others sought to demonstrate, thus illustrating a trajectory of supposed technological, cultural, and social progress over the millennia that culminated, not surprisingly, with themselves and their own eras.

Despite these and numerous other problems, the use of material ages as rough markers of historical eras have persisted even into the present, although other terms have come to the fore as well. We routinely speak of a Roman Age or Middle Age rather than highlighting whatever materials might have been particularly central to these societies. However, in the post-WWII period the idea that natural resources like stone, copper, or iron might be understand as *causal or agentic* historical phenomena increasingly fell out of favor, and it continues to be viewed with some suspicion today. Particularly for post-modern historians, with their focus on the explanatory power of cultural, social, and discursive factors, the concept of a Bronze Age or Iron Age seemed to put the causalities backwards. Bronze, iron, or any other material resources did not cause historical change so much as they reflected more important sociocultural and anthropocentric changes in societies. This approach was most clearly and influentially articulated by the advocates of the Social Construction of Technology (SCOT) that emerged in the 1980s to become the dominant paradigm for that area of study. Advocates of SCOT did not, of course, dismiss the influence of bronze, iron, or moving into the modern age, steel. However, they focused most of their analytical efforts on how these and other materials and technologies were constructed and shaped by different sociocultural groups. To be sure, these analyses were not usually focused on a specific material so much as the technologies made from these materials, as with the bicycle, for example, which social constructivists emphasized was shaped by a variety of different groups, from daredevil male racers to more safety-oriented women (Bijker, 1987). Regardless, in the view of many social and cultural constructivists, emphasizing the causal force of material things seemed to be a manner of technological determinism that they argued tended to underestimate the importance of more human factors.

Which in many ways it did. However, in guarding against a simplistic determinism, the constructivists often neglected how things like copper or other material resources can shape human culture and history, in ways both subtle and profound. Part of the constructivist confusion on this score arose from their often unexamined but misleading model of human cognition that posited a human body and brain that are largely abstracted and independent from the material environment. In this view it seemed as if a sheer act of intellectual imagination might easily enough shrug of the merely material environment that surrounded it to think in entirely novel ways. Such truly original and immaterially derived human thought might, perhaps, be a theoretical possibility. Yet such a view tends to exaggerate the centrality of abstract human thought at the price of a more grounded understanding of how we truly think. As will be discussed in the following section, in more recent years a number of archaeologists, anthropologists, and others have emphasized the materially embedded nature of human thought. The basic idea has an intuitive appeal. If we consider a simple thought experiment, it seems readily evident that a people who have only ever known the material possibilities of wood and stone would struggle to even imagine a world where the material copper was ubiquitous. When these people of stone and wood thought of seemingly abstract concepts like "hard," "malleable," "sharp," and so on, these ideas would largely be derived from their embodied experience of the properties of the material things with which they had lived for their entire existence. This lived experience of the material environment – what we are here thinking of as a "life world"-would become the very thing through which they thought and imagined any alternative material realities. A creative individual might well imagine that it would be useful to have a material that could take an edge as hard and sharp as a flint blade yet would also be as easy to form and shape as wood. Nonetheless, this abstract ideational concept would be radically different than the concept of malleability that someone who has actually lived and worked with a real copper or bronze knife might have. In this sense, malleability is a lived affective phenomenon rather than a solely abstract or linguistic one. As the anthropologist Tim Ingold insightfully observes, the mere idea of an artifact is radically different than the embodied experience of that artifact, whether that be a cello or a copper knife. In this sense, the culture related to these artifacts is thus inseparable from the lived human engagement with a material thing (Ingold, 2004, pp.209-21).

In sum, people of stone and wood (or, looking ahead, copper and computers) would have very different "life worlds," both physically and cognitively, than those who spent their days working with copper or iron. With this term, I aspire to capture the lived experience of material things in the day-to-day life of individuals and societies, and to suggest that these lived experiences play a significant role in shaping how they think, feel, and act. Key here is to set aside the conventional modernist assumption that humans (and other organisms) live in largely passive material environments that are distinctly separate from their minds and bodies. Instead, in a "life world" the entire array of human behaviors is seen as emerging, at least in part and in varying levels, from the materials with which they engage. In this new sense, historians and other humanists might indeed find the concept of a Bronze or Iron Age useful, but the focus would be on the many and often surprising and unpredictable ways in which such life worlds were the product of an engagement between creative humans and the potentialities afforded by creative metals.

To better understand this approach, a deeper engagement with neo-materialism and the attendant concept of "deep culture" will be helpful.

Neo-Materialism and Deep Culture

At base, the central goal of neo-materialist theory is to escape the long-standing faith (whose origins lie at least in part in earlier religious and philosophical ideas) that we are mostly creatures of a disembodied and displaced mind or spirit. Neo-materialism seeks instead to put humans and their cultures back into the material world. At some level, this basic idea has been kicking around for many years. In 2005, the feminist material theorist Elizabeth Groz captured it nicely, observing that "nature and culture can no longer be construed as dichotomous or oppositional terms when nature is understood as the very field on which the cultural elaborates and develops itself" (Groz, 2005, p.44). Indeed, the broader umbrella term of the New Materialisms covers such a wide range of often ill-fitting ideas and methods as to resist definitive definition (Gamble, 2019). My own preference has been to distinguish the more scientifically and environmentally grounded varieties of the New Materialisms with the term "neo-materialism" (LeCain, 2017). The intent is not to dismiss other approaches, but rather to suggest that the union of some key contemporary scientific insights with old humanistic questions offers the most exciting and productive path to new insights into the past.

What constitutes such a new or neo-materialist theory? Three points seem broadly diagnostic:

- That humans are inescapably material creatures, not just in the obvious sense that we are embedded in complex ecologies, but also because our thoughts, ideas, societies, and cultures emerge in significant part from our embodied engagement with a dynamic and vibrant material world, both in its anthropogenic and non-anthropogenic manifestations;
- That this material environment is best understood not primarily as a limiting factor on an abstract and solely human imagination, but rather as a creative force that sparks and nurtures human (and non-human) thoughts, beliefs, cultures, and actions;
- And that previously justifiable fears of some sort of materialist determinism are in this new framing misplaced because they (1) presuppose a mistaken modernist dualism between the human and the environment, and (2) wrongly assume that the non-human material world is largely static rather than creative.

Not surprisingly, many of the scholars most closely identified with various flavors of the new materialism reflect a growing dissatisfaction with limits of post-modern, linguistic, and social constructivist theories already discussed. But the rising materialist tide is not primarily reactionary. Rather than emphasizing an immaterial concept of culture that constructs the material world, new and neo-materialist thought seek to identify the ways in which cultural phenomena emerge from the embodied human engagement with a creative material world. Rather than seeing materiality as determinative or limiting, they simply recognize additional novel sources of human diversity and change by seeing a dynamic material world as a co-creator of culture and history. As greater weight is shifted to the non-human material world, this inevitably decenters the human, a shift that finds expression in closely related movements such as post-humanism and the non-human turn.

Pivotal to all these trends was the development of Actor Network Theory (ANT) by Bruno Latour, John Law, Michael Callon, and others in the 1980s. While it had some roots in post-modern linguistic and constructivist theories, ANT also opened the door to the contemporary material and post-anthropocentric turn by including all-manner of potential non-human "actants" in its complex networks and insisting that agency was therefore distributive rather than confined solely to humans. With his bold declaration that "we have never been modern," Latour suggested that what was supposedly a clear line dividing the human and non-human, cultural and material, and technological and natural, was nothing but a modernist conceit. Latour proposed instead a "flat ontology" in which the ideal and material continually emerged together through a complex web of interactions. Reality did not exist so much as it became, and the non-human could be a force for change and creativity as much as the human (Latour, 1993). The theory thus provided a powerful, if not always fully realized, means to escape a one-sided anthropocentric social constructivism and linguistic essentialism, and to instead grasp how material things too shaped humans.

Many new materialist thinkers also take inspiration from the work of the French philosophers Gilles Deleuze and Félix Guattari. In influential works like *A Thousand Plateaus*, Deleuze and Guattari develop a sophisticated realist ontology to explain how things in and of themselves exist independently of the human mind. As with Latour and Actor Network Theory, the pair insist that this material world does not exist fully formed, a sort of pre-existing stage onto which humans emerge and play out their stories. Rather, their matter is dynamic, possessing mercurial properties that emerge through interactions with other actors, humans only one among them. There is no structure that shapes reality in an enduring manner, but rather a series of temporal events and assemblages from which previously polarized phenomena, like nature-culture, matter-idea, and the human-nonhuman, are understood to emerge together and simultaneously. Humans and their cultures, as with all other organisms and things, are not fixed and enduring but rather emergent relational phenomena (Deleuze and Guattari, 1987).

The influence of Latour, Deleuze, and Guattari are evident in a 2010 attempt to take the measure of the emerging materialist movement in a collection edited by the political ecologists Diana Coole and Samantha Frost, *The New Materialisms*. In an insightful introduction, Coole and Frost argue that human beings "inhabit an ineluctably material world." Coole and Frost note that this essential materiality has been marginalized in recent decades by the dominant constructivist orientation. But while a new materialism need not be antithetical to constructivism, they call for a far more vibrant role for matter in its interaction with humans and their social systems. Theirs is a matter that is "active, self-creative, productive, unpredictable," a matter that "becomes" rather than simply "is" (Coole and Frost, 2010, p.9). In another influential new materialist work noted earlier, the 2010 book *Vibrant Matter*, the Johns Hopkins political ecologist Jane Bennett takes a similar stance in arguing for what she terms a "vital materialism." Scholars, Bennett argues, should "read just the status of human actants: not by denying humanity's awesome, awful powers, but by presenting these powers as evidence of our own constitutions as vital materiality." In perhaps one of the most succinct statements of the potential significance of new materialist ideas to date, Bennett asserts that, "human power itself is a kind of thing-power" (Bennett, 2010, p.10).

Feminist scholars have also been leaders in developing the new material turn. The feminist theorist Karen Barad takes inspiration from quantum physics, particularly the work of Niels Bohr, which provide an empirical basis for the entanglement of all matter. As the famous example of Schrödinger's cat suggests, the act of observation in itself forces a previously undetermined quantum state to resolve – it seems the human engagement with the material world literally creates that world. This is not to suggest there is no "reality," but rather that (in keeping with the ontology of Deleuze and Guattari) this reality emerges from the real-time interaction of a multitude of actors and things out of which a specific state emerges and is temporarily held in place (Barad, 2007). As the philosopher Rosi Braidotti notes, in giving a greater role to the material world such theories diverge from long-standing assumptions about the unitary cohesion of the human subject. Accordingly, Braidotti mounts one of the most sustained new materialist critiques of anthropocentrism, noting its origins in modernist Enlightenment thought that squarely places humans (and Western male humans more specifically) as the ontological center of the material universe, subsuming all else to its will. In the place of traditional humanism's largely unexamined anthropocentrism, Braidotti thus proposes instead that a "post-humanities" reframe the human subject as emerging from an array of both human and non-human, cultural and material, natural and unnatural material actors and phenomenon. (Braidotti, 2013)

New theories and methods emerging from history's estranged sister discipline of archaeology have been equally important to developing neo-materialist theory and practice. In his aptly titled 2010 book, *In Defense of Things*, Olsen warns that the discipline's infatuation with a relational or semiotic theory of matter has badly underestimated the power of things to create or constitute human culture. "The univocal stressing of the relational," Olsen argues, "have caused us to lose sight of the individual qualities of things, their intrinsic power." Olsen calls for a more "symmetrical archaeology" in which "all those physical entities we refer to as material culture, are beings in the world alongside other beings, such as humans, plants and animals" (Olsen, 2010, pp.45-16.) Likewise, the archaeologist Nicole Boivin emphasizes the centrality of things in shaping the ways in which humans think and act, noting for example the power of mud brick walls both to generate the idea of different social classes and to sustain these into the future through their material presences. "The course of human history is therefore a process not only of human decisions, choices, and ideas," Boivin argues, "but also of the material force with which humans are surrounded, and with which they engage (Boivin, 2008, p.138)."

Expressing a similar dissatisfaction, the archaeological theorist Ian Hodder attempts to develop a more materially grounded theory in his innovative 2012 book, *Entangled*. "Entanglement," he writes, "is a mix of humans and things, culture and matter, society and technology" (Hodder, 2012, p.59.) In contrast to many other theories that often focus on matter as discrete objects, Hodder develops a more ecologically rooted understanding of things as processes. All things, he argues, "are involved in complex flows of matter, energy and information"-flows which also include the biological and cultural humans who can easily become ensnared by them. The human relationship to even inanimate things, Hodder suggests, can best be understood as a form of domestication, as things like "clay, metal, oil, nuclear particles, water, and so on" become dependent on humans for their care and maintenance, much like domesticated cattle or cotton (Hodder, 2012, p.86.)

The previous provides at least a quick overview of the recent growth in new materialist thinking, though there are many more scholars and thinkers who could be mentioned.

However, in my view much of the most exciting neo-materialist work today lies with the emerging new methodologies that bring together humanistic and scientific thinking in ways that strongly support the concepts mentioned earlier of life worlds and deep culture. In an extraordinary convergence of once seemingly distant fields, science and the humanities are now circling around many of the same ideas and insights, albeit having arrived at them via very different paths. Consider, for example, the recent realization that roughly 1.1 kilograms of bacteria and other non-human microorganisms we all carry around in our guts. While most historians today continue to assume that their human subjects are clearly unitary, bounded, and discrete subjects, today some students of the microbiome think of human beings as symbiotic "superorganisms" more akin to coral reefs than discrete actors. Superorganism is apt both physiologically and cognitively, as our microbial fellow travelers not only help to digest our food, but also play a significant role in how we feel and act. They synthesize, for example, much of the mood-regulating hormone serotonin found in our bodies (Reid and Greene, 2013).

The new scientific concept of Human Niche Construction also serves to narrow the gap between both the human animal and its environment and humanists and scientists. Human Niche Construction was first developed by ecologists to better understand non-human animals, yet inherent in the concept is the view that all organisms shape their environments or niches, which in turn act to create and define the organism. In this sense, the beaver – by which I ask you here to also think of the "human"-does not just create its dam, but rather the beaver in some sense is its dam, as the beaver or human cannot logically be understood apart from their novel niches. Even more broadly, the evolutionary biologist Kevin Laland's recent call for an Extended Evolutionary Synthesis seeks to incorporate niche construction, culture, and learned behaviors under the umbrella of natural evolutionary processes (Laland, 2017).

The Creativity of Metals?

With these ideas in mind, the metals-based historical ages noted earlier begin to take a new and more compelling logic, though they require that we give greater agency and creativity to the metals themselves. Here it is useful to focus in on one material for illustrative purposes: copper. To understand the life world of copper, begin by engaging the essential material nature of the copper itself. Because of the particular way in which copper atoms pack together, the metal is malleable enough to be easily hammered into desired shapes. As early as the late 9th millennium BCE, humans began to use deposits of relatively rare pure ("native") copper primarily to make jewelry and other decorative objects – a use that may have been further favored by copper's unusual reddish color, although archaeologists note that there were likely significant variations in color depending on source, treatment, weathering, and other factors (Kuijpers, 2018.) Likewise, the role of copper in diverse Bronze age societies is a matter of considerable archaeological debate, and scholars take some caution in discussing the possibility of universal meanings and behaviors across time and geography. The proximity of accessible and workable geological deposits, wide variations in metallurgical abilities, the degree of trade between dispersed settlements, and other factors would all have influenced the significance of copper and bronze in a specific culture or society (Radivojevic et al., 2018). Bearing these caveats in mind, it nonetheless seems readily apparent that individuals and societies that routinely fashioned native copper into attractive objects would eventually stumble across the fact that as the metal is hammered it becomes increasingly stiff and hard, a property known as "work hardening." Here we can begin to recognize the essential creative nature of the material itself as it comes into interaction with creative human beings. Even if the initial goal was primarily to create copper ornaments, it would have taken no great leap of insight to realize that it could be hardened to make other useful things, such as arrowheads, knives, or eventually even plows. Indeed, evolutionary science teaches us that the human brain has developed at least in part to maximize our ability to extract useful resources from the environment.

Copper would become even more important to those cultures as they realized through trial and error that more complex deposits of copper could be purified by heating it to high temperatures, a process later termed smelting. Archaeologists speculate that copper smelting was an accidental consequence of pottery making in what is today Iran, as early kilns would have been capable of achieving the necessary temperature to melt some copper ores. Perhaps a pottery maker embedded a piece of colorful copper ore like malachite into a pot only to discover that it melted during firing and released purified copper. In this sense, it seems readily evident that humans did not "invent" copper smelting so much as they were pushed towards this recognition by the creative material environment or niche in which they lived.

In sum, these ancient engagements of the human with the possibilities of copper created a novel life world, one which helped define the nature of those who lived in it and sparked new possibilities for thought and action. Indeed, once copper smelting and increasing mining provided a more abundant supply of the metal, the widespread development of Bronze became possible. A mixture of copper and a small amount of tin, bronze was initially no doubt an accident, as many copper deposits already have tin in them. Metalsmiths would only learn to deliberately add tin to copper much later. (Sass, 1998, pp.61-2). Regardless, the versatility of bronze provided the humans who worked with it entirely new creative possibilities that were distinct from other materials like copper, stone, or wood. Bronze was used to make an astounding variety of material things, from brooches to axes and swords. Plows made with bronze provided a tool that cut through hard soil much more effectively than wood or stone and that could be sharpened when it grew dull. Paired with domesticated draft animals like the ox and horse, the bronze plow inaugurated a rapid increase in agricultural productivity, ultimately providing enough food to sustain growing urban settlements. (Sass, 1998, p.66).

Explained in this manner, the history of the human-bronze engagement may indeed begin to seem overly deterministic. Obviously, these developments presuppose a society, economy, and culture in which increased supplies of copper and the "benefits" of increased agricultural production were widely accepted. As James Scott has insightfully observed in his recent book, *Against the Grain*, the development of agriculture was far from an unalloyed good, as it often came at the price of increasingly autocratic states and inequalities of wealth and power – yet another consequence of a particular life world. Likewise, there are numerous instances of peoples who for a variety of reasons preferred to maintain more traditional ways of life and might well have rejected at least some, and perhaps all, elements of what copper might offer to them (Scott, 2017). But to recognize that individual humans and collectivities clearly made some choices in the matter should not keep us from grasping the equally important point that once humans began to engage with copper, its potential powers would exert a fundamental material attraction that should not be reduced to a mere social construct.

Here it is useful not to think in terms of the determinism of any one particular material, but rather of the influence of an entire material environment or, as Laland and others suggest, a niche in which humans live and think (Laland, 2017). A neo-materialist approach, for example, seeks to avoid the conventional distinction between extraction and use of a resource, and to instead consider the effects of a mineral like copper in every environment, from its extraction to its use to its disposal or recycling. In this view, copper becomes an active environmental agent at every stage of its engagement with humans – including the office that I am in right now. In this framing, the "environmental" effect of copper might well be most pronounced not during its extraction or recycling phases, but rather when it is being used in the anthropogenic built environment like my room. That scholars have not, until recently, viewed a bronze plow or a copper electric wire as part of the "environment" reflects the persistence of modernist ideas that draw a clear line between humans and nature, and perhaps more importantly, culture and matter. This is perhaps seen most clearly when both historians and scientists speak of "eco-system" services that provide clear air and water, yet fail to recognize that materials like wood, rock, and copper also are products of an ecological system, and that they continue to shape the ecology as they are used.

Deep Culture and the Extended Mind

However, if neo-materialist theory is to truly develop concepts like life worlds and deep culture, it must aspire to explain how humans come to think through and with the material things around them. In this regard, neo-materialist theory insists that even our much-vaunted human intelligence – presumably the first source of what we typically think of as an abstract concept of culture – must also be understood as a material phenomenon. By this neo-materialism suggests not so much the largely undisputed point that all thought and consciousness emerge from entirely physical biochemical processes. Rather, it draws on the pioneering work of some cognitive scientists and philosophers who argue that the human mind is not confined to our skulls, or even our bodies, but is rather extensive with its surrounding environment.

Andy Clark, the most prominent advocate of this "extended mind" thesis, argues that human cognitive abilities can be distributed in a network of external props and aids like notes, maps, and even metal filing cabinets – aspects of our material surroundings without which some fundamental part of what we consider to be our intelligence would vanish. Obviously, many might object that these external material things are merely tools or scaffolding for an internal mind located solely in the brain. Yet Clark insists there are good reasons to embrace the idea that mind is literally extensive, as "it drives home the degree to which environmental engineering is also self-engineering." In changing our material physical environment, Clark suggests, we also reconfigure "our minds and our capacities of thought and reason" (Clark, 2008, p.xxviii).

In applying theories of cognition and the mind to the analysis of the past, archaeologists are again doing much trail breaking work. The prominent Cambridge archaeologist, Colin Renfrew, and several of his students have become leaders in exploring how ideas like the extended mind can inform bold new understandings of the past (Renfrew, 2008). In his path-breaking 2013 book, *How Things Shape the Mind,* Renfrew's former student, Lambros Malafouris, draws on Clark and others to develop what he terms Material Engagement Theory, arguing for an analytical approach that views human intelligence as a phenomenon that spreads out "beyond the skin into culture and the material world." Within this frame, he offers a highly original and compelling new understanding of "how human minds came to be" in which material things play a central role in creating and shaping both the extended human mind and the organic human brain within the skull (Malafouris, 2013, pp.2; 8).

In a different though related manner, the recent development of "neurohistory" also suggests the importance of considering the materiality of cognition in our analysis of the past. Rather than pursuing the idea that the mind (in distinction to the brain) is extensive with the material environment, Daniel Lord Smail and other advocates of neurohistory focus more on the biological brain itself. Nonetheless, their concept of the brain is similarly linked to the material world. Drawing on recent insights from neuroscience, they point out that the brain is highly plastic, capable of both shaping and being shaped by its material environment. As humans use their intelligence and culture to change their material surroundings – in other words, to develop a new niche – Smail argues that they practice new patterns of behaviors that in turn "generate new neural configurations or alter brain-body states" (Smail, 2008, p.155).

As Clark, Malafouris, Smail, and other recent cognitive theorists suggest, our brains and minds are porous rather than bounded, plastic rather than fixed, and shaped by matter rather than merely a means of shaping it. Contemporary cognitive science and theory thus offers perhaps the most direct attack on the still dominant Cartesian and post-modernist idea of an abstract human mind – and thus culture and life worlds – that exists in isolation from its material environment. Such an approach doesn't obviate the importance of cultural ideas and practices so much at it recognizes how these are embedded in, created by, and sustained by a non-human material environment – a deep culture.

Metallic Life Worlds and the Age of Immaterialism

With this admittedly cursory overview of neo-materialist and scientific theories in mind, let me now return to the metallic things in my office. Seen now not just as passive natural resources but rather as dynamic agents, the metallic life world around me appears to be a good deal livelier than we might first have thought. Even as I speak the iron around me is literally, albeit slowly by a human time scale, burning as the oxygen and moisture in the air drives its oxidation. We humans think of this process as the insult of "rusting" that is visited upon our cars and bicycles, yet it can also be usefully understood as a process of creativity, as one material gives rise to another. Likewise, while I do not have the ability to see it, the copper wires in my walls are anything but static things, as they surge with electromagnetic fields generated by the pulse of electric charges. These metallic resources may not be alive as we typically understand the term, yet they exist and change through processes that are fundamentally no different than those that create and sustain our own bodies and brains.

Yet if this metallic life world is in some sense bursting with vibrant energy in its own right, what most concerns us here is our embodied human interaction with these metal things. How is that individuals and societies emerge from this dynamic metallic world on fire? How do we become human through our engagement with the non-human? Here Clark's concept of extended minds and Smail's plastic brain seem most useful. Returning once again to the example of copper, the metal can now be understood not only a key metal of modern technology but also a key metal of modern thinking. Once removed from the earth and distributed around the world, copper is able to interact with humans and other organisms and things around it to produce novel and often entirely unanticipated new niches and historical phenomena. When formed into immense networks of wire strung across the landscape, copper becomes a geographical force of nature not dissimilar to a river, a conduit that can be used in many ways yet whose potential is inherent in its power of flow, transmission, and connectivity. Because of its excellence as an electrical conductor, copper wires could carry power far from where it had been initially generated, whether that was at a hydropower plant driven by a river or a steam engine driven by the heat of burning coal. In contrast to nearly all earlier means of transporting energy – as when coal from one place is physically moved to the site where it will generate power – absolutely *nothing* material is actually moved when transmitting electric power over a copper wire. Even the electrons that transfer the electricity do not themselves move from the site of generation to the site of use, as any individual electron jumps no farther than to the neighboring copper atom.

It was from this mysterious and almost magical power of electricity that a radically new and modern human idea of space began to emerge, a deep culture or material life world that helped to generate a modernist illusion of immaterial abstraction. Take, for example, the role of copper wire as a carrier of electrical current in the modern era. As the historian of technology David Nye notes, prior to Edison's development of a practical electric light bulb, it was assumed that to create light something must be burned (Nye, 1996). With candles, gaslight, and fireplaces, the generation of light had been inseparable from the burning of wax, gas, and wood – material things that had been transported from their original sites of extraction. With an electric light bulb, nothing material was moved and no combustion took place. Rather, in the case where some material thing *was* burned, such as coal, it could take place tens or even hundreds of miles away. Where moving water generated electric power, even combustion itself was eliminated.

When I turn on the lights in my office, tonight and countless other times before, in that moment I become part of a radical new life world from which emerge new ways of thinking and feeling space. Ironically, it could be that the sheer omnipresent materiality of copper opened up the possibility of ignoring or rejecting the essential material nature of the system. Metals like copper could help foster a new sense of *im*materialism, which in turn became embedded in modernist economic theory. Another key metal of modernity, aluminum, might also have contributed to this illusory distancing from materiality. As Mimi Sheller points out in her insightful book, *Aluminum Dreams*, aluminum was the metal of "light modernity." Because of its extraordinary strength to weight ratio, the metal has been a key driver of the world's unrelenting pursuit of ever-greater speed, enabling not only faster aircraft, but also speedier and more fuel-efficient cars, trains, and ships that transcended earlier concepts of space and time (Sheller, 2014). Yet Sheller points out that this "light modernity" had its material dark side (as was also true of copper), as the bauxite mineral from which aluminum is made was often gouged out of pristine rainforests in South America, Jamaica, and elsewhere, devastating indigenous cultures and economies, which were left with the abandoned toxic waste sites, while most of the profits and material benefits went to the developed world. Of courses, the global movement of commodities is nothing new. Yet Sheller suggests light aluminum facilitated the speed and thus seeming ease with which these movements take place in the modern world. Somewhat like a copper wire that carries "clean" electricity from a coal-burning power plant to my office, so too could speedy light aluminum ships and trains put purified aluminum soda cans in my refrigerator that seem utterly divorced from the distant bauxite mines from which they came.

Sheller's model offers a useful way of understanding how a neo-materialist focus can help us think about humans and their deep cultures more clearly and insightfully. In the first instance, a *neo*-materialist analysis is not so different from a good old-fashioned materialist approach or the more recent theory of commodity chains. It helps us to see how the shiny promise of "light modernity" is rooted in the harsh material realities of destructive global mining and profligate energy consumption. But more importantly, a neo-materialist approach also reveals how the seemingly abstract and immaterial idea of a culture of speed and modernity is in significant part the result of the human engagement with an extraordinary and in some sense *creative* metal. The culture of modernity is in this sense a deep culture.

Conclusion

In many ways, a certain arrogant strain of anthropocentrism is the defining feature of the modern world. To be sure, many earlier humans no doubt held themselves in high regard. Yet it was only in the modern age that industrialized humans began to see themselves as something akin to gods, capable of determining not only their own fates, but the fate of the entire planet. As the historian David Noble writes in his insightful study, *The Religion of Technology*, the faith that humans, or at least a select group of Christian humans living primarily in the global north and west, are destined for both spiritual and material transcendence has been an impetus for technological change since at least the Middle Ages (Noble, 1997). This Promethean anthropocentrism is perhaps nowhere more evident than in the modern infatuation with a theory of creativity and invention that celebrates the genius of the human creator while dismissing the material world from which inventions are made as nothing more than passive "natural resources" or "raw materials." Perhaps it is no surprise, then, that a post-war generation of scholars embraced the apotheosis of immaterialist thinking to claim that human ideas, discourse, and culture were the truly generative and determinative forces of the modern world?

Yet if post-modernism was at least in part the product of its own material times, perhaps so too is the contemporary neo-material turn. As the advent of global climate change and the so-called Anthropocene (nonetheless still anthropocentric in its name) mark deep changes in the nature of our material environment, we can also begin to think in new ways that had been difficult if not impossible to imagine even just a generation ago. As Dipesh Chakrabarty argued in his now seminal 2009 essay, "The Climate of History," the reality of climate change explodes the conventional modernist separation between humans and nature that had been at the heart of the post-modern discursive turn (Chakrabarty, 2009). By analyzing material things like copper, aluminum, and other material resources as inseparable from the human mind and culture, perhaps neo-materialist theories may offer a more effective way of understanding the human animal as it enters into a perilous, yet perhaps also creative, new age.

References

Andrews, Th., 2008. *Killing for Coal: America's Deadliest Labor War*. Oxford: Oxford University Press.

Barad, K., 1996. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* Durham, NC: Duke University Press.

Bennett, J., 2010. *Vibrant Matter: A Political Ecology of Things*. Durham, NC: Duke University Press.

Bijker, W., Th. Parke Hughes and T. Pinch, 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press.

Boivin, N., 2008. *Material Cultures, Material Minds*, Cambridge: Cambridge University Press.

Braidotti, R., 2013. *The Posthuman.* New York: Polity.

Chakrabarty, D., 2019. The Climate of History: Four Theses. *Critical Inquiry,* 35, pp.197-222.

Clark, A., 2008. *Supersizing the Mind: Embodiment, Action, and Cognitive Extension.* Oxford: Oxford University Press.

Coole, D., and S. Frost, 2010. *The New Materialisms: Ontology, Agency and Politics.* Durham, NC: Duke University Press.

Deleuze, G. and G. Félix, 1987. *A Thousand Plateaus: Capitalism and Schizophrenia.* Minneapolis, MN: University of Minnesota Press.

Gamble, Ch., 2019. "What is New Materialism?" *Angelaki Journal of Theoretical Humanities,* 24(6), pp.111-134.

Gräslund, B., 1987. *The Birth of Prehistoric Chronology. Dating methods and dating systems in nineteenth-century Scandinavian archeology*. Cambridge: Cambridge University Press.

Groz, E., 2005. *Time Travels: Feminism, Nature, Power.* Durham, NC: Duke University Press.

Hodder, I., 2012. *Entangled: An Archaeology of the Relationship Between Humans and Things.* Malden, MA: Wiley-Blackwell.

Ingold, T., 2004. Beyond Biology and Culture: The Meaning of Evolution in a Relational World. *Social Anthropology*, 12, pp.209-21.

Kuijpers, M., 2018. A Sensory Update to the *Châine Opératoire* in Order to Study Skill: Perceptive Categories for Copper-Compositions in Archaeometallurgy. *Journal of Archaeological Method and Theory*, 25, pp.863-891.

Laland, K., 2017. *Darwin's Unfinished Symphony: How Culture Made the Human Mind.* Princeton, NJ: Princeton University Press.

Latour, B., 1993. *We Have Never Been Modern.* Cambridge, MA: Harvard University Press.

LeCain, T., 2009. *Mass Destruction: The Men and Giant Mines That Wired America and Scarred the Planet*. New York: Rutgers University Press.

LeCain, T., 2017. *The Matter of History: How Things Create the Past.* Cambridge: Cambridge University Press.

Malafouris, L., 2013. *How Things Shape the Mind: A Theory of Material Engagement*. Cambridge, MA: MIT Press.

Murphy, M., 2006*. Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers.* Durham, NC: Duke University Press.

Noble, D., 1997. *The Religion of Technology: The Divinity of Man and the Spirit of Invention.* New York: A. A. Knopf.

Nye, D., 1996. *American Technological Sublime.* New York: MIT Press.

Olsen, B., 2010. *In Defense of Things: Archaeology and the Ontology of Objects.* Lanham, MD: AltaMira.

Radivojević, M., 2018. The Provenance, Use, and Circulation of Metals in the European Bronze Age: The State of Debate. *Journal of Archaeological Resources*, 27, pp.131-185.

Reid, A. and Sh. Shannon Greene, 2013. *Human Microbiome: A Report from the American Academy of Microbiology*. Washington, DC: American Academy of Biology.
Renfrew, C., 2008. *Prehistory: The Making of the Human Mind*. London: Modern Library Chronicles.
Sass, St., 1998. *The Substance of Civilization: Materials and Human History from the Stone Age to the Age of Silicon*. New York: Arcade.
Scott, J., 2017. *Against the Grain: A Deep History of the Earliest States.* New Haven, CT: Yale University Press.
Smail, D., 2008. *Deep History and the Brain*. Berkeley, CA: University of California Press.
Thomas, J., 2014. Reclaiming Ground: Japan's Great Convergence. *Japanese Studies,* 34, pp.253-63.
White, R., 1996. Are You and Environmentalist or Do you Work for a Living?. In: W. Cronon, ed., *Uncommon Ground: Rethinking the Human Place in Nature*. New York: W. W. Norton.

Resource-Scapes: Interwoven practices between appropriation and alienation in premodern mining communities

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This article focuses on the narrativisation of appropriation and alienation in premodern resource-scapes. New Materialism concepts about the appropriation of the world and its resources are particularly well-suited to illustrate the connections between individual bundles of practice in the of raw materials. These practices oscillate between ideational construction and its entry into cosmologies of world appropriation and alienation through rupture. Narratives can be distorted through progressive multiplication, for example through the commercialisation of raw materials. This article argues that the roots of modern extractivism lie in the distant past. Its origins can be identified in the alienation between producers and consumers that occurred during the early metal ages as a result of increased inequality in the demand for raw materials. This development has been demonstrated in the exploitation of metals such as copper, tin and iron, as well as for rock salt and quarry products. The result was mass production and a lasting change in the original appropriation dispositifs (*sensu* M. Foucault). Understanding these processes is crucial for defining resource-scapes as cosmological constructs of past raw-material acquisition.

Resource-scape; raw-material practices; new materialism; raw-material appropriation and alienation

Humans and their interaction with raw materials and environments through the lens of New Materialism

Since the earliest prehistoric times, human beings have experienced their living environment anew time and again. It is easily understood that learning about and using natural materials as well as the transformation of these materials into a resource, which then follows certain

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use patterns, are part of a variable process. Experience and use, the need of raw materials and the associated narratives are linked to the tangibility of the material world in various ways. The experiences and narrative condensations that are associated with this occurrence form the basic to understanding the appropriation of the world. The accompanying social construction of resources as materials, substances and means that can be used by humans is a process that has shaped human worlds of experience and knowledge since the earliest stages of humankind. Early in this process, people generally internalise their environment and therefore also their resources intuitively and rarely in a planned way. In this sense, resources occur (Hillebrandt, 2017). In their existence, substances within an environment oscillate in a field of tension between conscious effect and unconscious happening. Research in cultural studies and anthropology has described these processes and embedded them in spatial contexts (Ingold, 2000; 2007). The sensual experience of (raw) materials, their use and the process of learning how to deal with those materials considered a resource, are inevitably linked to the development of discursive concepts and representations of material things and bodies. In this context, it is of particular interest that people's first perception of a material and its sensory experiences depends on the affordance (*sensu* Gibson, 1977) of a material world (on this, e.g. Latour, 2005; Olsen, 2010). The perceived purpose of the material depends on past experiences, needs, and internalised concepts and narratives. As appropriation experiences and prompting narratives are assembled into incorporated practices and discourses, they are at the same time subject to constant change and drive the emergence of interweaving textures of daily life practices.

The consensus in the existing literature is that humans have used raw materials and other georesources since the time of Palaeolithic hunter-gatherer societies. Immediate need appears to be the central motivation for the use of various (mineral) georesources, such as lithic raw materials. Within the framework of subsistence-driven mobility behaviour, the "integration of the environment into the cultural sphere" (as a kind of cultural appropriation) of the wider environment also took place (for a general overview with contemporary examples: Rogers, 2006). Knowledge about the resource qualities of certain places and spaces, which eventually consolidates into narratives of the environments, has likely evolved since that period. It also likely that this evolution produced a narrative "dispositif" (Deleuze, 1992; Agamben, 2008) about an environment already in Paleolithic times. In the case of hunter-gatherer groups, these dispositifs may have been connected to the mobility behaviour of game, the localisation of certain resources or the duration of resource accessibility. According to M. Foucault (1978, 119-120)'s definition, a dispositif is the development of narratives and practices behind ad hoc decision-making. It is often unspoken, similar to a historical *apriori* and frequently develops in relation to existential crisis experiences. The narratives and perceptions about the environment likely produced related dispositifs and thus are also constitutive for a specific task-scapes (for this concept: Ingold, 1993, 158 "an array of related activities"; more general in relation to environments: Ingold, 2000). Following the task-scape concept, resource-scapes can be defined as an array of resource-producing, distributing and consuming activities.

In the case of hunters and gatherers, for example, these narratives may include the mobility behaviour of game, the localisation of certain resources, and the duration of accessibility. Knowledge and world perspectives may have been cosmologically bound in these communities, an assumption that is supported by ethnographic evidence (e.g. for the Khoisan in South Africa: Hewitt, 1986). World thinking thus is the result of a comprehensive

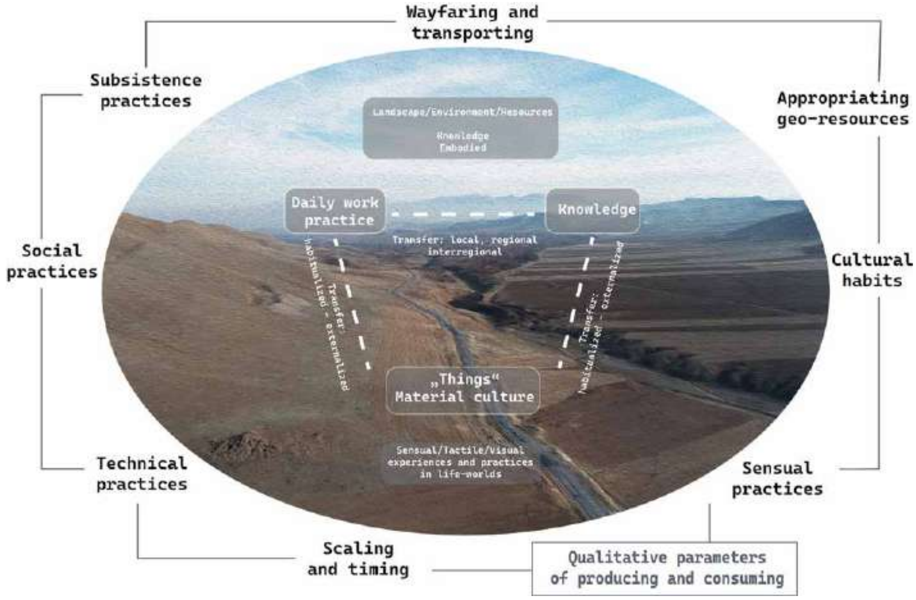

Figure 1: Resource-scapes in a holistic concept of practices, forms of knowledge and its materialized transfer (courtesy: DBM/RUB, Th. Stöllner, F. Schapals).

appropriation of the environment, which in Khoisan belief, for instance, encompasses winds and smells as ontological resources for healing and hunting (Low, 2007). It can be assumed that the narratives produced an *apriori* in an environment that goes back to long discursive imprints, for example on the localisation of resources and the way they were found and culturally appropriated. In Palaeolithic hunter and gatherer groups, these practices were closely linked with the groups' subsistence (through their use as projectile points, knives and scrapers for meat and fur processing).

This definition of a resource-scape opens up a space for observation that steers away from the traditional and systemic concept of the mining landscape towards an expanded practical space (e.g. as done by Stöllner, 2008; for more recent perspectives see Nita, 2014) (Fig. 1). Considering the associated parameters, which are not determined solely by human actors, is particularly important. They also include relationships with materials (such as a raw materials), life forms (e.g. symbiotic relationships with domestic or wild animals) and the environment (such as deposits, soils or space) and are thus intertwined with the cultural and spatial concepts of human societies. In this sense, materiality has a nexus whose determining factor is not just humans, but all "things" in its environment, which goes beyond the sensory affordance discussed previously.

Two important basic conditions have thus shaped the development of resource-scapes and their social, organisational, technical and economic structures (for the general factors involved, see Stöllner, 2003). First, the nature of the natural resource supply, such as the type and the yield of a deposit. Second, the nature of its technical, social and cultural appropriation, which reflect the knowledge complexes of the societies involved. Knowledge about the resource qualities of places and spaces, amalgamated into narratives about the environments, derives from specific practices.

Of particular importance within the resource-scapes are the spatial relationships between the primary subsistence conditions of a society and its mineral resources. Subsistence and raw-material practices generally develop jointly. They also include materials (such as a raw materials), life forms (e.g. symbiotic relationships with domestic or wild animals) and the environment (such as deposits, soils or space), which are reconstructed into a relational, symmetrical relationship and thus into a relationship with the cultural and spatial concepts of human societies (as understood in New Materialism: Bennett, 2010; Barad, 2012; Hillebrandt, 2022). In this sense, materiality is interrelational and the human being is not the only determining factor; all relationships between the "things" in its ecologies are equally important, thus going beyond the "affordance" discussed previously.

For the present analysis, the concept of "materialised practice" (DeMarrais, et al., 2004; Olson, 2010; von Rüden, 2017) is suitable to approach the lifeworlds and explicit knowledge of the actions and processes associated with the resource landscape. The utterances of miners, for example, continue to open up very specific spaces of action in the present and often have an identity-forming effect for all who act on these practices or have a detailed knowledge about them. It is precisely here that a space for observation opens up for archaeology, which enables bridging the gap between a written material legacy and an identity-forming (oral) narrative space. Since the fundamental work of André Leroi-Gourhan (1964/1980), the connection between technical practice and equipment as a semantic unit has been recognised by archaeologists in different fields of materiality (e.g. Sellet, 1993; Porqueddu, et al., 2023). This unit reflects specific routines and constitutes an expression of long processes of experience and adaptation that involved vivid practices and endured for an extended period. The types of equipment used in certain mining environments clearly demonstrate this – especially equipment used in manual labour. The mining equipment, for example the use of handles and their repair, requires recurring actions that change in small, barely noticeable steps, but ultimately produce shared sensory worlds of experience (Stöllner, 2022). As recent experiments on salt mining in the Iron Age salt mines of Hallein-Dürrnberg and Chehrabad (Iran) have shown, these sensory worlds are shared among groups of workers and become an identity-forming process through routines and adaptations (Kosczinski and Vollmer, 2020; Stöllner, et al., 2012). Manual pick work, for example, encompasses numerous other perceptual effects that extend to the perception of time (e.g. the physical perception of exhaustion), routines and sensory perception of tool guidance on the stone, etc.) (Fig. 2). Work, especially when it takes place in unusual topographies, is also closely linked to places and spaces, particularly in underground worlds where distinctive sensory conditions of perception apply (for this aspect, see Mumford, 1934, pp.69-70; see also Stöllner, 2022). It is abundantly clear from connections between tools and people that these practices are adapted to specific conditions that require explicit knowledge that is exchanged between people as well as embodied practices in their application.

Work and the related social practices in an underground mining environment form the basis for approaching narrative elements (not the narration itself) from archaeological features in the materialised world of a mine. Many artefacts as well as mining debris were directly related to production techniques, both in terms of expertise and the spatial circumstances of the production sites (e.g. the mine, the ore dressing, the smelting). When these symmetries between embodied practices and explicit knowledge formulation are considered, for example along an empirically determined *chaîne opératoire* of production processes, the complexity of knowledge and narrative spaces in prehistoric and protohistoric societies becomes immediately apparent.

Figure 2: Salt mining: Underground salt mining experiments at the Dürrnberg with wooden handled iron picks (Hallein, Salzburg, Austria); a) Picking alongside vertical cuts ("Brunnenschlagen"); b) Picking in work groups; c) Repairing tools: sharpening the iron picks with wetstones, changing wooden handles (courtesy: DBM, Gero Steffens).

Raw materials between appropriation and alienation

How was appropriation organised within individual environments? Different regional conditions clearly impacted the course of development and people's perspectives on natural materials. Similar processes have also been recognised and described in the development of agricultural systems worldwide (e.g. Barker, 2006). Allochthonous resource-concepts and agricultural practices were adapted precisely when they integrated or developed autochthonous knowledge. It should be emphasised here that these processes have not yet been systematically described for individual mineral resources in terms of prehistoric, anthropological or ethnographic sources. In this respect, an archaeology of raw materials also lags behind more recent historical and cultural science disciplines, for which material histories (e.g. of industrial raw materials) have been developed.

A well-known example of this kind of "cultural" appropriation is the development of metallurgy by the first working of greenstone (e.g., malachite, azurite) and their subsequent experimental handling as beads (e.g. Schoop, 1995). Colourful stones were transformed into beads by a continuous practice: collecting colourful stone triggered the wish to adorn the body with them. Drilling and preparation for wearing show that the stone was transformed to a "thing" to be desired by people. "Things" are therefore approached either via their "analytical" (as well as their empirical) quality, by their social construction, or by the way they are entangled in human practices. The transformative character of these ore minerals was not recognised until later, for example in the production of metals, a process that involves continued learning and experience processes in a multitude of ways. This practice of using green pigments and stones for body adornment formed the basis of what later became the development of metallurgy in different regions (Balkans, Caucasus, East Anatolia/the Levant: Radivojevic and Roberts, 2021; Courcier, 2014; Lehner and Yener, 2014; Yalçın, 2000).

Numerous examples include striking variability when different societies and their use of raw materials take different paths. North and South American cultures, for example, did not embed iron metallurgy into their social, technical and economic fabric. This is almost certainly not the result of a lack of knowledge about metallurgy in general or a lack of innovativeness (Lechtman, 1979; Rovira Llorens, 1990; for an overview of mining and metallurgy, see Stöllner, 2011). Andean cultures developed a metallurgical tradition with sophisticated metal techniques involving non-ferrous and precious metal alloys. Andean copper and gold metallurgy also has social and cosmological connotations (Lechtman, 1979; 1984; 2007). Gold and copper were the first metals worked on the American continent (Aldenderfer, et al., 2008; Burger, et al., 1998). But it is unclear why iron ores were not also reduced, as smelting processes for copper ores were developed during the Early Intermediate Period (from the 2nd century BCE to the 6th century CE) at the latest. The availability of ore may have played a minor role, as iron-rich deposits are also present in the Andean region (and have been exploited since the 11th millennium BCE: Salazar, et al., 2011) and do not differ significantly from deposits in other parts of the world. Iron reduction must therefore have been observed in the smelting processes, but this observation remained without any further consequences.

Early experiences and appropriation processes in different parts of the world and the social structures associated with them were decisive factors for the direction of the innovation process. Elsewhere, I have referred to this as cultural "path dependency", extending the scope of discussions in the field of macroeconomics (e.g. North, 1994; 2005), and emphasised the significance of the concept for the historical and archaeological investigation of raw-material exploitation (Stöllner, 2017, 13-15). The influential role of cultural decisions and cultural settings on institutional development has been examined and modelled by game theory in political economics (e.g. Bendar and Page, 2018). These studies made a fundamental contribution to our understanding of how societies developed their unique resource perspectives, a topic that is increasingly disregarded today, in a time of global commodity markets. These decisions therefore also impact the emergence of certain spatial-cultural configurations and the ways societies have dealt with raw materials in areas within their control. Mining landscapes, i.e. resource-scapes characterised by the extraction of raw materials, thus have two important basic conditions that have shaped their developments and their social, organisational, technical and economic structures (generally: Stöllner, 2003; 2008). Firstly the extraction of raw materials is no less dependent on the fundamental differences between individual environments (the type and yield of a deposit) and secondly on the knowledge complexes associated with their appropriation.

Examples are manifold throughout prehistoric and ancient mining: the yield of polymetallic ore bodies or that of cassiterite and polymetallic tin-copper mineralisation in the tin belt (which partly overlap in the Tethyan Eurasian Metallogenic Belt [TEMB]) is one such example. Fire setting and the use of hammerstones and other mining and processing equipment spread across a wide area of Europe and Eurasia within this deposit zone (e.g. Stöllner, et al., 2012; Garner, 2014; O'Brien, 2015; see also the arguments by Stöllner, 2023a, Fig. 1). Other zones can also be described in this way, for instance the spread of certain techniques used in flint mining (e.g. Barber, et al., 1999; Weisgerber, et al., 1999; Körlin and Weisgerber, 2006). Another example are the Bronze Age knowledge bundles that spread along the eastern and central Alps during the 2nd millennium BCE. Deep mining, beneficiation, smelting and subsistence techniques clearly reflect the transfer of knowledge and its adaptation to ecologically similar landscapes and deposit types (in carbonate and greywacke host rocks: O'Brien, 2015; Stöllner, 2019).

The appropriation of associated practices makes it clear that these practices are also at the centre of a number of technical and social developments that go hand in hand with the utilisation of raw materials. The relationship is superficially simple: when a raw-material complex begins production, it is always associated with economic and social investments, with technical adaptations and ultimately with a certain level of consumption (for a general overview in the context of mining, see Godoy, 1985). The more permanently the utilisation shapes a society and ultimately also an environment, the greater the mutual dependencies. This also applies to the dissolution phases of specialised resource landscapes, such as downturns in production processes. Modern extractive practices not only had a direct impact on the social and economic fabric of societies, but certain narratives also endured and remain effective (e.g. Ballard and Banks, 2003; Jacka, 2018; Chagnon, et al., 2022). One need only think of permanent changes in mining and cultural landscapes, which can ultimately be condensed into an eternally perceived conditionality. Mine dewatering, nuclear waste disposal and soil contamination are the eternal burden of a modern industrial society, for example, but such conditionalities can be found in numerous other social and ecological conurbations.

The many centuries or even millennia-old cultivation of grass pastures induced a similar specific concept of utilisation; at the same time, narratively and culturally condensed ecosocial spaces of practice were also built on it (Cribb, 1991; Galaty, 2015). Their gradual abandonment today is not only altering economic practices, but also the social identities associated with them. This process has been studied for instance Alpine pastoral farming landscapes. Traces of the old narratives and practices are preserved in an imagined cultural and identity landscape (in the sense of the German *Kulturlandschaft)*. Various conflicts between traditional pastoral economies, environmental protection and tourism can be discerned at present (e.g. Mayer and Job, 2010; for a general overview, see Brugger and Wohlfahrter, 1983). Traditional Alpine pastoral farming narratives have become a preserved remembrance. They originally served the economic practices and identities of the farming communities but no longer perform this important function. On closer inspection, however, it is apparent that the current narrative is not so much the preservation of an original narrative surrounding pastoral activities (such as the promise of income from the resource complex, e.g. from grazing areas), but has been covered with new narratives that makes use of the old ones (e.g. for tourism or political arguments) (Kirchengast, 2008). Similar narrative changes can be found in other economised regions, for example in the mechanised protection and heritage processes in the Ruhr area (for use of the term "Industriekultur" to develop heritage research, protection and tourism: Berger 2019; Berger, et al., 2018). For both these resource-scape narratives, it can be argued that the newly emerging narratives are essentially detached from the original narratives and thus alienated, and ultimately something of their own. Blue milk cows and Alpine holiday idylls or myths about hard-coal mining work in the Ruhr underground mines are displayed in memorialising articles or condensed remembrance culture (e.g. Bösch, 2010; Brüggemeier, et al., 2018; for general overview articles, see Spode, et al., 2005). The original contexts for the pumping of mine water, for instance, will soon be forgotten by many (in addition to its consequences for the water levels in the Ruhr area, an eternity burden of the area), as will the circumstances that led to the development of dairy and livestock farming and the maintenance of grass and meadow pastures in rural areas. This obliviating demonstrates the fundamental alienation from the original appropriation narratives, which occurred as less of a rupture, but rather a change accompanied by originally positive atmospheric images.

Alienation can also take effect in other ways. The classic approach to alienation by K. Marx and F. Engels (1844; 1848: Marx and Quante, 2009; Marx and Engels, 2008) refers to the machine-like alienation of the working class from the products of its own labour through capitalist production modes. It negates all sensuality of labour and thereby shapes labour as a whole into an alienated practice. The individual wage labourer becomes alienated from the promise of production as a prosperity-enhancing and positive narrative through exploitation. This kind of decoupling is recognisable in the increasing complexity of production and distribution practices. Based on E. Durkheim's and M. Heidegger's approaches to alienation (loss of social and religious traditions, individualisation, "forgetting of being"), in 1948 T.W. Adorno and M. Horkheimer (Horkheimer and Adorno, 2000) offered explanatory mechanisms and dependencies for the classic alienation processes. However, alienation should be considered further, for example in the sense of self-alienation through individualisation and parallel narratives in affluent societies, which dissolve the original effectiveness of the social as a resource (Jaeggi, 2005). Alexander Grau recently dissected the narcissistic self-alienation processes of modern, individualised people in a noteworthy essay and described it as a phenomenon common to modern societies (Grau, 2022).

Various kinds of alienation can therefore be observed when it comes to changes in production and consumption modes within resource-scapes. One example is the alienation that occurs when products are decoupled from the producers, for instance in commodity-driven commercial trade systems. Without direct involvement in the extraction and procurement process, the traditions, narratives and knowledge associated with the original appropriation of things and raw materials no longer play a role. This development can be observed in West Asia, for example, starting in the 3rd millennium BC around the Persian Gulf, where copper trading networks existed between South Mesopotamia, the Gulf of Oman, the Iranian Highlands and the Indus Valley. The Magan copper trade is especially relevant in this context (Weisgerber, 1986; Crawford, 1998; Potts, 1990). The land of Makkan/Magan mentioned in Sumerian sources (for sources, see Oppenheim, 1954; Hirsch, 1963; Englund, 1983, among others) almost certainly occupied the coastal and mountainous zones of the Omani peninsula. The mining archaeological and other archaeological evidence indicates the presence of copper supplies, especially in the second half of the 3rd millennium BC and the beginning of the 2nd millennium BC (e.g. Hauptmann, 1985; Weisgerber, 2007; see also Weeks, 2004; Giardino 2019). The geochemical data of metals, educts (e.g. slags) and ores further confirms the archaeological and historical findings (Prange, 2001; Begemann and Schmitt-Strecker, 2009; Begemann et al. 2010). The complaints of Sumerian traders that may reflect fraud in the interregional exchange systems are of interest here. One such complaint, that of a trader in Ur named Nanni, is well-known. He complained to Dilmun trader Ea-nasir about low-quality copper that had been exchanged to him (British Museum Tablet UET 5 81: Oppenheim 1967, pp.82-83). Low-quality copper has also been attested archaeologically. Among the archaeological examples are ingots found at the coastal site Ra's al Hadd and the inland site Al-Aqir (Prange, 2001, pp.11-12 Abb. 6; Craddock, et al., 2003; for a different perspective: Weisgerber and Yule, 2003). Both ingots consist of matte and slag inclusions embedded into a metallic skin. These findings make the complaints easily understandable.

It is unclear who benefited from this fraud, the producers of the ingots or those who sold them. In either case, the fraud was made possible by the increasing alienation from the original production chains and the associated social interaction in which things become commodities. Clearly, certain changes go hand in hand with the commercialisation of goods. Instead of the material quality, above all their value is being commercialised. However, the cultural processes of value measurement and narrative condensation are not unidirectional. Igor Kopytoff (1986) discussed the commoditisation of objects, and illustrated the discussion with numerous examples of a renewed narrative connection that in turn can lead to a singularisation of objects and object groups. At present, the increasing distance between the original extraction of raw materials and end products has reached global proportions. The high complexity of goods such as computers and cars does not allow proximity and connection to the miners and their work extracting rare earths, gold, oil and other eventually processed goods. Commodity branding further obscures these connections; today, for example, greenwashing is a highly debated and politicised concept (Wren Montgomery, et al., 2023). However, the effects of commoditisation are not new, as K. Polanyi pointed out in his *Great Transformation* (Polanyi, 1957/2001).

The loss of narrative practice is therefore a striking aspect of alienation: it can affect individuals and small groups alike, as the example of stone-axe cutter Delayat Kiroman aptly shows. In the 1990s, he was the last stone cutter of the Kimyal, a community in the New Guinea highlands. As he was the last initiate familiar with the ritual, technical and social practices of stone extraction from a particular volcanic river (Laschimke, 2013) (Fig. 3), the Kimyal's stone extraction practice centred on him at the end and disappeared after his death. As a result, the Kimyal not only became alienated from their traditional resource and earth cosmologies (in many other highland societies today, the western steel axe has gained the upper hand), but the community's identity-forming practices were also damaged.

Appropriation and alienation thus constitute ongoing and changing elements of the practices of resource-dependent societies and are fluid in certain states of entanglement: the degree of this fluidity and the degree of causality in complexes of interwovenness (such as proximity and distance to resource acquisition) are crucial discussion topics.

Figure 3: Delayat Kiroman at "tabu site" of volcano Min Muchabya, where only he was allowed to split and win the basaltic rocks for the adze-production (after: Laschimke2013, 199, Fig. 15); Highlands men making ceremonial stone axes, Mount Hagen (after: P. Cochrane, Wollongong Archives, collection D160/4/133); Warrior from Kandep Enga Province with steel axe, Papua New Guinea (courtesy: Highlander Photography).

Cosmological narrativisation of a resource environment: direct access modes in prehistoric and in a more recent context

Investigation of the social, organisational, technical and economic structures in mining (general factors: Stöllner, 2003; 2008) (Fig. 4) requires analysing the context of the environmental conditions, especially in fringe situations (e.g. mountains). In such conditions it is thus not be surprising if specific practices were established that repeatedly became formative. These practices can thus be regarded a specific aspect of a larger space. This certainly includes practices of appropriation and access, which could be described as "direct access" (for direct access modes, see for instance Burton, 1984; Bloedow, 1987; for ritual narrativisation: Boivin, 2004; for ethnography, for instance Pétrequin and Pétrequin, 2012).

Targeted expeditions were carried out in many cases, at regular intervals and in certain ritualised forms (see examples below). The latter practices often required the support of those in power. Visits to and use of the site were exclusive and did not necessarily involve an economic goal in addition to the social one.

Figure 4: Scheme of principal components of mining economies in early societies (author).

The early history of human interaction with raw materials includes numerous examples that reveal a connection to certain resources over an extended period. It is not always the material quality of the raw material itself that is a decisive factor in the longevity of the connection. It can therefore be assumed that it was the narrative surrounding the material and the social quality that was passed on, resulting in people travelling long distances and going to great lengths to procure these materials.

Investigation of the Upper Palaeolithic ochre mines of Tzines on the Greek island of Thasos has demonstrated the power of narrativisation over an extended period: excavations in the 1980s and 1990s demonstrated that the ochre deposit had been exploited for thousands of years (although some of the dates need to be confirmed). The hill of Tzines is in the southern part of the island, a few kilometres from the village of Limenaria. Two relatively small underground mines, labelled T1 and T2, were established within the hill, which is rich in iron oxides (Fig. 5 above). The hill exhibits traces of other potential mining sites, two of which have been partially investigated (T3 and T6). The underground mines, T1 and T2, were excavated during the 1980s and 90s (Koukouli-Chrysanthaki and Weisgerber, 1999; Weisgerber et al., 2008) (Fig. 5 below). Processing of finds from these excavations started anew 2016. This work included a detailed examination of various artefact types, particularly the macrolithic tools (Levato, 2024). Analysis of the hand-held hammerstones revealed differences in extraction technique between pits T1 and T2; in pit T1, antlers from cattle (Bos primigenius) and in one case even from a saiga antelope (Saiga tartarica) were used to loosen the red pigment (hematites, specularites) (Fig. 5, bottom right). Recent AMS-14C dating on two bone finds (2021) indicates a date between the 27th and 26th millennium BCE for one of these bones (23970 ±90 yr BP; MAMS 53686; 95.4 % confidence interval: 26482-25855 cal.BC using OxCal. v4.4 [Bronk Ramsey 2021]). AMS dating carried out at the end of the 1990s on a cattle horn from pit T1 indicates a somewhat more recent date (20350 ± 160; yr BP; ETH 11573; 95.4 % confidence interval: 23027-22072 cal.BC using OxCal. v4.4 [Bronk Ramsey 2021]). These findings indicate access to the deposit occurred over an extended period. Pebbles and hammer blanks were collected from streams in the surrounding area, but preferences for certain rock types (mainly marble, gneiss and gneiss-schist) changed. While pit T2 was created in a higher part of the deposit, the red pigment from pit T1 was extracted later and from a different, deeper part of the deposit. This part of the deposit was more difficult to work for geological reasons

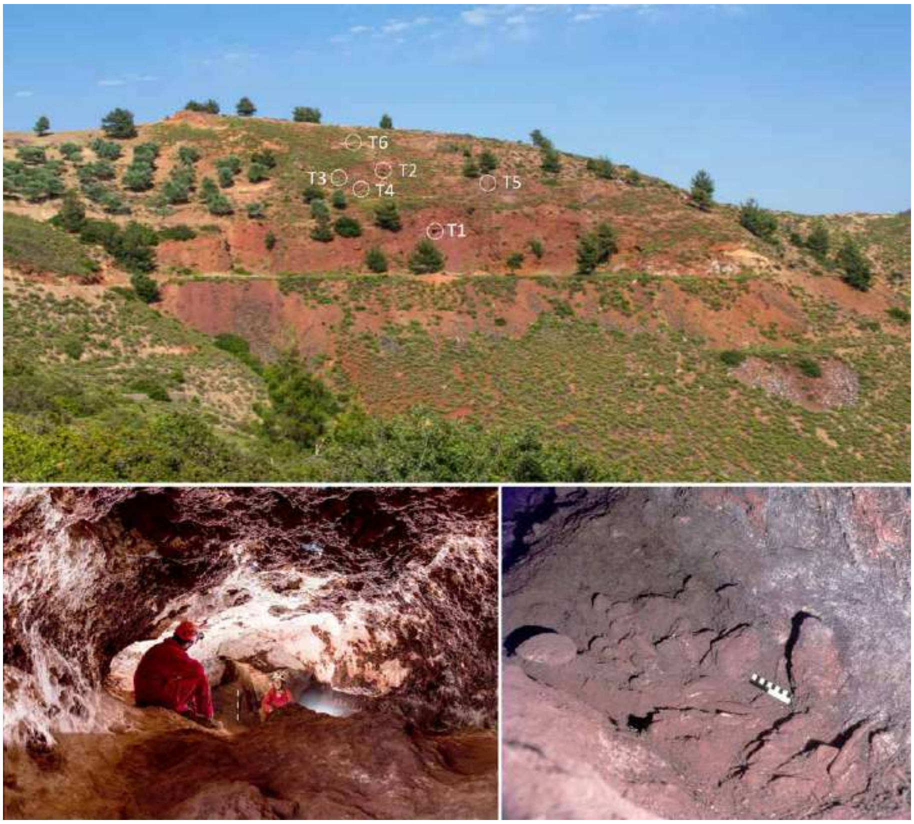

Figure 5: Thasos, the Tzines hill, location of a upper Paleolithic ocre mining, above: the hill of Tzines, with the location of the mines T1 to T6; below, left: view of the first gallery of the mine T1; below, right: the rear chamber of the mine T1, with debris and artefacts on the mine wall (courtesy: DBM, G. Steffens, J. Cierny).

(deeper and harder, not weathered part of the deposit). This difficulty may explain the different techniques and selection of raw materials for extraction. Thasos was not an island at the beginning of the last cold maximum (a cooling phase between 27 kyr and 22 kyr) but was connected to the northern Greek mainland (Perissoratis and Conispoliatis, 2003; Sakellariou and Galanidou 2016). Only a few Gravettian sites have been documented in northern Greece, which appears not to have been a densely populated area during that period (Adam, 2007; Tourloukis and Harvati, 2018). Therefore, it is likely that the deposit was already occasionally visited by targeted expeditions. Is it possible that a memory of the site was preserved over a long period and passed down through many generations in the southwest of the island?

Melian obsidian, which was widely distributed in the Aegean region until the 2nd millennium (for a general overview: Renfrew, et al., 1965; Renfrew, 1975; Torrence, 1986; Carter, 2016), had to be painstakingly procured via ship expeditions and maritime networks. This material was so abundant that it has been found in the most remote areas and among the smallest lithic fragments (e.g. Sørensen, 2010) (Fig. 6 below left). It is interesting to note that its first use (Franchti Cave, Epipalaeolithic open-air station on Kythnos, Boeotia or Crete as well as the southwest Anatolian coast: Perlès, 1990; 1999;

Sampson, 2009; Carter, et al., 2016; Gemici, et al., 2022) dates back to the late Pleistocene or the early Holocene. During this period, the water level in the Aegean was so low that Melos could be reached much more easily by seafaring. The first cultural appropriation of Melian obsidian clearly dates to this period (for an overview of this widely debated topic, see Sampson, 2019, pp.32-33). This cultural meaning was clearly so important that it was preserved until more recent periods, when the procurement became a regular seafaring practice.

Numerous examples of such stable raw-material networks have been documented in prehistoric societies. In the last 20 years, for example, the Europe-wide exchange networks of western Alpine jadeite have become widely known. P. and A. Pétrequin and colleagues determined that a western European network of appropriation and a determining social dispositif of socially recognised prestige and social chains of action were established around jadeite (Pétrequin, et al., 2012; 2017; 2020) (Fig. 6 above). This network also involved targeted procurement via long-distance travel and social-religious ideas, which are represented in the abundance of jadeite axes, engravings and the monumentality of Morbihan Neolithic communities. P. Pétrequin, et al. (2020, 106) conclude: “This is why these Alpine jade artefacts were so successful. So, it is in the realm of religious beliefs that we have to seek to understand the originality and the dynamism of the Europe of jade. And towards the middle of the fifth millennium these beliefs included the idea, and the reality, of social domination by men”.

The fact that the cosmological narrativisation of a particular raw material can remain tied to certain social practices over a long period of time while other equivalent materials are disregarded can be observed in many ethnographical examples (e.g. McBryde, 2000b; Boivin, 2004; Huntley, 2021). In some cases, raw-material expeditions re-narrated original myths in the context of pilgrimage; examples are the emu myth associated with ochre expeditions in South Australia (Jones, 1984), the expeditions to stone-axe quarries in Papua-New Guinea (Burton, 1984; Pétrequin and Pétrequin, 1993; 2012; Laschimke, 2013), and the Hopi “War Twins” myth in the southwestern US (Titiev, 1937). Many of the narratives refer to numinous powers (gods, ancestors, mythical beings) who protect the source and the resource. Nevertheless, other social effects may have been inscribed in them, such as the prestige and status accorded to leaders and participants who successfully completed the task. Expeditions, such as those undertaken by the Papuan highland societies, were particularly attractive to young, unmarried men in traditional societies.

The network around Kulin axes from the Mount William stone-axe quarry in Victoria, Australia is an example of these dynamics (McBryde, 1978; 1984; 2000a; Brumm, 2010). The source itself is (to this day) ritually protected, but even more significant is the socially integrating power of the hatchets, used in intertribal festivals, weddings and the exchange of prestige goods, which not only promoted but ultimately determined the social integration and identity of the Kulin (especially Brumm, 2010) (Fig. 6 below right). Only the gradual dissolution of social practices and other mythically charged spatial narratives resulting from the white colonisation of Australia robbed the hatchets of their social role. The first white men to visit the site in the 19th century commented on this role, which still existed at that time (von Blandowski, 1855; Howitt, 1904). The dissolution of the narratives that came into existence alongside the appropriation of raw materials became distorted and finally led to the fracturing of the narrative context (and thus to the end of axe production and circulation) (McBryde, 2000a).

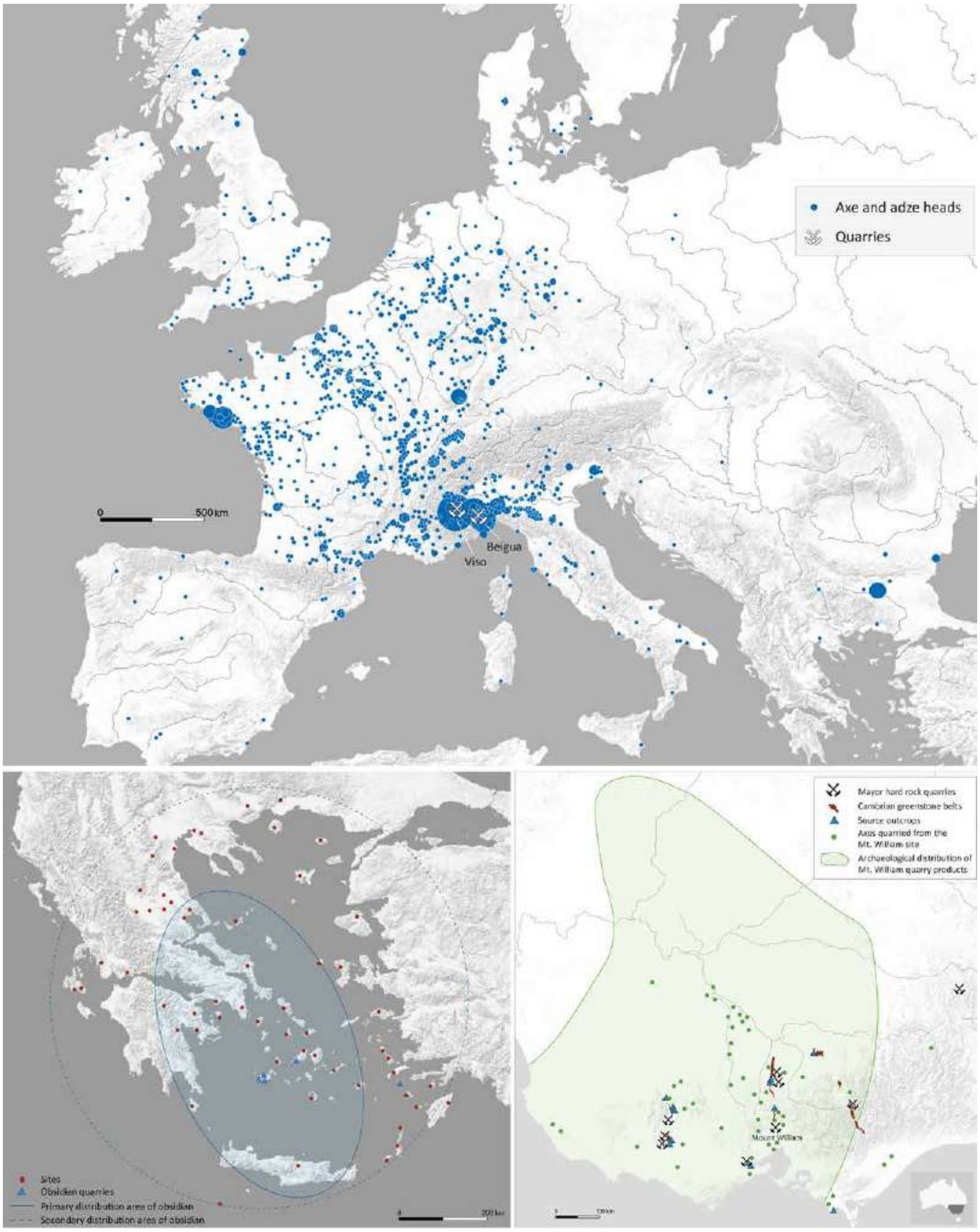

Figure 6: above: The distribution of large (13.5 cm-46.6 cm long) axe-and adze-heads (and chisels) of Alpine rocks, as of May 2016. Source: JADE2, directed by Pierre Pétrequin (after: Pétrequin, et al., 2020); below left: Melian obsidian, map with selected Late and Final Neolithic sites in the Aegean, and the Aegean obsidian sources with the primary and secondary distribution areas indicated (after: Sørensen. 2010); below, right: Kulin stone axe network in South Australia (after: McBryde, 1976; 1984).

Investigation of direct access modes has made it apparent that shared knowledge was directly linked with raw materials (the technical and social qualities and use of raw materials, accessibility and embedding in landscapes as a mental map, etc.). Narratives were likely passed down from one generation to the next and shaped the community's practices that were bound to the resource environments. Such narratives are therefore part of a complex, concept of practices that can be called an interweaving complex (for the concept of interwovenness/enmeshment in mining landscapes, see for instance Stöllner, 2019; 2022). These practices are thus materially and immaterially interwoven through narratives (for the entanglement concept, see Hodder, 2012).

Narrativisation in times of commoditisation: thoughts on resource-scapes and their characteristics across time and space

Due to the commoditisation of mineral resources, mining has changed, not only in its technical aspects, such as infrastructure, location stability, durability and logistics, but also in the intensity of extraction. In the early history of mining, the first "mining centres" date to the late 4th and the 3rd millennium BCE. Some of the earliest examples are Fenan and the Wadi Arabah in Jordan (Hauptmann, 2007, Barker, et al., 2007, Hauptmann and Löffler 2013) (Fig. 7, above right), the Hajjar mountains in Oman (Hauptmann, 1985; Prange, 2001; Weisgerber, 2007), Cyprus and the Troodos (Kassianidou, 2013) (Fig. 7, above left), Kargaly in the southern Urals (Chernykh, 2007) and the eastern Alps (Stöllner, 2019) (e.g. Fig. 7 bottom). The social and environmental impact of mining landscapes increased significantly over time. A growing demand for raw materials was accompanied by an increase in (technical) efforts as well as infrastructural and social investments. It thus promoted economic and social processes as well as their integration within the landscapes shaped by raw materials.

It can also be assumed that increased production (which can be seen in the mining archaeological record through an intensification, mechanisation and expansion of mining) led to a specialisation of the mining process and the associated trade. It thus also led to a decoupling from traditional forms of appropriation (e.g. what is referred to as an industrial phase in premodern mining landscapes; for the theoretical context: Stöllner, 2003). The associated alienation through production practices and eventually a detachment from traditional legal and appropriation narratives was especially likely to occur if the raw materials fed into a supra-regional market and were thus subject to greater monetisation (e.g. by the introduction of coinage: e.g. Schaps, 2004) or commoditisation (Kopytoff, 1986). A stronger "state" control of raw-material mining becomes evident in this situation (in the medieval period, for instance, castles appear in mining areas: Steuer, 2012) and narrativisation can thus be inferred. Centralised cults, mining laws, taxation and property rights certainly contributed to certain narratives that evolved in mining landscapes under these conditions; this is especially true for cult and ritual activities in mining landscapes. The most well-known examples are the veneration of Hathor at Egyptian mining sites (e.g. Serabit el Khadim, Gebel Zeit, Timna, for a general overview of the cosmological dimensions: Aufrère, 1997) and central cult places (e.g. the cult place at the Ras Jebel Khalid in Fenan: Weisgerber, 2003). In Kargaly, feasting and the refilling of underground structures in the settlement of Gorny were interpreted as examples of these practices (for deposition rituals in Kargaly see: Chernykh, 2007; general remarks by O'Brien, 2015, pp.253-263). Many cases of mine refilling do not have a technical explanation and can be interpreted as ideological actions in the sense of "healing the earth". The myriad examples include flint

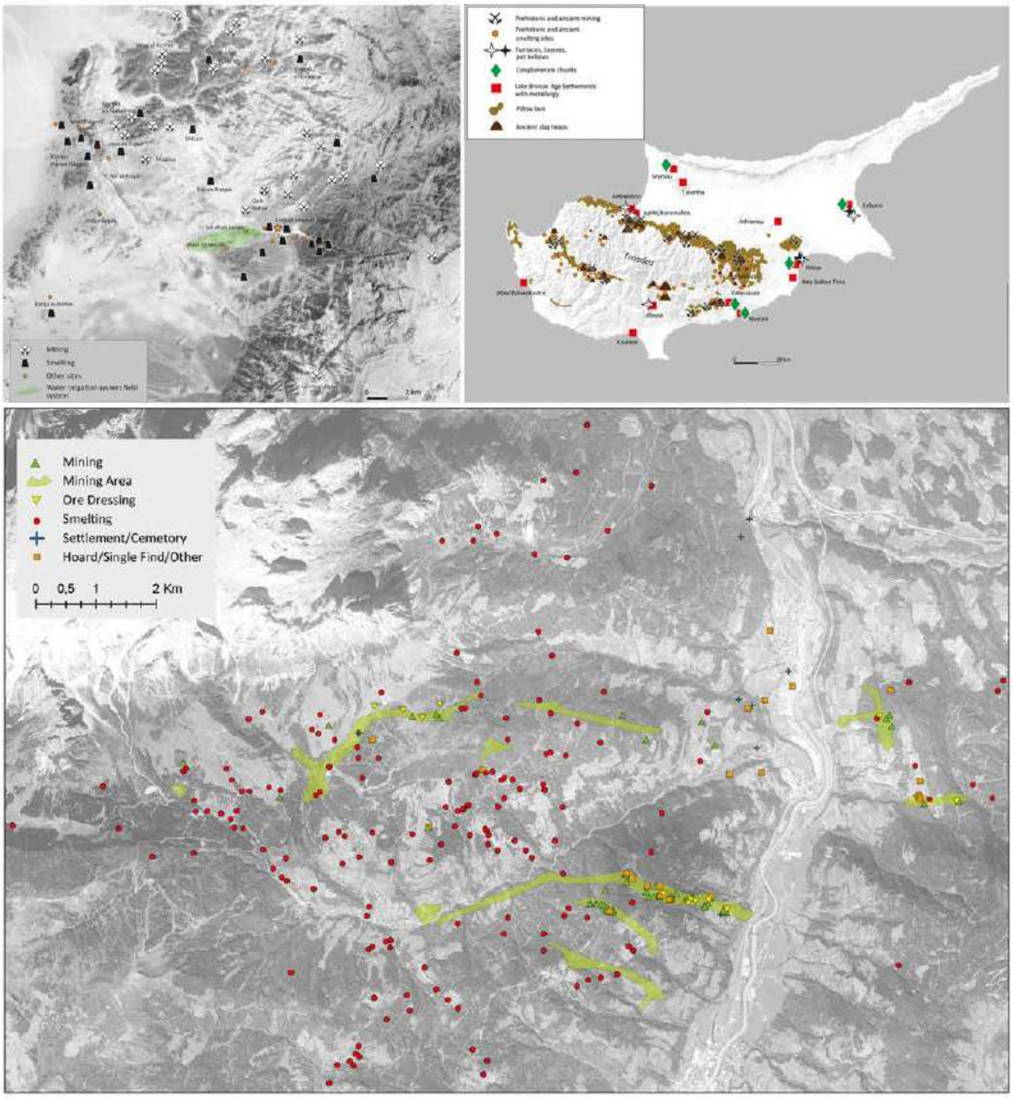

Figure 7: Condensed Bronze Age Mining Landscapes (copper): above left: The mining landscape of Fenan during the Bronze and Iron Ages (modified after: Hauptmann, 2007); above right: Mining landscape of the Bronze/Iron Ages and antiquity in Cyprus (after: Stöllner, 2003; Kassianidou, 2013).

mines (e.g. Grime's Graves or Spiennes: Barber et al., 1999; Collet, 2006, pp.67-72, tin-ore mines, such as Kestel: e.g. Andrews, 1994, pp.19-21 and copper mines: Aibunar: Chernykh, 1978, pp.203-217; Mitterberg, Arthurstollen: Stöllner, et al., 2006; Chinflon: Andrews 1994, p.17) (Fig. 8). During the Bronze Age, mine refilling was done deliberately with debris that often included beneficiated/crushed material (Fig. 8, d-g). This indicates that the backfill that remained after metal ore concentrates were extracted was considered a worthy remnant. The refilling itself involved significant effort, as the debris was carefully sorted by hand and even remote parts of the mine were backfilled (Fig. 8, a-d). In late Bronze Age Cyprus, ritual activities and iconographies surrounding metal production appear to be institutionalised and based on elements of Cypriot cultural practice (for the Cypriot ingot deities: Schaeffer, 1966; Negbi, 1976; general: Webb, 2001; Kassianidou, 2005). Detailed analyses of one of the oldest gold-production processes in the Georgian Sakdrisi/Dzedzvebi complex allowed understanding of an all-encompassing ritual practice strongly connected to the various steps of the gold and metal production (Stöllner and Gambashidze, 2017). In the Christian era, churches and the veneration of Saint Barbara (Jontes, 2008) and the Virgin Maria display a similar all-encompassing cosmology in medieval and more recent mining contexts. Use of the Latin *resurgere*, in connection with a Christian cosmology, illustrates the connection to the resurrection and to the metaphor of growth that has been incorporated into the terminology of modern, explanatory natural science (such as the concept of the vein of ore/ similar to a blood vein) (Asmussen, 2023). This development reflects different beliefs in a broader cosmological dimension that may have had its roots in older practices and narratives, although these traditions were often a reinvention or at least a kind of renarration. For example, in the case of the Serabit site in the Sinai, a hybridisation of local veneration and Egyptian cosmologies has been documented (Valbelle, 1998; Valbelle and Bonnet, 1996) (Fig. 9). A more recent mining cult site has been discovered in Timna (during the Iron Age industrial phase this site saw a renarration involving local symbolism that diverges from the Hathor cults of the older Egyptian phase: Rothenberg, 1999; Amzallag, 2018). Of course, much is dependent on whether cult practices continue through worshipping. If so, a cultural alienation by hybridisation can be argued from the archaeological evidence (as in Timna).

The processes of a possible cultural alienation from the previously dominant resource narratives indicates important changes within resource-scapes. A stronger use and quantification of resource production and trade is inconceivable without correspondingly efficient agro-pastoral economic sectors. Therefore, in the present context, questions about connections with rural environments are pertinent. Examining these contexts can clarify whether the economic and social processes surrounding the extraction of raw materials had a stabilising effect on the living conditions of the societies involved, or whether colonial, monetised access destabilised traditional subsistence systems and plunged them into crisis-like conditions (see in general Stöllner 2023b; in regard to extractivism see: Ballard and Banks, 2003; Jacka, 2018).

The role of environmental parameters is particularly relevant in extreme climatic and spatial situations (see for instance the "fringes": Chagnon et al., 2022). High altitude and extremely hot or cold temperatures forced people interested in raw materials to adopt certain patterns of behaviour adapted to the hostile environment. Those fringes of the temperate living spheres were often narrativised as desirable "El Dorados" and became dependent on the extractivism narratives of early commoditised societies. It is not by mere chance that the earliest narratives about foreign, desirable lands originated around 3000 BCE in Mesopotamian urban societies (the Land-of-Aratta myth: Hansman, 1978; Potts, 2009).

In extreme locations, for example, adapted animal husbandry with specific grazing conditions was an important pillar of raw-material procurement. In mountainous areas, the greater importance of extensive pastoral subsistence systems and a unique link with a connected but rather temporary raw-material exploitation can be inferred (Galaty, 2015; e.g. Pearce this volume). This miner-herder strategy (the term used in e.g. Stöllner 2023b) likely shaped the strategy of high-altitude exploitation since at least the later 4th millennium BCE (e.g. Maggi and Pearce, 2005; see also M. Pearce this volume), and may even date back to

Figure 8: Refilled Bronze Age mining galleries: Arthurstollen, Austria, copper ore mining, search galleries (a) North gallery, (b) Cierny gallery, (c) profiles; Sakdrisi, Georgia, mine 1/2 North extension, western extraction gallery, gold mining (d); Askaraly II, Kazakhstan, tin ore mining, extraction galleries: East gallery (e), west gallery, detail of debris refilled upper part (f), and top view of refilled mining debris (g) (courtesy: DBM/RUB, J. Cierny, Th. Rabsilber, Th. Stöllner, P. Thomas).

the Neolithic (for the Caucasus: Marro and Stöllner, 2021; Stöllner, 2021). In my opinion, this way of combining different territorially bound strategies should be distinguished from the even more traditional concepts of direct access via expeditions.

The peculiarity of practices in environments of a particular spatial, social and cultural nature also shaped the perspective and conceptualisation of geographical space as such, especially if a continuous mining process became established (in the sense of "spacing": Bender, 1993; Löw, 2001). In intensively worked mining landscapes, mental,

Figure 9: Hathor veneration in Egyptian mining enterprises: a- Hathor 'Mistress of Carnelian', stela from Gebel el-Asr (courtesy: I. Shaw); b- Serabit el-Khadim, Sinai, stela show veneration of Hathor 'Mistress of Turquoise' (courtesy: DBM, G. Weisgerber); c -Timna site 200, Hathor mask (courtesy: DBM, G. Weisgerber); d- Timna site 200 later Midianite sanctuary, reconstruction (courtesy: B. Rothenberg).

cultural, religious and other social processes more clearly demonstrate the impacts of environmental and raw-material factors, transport topography, the availability of technical knowledge and subsistence factors (listed in Stöllner 2008). What can be archaeologically observed in a mining landscape (e.g. extraction sites, platforms, paths, settlement sites, production sites) is therefore the result of networked practices that were established over an extended period and in turn influenced specific actions as well as economic and social concepts. These practices led to an ongoing interwovenness within the resource-scapes even in prehistoric societies, as can be observed in the eastern Alps (e.g. Stöllner, 2019), in Cyprus (Kassianidou, 2013) and Fenan (Barker, et al., 2007; Weisgerber, 2003; Hauptmann, 2007; Hauptmann and Löffler, 2013).

A possible conclusion: Looking for narrativisation conditions in prehistoric and ancient resource societies

A deeper understanding of the prehistoric narratives that accompanied the different actions involved in the appropriation and production of (mineral) resources can rarely be achieved. The process of narrativisation likely had as many variations as the practices and knowledge involved in the various aspects of appropriation. Much of this understanding is based on the assumption that the use of raw materials and other georesources since the time of the hunter-gatherer societies of the Palaeolithic took place in the form of direct access. The immediate needs of individuals and groups appear to be the central motivation for the utilisation of various (mineral) georesources, such as lithic raw materials. Because these materials are well preserved, they can be used for assessing the raw-material behaviour of small groups of hunters and gatherers. In the context of a mostly subsistence-driven mobility behaviour, the cultural appropriation of the wider environment took place as well, leading to the consolidation of knowledge about certain resource qualities of places and spaces. This process likely led to various narrativisations of the environment, which may have produced a certain disposition towards an environment. The life-worlds of prehistoric and modern hunter and gatherer groups (e.g. for the Khoisan in South Africa: Hewitt, 1986) produce a very specific and environment related *narratival apriori* for their daily practices. And this applies to other communities that practice this kind of small scale "world" appropriation.

One could argue for a different, more dichotomised narrativisation practice in a commoditised environment that produces a higher level of standardisation and regularity – simply because a larger workforce or even mechanisation was involved. Was such a narrativisation more profane in the end? An examination of the many appeasement strategies and belief narrations connected with mining casts doubt on this inference. Instead, a more provocative question arises: does modern capitalism and extractivism include many modernised meta-narratives that make us believe in the unavoidability of exploitation (see the general overview by Chagnon, et al., 2022). Similar circumstances in prehistory and antiquity also contributed to alienation and could lead to significant social conflicts (for instance in slave revolts, seminal writings: Rickard, 1928, 130, 132; Wilsdorf, 1952; Lauffer, 1956). This process can be seen in the effects of the ruthless extractivism of large corporations in the current era, which cannot resolve the actual conflict between different appropriation narratives (e.g. Ballard and Banks, 2003; Jacka, 2018). I conclude that the raw-material and resource practices that exist today have their roots in an alienation that began in the early metal ages as a result of increased inequalities in the demand for raw materials (along these lines, see Stöllner, 2023a). Demand increased for metals such as copper, tin and iron, as well as for rock salt and quarry products, resulting in mass production and a lasting change in the original appropriation dispositifs. A detailed investigation of these issues, seeking to find out when and how the dichotomisation of producers and consumers took place in terms of materialised social practices in different regions of the world, is an interesting topic for future research.

References

Adam, E., 2007. Looking out for the Gravettian in Greece. *Paléo* 19, pp.145-158.

Agamben, G., 2008. *Was ist ein Dispositiv?* Zürich: Diaphanes.

Aldenderfer, M., Craig, N.M., Speakman, R.J. and Popelka-Filcoff, R., 2008. 4000-year-old gold artifacts from the Lake Titicaca basin, in southern Peru. *PNAS* 105(13), pp.5002-5005. Available at: DOI:10.1073/pnas.0710937105 [Accessed 29 November 2024].

Amzallag, N., 2018. Who was the deity worshipped at the tent-sanctuary at Timna? In: E. Ben-Yosef, ed., *Mining for Ancient Copper. Essays in Memory of Beno Rothenberg*. Tel Aviv University Monograph Series 37. Tel Aviv: Tel Aviv Press, pp.127-136.

Andrews, P., 1994. Excavating mines – with examples from Cwmystwyth, Chinflon and Kestel. *Bulletin of the Peak District Mines Historical Society* 12(3), pp.13-22.

Asmussen, T., 2023. The cosmologies of early modern mining landscapes. In: C. Göttler and M. Mochizuki, eds., *Landscape and Earth in Early Modernity. Picturing Unruly Nature*. Amsterdam: Amsterdam University Press, pp.239-266. Available at: DOI:10.1017/9789048552153.007 [Accessed 29 November 2024].

Aufrère, S., 1997. L'univers minéral dans la pensée égyptienne; essai de synthèse et perspectives (Autour de l'univers minéral X). *Archéo-Nil* 7, pp.113-144.

Ballard, C. and Banks, G., 2003. Resource wars: The anthropology of mining. *Annual Review of Anthropology* 32, pp.287-313.

Barad, K., 2012. *Agentieller Realismus. Über die Bedeutung materiell-diskursiver Praktiken.* Edition Unseld 45. Berlin: Suhrkamp.

Barber, M., Topping, P. and Field, D., 1999. *The Neolithic Flint Mines of England.* Swindon.

Barker, G., ed., 2006. *The Agricultural Revolution in Prehistory: Why Did Foragers Become Farmers?* Oxford/New York: Oxford University Press.

Barker, G.W., Gilbertson, D.D. and Mattingly, D.J., eds., 2007. *Archaeology and Desertification: The Wadi Faynan Landscape Survey, Jordan.* Oxford.

Bednar, J. and Page, S., 2018. When order affects performance: Culture, behavioral spillovers, and institutional path dependence. *American Political Science Review* 112(1), pp.82-98. Available at: DOI:10.1017/S0003055417000466 [Accessed 29 November 2024].

Begemann, F. and Schmitt-Strecker, S., 2009. Über das frühe Kupfer Mesopotamiens. *Iranica Antiqua* 44, pp.1-45.

Begemann, F., Hauptmann, A., Schmitt-Strecker, S. and Weisgerber, G., 2010. Lead isotope and chemical signature of copper from Oman and its occurrence in Mesopotamia and sites on the Arabian Gulf coast. *Arabian Archaeology and Epigraphy* 21, pp.135-169.

Bender, B., ed., 1993. *Landscape, Politics and Perspectives.* Oxford: Berg.

Berger, S., 2019. Narrativisations of an industrial past: Labour, the environment and the construction of space in comparative perspective. In: S. Berger, ed., *Constructing Industrial Pasts: Heritage, Historical Culture and Identity in Regions Undergoing Structural Economic Transformation.* New York/Oxford: Berghahn, pp.288-305.

Berger, S., Golombek, J. and Wicke, C., 2018. A post-industrial mindscape? The mainstreaming and touristification of industrial heritage in the Ruhr. In: C. Wicke, S. Berger and J. Golombek, eds., *Industrial Heritage and Regional Identities.* London: Routledge, pp.111-135.

Berkenbosch, K., Groote, P. and Stoffelina, A., 2022. Industrial heritage in tourism marketing: Legitimizing post-industrial development strategies of the Ruhr region, Germany. *Journal of Heritage Tourism* 17(3), pp.327-341. Available at: DOI:10.1080/1743873X.2022.2026364 [Accessed 29 November 2024].

Bloedow, E.F., 1987. Aspects of ancient trade in the Mediterranean: Obsidian. *Studi Micenei ed Egeo-Anatolici* 26, pp.59-124.

Boivin, N., 2004. From veneration to exploitation: Human engagement with the mineral world. In: N. Boivin and M.A. Owoc, eds., *Soils, Stones and Symbols: Cultural Perceptions of the Mineral World.* London/Portland, OR: Cavendish, pp.165-186.

Bösch, D., 2010. *Grubengold: Mythos Ruhrgebiet.* Essen: Klartext.

Bronk Ramsey, C., 2021. OxCal 4.4.4. Available at: http://c14.arch.ox.ac.uk/oxcal [Accessed 29 November 2024].

Brugger, O. and Wohlfarther, R., 1983. *Alpwirtschaft heute.* Graz: Leopold Stocker.

Brüggemeier, F.J., Farbenkopf, M. and Grütter, H.T., eds., 2018. *Das Zeitalter der Kohle: Eine europäische Geschichte.* Essen: Klartext.

Brumm, A., 2010. The falling sky: Symbolic and cosmological associations of the Mt William greenstone axe quarry, Central Victoria, Australia. *Cambridge Archaeological Journal* 20(2), pp.179-196. Available at: DOI:10.1017/S0959774310000223 [Accessed 29 November 2024].

Burger, R.L. and Gordon, R.B., 1998. Early Central Andean metalworking from Mina Perdida, Peru. *Science* 282(5391), pp.1108-1111.

Burton, J., 1984. Quarrying in a tribal society. *World Archaeology* 16(2), pp.234-247.

Carter, T., 2009. L'obsidienne égéenne: caractérisation, utilisation et culture. In: M.-H. Moncel and F. Fröhlich, eds., *L'Homme et le Précieux: Matières Minérales Précieuses de la Préhistoire à Aujourd'hui.* BAR International Series 1934. Oxford: Archaeopress, pp.199-212.

Carter, T., 2016. Obsidian consumption in the Late Pleistocene – Early Holocene Aegean: Contextualising new data from Mesolithic Crete. *Annual of the British School at Athens* 111, pp.13-34. Available at: DOI:10.1017/S006824541600006X [Accessed 29 November 2024].

Chagnon, C.W., Durante, F., Gills, B.K., Hagolani-Albov, S.E., Hokkanen, S., Kangasluoma, H., Kontinen, S.M.J., Kröger, M., Lafleur, W., Ollinaho, O. and Vuola, M.P.S., 2022. From extractivism to global extractivism: The evolution of an organizing concept. *The Journal of Peasant Studies* 49(4), pp.760-792. Available at: DOI:10.1080/03066150.2022.2069015 [Accessed 29 November 2024].

Chernykh, E.N., 1978. Aibunar – a Balkan copper mine of the fourth millennium B.C. *Proceedings of the Prehistoric Society* 44, pp.203-217.

Chernykh, E.N., ed., 2007. *Kargaly V. Kargaly: Phenomenon and Paradoxes of Development. Kargaly in the Systems of Metallurgical Provinces. Hidden (Sacral) Life of Archaic Miners and Metallurgists.* Moscow: Languages of Slavonic Culture.

Collet, H., 2006. The flint mines of Petit-Spiennes (Province de Hainault): An update. In: G. Körlin and G. Weisgerber, eds., *Stone Age – Mining Age. International Flint Symposium 1999. Der Anschnitt*, Beiheft 19. Bochum: Deutsches Bergbau-Museum, pp.67-72.

Courcier, A., 2014. Ancient metallurgy in the Caucasus from the sixth to the third millennium B.C. In: B.W. Roberts and C.P. Thornton, eds., *Archaeometallurgy in Global Perspective: Methods and Syntheses.* New York/Heidelberg/Dordrecht/London: Springer, pp.579-664.

Crawford, H.E.W., 1998. *Dilmun and Its Gulf Neighbours.* Cambridge: Cambridge University Press.

Craddock, P., La Niece, S. and Hook, D.R., 2003. Evidence for the production, trading and refining of copper in the Gulf of Oman during the third millennium BC. In: Th. Stöllner, G. Körlin, G. Steffens and J. Cierny, eds., *Man and Mining. Studies in Honour of Gerd Weisgerber. Der Anschnitt*, Beiheft 16. Bochum: Deutsches Bergbau-Museum, pp.103-112.

Cribb, R., 1991. *Nomads in Archaeology.* Cambridge: Cambridge University Press.

Deleuze, G., 1992. What is a dispositif? In: T.J. Armstrong, ed., *Michel Foucault, Philosopher.* Hemel Hempstead: Harvester Wheatsheaf, pp.159-168.

Demarrais, E., Gosden, C. and Renfrew, C., eds., 2004. *Rethinking Materiality. The Engagement of Mind with the Material World.* McDonald Institute Monographs. Cambridge: Oxbow Books.

Englund, R., 1983. Dilmun in the Archaic Uruk Corpus. In: D.T. Potts, ed., *Dilmun. New Studies in the Archaeology and Early History of Bahrain* (Berliner Beiträge zum Vorderen Orient 2). Berlin, pp.35-37.

Foucault, M., 1978. *Dispositive der Macht. Über Sexualität, Wissen und Wahrheit.* Berlin: Merve.

Galaty, J.G., 2015. Pastoralism in anthropology. In: J.D. Wright, ed., *International Encyclopedia of the Social & Behavioral Sciences*, 2nd ed., Vol. 17. Oxford: Elsevier, pp.577-583.

Garner, J., 2014. *Das Zinn der Bronzezeit in Mittelasien II: Die montanarchäologischen Forschungen an den Zinnlagerstätten. Archäologie in Iran und Turan* 12. Berlin – Bochum.

Gemici, H.C., Dirican, M. and Atakuman, Ç., 2022. New insights into the Mesolithic use of Melos obsidian in Anatolia: a pXRF analysis from the Bozburun Peninsula (southwest Turkey). *Journal of Archaeological Science: Reports* 41, 103296. Available at: DOI: 10.1016/j.jasrep.2021.103296 [Accessed 29 November 2024].

Giardino, C., 2019. *Magan – The Land of Copper. Prehistoric Metallurgy of Oman.* Oxford: Archaeopress.

Gibson, J.J., 1977. The theory of affordances. In: R. Shaw and J. Bransford, eds., *Perceiving, Acting, and Knowing: Toward an Ecological Psychology.* Hillsdale, NJ: Lawrence Erlbaum, pp.67-82.

Godoy, R., 1985. Mining. Anthropological perspectives. *Annual Review of Anthropology* 14, pp.199-217.

Grau, A., 2022. *Entfremdet. Zwischen Realitätsfalle und Identitätsfalle.* Springe: Zu Klampen.

Hansmann, J., 1978. The question of Aratta. *Journal of Near Eastern Studies* 37, pp.331-336.

Hauptmann, A., 1985. *5000 Jahre Kupfer in Oman. Band 1: Die Entwicklung der Kupfermetallurgie vom 3. Jahrtausend bis zur Neuzeit. Der Anschnitt*, Beiheft 4. Bochum: Deutsches Bergbau-Museum.

Hauptmann, A., 2007. *The Archaeometallurgy of Copper: Evidence from Faynan, Jordan.* Natural Science in Archaeology. Berlin/Heidelberg: Springer.

Hauptmann, A. and Löffler, I., 2013. Technological innovations and organisational structures of prehistoric mining and metal production – examples from Faynan, Jordan. In: S. Burmeister, S. Hansen, M. Kunst and N. Müller-Scheeßel, eds., *Metal Matters. Innovative Technologies and Social Change in Prehistory and Antiquity.* Rahden: VML, pp.65-89.

Hewitt, R.L., 1986. *Structure, Meaning, and Ritual in the Narratives of the Southern San.* Quellen zur Khoisan-Forschung 2. Hamburg: Helmut Buske Verlag.

Hillebrandt, F., 2017. The resources in practice: A new notion of materiality in sociology. In: P. Eisenach, Th. Stöllner and A. Windler, eds., *The RITaK Conferences 2013-2014. Raw Materials, Innovation, Technology of Ancient Cultures.* RITaK 1. *Der Anschnitt*, Beiheft 34. Bochum/Rahden/Westf.: VML, pp.59-68.

Hillebrandt, F., 2022. Practices – viewed from a sociological perspective. In: K.-H. Johansen and U. Schmidt, eds., *Practice, Practice Theory and Theology. Scandinavian and German Perspectives.* Praktische Theologie im Wissenschaftsdiskurs 28. Berlin: De Gruyter. Available at: https://www.degruyter.com/document/doi/10.1515/9783110743791-005/html [Accessed 29 November 2024].

Hirsch, H., 1963. Die Inschriften der Könige von Agade. *Archiv für Orientforschung* 20, pp.1-82.

Hodder, I., 2012. *Entangled: An Archaeology of the Relationships between Humans and Things.* Malden, MA: Wiley-Blackwell.

Horkheimer, M. and Adorno, T.W., 2000. *Dialektik der Aufklärung: Philosophische Fragmente.* Fischer Wissenschaft 7404. Frankfurt am Main: Fischer Taschenbuch.

Howitt, A.W., 1904. *The Native Tribes of South-East Australia.* London: Macmillan.

Huntley, J., 2021. Australian Indigenous ochres: Use, sourcing, and exchange. In: I. McNiven and B. David, eds., *The Oxford Handbook of the Archaeology of Indigenous Australia and New Guinea*, pp.1-31. Available at: DOI: 10.1093/oxfordhb/9780190095611.013.21 [Accessed 29 November 2024].

Ingold, T., 1993. The temporality of the landscape. *World Archaeology* 25(2), pp.152-174.

Ingold, T., 2000. *The Perception of the Environment: Essays on Livelihood, Dwelling and Skill.* London: Routledge.

Ingold, T., 2007. *Lines: A Brief History.* New York: Routledge.

Jacka, J.K., 2018. The anthropology of mining: The social and environmental impacts of resource extraction in the mineral age. *Annual Review of Anthropology* 47, pp.61-77.

Jaeggi, R., 2005. *Entfremdung. Zur Rekonstruktion eines sozialphilosophischen Begriffes.* Frankfurt am Main/New York: Campus.

Jones, P., 1984. Red ochre expeditions: An ethnographic and historical analysis of Aboriginal trade in the Lake Eyre Basin. *Journal of the Anthropological Society of South Australia* 22(7), pp.3-10; 22(8), pp.10-19.

Jontes, G., 2008. Bergmännische Glaubenswelten. Vom Berggeist bis St. Barbara. *Res montanarum* 46, pp.7-12.

Kassianidou, V.L., 2005. Was copper production under divine protection in Late Bronze Age Cyprus? Some thoughts on an old question. In: V. Karageorghis, H. Matthäus and S. Rogge, eds., *Cyprus: Religion and Society from the Late Bronze Age to the End of the Archaic Period.* Proceedings of an International Symposium, Erlangen, Germany, 23-24 July 2004. Möhnesee: Bibliopolis, pp.127-141.

Kassianidou, V.L., 2013. Mining landscapes of prehistoric Cyprus. *Metalla* 20(1), pp.36-45.

Kirchengast, C., 2008. Über Almen zwischen Agrikultur & Trashkultur. *Alpine Space – Man & Environment* 5. Innsbruck: University Press.

Kopytoff, I., 1986. The cultural biography of things: Commoditization as process. In: A. Appadurai, ed., *The Social Life of Things. Commodities in Cultural Perspective.* Cambridge: Cambridge University Press, pp.64-91.

Körlin, G. and Weisgerber, G., eds., 2006. *Stone Age – Mining Age. VIII International Flint Symposium, Bochum, 13-17 September 1999. Der Anschnitt*, Beiheft 19. Bochum: Deutsches Bergbau-Museum.

Kosczinski, K. and Vollmer, P., 2020. Das Experiment Salzbergbau. In: Th. Stöllner, A. Aali and N. Bagherpour, eds., *Tod im Salz – Eine Archäologische Ermittlung in Persien.* Begleitbuch, Katalog und Graphic Novel. Offenbach/Bochum, pp.147-152.

Koukouli-Chrysanthaki, C. and Weisgerber, G., 1999. Prehistoric ochre mines on Thasos. In: C. Koukouli-Chrysanthaki, A. Mueller and S. Papadopoulos, eds., *Thasos. Matières premières et technologie de la préhistoire à nos jours.* Actes du colloque international, Thasos, Liménaria, 26-29.9.1995. Paris: De Boccard, pp.129-144.

Lauffer, S., 1956. *Die Bergwerkssklaven von Laureion – Arbeits- und Betriebsverhältnisse, Rechtsstellung.* Akademie der Wissenschaften und der Literatur, Abh. Geistes- und Sozialwiss. Klasse 12. Wiesbaden: Franz Steiner.

Laschimke, R., 2013. Steinbeile im zentralen Bergland von Irian Jaya. In: G. Schöbel, ed., *Experimentelle Archäologie in Europa 12. Bilanz 2013.* Unteruhldingen, pp.192-200.

Latour, B., 2005. *Reassembling the Social: An Introduction to Actor-Network-Theory.* Clarendon Lectures in Management Studies. Oxford: Oxford University Press.

Lechtman, H., 1979. Issues in Andean metallurgy. In: E.P. Benson, ed., *Pre-Columbian Metallurgy of South America.* Dumbarton Oaks Conference 1975. Washington, DC: Trustees for Harvard University, pp.1-40.

Lechtman, H., 1984. Andean value systems and the development of prehistoric metallurgy. *Technology and Culture* 25(1), pp.1-36.

Lechtman, H., 2007. The Inka and Andean metallurgical tradition. In: R. Burger, R. Morris and R. Matos Mendieta, eds., *Variations in the Expression of Inka Power.* Dumbarton Oaks Symposium 1997. Washington, DC: Dumbarton Oaks Research Library, pp.313-355.

Lehner, J.W. and Yener, K.A., 2014. Organization and specialization of early mining and metal technologies in Anatolia. In: B.W. Roberts and C.P. Thornton, eds., *Archaeometallurgy in Global Perspective. Methods and Syntheses.* New York/Heidelberg/Dordrecht/London: Springer, pp.529-557.

Leroi-Gourhan, A., 1964/1980. *Hand und Wort – Die Evolution von Technik, Sprache und Kunst* [1964/65]. Frankfurt a.M.

Low, C., 2007. Khoisan wind: Hunting and healing. *Journal of the Royal Anthropological Institute* 13(N.S.), pp.71-90. Available at: DOI:10.1111/j.1467-9655.2007.00402.x [Accessed 29 November 2024].

Löw, M., 2001. *Raumsoziologie.* Frankfurt am Main: Suhrkamp.

Marro, C. and Stöllner, Th., 2021. On salt, copper and gold. The story behind shepherds, metallurgists and miners in the first mining enterprises of the Caucasus. In: C. Marro and Th. Stöllner, eds., *On Salt, Copper and Gold: The Origins of Early Mining and Metallurgy in the Caucasus.* Proceedings of the conference, Tbilisi (Georgia), 16-19 June 2016. *Archéologie(s).* Lyon: MOM Éditions, pp.13-26.

McBryde, I., 1978. Wil-Im-Ee Bog-Ring or, Where Do Axes Come From? *Mankind* 11, pp.354-382.

McBryde, I., 1984. Kulin greenstone quarries: The social contexts of production and distribution for the Mt William site. *World Archaeology* 16(2), pp.267-285.

McBryde, I., 2000a. Continuity and discontinuity: Wurundjeri custodianship of the Mt William Quarry. In: M. Neale, S. Kleinert and R. Bancroft, eds., *The Oxford Companion to Aboriginal Art and Culture.* Melbourne/New York: Oxford University Press, pp.247-251.

McBryde, I., 2000b. Travellers in storied landscapes: A case study in exchanges and heritage. *Aboriginal History* 24, pp.152-174.

Maggi, R. and Pearce, M., 2005. Mid fourth-millennium copper mining in Liguria, northwest Italy: The earliest known copper mines in western Europe. *Antiquity* 79(303), pp.66-77.

Mayer, M. and Job, H., 2010. Raumrelevante Konflikte zwischen Almwirtschaft, Naturschutz und Tourismus: Ergebnisse einer Befragung in den oberbayerischen Alpen. *Naturschutz und Landschaftsplanung* 42(2), pp.55-63.

Marx, K. and Engels, F., 2008. *Manifest der Kommunistischen Partei.* Edited by Sálvio M. Soares. Amsterdam: MetaLibri.

Marx, K. and Quante, M., 2009. *Ökonomisch-philosophische Manuskripte.* Suhrkamp Studienbibliothek 15. Frankfurt am Main: Suhrkamp.

Mumford, L., 1934. *Technics and Civilization.* New York: Harcourt, Brace and Company.

Negbi, O., 1976. *Canaanite Gods in Metal. An Archaeological Study of Ancient Syro-Palestinian Figurines.* Tel Aviv: Tel Aviv University, Institute of Archaeology.

North, D.C., 1994. Economic performance through time. *American Economic Review* 84(3), pp.359-368.

North, D.C., 2005. *Understanding the Process of Economic Change.* Princeton, NJ: Princeton University Press.

Nita, J., 2014. Mining landscape as a type of cultural landscape. *Prace Komisji Krajobrazu Kulturowego. Dissertations of Cultural Landscape Commission* 23, pp.203-212.

O'Brien, W., 2015. *Prehistoric Copper Mining in Europe, 5500-500 BC.* Oxford: Oxford University Press.

Olsen, B., 2010. *In Defense of Things: Archaeology and the Ontology of Objects.* Archaeology in Society Series. Lanham, MD: AltaMira Press.

Oppenheim, A.L., 1954. The seafaring merchants of Ur. *Journal of the American Oriental Society* 74, pp.6-17.

Oppenheim, A.L., 1967. *Letters from Mesopotamia: Official, Business, and Private Letters on Clay Tablets from Two Millennia.* Chicago/London: University of Chicago Press.

Porqueddu, M.E., Sciuto, C. and Lamesa, A., 2023. Reconsidering the chaîne opératoire: At the crossroad between people and materials. *Open Archaeology* 9(1), pp.1-10. Available at: DOI:10.1515/opar-2022-0296 [Accessed 29 November 2024].

Perlés, C., 1990. *Les industries lithiques taillées de Franchthi (Argolide, Grèce). Tome II, Les industries du Mésolithique et du Néolithique initial.* In: T.W. Jacobsen, ed., *Excavations at Franchthi Cave, Greece*, Fascicle 5. Bloomington/Indianapolis: Indiana University Press.

Perlés, C., 1999. Long-term perspectives on the occupation of the Franchthi Cave: Continuity and discontinuity. In: G.N. Bailey, E. Adam, E. Panagopoulou, C. Perlés and K. Zachos, eds., *The Palaeolithic Archaeology of Greece and Adjacent Areas: Proceedings of the ICOPAG Conference, Ioannina, September 1994.* London: British School at Athens, pp.311-318.

Perissoratis, C. and Conispoliatis, N., 2003. The impacts of sea-level changes during latest Pleistocene and Holocene times on the morphology of the Ionian and Aegean seas (SE Alpine Europe). *Marine Geology* 196(3), pp.145-156.

Pétrequin, P. and Pétrequin, A.M., 1993. *Écologie d'un outil: la hache de pierre en Irian Jaya (Indonésie).* Paris: CNRS.

Pétrequin, P. and Pétrequin, A.M., 2012. Les modèles ethnoarchéologiques de Nouvelle-Guinée. In: P. Pétrequin, S. Cassen, M. Errera, L. Klassen, A. Sheridan and A.M. Pétrequin, eds., *Jade. Grandes haches alpines du Néolithique européen. Ve et IVe millénaires av. J.-C.* Cahiers de la MSHE C.N. Ledoux. Besançon: Presses Universitaires de Franche-Comté and Centre de Recherche Archéologique de la Vallée de l'Ain, pp.27-45.

Pétrequin, P., Cassen, S., Errera, M., Sheridan, A. and Pétrequin, A.M., eds., 2012. *Jade. Grandes haches alpines du Néolithique européen. Ve et IVe millénaires av. J.-C.*, Cahiers de la MSHE C.N. Ledoux, tomes 1-2. Besançon: Presses Universitaires de Franche-Comté and Centre de Recherche Archéologique de la Vallée de l'Ain.

Pétrequin, P., Gauthier, E. and Pétrequin, A.M., eds., 2017. *Jade. Objets-signes et interprétations sociales des jades alpins dans l'Europe néolithique.* Cahiers de la MSHE Ledoux, tomes 3-4. Besançon: Presses Universitaires de Franche-Comté – Centre de recherche archéologique de la vallée de l'Ain.

Pétrequin, P., Pétrequin, A.M., Sheridan, A., Cassen, S., Gauthier, E. and Errera, M., 2020. Alpine jades in the European Neolithic. In: M. Bernabò Brea, ed., *Italia tra Mediterraneo ed Europa: mobilità, interazioni e scambi. Rivista di Scienze Preistoriche* 70, S1, Firenze, pp.99-107.

Polanyi, K., 1957/2001. *The Great Transformation: The Political and Economic Origins of Our Time.* 2nd ed. Foreword by J.E. Stiglitz; introduction by F. Block. Boston: Beacon Press.

Potts, D.T., 1990. *The Arabian Gulf in Antiquity*, Vol. 1. Oxford: Clarendon Press.

Potts, D.T., 2004. Exit Aratta: Southeastern Iran and the Land of Marhashi. *Nāme-ye Irān-e Bāstān* 4(1), pp.1-11.

Prange, M., 2001. 5000 Jahre Kupfer im Oman; Band 2: Vergleichende Untersuchungen zur Charakterisierung des omanischen Kupfers mittels chemischer und isotopischer Analysenmethoden. *Metalla* 8, pp.1-126.

Radivojević, M. and Roberts, B.W., 2021. Early Balkan metallurgy: Origins, evolution and society, 6200-3700 BC. *Journal of World Prehistory* 34, pp.195-278. Available at: DOI: 10.1007/s10963-021-09155-7 [Accessed 29 November 2024].

Renfrew, C., Cann, J.R. and Dixon, J.E., 1965. Obsidian in the Aegean. *Annual of the British School at Athens* 60, pp.225-247.

Renfrew, C., 1975. Trade as action at a distance: Questions of integration and communication. In: J.A. Sabloff and C.C. Lamberg-Karlovsky, eds., *Ancient Civilization and Trade.* Albuquerque, NM: University of New Mexico Press, pp.3-60.

Rickard, T.A., 1928. The mining of the Romans in Spain. *The Journal of Roman Studies* 18, pp.129-143.

Rogers, R.A., 2006. From cultural exchange to transculturation: A review and reconceptualization of cultural appropriation. *Communication Theory* 16, pp.474-503.

Rothenberg, B., 1999. Archaeo-metallurgical researches in the Southern Arabah 1959-1990. Part 2: Egyptian New Kingdom (Ramesside) to Early Islam. *Palestine Exploration Quarterly* 131, pp.150-175.

Rovira Llorens, S., 1990. *La metalurgia americana: Análisis tecnológico de materiales prehispánicos y coloniales.* Madrid: Editorial de la Universidad Complutense.

Sakellariou, D. and Galanidou, N., 2016. Pleistocene submerged landscapes and Palaeolithic archaeology in the tectonically active Aegean region. *Geological Society, London, Special Publications* 411(1), pp.145-178. Available at: DOI: 10.1144/SP411.9 [Accessed 29 November 2024].

Salazar, D., Jackson, D., Guendon, J.-L., Salinas, H., Morata, D., Figuera, V., Manríquez, G. and Castro, V., 2011. Early evidence (ca. 12,000 B.P.) for iron oxide mining on the Pacific coast of South America. *Current Anthropology* 52(4), pp.463-475.

Sampson, A., 2019. *Paleolithic and Mesolithic Sailors in the Aegean and the Near East.* Newcastle upon Tyne: Cambridge Scholars Publishing.

Sampson, A., Kozłowski, J.K., Kaczanowska, M., Budek, A., Nadachowska, A., Tomek and Miękina, B., 2009. Sarakenos Cave in Boeotia, from Palaeolithic to the Early Bronze Age. *Eurasian Prehistory* 6(1-2), pp.199-231.

Schaeffer, C.F.-A., 1965. An ingot god from Cyprus. *Antiquity* 39, pp.56-57.

Schaps, D.M., 2004. *The Invention of Coinage and the Monetization of Ancient Greece.* Ann Arbor: University of Michigan Press.

Schoop, U.-D., 1995. *Die Geburt des Hephaistos. Technologie und Kulturgeschichte neolithischer Metallverwendung im Vorderen Orient.* Internationale Archäologie 24. Rahden/Westf.: Verlag Marie Leidorf.

Sellet, F., 1993. Chaîne opératoire: The concept and its applications. *Lithic Technology* 18(1-2), pp.106-112.

Sørensen, L., 2010. Obsidian from the Final Neolithic site of Pangali in western Greece: Development of exchange patterns in the Aegean. In: B. Valentin Eriksen, ed., *Lithic Technology in Metal Using Societies. Jutland Archaeological Society Publications* 67, pp.157-176.

Spode, H., Ziehe, I. and Canatauw, C., eds., 2005. *Gebuchte Gefühle. Tourismus zwischen Verortung und Entgrenzung.* Voyage 7. München/Wien: Profil.

Steuer, H., 2012. Burg und Bergbau – Herrschaft durch Wirtschaft. In: E. Beck, E.-M. Butz, M. Strotz, M. Zettler and Th. Zotz, eds., *Burgen im Breisgau: Aspekte von Burg und Herrschaft im überregionalen Vergleich. Archäologie und Geschichte: Freiburger Forschungen zum ersten Jahrtausend in Südwestdeutschland* 18. Ostfildern: Thorbecke, pp.297-329.

Stöllner, Th., 2003. Mining and economy: A discussion of spatial organisations and structures of early raw material exploitation. In: Th. Stöllner, G. Körlin, G. Steffens and J. Cierny, eds., *Man and Mining. Studies in Honour of Gerd Weisgerber. Der Anschnitt*, Beiheft 16. Bochum: Deutsches Bergbau-Museum, pp.415-446.

Stöllner, Th., 2008. Mining landscapes in early societies – imprinting processes in Pre- and Protohistoric economies? In: C. Bartels and C. Küpper-Eichas, eds., *Cultural Heritage and Landscapes in Europe. Landschaften: Kulturelles Erbe in Europa*, Veröffentlichungen des Deutschen Bergbau-Museums 161. Bochum: Deutsches Bergbau-Museum, pp.65-92.

Stöllner, Th., 2011. Präkolumbischer Bergbau in den Anden. In: R. Slotta and I. Schnepel, eds., *Schätze der Anden. Chiles Kupfer für die Welt.* Ausstellungskatalog. Bochum: Deutsches Bergbau-Museum, pp.181-212.

Stöllner, Th., 2017. Resources, innovation, technology: Theoretical approaches to abstract concepts and research content. In: P. Eisenach, Th. Stöllner and A. Windler, eds., *The RITaK Conferences 2013-2014. Raw Materials, Innovation, Technology of Ancient Cultures.* RITaK 1. *Der Anschnitt*, Beiheft 34. Bochum/Rahden/Westf.: VML, pp.11-23.

Stöllner, Th., 2019. Enmeshment within resource-scapes – Eastern Alpine copper production of the Bronze and Early Iron Age. In: R. Turk, Th. Stöllner and G. Goldenberg, eds., *Alpine Copper II – Alpenkupfer II – Rame delle Alpi II – Cuivre des Alpes II. New Results and Perspectives on Prehistoric Copper Production. Der Anschnitt*, Beiheft 42. Bochum/Rahden: VML, pp.13-30.

Stöllner, Th., 2021. From generalists to specialists? Transcaucasian communities and their approach to resources during the 5th and the 3rd millennium BCE. In: C. Marro and Th. Stöllner, eds., *On Salt, Copper and Gold: The Origins of Early Mining and Metallurgy in the Caucasus.* Proceedings of the conference held in Tbilisi (Georgia), 16-19 June 2016. *Archéologie(s)* 5. Lyon: MOM Éditions (2022), pp.445-476.

Stöllner, Th., 2022. Entangled connections: Materialized practices of knowledge-networks of mining. From the theoretical level to its empirical consequences in mining archaeology. In: M. Farrenkopf and S. Siemer, eds., *Material Cultures of Mining. Approaches, Aspects and Examples.* Veröffentlichungen Deutsches Bergbau-Museum 243. Berlin/Boston: De Gruyter, pp.317-344. Available at: DOI:10.1515/9783110729955-014 [Accessed 29 November 2024].

Stöllner, Th., 2023a. A new mineral age: From economic strategies to societal impacts of Early Metal Ages' mining and raw material procurement. In: E. Meunier, J.-M. Fabre, E. Hiriart, S. Mauné and C. Gabriel Tămaş, eds., *Mines et métallurgies anciennes. Mélanges en l'honneur de Béatrice Cauuet.* Pessac: Ausonius Éditions, pp.43-54. Available at: DOI:10.46608/dana9.9782356135377.6 [Accessed 29 November 2024].

Stöllner, Th., 2023b. Coping with problems of mining: Approaching resilience strategies through the study of resource-scapes in the Iranian highlands. In: R. Bernbeck, G. Eberhardt and S. Pollock, eds., *Coming to Terms with the Future. Concepts of Resilience for the Study of Early Iranian Societies.* Leiden: Sidestone Press, pp.183-203. Available at: https://www.sidestone.com/books/coming-to-terms-with-the-future [Accessed 29 November 2024].

Stöllner, Th. and Gambaschidze, I., 2017. The ritual interplay: Gold mining practices in the late 4th and early 3rd millennia BC. With an appendix by T. Skowronek, A. Courcier and Th. Stöllner. In: B.V. Eriksen, A. Abegg-Wigg, R. Bleile and U. Ickerodt, eds., *Interaktion ohne Grenze. Festschrift für Claus von Carnap-Bornheim zum 60. Geburtstag.* Kiel/Hamburg: Wachholtz Verlag, pp.119-136.

Stöllner, Th., Cierny, J., Eibner, C.S., Boenke, N., Herd, R., Maas, A., Röttger, K., Sormaz, T., Steffens, G. and Peter, P., 2009. Der bronzezeitliche Bergbau im Südrevier des Mitterberggebietes – Bericht zu den Forschungen der Jahre 2002 bis 2006. *Archaeologia Austriaca* 90, pp.87-137.

Stöllner, Th., Craddock, B., Timberlake, S. and Gambaschidze, I., 2012. Feuersetzen im frühesten Metallerzbergbau und ein Experiment im frühbronzezeitlichen Goldbergbau von Sakdrissi, Georgien. In: K. Oeggl and V. Schaffer, eds., *Die Geschichte des Bergbaues in Tirol und seinen angrenzenden Gebieten.* Proceedings 6. Milestone-Meeting Klausen 2011. Innsbruck: University Press, pp.65-77.

Torrence, R., 1986. *Production and Exchange of Stone Tools: Prehistoric Obsidian in the Aegean.* Cambridge: Cambridge University Press.

Titiev, M., 1937. A Hopi salt expedition. *American Anthropologist* 39, pp.244-258.

Tourloukis, V. and Harvati, K., 2018. The Palaeolithic record of Greece: A synthesis of the evidence and a research agenda for the future. *Quaternary International* 466, pp.48-65.

Valbelle, D., 1998. Les dieux égyptiens et la royauté au Sinaï. In: D. Valbelle and C. Bonnet, eds., *Le Sinaï durant l'Antiquité et le Moyen Âge: 4000 ans d'histoire pour un désert.* Paris: Éditions Errance, pp.50-55.

Valbelle, D. and Bonnet, C., 1996. *Le sanctuaire d'Hathor maîtresse de la turquoise.* Paris: Picard.

von Blandowski, W., 1855. Personal observations made in an excursion towards the central parts of Victoria, including Mount Macedon, McIvor, and Black Ranges. *Transactions of the Philosophical Society of Victoria* 1, pp.50-74.

von Rüden, C., 2017. From mechanics to embodiment: Some theoretical considerations on techniques. In: P. Eisenach, Th. Stöllner and A. Windler, eds., *The RITaK Conferences 2013-2014. Raw Materials, Innovation, Technology of Ancient Cultures.* RITaK 1. *Der Anschnitt*, Beiheft 34. Bochum/Rahden/Westf.: VML, pp.69-78.

Webb, J.M., 2001. The sanctuary of the Ingot God at Enkomi: A new reading of its construction, use and abandonment. In: P.M. Fischer, ed., *Contributions to the Archaeology and History of the Bronze and Iron Ages in the Eastern Mediterranean. Studies in Honour of P. Åström.* Österreichisches Archäologisches Institut Sonderschriften 39. Vienna: Österreichisches Archäologisches Institut, pp.69-82.

Weeks, L.R., 2004. *Early Metallurgy of the Persian Gulf: Technology, Trade, and the Bronze Age World.* Boston/Leiden: Brill.

Weisgerber, G., 1986. Dilmun – a trading entrepôt: Evidence from historical and archaeological sources. In: Sh.H.A.A. Khalifa and M. Rice, eds., *Bahrain through the Ages. The Archaeology.* London: Kegan Paul International, pp.135-142.

Weisgerber, G., 2003. Spatial organisation of mining and smelting at Feinan, Jordan: Mining archaeology beyond the history of technology. In: P.T. Craddock and J. Lang, eds., *Mining and Metal Production through the Ages.* London: The British Museum Press, pp.76-89.

Weisgerber, G., 2007. Production as seen from Al-Moyassar-1. In: S. Cleuziou and M. Tosi, eds., *In the Shadow of the Ancestors: The Prehistoric Foundations of the Early Arabian Civilization in Oman.* Muscat: The Ministry of Heritage & Culture, pp.251-254.

Weisgerber, G., Slotta, R. and Weiner, J., eds., 1999. *5000 Jahre Feuersteinbergbau. Die Suche nach dem Stahl der Steinzeit.* Bochum: Deutsches Bergbau-Museum.

Weisgerber, G. and Willies, L., 2000. The use of fire in prehistoric and ancient mining: Firesetting. *Paléorient* 26(2), pp.131-149.

Weisgerber, G. and Yule, P., 2003. Al-Aqir near Bahlā – an Early Bronze Age dam site with planoconvex ‘copper’ ingots. *Arabian Archaeology and Epigraphy* 14, pp.24-53.

Weisgerber, G., Cierny, J., and Koukouli-Chrysanthaki, C., 2008. Zu paläolithischer Gewinnung roter Farbmineralien auf der Insel Thasos. In: Ü. Yalçin, ed., *Anatolian Metal IV. Der Anschnitt.* Bochum: Deutsches Bergbau-Museum, pp.179-190.

Wilsdorf, H., 1952. *Bergleute und Hüttenmänner im Altertum bis zum Ausgang der römischen Republik. Ihre wirtschaftliche, soziale und juristische Lage.* Freiberger Forschungshefte Reihe D 1. Berlin: Akademie-Verlag.

Montgomery, A.W., Lyon, T.P. and Barg, J., 2023. No end in sight? A greenwash review and research agenda. *Organization & Environment* (online first). Available at: DOI: 10.1177/10860266231168905 [Accessed 29 November 2024].

Yalçın, Ü., 2000. Frühchalkolithische Metallfunde von Mersin-Yumuktepe: Beginn der extraktiven Metallurgie? *Türkiye Bilimler Akademisi Arkeoloji Dergisi / Turkish Academy of Sciences Journal of Archaeology* 3, pp.109-128.

Yalçın, Ü., 2003. Metallurgie in Anatolien. In: Th. Stöllner, G. Körlin, G. Steffens and J. Cierny, eds., *Man and Mining – Mensch und Bergbau. Studies in Honour of Gerd Weisgerber on Occasion of His 65th Birthday. Der Anschnitt*, Beiheft 16. Bochum: Deutsches Bergbau-Museum, pp.527-536.

Linked resources: The metallurgy-pastoralism nexus

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This paper examines the complementarity of pastoralism with copper mining and smelting, arguing that the pastoralism provides the economic basis and landscape knowledge essential for the practice of metallurgy. It further argues that likewise the exploitation of other resources, such as rock salt and chert, cannot be seen in isolation but should be understood in terms of integrated strategies of resource procurement. The discussion is illustrated by examples from Copper and Bronze Age Liguria and Trentino – Alto Adige / Südtirol, mountainous regions in northern Italy.

Mining; smelting; pastoralism; dairying; copper; salt; chert

In this paper I will explore the close links between the strategies for the prehistoric exploitation of two seemingly different classes of resource, pastoral and metallurgical, and I will illustrate my argument with examples from two mountainous areas in northern Italy, Liguria (the Maritime Alps and the Apennines) and the Trentino – Alto Adige / Südtirol (the south-eastern Alps).

It has long been suggested by English-language archaeologists that there is a link in the archaeological record between pastoralism and metallurgy. Vere Gordon Childe, the prescient prehistorian whose ideas still underlie much thinking by archaeologists in the "anglosphere", described the spread of metallurgy by "*warrior herdsmen*" (whom he calls the "*Beaker Folk*") in his *The Prehistory of European Society* (1958, p.144): "*… their objectives were not only pastures and arable lands, but also raw materials for trade and industry, and smiths accompanied them*". Likewise, pastoralism and metallurgy were linked for Andrew Sherratt (1981; 1983): his "secondary products revolution" hypothesis posited a step-change in the late Neolithic economy during which a whole series of innovations were introduced, including dairying and metallurgy. Beakers and metallurgy certainly seem to appear in the British Isles at the same time (Needham, 2012; Sheridan, 2012), with the earliest mining at Ross Island (Galway, Republic of Ireland) carried out by beaker-using metallurgists (O'Brien, 2004), but we now know that dairying was already practised in early Neolithic Europe (e.g. Salque, et al., 2013) rather than being an innovation of the

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 61-76.

late Neolithic. As we shall see in this paper, however, Childe and Sherratt were right to recognise a connection between metallurgy and the pastoral economy and I shall explore this complementarity below.

On one level, there is a technological link between dairying and metallurgy, for like metallurgy cheesemaking is also a pyrotechnology. Cheesemaking is a low-temperature pyrotechnology, but the success of the process depends on the careful control of the temperature of the milk, particularly at critical moments, to avoid the cheese spoiling or the milk boiling over (which would occur just above 100° C). For example, when making the artisanal Bagòs cheese in the area around Bagolino (BS, northern Italy), the milk is heated to about 36-37° C[1] (38-39° C when on higher-altitude Alpine pasture) before adding the rennet. After the curd has been broken up and whisked back into the whey twice, the milk is again heated to 47-52° C (the exact temperature depends on the altitude, the air temperature, the characteristics of the milk and whether the cheese is to be matured for a long period) before the curd forms again (Viviani, 1993, pp.59-64); after the curd is extracted, ricotta cheese[2] is made by reheating the whey to 90° C (Viviani, 1993, p.69). If the milk is heated to too high a temperature the curd will not form, and if the whey boils over, milk will be lost and the formation of the ricotta ruined. We can thus see how crucial temperature control is to the process.

In Europe, most of the outcrops of copper ore are found in mountainous areas, at a distance from the fertile agrarian lands of the plains[3]. This has two important consequences for the discovery and exploitation of the mineral resources: 1) prospectors need to explore areas which are likely marginal for sedentary agriculturalists; and 2) miners and smelters working away in the mountains need to be provisioned. Mountainous areas are however also an important resource for animal husbandry as they enable herders to raise their carrying capacity efficiently by allowing them to exploit extra land for grazing. If livestock are taken to upland grazing, away from the home farm, then the fodder that they would otherwise have consumed close to the farm can be harvested and stored for the winter, when the grass does not grow. If livestock graze on upland pasture for one third of the year, then one third of the fodder available close to the farm is saved and can be stored for the winter. Since the availability of winter fodder is the critical limit on the number of animals that can be kept over the winter, this allows more animals to be kept (Pearce, 2016, p.47). It should be noted that the exploitation of new land by mobile pastoralism is a key feature of Sherratt's (1981) "secondary products revolution".

The fourth-third millennium BC: Liguria.

The first appearance of metallurgy in northern Italy corresponds chronologically with a growing importance of pastoralism in later Neolithic (Chassey culture) Liguria (Maggi and Pearce, 2010, p.284). Chassey groups in northern Italy used copper in the second half of the fifth millennium cal BC (Pearce, 2007, pp.46-51; 2015, p.48), as demonstrated by copper awls at the Arene Candide cave (Finale Ligure SV), at Alba (CN; GX-25859-AMS: 5380±40 BP, 4336-4056 cal BC[4]; Venturino Gambari, 2002, p.410), at Sant'Andrea di Travo (PC; Bernabò Brea, et al., 2002,

1 Before thermometers were used, the cheesemaker (*casaro*) could tell whether the correct temperature had been reached from the size of the bubbles formed by flicking the surface of the milk with their fingers (Viviani, 1993, p.59).

2 Ricotta is of course not strictly a cheese (Viviani, 1993, p.70).

3 For an overview of the copper outcrops of northern Italy, see Pearce, 2007, pp.53-62.

4 All dates are calibrated to 95.4% using OxCal 4.4 and the IntCal20 curve: Bronk Ramsey, 2009; Reimer, et al., 2020.

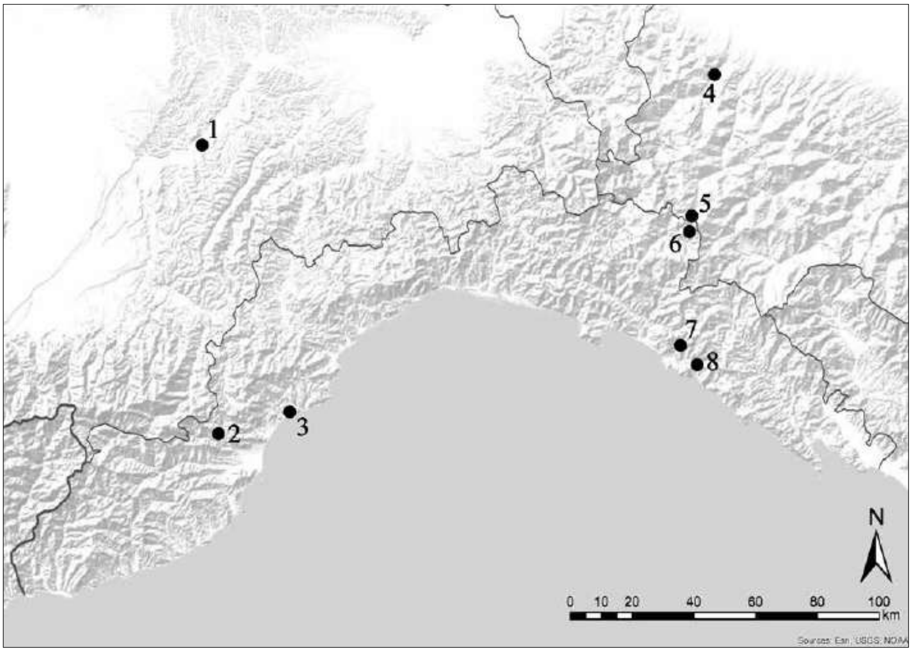

Figure 1: Sites mentioned in Liguria and the Apennines: 1. Alba; 2. Tana del Barletta; 3. Arene Candide; 4. Sant'Andrea di Travo; 5. Lago Nero; 6. Lago Riane; 7. Libiola; 8. Monte Loreto (base map generated by F. Saccoccio, source: ESRI, USGS and NOAA).

pp.384, 398, fig. 3.1), and at Botteghino (Parma PR; Hd-25298: 5619±25 BP, 4531-4361 cal BC and Hd-25314: 5456±25 BP, 4352-4253 cal BC), where evidence for metallurgy is also claimed (Mazzieri and Dal Santo, 2007).

The growing importance of the pastoral economy in the late fifth millennium (Maggi and Pearce, 2023, fig. 2) is well attested at the Arene Candide cave, where it seems to be associated with the Chassey culture (Nisbet, 1997, pp.115-116; Rowley-Conwy, 1997, p.166; Maggi, 1997, pp.638-639), and in the first half of the fourth millennium, high-altitude pasture begins to be opened up in the Maritime Alps and northern Apennines, contemporaneously with the first copper mining at Monte Loreto (Castiglione Chiavarese GE) and Libiola (Sestri Levante GE) (Fig. 2).

The process is documented in pollen diagrams for wetlands in the northern Apennines, which evidence the clearing of forest by fire to create pasture for grazing (De Pascale, et al., 2006), for example by charcoal found in a pollen core at Lago Nero (Ferriere PC), in a layer dated 3710-3527 cal BC (Grn-14430: 4855±40 BP) and 3520-3125 cal BC (GrN-14431: 4610±40 BP) (Cruise, 1990, p.177, tab.1, fig.2). A pollen core from Lago Riane (Santo Stefano d'Aveto GE) documents a decline in *Abies* woodland and a resulting expansion of *Fagus* around *4150 cal BC*[5], perhaps as a result of increasing anthropic impact, with a local episode of upland clearance, likely for pastoralism, around *3,600-3450 cal BC*, documented by a temporary decline in *Abies* and a peak in *Fagus*, increased deposition of mineral sediments, a peak

5 The dating of the pollen core is based on an age-depth model: for details see Branch, 2013, p.320; Braithwaite, et al., 2014, p.298.

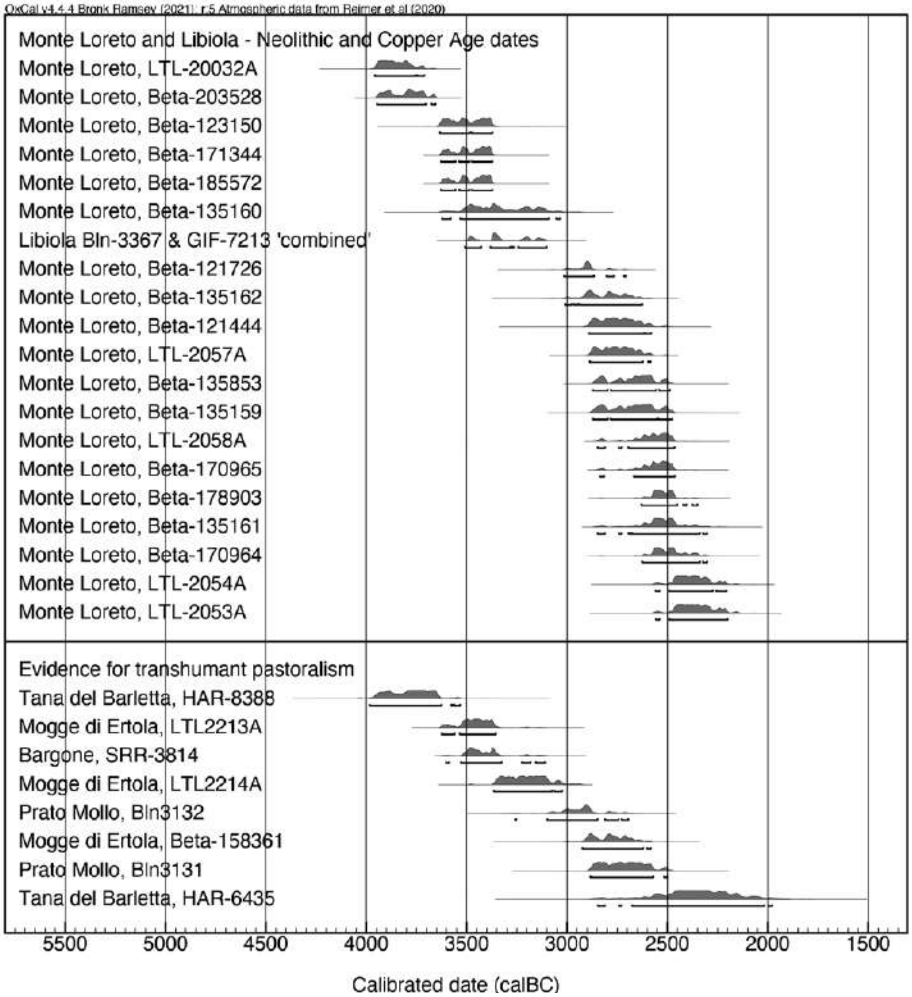

Figure 2: Radiocarbon dates for copper mining and evidence of transhumant pastoralism in fourth-third millennium Cal BC Liguria (Plot generated by M. Pearce using OxCal 4.4 and the IntCal20 curve; dates are calibrated to 95.4%: Bronk Ramsey, 2009; Reimer, et al., 2020).

in *Cyperaceae* and a horizon of microscopic charcoal (Branch, 2013, pp.322-323, 329, fig. 3; Braithwaite, et al., 2014, pp.299, 304). Evidence for the use of upland caves for the stabling of animals seems to document the beginning of small-scale vertical transhumance (Maggi and Nisbet, 1991, pp.266-272). For example, the Tana del Barletta cave (Castelbianco SV) in the Val Pennavaira, located at around 950 m a.s.l. along transhumance routes that lead to upland grazing on Monte Galero, was first used in the first half of the fourth millennium cal BC (HAR-8388: 4980±100 BP, 3990-3530 cal BC from charcoal in a hearth, OxA-V-2772-16: 4957±31 BP, 3795-3645 cal BC from a cattle tooth) to stable animals[6], largely consisting of

6 Very little pottery was found in the cave, suggesting it is unlikely to have functioned as much more than a temporary shelter for humans and their animals (Maggi, 1996, p.317).

sheep/goat (54.2% of identifiable bone) but with some cattle (21.9%)[7], which likely grazed in the lowlands of Albenga in the winter months and spent the summer months on the upland pastures of the Maritime Alps (Barker, et al., 1990; Maggi, 1996, p.317, figs.1 & 2; Morandi, et al., 2021).

The new economic emphasis on pastoralism thus sees the intensive exploitation of new territories, the uplands, for short-range, summer transhumance, and this is contemporary with the exploitation of other mountain resources, copper ore but also chert for stone tools (Maggi, 2002). This opening up of the mountainous interior of Liguria for pastoralism arguably led to the discovery of these mineral resources (Maggi and Pearce, 2010, p.286); certainly it can be argued that more intensive food production based on secondary products of pastoralism is likely to have provided the economic basis for the exploitation of copper and chert (Pearce and Maggi, 2021).

The fourth-third millennium BC: Trentino – Alto Adige / Südtirol.

Copper and Early Bronze Age copper smelting is known both around Trento and in the upper Valsugana in Trentino, and in the Bressanone / Brixen basin in Alto Adige / Südtirol, dating to the third millennium cal BC (Pearce, et al., 2022, fig.1 with site list and bibliography in supplementary data). It is worth noting that as in Liguria, the fourth millennium BC also seems to see the beginning of use of high pasture in parts of the Italian southern Alps (De Marinis and Pedrotti, 1997, p.290): for example Favilli et al. (2010, p.75, tabs. 1, 3) report that the first evidence for human interference recorded by charcoal in the "Cad" soil profile, at 1521 m a.s.l. near Peio (TN) in the Val di Sole, dates to 3500-3030 cal BC (at 95.4%; 3380-3080 cal BC at 87.9%; 4550±55 BP: no lab number given). Further evidence for the use of high altitudes at this time is, of course, provided by the Iceman, found at the Hauslabjoch (Similaun) at about 3213 m a.s.l. and dating to around 3370-3100 cal BC (Höpfel, Platzer and Spindler, eds., 1992), though it is very unlikely that he was involved in pastoral activities or that the pastures of the Schnals valley were being used for transhumant pastoralism at that time (Putzer, Festi and Oeggl, 2016).

The provisioning of the metallurgical workforce

The conduct of later prehistoric metallurgy required a large labour force (miners, porters, ore-dressers, wood-cutters, charcoal-burners, transporters, smelters), not least because large amounts of wood are required for the mining and smelting. Indeed, Zschocke and

7 20.8% of the faunal assemblage in the early fourth millennium consists of pig. It was originally argued, on account of their relative size, that these bones were from wild pig (Barker, et al., 1990, p.117) but it is now clear that domestic pigs in Early and Middle Neolithic northern Italy were relatively large, perhaps as a result of local domestication (Albarella, et al., 2006), which suggests that these pig bones at Tana del Barletta may in fact document domestic pigs (but see Rowley-Conwy, et al., 2020, p.131). It is possible that domestic pigs were involved in the postulated movements between the coastal plain and upland pastures (similar movements have been suggested in the Bronze Age Trentino at Mandrom de Camp [Brentonico TN; Riedel and Tecchiati 2001, p.110] and for an example of pig transhumance in the mountains of medieval Sicily, see Bresc, 1983, p.950) and they may also have been kept free-range and loosely-managed in the woodlands around the site (see Albarella, et al., 2007 for examples of this practice from Corsica and Sardinia). It should also not be forgotten that traditionally domestic pigs have been fed on the by-products of dairying (Collis, 2016, p.4). If domestic pigs were found to be present at Tana del Barletta it might support the suggestion by Morandi et al. (2021), on the basis of $\delta^{18}O$ in cattle and sheep/goat tooth enamel, that the animals spent most of their lives at high altitudes.

Preuschen (1932, pp.66-67) estimated that a workforce of 180 would have been required to operate a Bronze Age mine at Mühlbach-Bischofshofen and Giuseppe Šebesta (1992, p.9) notes that in 1783 the iron mine and smelting activity at Carvagnana (Lezzeno CO) required a workforce of 162. It is therefore likely that a very large labour force was required for the intensive mining and smelting activities in the later Bronze Age Trentino (cf. Marzatico, 1997, pp.575-576). This workforce is unlikely to have been involved in food production, particularly in the high Alps, where mining and metallurgy can only be carried out in the summer months, which are also those suitable for subsistence production, and we must therefore assume that the workforce was specialised and had to be provisioned. Šebesta (1992, p.8) noted that there is frequently a spatial relationship between copper smelting installations and modern day alpine pasture: he argued that forest clearance and the poisoning of vegetation by heavy metals produced areas of open grassland that were then naturally exploited by pastoralists, leading to the opening up of Alpine pasture. In a previous study, written with Armando De Guio, we argued conversely that this spatial relationship between metallurgical production and pastoralism could rather be explained with the hypothesis that dairy products produced on the alpine pastures by transhumant herders provided necessary high protein foodstuffs to the miners and smelters of the Trentino (Pearce and De Guio, 1999). Noting ethnographic evidence from Tibet, where sheep are used to carry loads of up to 10 kg (Orme, 1981, pp.256-257; Roberto Maggi, pers. comm.), we also argued that the animals may have been used as a means of transport; indeed, cattle would likely have been able to carry even heavier and bulkier loads than sheep.

The second millennium BC: Trentino – Alto Adige / Südtirol.

Although it is possible that copper smelting continued from the Early Bronze Age throughout the second millennium BC in the Trentino (Pearce, Bellintani and Nicolis, 2021, pp.193-196; cf. Mottes, et al., 2014), the present consensus in the literature is that there is a hiatus in copper production south of the Alps (Perini, 1989; Marzatico, 1997). There is currently controversy, however, concerning the date of the reprise of copper production. On the basis of the chronology of artefacts made of copper compatible with the southern Alpine lead isotope signature and found in Scandinavia and the Balkans (Melheim, et al., 2018; Ling, et al., 2019; Mehofer, et al., 2021) and a thorough review of radiocarbon dates for smelting, Pearce, Bellintani and Nicolis (2020; 2021) have argued that the second phase, copper production began in the sixteenth, or at the latest in the fifteenth century cal BC (i.e. during the Middle Bronze Age) and ended in the ninth century BC. On the other hand, on the basis of the typology of pottery found at smelting sites, Marzatico (2021) maintains that the smelting should be dated to the Italian Recent (1350-1150 cal BC) and Final Bronze Ages (1150-950 cal BC).

The second millennium sees the establishment of seasonal high-altitude summer farms in the Trentino. The two best-known sites are in the Chiese valley at Storo (TN) and are situated less than 500 m apart: Dosso Rotondo (1876 m a.s.l.; Bassetti, et al., 2008; Mottes and Nicolis, 2004; Nicolis, et al., 2016) and Malga Vacil (1820 m a.s.l.; Marzatico, 2001, p.379, note 61 on p. 411; 2007, pp.169-173, figs.2-10). The sites would have been located below the contemporary tree-line, whereas nowadays they are in open pasture lands used for summer grazing (Nicolis, et al., 2016, p.131). Both sites have been interpreted as seasonal settlements (summer farms) connected with animal husbandry. Malga Vacil seems to date from the Middle Bronze Age and Marzatico (2007, pp.169, 173, fig.7) has argued that a flint sickle blade found there may have been used to cut grass fodder.

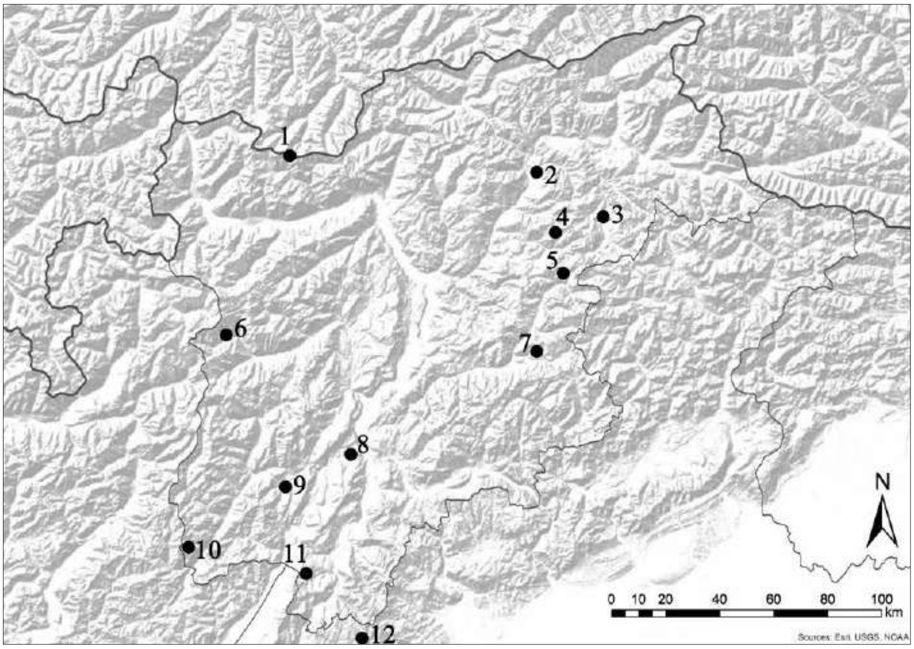

Figure 3: Sites mentioned in Trentino – Alto Adige / Südtirol and the Veneto: 1. Hauslabjoch (Similaun); 2. Albanbühel; 3. Sotćiastel; 4. Lech Sant; 5. Sella pass; 6. Peio; 7. Castelir di Bellamonte; 8. Dos Grum di Cadine; 9. Fiavé; 10. Dosso Rotondo and Malga Vacil; 11. Mandrom de Camp; 12. Covolo di Camposilvano (base map generated by F. Saccoccio, source: ESRI, USGS and NOAA).

More information is available concerning Dosso Rotondo (Nicolis, et al., 2016). A radiocarbon date allows us to suggest that the site was likely established in a forest clearing in the latter part of the Early Bronze Age, around 1865-1545 cal BC (at 95.4%; KIA-12453: 3387±31 BP), perhaps around 1755-1610 cal BC (at 91.6%; 1735-1625 cal BC at 68.3%). Bassetti et al. (2008, p.123) have suggested cheese-making at the site on the basis of the large amount of charcoal and this would seem to be corroborated by the presence of pottery "cheese-strainers" (Nicolis, et al., 2016, p.132, fig.8.18), mostly found close to a "*combustion structure*", though there are no available lipid analyses to confirm this interpretation. Use wear on sickle blades probably relates to cereal harvesting at lower altitudes but may document the local cutting of fodder around the site for livestock (Nicolis, et al., 2016, pp.128-130, 132, figs. 8.15, 8.16).

It has been suggested that other high altitude sites in the Trentino were also used for seasonal pastoralism in the latter half of the second millennium BC, such as Mandrom de Camp (Brentonico TN) at around 1700 m a.s.l. (Mottes, Nicolis and Tecchiati, 1999, p.89; Riedel and Tecchiati, 2001, p.110) and Castelir di Bellamonte (Predazzo TN), at 1548 m a.s.l. (Leonardi and Leonardi, 1991, p.100). Because of the difficulties of overwintering, we may posit that high altitude sites in Alto Adige / Südtirol were also likely seasonally occupied for summer grazing, for example sites located at 2000-2250 m a.s.l. in the area of the Sella pass (Selva di Val Gardena / Wolkenstein in Gröden BZ – Bagolini and Tecchiati, 1993, pp.50-51). A fragment of a bronze sickle, which may have been used to cut fodder locally (but note the discussion of the flint sickle blades at Dosso Rotondo, above) was found at Lech Sant (Santa Cristina Valgardena / Sankt Christina in Gröden BZ; 2096 m a.s.l.; Bagolini and Tecchiati, 1993, p.50). Further south, in the Lessini Mountains of the Veneto, Giovanni Leonardi (2006, p.438) has argued that Middle Bronze Age evidence from the Covolo di Camposilvano (Velo Veronese VR), a cave situated at more than 1200 m a.s.l. and used until recently for maturing cheese because of its cold temperature, may likewise document dairying.

On the basis of a classic kill-off pattern of cattle for milk production (cf. Payne, 1973), Umberto Tecchiati (1998, pp.384-385; Riedel and Tecchiati, 1998a, pp.293-294) has argued for cheese production at the permanently-occupied Middle Bronze Age fortified settlement of Sotćiastel (Badia / Abtei BZ; c. 1400 m a.s.l.). As well as to favour dairying, the culling of calves may also have been undertaken to obtain rennet for cheese-making (though vegetable rennet would have been available) or document slaughter motivated by a shortage of winter fodder (Riedel and Tecchiati, 1998a, p.293). A similar pattern can be seen at the lake village of Fiavé (TN), where sheep/goat make up 51.9% of the identified bone, cattle 28.5% and pig 6.5% (Jarman, 1976, p.543, tab.20). More than 50% of sheep/goat and more than 40% of cattle were slaughtered at the site in their first two years of life, suggesting a milk-based economy, and almost all the cattle were killed before they reached 5 years old, likely the age at which they were no longer productive milkers (Jarman, 1976, pp.543-544, tabs.10 & 11; Gamble and Clark, 1987, p.427).

Although upland alpine grazing is dominated by cattle in modern times, this is a relatively recent phenomenon (Anesi, et al., 2015, pp.130-131) and sheep/goat dominate the Bronze Age faunal assemblages of the Trentino and the Alto Adige / Südtirol (Riedel and Tecchiati, 2001, p.107). At Sotćiastel sheep/goat amount to 45.8% MNI (= minimum number of individuals), with cattle 40.3% and pigs 5.5% (Riedel and Tecchiati, 1998a, p.288, tab.1) and we have seen that sheep/goat are even more dominant at Fiavé (51.9% of identified bone). At Albanbühel (Bressanone / Brixen BZ) sheep/goat are even more prevalent, at 60.71% MNI, while cattle are 24.55% and pig 7.14% (Riedel and Tecchiati, 1998b, p.325). The relatively low altitude site of Dos Grum di Cadine (Trento TN), at 647 m a.s.l., is a rare exception, and in its faunal assemblage cattle are 56% of identified bone, sheep/goat 30% and pigs 13% (Riedel and Tecchiati, 2001, pp.108, 112).

A key element in upland grazing and cheese production is salt (Pearce, 2016, p.52). Rock salt licks are used to control stock (the animals will return regularly to the salt) and salt is used in cheese-making both as a preservative and a flavour-enhancer (Pearce, 2016, p.52), but also in the preparation of rennet extract (O'Connor, 1993, p.6). Salt will also have been used to preserve meat, and both this and cheese will have been key elements in the provisioning of the mining and smelting sites, located in the mountains at a distance from the permanent farms in the valleys. It is perhaps not a coincidence that rock salt was mined at Hallstatt in the Upper Austrian Salzkammergut from the 15th century BC onwards (Reschreiter and Kowarik, 2009), the beginning of salt mining coinciding with a more intensive exploitation of the uplands for dairy products.

The likelihood that upland sites like Dosso Rotondo were occupied seasonally and used for cheese production suggests the practice of a form of vertical Alpine pastoralism (Italian: *alpeggio*, German: *Alpwirtschaft*) in the Bronze Age, though the extent to which this corresponded to the traditional model of the Alpine *malga* (German: *Alm*) is controversial, with Nicolis et al. (2016) and Pearce (2016) arguing for summer-pasture based cheese production in a form similar to the modern day *economia di malga* (German: *Almwirtschaft*) and Marzatico (2007, pp.171-176) suggesting that such a model is anachronistic.

Whatever the exact socio-economic form of this upland production, it is clear that the new Bronze Age summer farms allowed an expansion of the land exploited in the southern

Alps, and therefore permitted an increase in production. This is of fundamental importance to the explosion of copper production in the Trentino – Alto Adige / Südtirol region in the second half of the second millennium, as it provided the economic basis to free up the workforce for copper mining and smelting as well as the ancillary tasks (wood-cutting, charcoal burning, haulage etc.)

Conclusion: linked resources

It is thus clear that we cannot understand metallurgical production or pastoralism in isolation, but the same is true for chert mining and salt mining – they are linked strategies because the resources that they provide are complementary: pastoral production provided the economic basis for prehistoric metallurgy. This of course also means that while the detail of the models proposed by Gordon Childe (1958, p.144) and Sherratt (1981; 1983) may be incorrect, they were right to see a connection between pastoralism and dairying on the one side and metallurgy on the other. While this link may not be of universal application, the evidence from fourth-third millennium BC Liguria and fourth-second millennium BC Trentino – Alto Adige / Südtirol is best interpreted as attesting the complementarity of pastoralism with copper mining and smelting, with pastoralism likely providing the economic basis and landscape knowledge essential for the practice of metallurgy in the two regions.

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References

Albarella, U., Tagliacozzo, A., Dobney, K. and Rowley-Conwy, P., 2006. Pig hunting and husbandry in prehistoric Italy: a contribution to the domestication debate. *Proceedings of the Prehistoric Society* 72, pp.193-227.

Albarella, U., Manconi, F., Vigne, J.-D. and Rowley-Conwy, P., 2007. Ethnoarchaeology of pig husbandry in Sardinia and Corsica. In: U. Albarella, K. Dobney, A. Ervynck and P. Rowley-Conwy, eds., *Pigs and Humans: 10,000 Years of Interaction.* Oxford: Oxford University Press, pp.285-307.

Anesi, G., Angelucci, D.E., Carrer, F. and Rapanà, M., 2015. La nascita di un paesaggio pastorale: il tardo Medioevo e la prima età moderna. In: D.E. Angelucci and F. Carrer, eds., *Paesaggi pastorali d'alta quota in Val di Sole (Trento): le ricerche del progetto ALPES – 2010-2014.* Trento: Università degli Studi di Trento, Dipartimento di Lettere e Filosofia, pp.128-132.

Bagolini, B. and Tecchiati, U., 1993. Osservazioni sul popolamento delle valli ladine tra Neolitico ed età del Bronzo nel quadro della preistoria del bacino atestino. In: *Archeologia nelle Dolomiti. Ricerche e ritrovamenti nelle valli del Sella dall'età della Pietra alla Romanità. Catalogo della mostra.* Vigo di Fassa: Istitut Cultural Ladin 'Majon di Fashegn' / San Martin de Tor: Istitut Cultural Ladin 'Micurà de Rü', pp.47-55.

Barker, G., Biagi, P., Clark, G., Maggi, R. and Nisbet, R., 1990. From hunting to herding in the Val Pennavaira (Liguria – northern Italy). In: P. Biagi, ed., *The Neolithisation of the Alpine Region.* Monografie di “Natura Bresciana” 13. Brescia: Museo Civico di Scienze Naturali di Brescia, pp.99-121.
Bassetti, M., Dalmeri, G., Mottes, E. and Nicolis, F., 2008. La frequentazione delle alte quote nell’età del Bronzo. Il sito di Storo – Dosso Rotondo. In: E. Mottes, F. Nicolis and G. Zontini, eds., *Archeologia lungo il Chiese. Nuove indagini e prospettive della ricerca preistorica e protostorica in un territorio condiviso fra Trentino e Lombardia. Atti del 1° convegno interregionale, Storo, 24-25 ottobre 2003.* Judicaria Summa Laganensis 18. Tione: Centro Studi Judicaria, pp.107-127.
Bernabò Brea, M., Castagna, D., Cremona, M.G., Ferrari, E., Maffi, M., Mazzieri, P. and Occhi, S., 2002. Strutture e aspetti culturali dei siti Chassey – Lagozza nel Piacentino. In: A. Ferrari and P. Visentini, eds., *Il declino del mondo neolitico. Ricerche in Italia centro-settentrionale fra aspetti peninsulari, occidentali e nord-alpini.* Atti del Convegno (Pordenone, 5-7 aprile 2001). *Quaderni del Museo Archeologico del Friuli Occidentale* 4. Pordenone: Bianchettin, pp.379-402.
Braithwaite, R., Black, S., Branch, N.P. and Maggi, R., 2014. Evaluating the environmental impact of metallurgical activities during the Copper Age and Bronze Age (~5800-2900 cal yrs BP) in the Ligurian Apennines, north-west Italy: a pilot study. *Archeologia Postmedievale* 17(2013), pp.297-308.
Branch, N.P., 2013. Early – Middle Holocene vegetation history, climate change and human activities at Lago Riane (Ligurian Apennines, NW Italy). *Vegetation History and Archaeobotany* 22(4), pp.315-334.
Bresc, H., 1983. “Disfari et perdiri li fructi et li aglandi”: economie e risorse boschive nella Sicilia medievale (XIII – XV secolo). *Quaderni storici* 18, 54(3), pp.941-969.
Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1), pp.337-360.
Childe, V.G., 1958. *The Prehistory of European Society.* Harmondsworth: Penguin.
Cruise, G.M., 1990. Holocene peat initiation in the Ligurian Apennines, northern Italy. *Review of Palaeobotany and Palynology* 63, pp.173-182.
Collis, J., 2016. Summer farms: an introduction. In: J. Collis, M. Pearce and F. Nicolis, eds., *Summer Farms: Seasonal Exploitation of the Uplands from Prehistory to the Present.* Sheffield Archaeological Monographs 16. Sheffield: J.R. Collis Publications, pp.1-20.
De Marinis, R.C. and Pedrotti, A.L., 1997. L’età del rame nel versante italiano delle Alpi centro-occidentali. In: *Atti della XXXI Riunione Scientifica. La Valle d’Aosta nel quadro della preistoria e protostoria dell’arco alpino centro-occidentale.* Courmayeur, 2-5 giugno 1994. Florence: Istituto Italiano di Preistoria e Protostoria, pp.247-299.
De Pascale, A., Maggi, R., Montanari, C. and Moreno, D., 2006. Pollen, herds, jasper and copper mines: economic and environmental changes during the 4th and 3rd millennia BC in Liguria (NW Italy). *Environmental Archaeology* 11(1), pp.115-124.
Favilli, F., Cherubini, P., Collenberg, M., Egli, M., Sartori, G., Schoch, W. and Haeberli, W., 2010. Charcoal fragments of Alpine soils as an indicator of landscape evolution during the Holocene in Val di Sole (Trentino, Italy). *The Holocene* 20(1), pp.67-79.
Gamble, C. and Clark, R., 1987. The faunal remains from Fiavé: pastoralism, nutrition and butchery. In: R. Perini, *Scavi archeologici nella zona palafitticola di Fiavé-Carera. Parte II: Campagne 1969-76: Resti della cultura materiale: metallo – osso – litica – legno.*

Patrimonio storico e artistico del Trentino 9. Trento: Provincia Autonoma di Trento, Servizio Beni Culturali, pp.423-445.

Höpfel, F., Platzer, W. and Spindler, K., eds., 1992. *Der Mann im Eis*, Bd. 1: Bericht über das Internationale Symposium 1992 in Innsbruck. Veröffentlichungen der Universität Innsbruck 187. Innsbruck: Universität Innsbruck.

Jarman, M., 1976. Prehistoric economic development in sub-Alpine Italy. In: G. de G. Sieveking, I.H. Longworth and K.E. Wilson, eds., *Problems in Economic and Social Archaeology.* London: Duckworth, pp.523-548.

Leonardi, G., 2006. L'insediamento nell'ambito collinare e montano veneto nell'età del Bronzo: il territorio veronese e vicentino. In: *Studi di protostoria in onore di Renato Peroni.* Borgo San Lorenzo (FI): All'Insegna del Giglio, pp.435-444.

Leonardi, P. and Leonardi, G., 1991. Il "Castelir" di Bellamonte in Val Travignolo. In: P. Leonardi, ed., *La Val di Fiemme nel Trentino dalla Preistoria all'Alto Medioevo.* Calliano: Manfrini, pp.68-100.

Ling, J., Hjärthner-Holdar, E., Grandin, L., Stos-Gale, Z., Kristiansen, K., Melheim, A. L., Artioli, G., Angelini, I., Krause, R. and Canovaro C., 2019. Moving metals IV: swords, metal sources and trade networks in Bronze Age Europe. *Journal of Archaeological Science: Reports* 26, e101837. Available at: DOI: 10.1016/j.jasrep.2019.05.002 [Accessed 19 November 2024].

Maggi, R., 1996. Le grotte e la loro funzione. L'Italia settentrionale. In: D. Cocchi Genick, ed., *L'antica età del bronzo: Atti del Congresso di Viareggio, 9-12 gennaio 1995.* Florence: Octavo, pp.313-322.

Maggi, R., 1997. Summary: a modern excavation carried out fifty years ago. In: R. Maggi, ed., *Arene Candide: a functional and environmental assessment of the Holocene sequence (Excavations Bernabò Brea – Cardini 1940-50). Memorie dell'Istituto Italiano di Paleontologia Umana*, n.s. 5. Rome, pp.635-642.

Maggi, R., 2002. Pastori, miniere, metallurgia nella transizione fra Neolitico ed età del Rame: nuovi dati dalla Liguria. In: A. Ferrari and P. Visentini, eds., *Il declino del mondo neolitico… Quaderni del Museo Archeologico del Friuli Occidentale* 4. Pordenone: Bianchettin, pp.437-440.

Maggi, R. and Nisbet, R., 1991. Prehistoric pastoralism in Liguria. In: R. Maggi, R. Nisbet and G. Barker, eds., *Archeologia della pastorizia nell'Europa meridionale. Atti della tavola rotonda internazionale. Rivista di Studi Liguri* 56(1990), pp.265-296.

Maggi, R. and Pearce, M., 2010. Changing subsistence structures and the origins of mining in the Ligurian Apennine mountains. In: P. Anreiter et al., eds., *Mining in European History and Its Impact on Environment and Human Societies.* Innsbruck: Innsbruck University Press, pp.283-287.

Maggi, R. and Pearce, M., 2023. L'età del Rame in Liguria: relazione introduttiva. In: *Preistoria e Protostoria della Liguria. Rivista di Scienze Preistoriche*, 73(S3), pp. 89-109.

Marzatico, F., 1997. L'industria metallurgica nel Trentino durante l'età del Bronzo. In: M. Bernabò Brea, A. Cardarelli and M. Cremaschi, eds., *Le Terramare. La più antica civiltà padana.* Milan: Electa, pp.570-576.

Marzatico, F., 2001. L'età del Bronzo recente e finale. In: M. Lanzinger, F. Marzatico and A. Pedrotti, eds., *Storia del Trentino I: La preistoria e la protostoria.* Bologna: Il Mulino, pp.367-416.

Marzatico, F., 2007. La frequentazione dell'ambiente montano nel territorio atesino fra l'età del Bronzo e del Ferro: considerazioni sulla pastorizia transumante e "l'economia di malga". *Preistoria Alpina* 42, pp.163-182.

Marzatico, F., 2021. Produzione metallurgica primaria e circolazione del rame nelle Alpi sud-orientali fra dati acquisiti e problemi aperti. In: P. Bellintani and E. Silvestri, eds., *Fare Rame: La metallurgia primaria della tarda età del Bronzo in Trentino.* Trento: Provincia Autonoma di Trento, Soprintendenza per i beni culturali, Ufficio beni archeologici, pp.199-221.

Mazzieri, P. and Dal Santo, N., 2007. Il sito del Neolitico recente di Botteghino (Parma). *Rivista di Scienze Preistoriche* 57, pp.113-138.

Mehofer, M., Gavranović, M., Kapuran, A., Mitrović, J. and Putica, A., 2021. Copper production and supra-regional exchange networks – Cu-matte smelting in the Balkans between 2000 and 1500 BC. *Journal of Archaeological Science* 129, e105378. Available at: DOI: 10.1016/j.jas.2021.105378 [Accessed 19 November 2024].

Melheim, L., Grandin, L., Persson, P.-O., Billström, K., Stos-Gale, Z., Ling, J., Williams, A., Angelini, I., Canovaro, C., Hjärthner-Holdar, E. and Kristiansen, K., 2018. Moving metals III: possible origins for copper in Bronze Age Denmark based on lead isotopes and geochemistry. *Journal of Archaeological Science* 96, pp.85-105.

Morandi, L.F., Frémondeau, D., Müldner, G. and Maggi, R., 2021. Sequential analyses of bovid tooth enamel and dentine collagen ($\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$): new insights into animal husbandry between the Late Neolithic and the Early Bronze Age at Tana del Barletta (Ligurian Prealps). *Archaeological and Anthropological Sciences* 13, e147. Available at: DOI: 10.1007/s12520-021-01418-w [Accessed 19 November 2024].

Mottes, E. and Nicolis, F., 2004. Storo – Dosso Rotondo (Trento): un sito di alta quota dell'Età del Bronzo in Valle del Chiese. *Annali del Museo* (Gavardo) 19(2001-2002), pp.80-88.

Mottes, E., Nicolis, F. and Tecchiati, U., 1999. Aspetti dell'insediamento e dell'uso del territorio nel III e nel II millennio a.C. in Trentino – Alto Adige. In: P. Della Casa, ed., *Prehistoric Alpine Environment, Society and Economy. Papers of the International Colloquium PAESE 1997 in Zurich.* Universitätsforschungen zur prähistorischen Archäologie 55. Bonn: Rudolf Habelt, pp.81-97.

Mottes, E., Bassetti, M., Silvestri, E. and Stefan, L., 2014. Il sito archeometallurgico dell'età del Rame di Riparo Marchi in Valle dell'Adige (Trento). *AdA: Archeologia delle Alpi* 2014, pp.38-43.

Needham, S., 2012. Case and place for the British Chalcolithic. In: M.J. Allen, J. Gardiner and A. Sheridan, eds., *Is There a British Chalcolithic? People, Place and Polity in the Later 3rd Millennium.* Prehistoric Society Research Paper 4. Oxford: Prehistoric Society & Oxbow Books, pp.1-26.

Nicolis, F., Mottes, E., Bassetti, M., Castiglioni, E., Rottoli, M. and Ziggiotti, S., 2016. Going up the mountain! Exploitation of the Trentino highlands as summer farms during the Bronze Age: the Dosso Rotondo site at Storo (northern Italy). In: J. Collis, M. Pearce and F. Nicolis, eds., *Summer Farms…* Sheffield Archaeological Monographs 16. Sheffield: J.R. Collis Publications, pp.109-138.

Nisbet, R., 1997. The phytoliths from the Neolithic levels of Arene Candide. In: R. Maggi, ed., *Arene Candide… Memorie dell'Istituto Italiano di Paleontologia Umana*, n.s. 5. Rome, pp.113-118.

O'Brien, W., 2004. *Ross Island: Mining, Metal and Society in Early Ireland.* Bronze Age Studies 6. Galway: Department of Archaeology, National University of Ireland, Galway.

O'Connor, C.B., 1993. *Traditional Cheesemaking Manual.* Addis Ababa: International Livestock Centre for Africa.

Orme, B., 1981. *Anthropology for Archaeologists: An Introduction.* London: Duckworth.

Payne, S., 1973. Kill-off patterns in sheep and goats: the mandibles from Aşvan Kale. *Anatolian Studies* 23, pp.281-303.

Pearce, M., 2007. *Bright Blades and Red Metal: Essays on North Italian Prehistoric Metalwork.* Specialist Studies on Italy 14. London: Accordia Research Institute.

Pearce, M., 2016. Hard cheese: upland pastoralism in the Italian Bronze and Iron Ages. In: J. Collis, M. Pearce and F. Nicolis, eds., *Summer Farms…* Sheffield Archaeological Monographs 16. Sheffield: J.R. Collis Publications, pp.47-56.

Pearce, M. and De Guio, A., 1999. Between the mountains and the plain: an integrated metals production and circulation system in later Bronze Age north-eastern Italy. In: P. Della Casa, ed., *Prehistoric Alpine Environment, Society and Economy…* Universitätsforschungen zur prähistorischen Archäologie 55. Bonn: Rudolf Habelt, pp.289-293.

Pearce, M. and Maggi, R., 2021. Perceiving mining landscapes: metallurgical origins and the perception of resources in the landscape. In: M. Kunst and D. Steiniger eds., *Settlement Structures and Metallurgy. The Relations between Italy and the Iberian Peninsula in the Early Chalcolithic.* Palilia 33. Wiesbaden: Harrassowitz, pp.77-86.

Pearce, M., Bellintani, P. and Nicolis, F., 2020. Frattesina and the later Bronze Age – early Iron Age metals trade: the absolute chronology of smelting sites in the Trentino-Alto Adige/Südtirol. *Padusa* 55(2019), pp.67-86.

Pearce, M., Bellintani, P. and Nicolis, F., 2021. L'inizio della seconda fase della coltivazione del rame nel Trentino – Alto Adige/Südtirol. In: P. Bellintani and E. Silvestri, eds., *Fare Rame…* Trento: Provincia Autonoma di Trento, Soprintendenza per i beni culturali, Ufficio beni archeologici, pp.187-198.

Pearce, M., Merkel, S., Hauptmann, A. and Nicolis, F., 2022. The smelting of copper in the third millennium cal BC Trentino, north-eastern Italy. *Archaeological and Anthropological Sciences.* 14: 10.

Perini, R., 1989. Testimonianze di attività metallurgica dall'Eneolitico alle fasi finali dell'Età del Bronzo nel Trentino. In: *Per Giuseppe Šebesta: scritti e nota bio-bibliografica per il settantesimo compleanno.* Trento: Biblioteca Comunale di Trento, Comune di Trento, pp.377-404. Reprint 2004 in: R. Perini, *Scritti di archeologia*, II parte. Trento: Provincia Autonoma di Trento, Soprintendenza per i beni archeologici, pp.1115-1120.

Putzer, A., Festi, D. and Oeggl, K., 2016. Was the Iceman really a herdsman? The development of a prehistoric pastoral economy in the Schnals Valley. *Antiquity* 90(350), pp.319-336.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A. and Talamo, S., 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0-55 cal kBP). *Radiocarbon* 62(4), pp.725-757.

Reschreiter, H. and Kowarik, K., 2009. The start of salt mining. In: A. Kern, K. Kowarik, A.W. Rausch and H. Reschreiter, eds., *Kingdom of Salt: 7000 Years of Hallstatt.* Veröffentlichungen der Prähistorischen Abteilung 3. Vienna: Natural History Museum, pp.50-51.

Riedel, A. and Tecchiati, U., 1998a. I resti faunistici dell'abitato della media e recente età del Bronzo di Sotćiastel in Val Badia. In: U. Tecchiati, ed., *Sotćiastel: un abitato fortificato dell'età del Bronzo in Val Badia.* Bolzano: Istitut Cultural Ladin 'Micurà de Rü' / Soprintendenza Provinciale ai Beni Culturali di Bolzano, pp.285-319.

Riedel, A. and Tecchiati, U., 1998b. Gli insediamenti gemelli di Albanbühel (Bressanone) e Sotćiastel. Una comparazione delle faune. In: U. Tecchiati, ed., *Sotćiastel...* Bolzano: Istitut Cultural Ladin 'Micurà de Rü' / Soprintendenza Provinciale ai Beni Culturali di Bolzano, pp.323-331.

Riedel, A. and Tecchiati, U., 2001. Settlements and economy in the Bronze and Iron Age in Trentino – South Tyrol: notes for an archaeozoological model. *Preistoria Alpina* 35(1999), pp.105-113.

Rowley-Conwy, P., 1997. The animal bones from Arene Candide: final report. In: R. Maggi, ed., *Arene Candide... Memorie dell'Istituto Italiano di Paleontologia Umana*, n.s. 5. Rome, pp.153-277.

Rowley-Conwy, P., Panelli, C., Rossi, S., Nisbet, R. and Maggi, R., 2020. First farmers in Liguria, north-western Italy: new evidence from Arene Candide and nearby sites. In: K.J. Gron, L. Sørensen and P. Rowley-Conwy, eds., *Farmers at the Frontier: A Pan-European Perspective on Neolithisation.* Oxford: Oxbow, pp.125-143.

Salque, M., Bogucki, P.I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M. and Evershed, R.P., 2013. Earliest evidence for cheese making in the sixth millennium BC in northern Europe. *Nature* 493(7433), pp.522-525.

Šebesta, G., 1992. *La via del rame.* Supplement of *Economia Trentina* 3 (1992), Trento. Reprint 2000. San Michele all'Adige: Museo degli Usi e Costumi della Gente Trentina.

Sheridan, A., 2012. A Rumsfeld reality check: what we know, what we don't know and what we don't know we don't know about the Chalcolithic in Britain and Ireland. In: M.J. Allen, J. Gardiner and A. Sheridan, eds., *Is There a British Chalcolithic?* Prehistoric Society Research Paper 4. Oxford: Prehistoric Society & Oxbow Books, pp.40-55.

Sherratt, A., 1981. Plough and pastoralism: aspects of the secondary products revolution. In: I. Hodder, G. Isaac and N. Hammond, eds., *Pattern of the Past: Studies in Honour of David Clarke.* Cambridge: Cambridge University Press, pp.261-305.

Sherratt, A., 1983. The secondary exploitation of animals in the Old World. *World Archaeology* 15(1), pp.90-104.

Tecchiati, U., 1998. Osservazioni conclusive: problemi e prospettive della ricerca. In: U. Tecchiati, ed., *Sotćiastel...* Bolzano: Istitut Cultural Ladin 'Micurà de Rü' / Soprintendenza Provinciale ai Beni Culturali di Bolzano, pp.379-386.

Venturino Gambari, M., 2002. Il Neolitico recente in Piemonte. In: A. Ferrari and P. Visentini, eds., *Il declino del mondo neolitico… Quaderni del Museo Archeologico del Friuli Occidentale* 4. Pordenone: Bianchettin, pp.409-420.

Viviani, M., 1993. *Bagòs: una storia della montagna lombarda. Cultura alpina tra passato e futuro.* Brescia: Grafo.

Zschocke, K. and Preuschen, E., 1932. *Das urzeitliche Bergbaugebiet von Mühlbach-Bischofshofen. Materialien zur Urgeschichte Österreichs* 6. Wien: Anthropologische Gesellschaft in Wien.

Local Knowledge and Sacralisation of Resources in the Iron Age Apennines (Italy). From Resource Landscapes to ResourceCultures

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The resource landscape of the Apennine mountains can be analysed as a network of tangible and intangible resources, and of the sociocultural dynamics connected to the social evaluation and use of these resources. The paper focuses on two components of this network: knowledge of resources and their sacralisation. The comparison of these components in two different regions of the Apennines (Etruria and Hirpinia during the Iron Age) shows how not only the resources, but also their interactions define the complexity and the fluidity of this dynamic network, changing over time. The proposed heuristic model, based on ResourceCultures, enables us to gain new insights into the relationship between resources and ancient life-worlds, encompassing the dynamics of interaction between material and immaterial resources, their social evaluation, and their contingencies and permanencies.

Knowledge Transmission, Sacred Landscape, Mobile Pastoralism, Networks, Infrastructures, Etruscans, Samnites

The Apennines in the Iron Age as a contact zone

The Apennines, a 1200 km long mountain chain that crosses the Italian Peninsula longitudinally from north to south, has traditionally been considered a natural boundary, dividing Central Italy from Northern Italy, and the Tyrrhenian from the Adriatic regions (Fig. 1).

This perceived geographical division was already present in ancient sources and ancient cartography from Roman times on. The ancient sources concerning the legendary Etruscan archaic colonisation (Harari, 2010, p.52), as well as those on the later Hannibal

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 77-108.

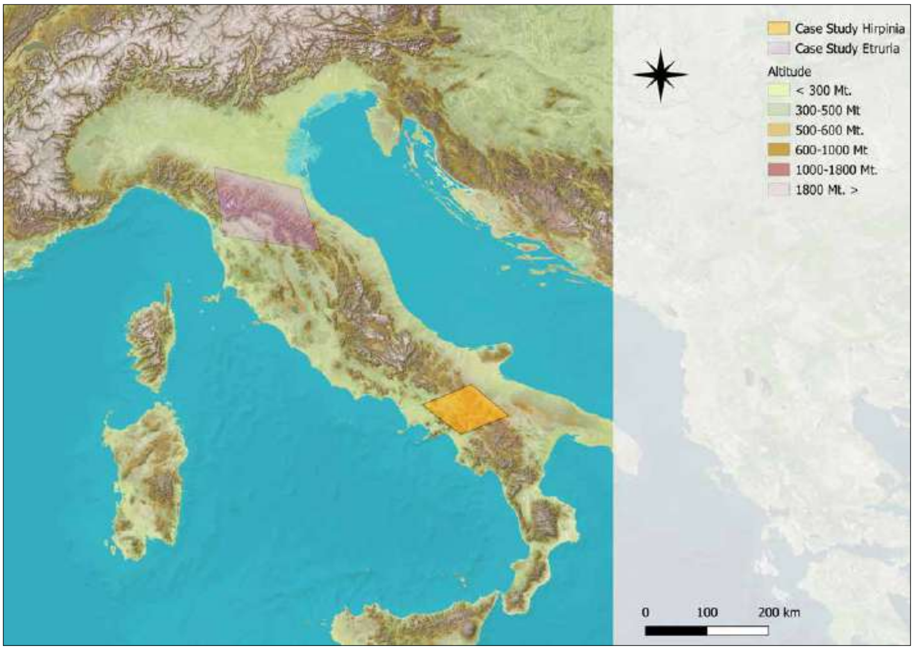

Figure 1: The Apennines with the position of the case studies (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1, with layout layer Bing Virtual Earth).

expedition repeatedly describe the Apennines as a barrier, comparing them to the Alps (for a review of this sources: Diana, 1987). The *tabula Peutingeriana*, a medieval copy of a late antique *itinerarium pictum*, depicts the Apennines as a continuous line cutting Italy in two parts (Bosio and Rosada, 2020, pp.119-121). This idea is also present in early Imperial Latin literary sources, such as Livius (Liv. 26, 15, 6: *Appennini dorso Italia dividitur*: Italy is divided by the ridge of the Apennines). It is not only such ancient opinions, but also more recent historical events, in particular the establishment of the Gothic line along the summits of the northern Apennines during the Second World War (Baldissara, 2018), that have affected the perspectives of researchers in archaeology and ancient history right up to recent years, leaving them inclined to view the Apennines as a boundary or barrier between ancient communities (see Zamboni, 2018, pp.17-34).

Although this idea shaped the literary sources and the historical interpretation, material culture studies now prove that throughout the centuries, the Apennines were in fact a place of exchanges and encounters between people and communities living on both sides of the ranges. Starting from this material basis, current studies have therefore begun to consider the Apennine mountains as a key site of ancient connectivity (Stoddart, 2016, p.44), as well as a broader contact zone and place of encounters (Heitz, 2022, pp.216-220; Gleba, et al., 2018; Zamboni, 2018; 2012). Within the archaeological remains, the pottery distribution and evidence of religious practices are particularly rich in information concerning cultural contacts across the Apennines. Not only importations, but also local copies and hybridized versions of the original models indicate the exchange of ideas, stylistic patterns, taste, and techniques (Zamboni, 2018, pp.238-239). Votive materials, such as miniature pottery and bronze and clay figurines, as well as the typology of cult practices and the deities

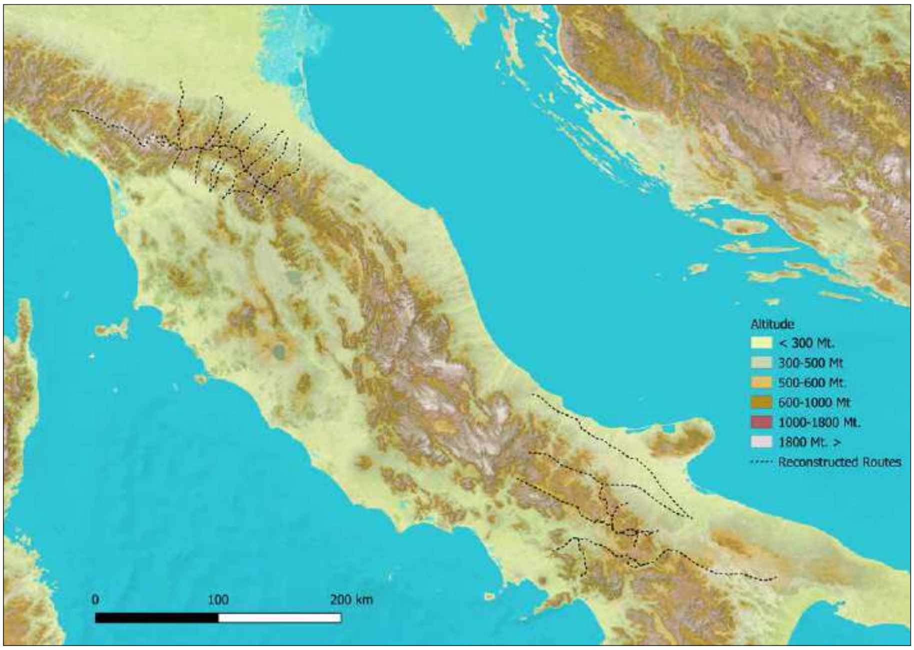

Figure 2: Route network and Infrastructures for both case studies (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1).

worshipped, also provide us with strong proxies for studying these repeated and long-lasting contacts (Da Vela, 2023). The presence of central cult places located directly in the mountains, and the distribution of votive objects along the route-networks connecting them with the plains and foothills, are of particular relevance here. The cult places of the Iron Age are located exclusively at sites containing valuable natural reserves, especially water and stone, and along the routes traditionally used by mobile pastoralists. The shared raw materials and infrastructures acted as triggers for human mobility, the exchange of knowledge, and the diffusion of common religious practices and cultural references.

These mountains can thus be considered a unique resource landscape in which material resources, as well as immaterial resources like traditional ecological knowledge, and even sociocultural dynamics such as religious practices, have been shared and negotiated over a long period of time. In particular, some features of the route network in the northern Apennines confirm the function and perception of the mountains as a contact zone, rather than as a boundary. Beside the frequent and numerous trails and passes, following the narrow valleys formed around creeks and streams, there was another form of connectivity, referred to today as the *alta via*. This was the passage along the ridges of the Apennines. The distribution of settlements and archaeological materials from the Bronze Age onwards shows how both route networks (Cardarelli, 2006, pp.52-66), the one comprising the mountain passes across the Apennines, and the longitudinal one offering passage along the ridge trails, were complementary parts of the same infrastructural system. The route infrastructure of the Apennines therefore integrated a vertical network, conducting movement from the plains to the mountain tops, and a horizontal one, conducting movement along the ridge. This would have allowed for transversal connections between the inhabitants of the upper reaches, the foothills, and the plains of different neighbouring regions (Fig. 2). When considering the Apennines as a resource landscape, it is thus essential to take into account the strong integration of the mountain ecological systems with those of the mid-lying regions (the sub-Apennines), hills, foothills, and plains, as well as with the rivers and creeks springing from the Apennines and flowing into the plains. These supplied water seasonally to the main streams, which flowed into the Mediterranean Sea on both sides of the Italian peninsula, towards the Tyrrhenian Sea to the west and the Adriatic Sea to the east. This integration suggests that it is both possible and valuable for us to consider the Apennines as a 'vertical' resource landscape running from the mountain ridges to the plains and including areas that supersede both the geographic location and the conception of a 'mountain chain' (for the conceptualization of vertical resource landscapes: Mader, 2020, pp.142-143).

The Apennines: from Resource Landscape to ResourceComplex

The natural reserves of the Apennines are similar to most continental mountainous landscapes rising between 800 to 2500 meters in altitude within a temperate zone. During the Iron Age, these resources were mostly represented by waters, minerals such as copper, pyrite and sulphur, different sedimentary and metamorphic stones, and the vegetal and animal resources present in the rangeland, grassland and forest ecosystems: herbage, deciduous (especially beech, birch and oak) and coniferous trees, fungi and musk-producing plants, wild animals (e.g. deer, wild boars, bears, wolves, birds, and fish), and domesticated animals (e.g. cattle, ovicaprines, donkeys, and bees). The exploitation of these resources is archaeologically attested along the whole extension of the mountain chain by both direct and indirect evidence. For the Iron Age, this evidence is mostly constituted by material remains, as well as rare epigraphic attestations and iconographic sources, contextual associations, and the results of archaeometric analysis. Amongst the material remains, good proxies for the exploitation of resources are pollen, kernels, and corns (Marchesini and Marvelli, 2002; Marchesini, et al., 2008), the animal bones found in domestic and cult contexts (Farello, 2002; 2008), and wooden and stone artefacts (Franciosi, 2017). Material remains frequently also provide us with indirect information about the transformation of local resources via production processes, for example textile tools for spinning and weaving, which are well distributed along the whole of the Apennines (Gleba, 2008). The employment of raw materials, such as stone, wood, and clay in building processes (Miller, 2017, pp.184-196) and in firing processes, (Peinetti, et al., 2019), permit us to evaluate the impact of the Apennines' resources from upon the economy and life-worlds of the mountain, foothills and plains communities.

The location of cult places was clearly strongly oriented around the presence of natural reserves and refuges, such as caves, sulphureous fumaroles, springs, lakes, rivers, and the transhumance droveways (Bassani, 2019; Battiloro, 2017, p.228; Scopacasa, 2015, pp.193-194; Colucci Pescatori, 2017, p.143; Loffredo, 2012). This indicates that the evaluation of these resources was not only motivated by pragmatic goals, but also embodied in the imagery of local communities. Furthermore, the choice of local raw materials, such as wood and stone for the realisation of cult and funerary statues (see the *xoana* of Mephitis in the Ampsanctus Valley: Franciosi, 2017; Battiloro, 2017, pp.61-62; the warrior of Capestrano: d'Ercole and Cella, 2007; the marble funerary statues – *suthina* – in Northern Etruria: Bonamici, 1991),

Tangible resources		**Intangible resources**	**Resource related socioculturals dynamics**
Waters	Routes	Knowledge	Consumption habitus
Minerals	Visibility	Skills	Social representation strategies
Stones		Transfer	
Grassland		Networks	Social networking
Wood		Imagery	
			Collective cultural memory
Wild animals		Tales	
Domesticated animals		Writing	Community of practices in pottery and textile productions

Table. 1 Tangible and intangible resources of the Iron Age Apennines and resource related sociocultural dynamics.

and the use of specific kind of stone for other monuments destined to become permanently fixed in the social memory, as in the case of funerary *Cippi* and stelae, not only in Etruria (Amann, 2010), but also elsewhere in Italy (Menozzi, 2020, pp.8-9), show how the materiality of different resources was transformed by social processes in terms of its cultural and symbolic value.

Iron Age iconographic sources found in the Apennines are not particularly rich. However, some of them, for example the representations of local animal resources in cult contexts (Arbeid, 2010, pp.29-38. 84-91; Bonifacio, 2001), indicate the social evaluation of hunting and breeding, as well as the modality of interaction between humans and animals. Moreover, the recent increase of archaeometric analysis (palynological and pedological analysis on the settlements: Cardarelli and Malnati, 2009; Ricciardi and Calò, 2007; petrographic analysis: Pallecchi 2011, pp.12-14; Guidi 2010, pp.62-66; Nannetti, et al., 2010; isotopic analysis on animal bones and wool: Trentacoste, et al., 2020; Pasquinucci, 2004, p.169) permits researchers to individuate new relationships between the natural reserves and relevant sociocultural dynamics. Two clear examples of the benefits this presents can be found in the geological analysis in Bracciano di Montese (Badiali, 2013, pp.324-325) and Albagino (Perkins, Nocentini and Warden, 2020, p.414), which facilitated our understanding of the connection between finds of Iron Age bronze votive statues and the existence of ancient lakes that have since disappeared.

Despite this abundance and variety of archaeological data, overall studies on the resources of the Apennines in the Iron Age are still lacking. However, the ancient resource landscape of the Apennines was not solely comprised of natural driven, material resources. If we adopt a relational definition of resources, as elements able "to create, sustain and alter social relations, units and identities within the framework of cultural ideas and practices" (Hardenberg, Bartelheim and Staecker, 2017, p.14; see also Bartelheim, Hardenberg and Scholten, 2021, pp.10-13) it becomes evident that human activities aimed at the acquisition and exploitation of the above-mentioned natural reserves also involved several intangible resources, such as skills, knowledge, and knowledge transmission (Tab. 1).

An example that clarifies how closely these intangible resources were intrinsically tied to the social evaluation and usage of tangible resources can be found in the breeding of animals, which left evident traces in the archaeological record of the Iron

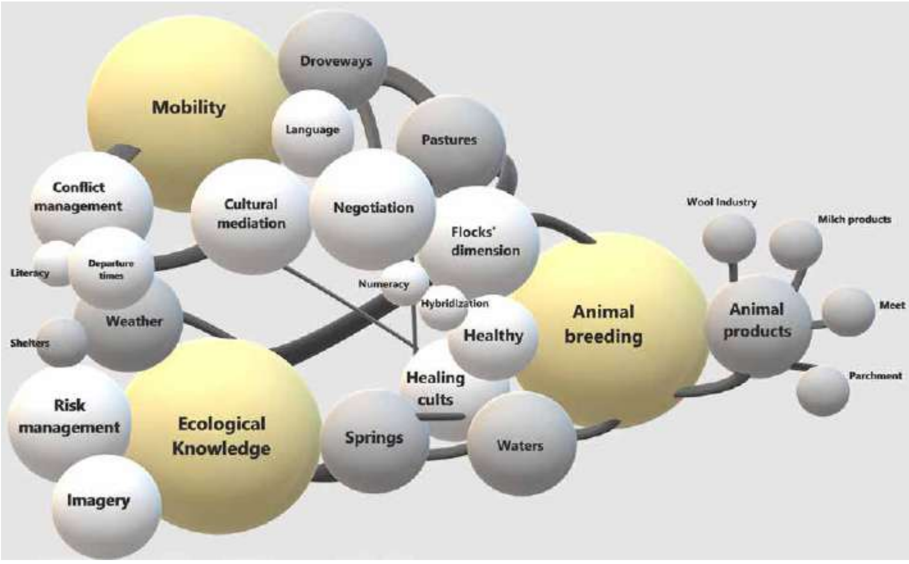

Figure 3: Network of tangible and intangible resources and socio-cultural dynamics (ResourceComplex) involved in transhumance practices (author with paint 3D).

Age Apennines. The local climatic conditions, with snowy winters, makes the sedentary breeding of bovines and ovicaprines, and keeping of herds and flocks quite difficult, and in some cases completely impossible. The climate thus necessitated the practice of mobile pastoralism or transhumance (Heitz, 2022; Da Vela, 2020; Vanni, 2019; Costello and Svensson, 2018; Heitz, 2015; Santillo Frizell 2004; van Wonterghem, 1999). Transhumance, along with the accompanying and complementary activities of agriculture and forestry, are all interconnected to various intangible resources. In the case of transhumance, these intangible resources are constituted by the infrastructures facilitating seasonal mobility, as well as the skills and the knowledge required for the care and maintenance of the herds or flocks. Some of the infrastructural resources facilitating seasonal mobility are tangible, such as water reserves and widely distributed grasslands, and some of them are intangible, such as connectivity, knowledge of the location of the pastures, landmarks serving orientation within the landscape, and the capacity to reach agreements on the timing of animal and human movements and grazing rights.

Changes in immaterial resources can affect the system as well, for example the introduction of a new skill to improve the processing of raw animal products, or the acquisition of new knowledge in animal care. Moreover, new ways of interconnecting resources, or new forms and levels of dependency between resources can affect their social value, for example when political decisions or conurbation have an impact on the infrastructural system, demography, or the abundance or scarcity of resources. For this reason, thinking about the Apennines as a dynamic network of resources, socio-cultural dynamics, and social agents can be useful to move on from the descriptive approach, towards a relational understanding of resources. Adopting the new terminology of the ResourceCultures, this dynamic network of resources, socio-cultural dynamics and social agents is defined as a ResourceComplex (Teuber and Schweizer, 2020, pp.12-13; Klocke-Daffa, 2017) (Fig. 3).

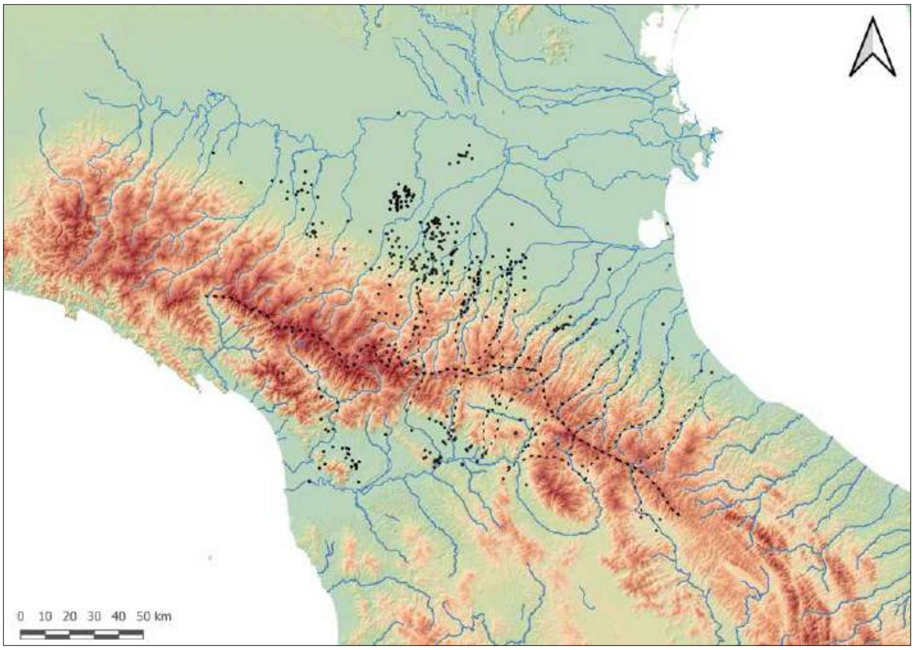

Figure 4: The Etruscan Apennine in the Iron Age (9th to 5th centuries BCE) (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1; vector data collected by the author).

In the following, two components of this ResourceComplex will be analysed more deeply: firstly, one immaterial resource, namely local knowledge, and one related sociocultural dynamic, namely the sacralisation of water reserves, and of trails. For a better understanding of how different societies adopted different approaches to their resources and how these approaches result in varied ResourceComplexes, each topic will be presented via two case studies, the first one in the northern Apennines (Etruscan Apennines) and the second one in the southern Apennines (Hirpinian Apennines). In the first case study (Fig. 4), the Apennine mountains constitute a contact zone between the communities of the Po-Plain and the Etruscan core land (Zamboni 2012; 2018, pp.236-239). The core land of the Etruscans, south of the Apennines, was defined by the Arno and Tiber rivers, and was occupied from at least the 7th century BC by city-states, mostly comprising an upper-city on a hill, similar to the polis-model known in the Magna Graecia, in Greece, and in other regions of the eastern Mediterranean (Cerchiai, 2017). On the other side of the mountains, a few urban centres such as Felsina (Bologna) and Spina characterized the landscape of the Po-Plain, with the rest occupied by sparse or smaller settlements. In the second case study (Fig. 5), the Apennines constitutes the contact zone between the Hirpinian people, an Oscan speaking group located in southern Samnium and the neighbouring Daunian, Lucanian, and coastal Campanian communities. In Hirpinia, there is no evidence of urban centres until the mid-4th century BC.

The territory was organised into small, sparse habitations such as isolated farms and houses along the transport routes, and small settlements, sometimes made up of multiple geographical cores (Rainini, 2000). This infrastructure can be thus considered a mixed, partially natural and partially anthropic resource, which shaped the identities

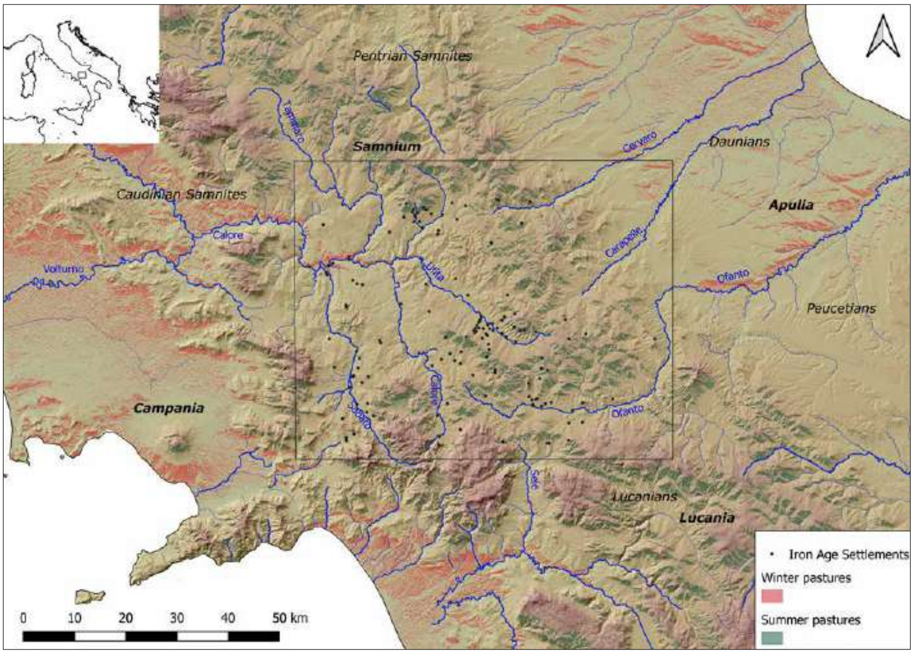

Figure 5: The Hirpinian Apennine in the Iron Age (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1).

of local communities and the connections between them. All the tangible and intangible resources within the Apennines' resource landscape were interconnected and maintained a relationship of hierarchical dependency or reciprocity with each other. For this reason, a descriptive approach to the resource landscape, as adopted above, seems to be unsatisfactory for understanding the complexity of interactions and the various levels of interdependence between tangible or intangible resources, and resource-related sociocultural dynamics. This means that when a single resource undergoes a change, it affects all other resources and their social evaluation. For example, if household-level pastoralism, managing very few animals, increases to become a mass breeding operation, then that operation will need more pastures and larger infrastructures, as well new ways of organising the work and life of the families involved.

Knowledge of Resources and Knowledge as a Resource

Knowledge is an asset that allows us to determine the value of things and actions (Teuber and Schweizer, 2020, p.11). It includes both theories and concepts, as well as practical skills and expertise. The special knowledge concerning resources, their locations, the ways in which they could be exploited, processed and thus transformed, and their availability or scarcity, could all be used to shape power relationships and social identities (Marinković and Ristić, 2019, pp.74-76; in ancient societies: Seidel, 2017, p.104). In addition, social power and social representation can be supported by the control of knowledge concerning available and important resources, including limitation of access to that knowledge. As an immaterial resource, knowledge is a means to determine group identities, for example, single craftsmen and professional corporations are both defined by the knowledge they possess. It can even

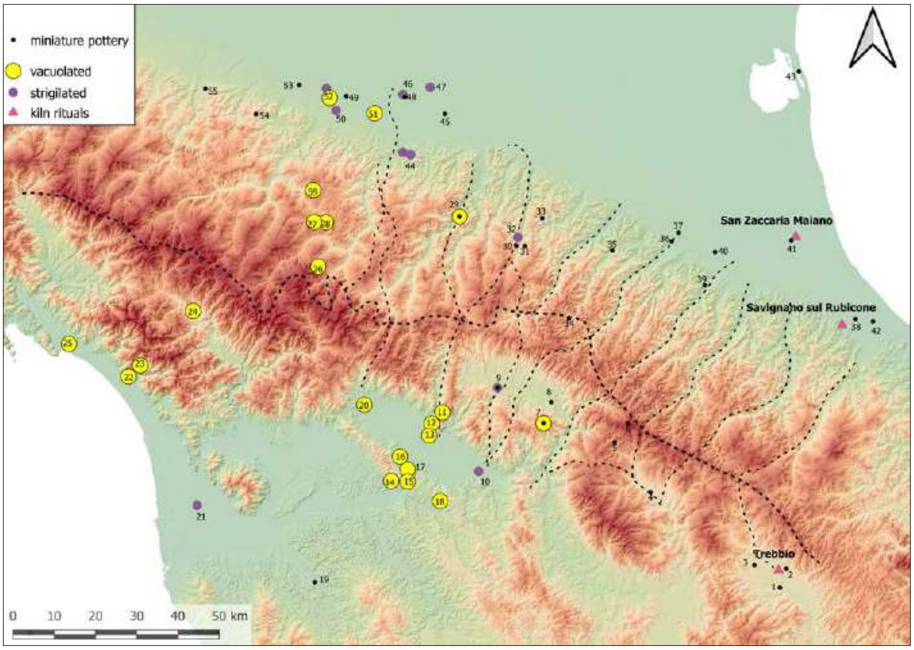

Figure 6: Distribution of miniature pottery, strigilated ollae and vacuolated pottery around the Northern Apennine. Disposal rituals of pottery workshops (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1, with layout layer Bing Virtual Earth; vector data collected by the author, references at Table 2).

build community identities when it takes the form of 'local' knowledge. Local knowledge is used here to refer to "knowledge systems rooted (sic) in local or regional culture and ecology" (Antweiler, 1998, p.469). Traditional ecological knowledge is a particular form of knowledge, which includes "the kinds of knowledge that deal with resource-use practices, institutions and worldviews" (Berkes 2018, pp.26-27). In the archaeological record of the selected case studies, objects, structures, and contexts are useful for understanding how the knowledge of resources became a resource in and of itself for the local communities (for the broader conception of cultural knowledge as a resource for the building of social and cultural identities see also Schweizer, 2021b).

In the first case study, several pottery workshops show the adoption of common production processes on both sides of the Apennines (Da Vela, 2022a). The general knowledge of the resources necessary for pottery production must be noted here: the location of clay and mineral reserves, as well as fuel, the material properties of these resources, the ideal choice of location for the kilns, especially regarding the proximity of water and the exposure to wind, and finally the communication infrastructures between production hubs, and the settlements, farms, or sanctuaries requiring the products. This knowledge also includes the specific expertise possessed by artisans concerning the shapes and decoration of the pottery, and the skills related to the transformation of clay, such as the use of minerals as inclusions to produce different effects, flexibility and strength, the temperatures and ventilation during the firing process, the firing required time, and so on.

This kind of technical proficiency and its distribution are configured in the form of local knowledge within the ResourceComplex of the northern Apennines. Looking at the typology

Nr.	Site	V	s	m	References
1	Pistrino			X	Unpublished. Museum storage San Sepolcro
2	San Sepolcro, Trebbio			X	Unpublished. Museum storage San Sepolcro
3	Ca' di Marchetto			X	Unpublished. Museum storage San Sepolcro
4	Poppi			X	Da Vela, 2022a, p. 283-285
5	Serelli			X	Incammisa, 2013 , p. 73; Da Vela, 2022a, p. 287-288
6	Lago degli Idoli			X	Settesoldi, 2013 , n. 99, p. 126
7	Monte Giovi	X	X	X	Poggiali, 2017
8	Vicchio, Poggio Colla			X	Ducci et al., 2015 , inv. 137975, p. 17
9	S. Piero a Sieve, I Monti		X	X	Salvini, 1994; Salvini, 2009, pp. 25-26
1 0	Florence		X		Da Vela, 2019, p. 37
1 1	La Retaia	X			Perazzi and Poggesi, 2011 PO63
1 2	La Pietà	X			Perazzi and Poggesi, 2011
1 3	Fonti Alte	X			Perazzi and Poggesi, 2011 PO53
1 4	Montereggi	X			Serafini, 2019, fig. 4, p. 151
1 5	Pietramarina	X			Serafini, 2019
1 6	Carmignano	X			Serafini, 2019, p. 152
1 7	Artimino	X			Serafini, 2019, fig. 4, p. 151
1 8	Scandicci, Pog. La Sughera	X			Serafini, 2019, p. 152
1 9	Peccioli, Ortaglia			X	Sorrentino and Landini, 2015, p. 99
20	Pistoia	X			Poggiali, 2017, p. 119
21	Pisa	X	X		Serafini, 2019, fig. 4, p. 151
22	Borra dei Frati	X			Serafini, 2019, fig. 4, p. 151
23	Azzano	X			Poggiali, 2017, p. 219
24	La Murella	X			Poggiali, 2017, p. 123
25	Luni	X			Poggiali, 201 7, pp. 126-127. Fig. 112. 2-3
26	Sestola	X			SE19, Cardarelli and Malnati, 2006, p. 188
27	Ponte d' Ercole	X			PO9, Cardarelli and Malnati, 2006, p. 165
28	Monzone, La Casaccia	X			Serafini, 2019, pp. 155-156; PA11, Cardarelli and Malnati, 2006, p. 115
29	Marzabotto	X			Serafini, 2019, fig. 4, p. 151
3 0	Ca' di Buganè		X		Ammirati, 1990, pp. 78-80.
3 1	Pianella di Montesavino			X	Unpublished. Museum di Monte Bibele, Monterenzio
3 2	Montebibele			X	Gottarelli, 2017, pp. 120-123
3 3	Monterenzio Vecchio			X	Gottarelli, 2017, pp. 148-149
3 4	Mantigno			X	Unpublished. Museum Comprensoriale del Mugello
3 5	Grotta del Re Tiberio			X	Miari, 2000, p. 257
3 6	Persolino			X	Morico, in Masi von Eles 1981, p. 180
3 7	Faenza			X	Bertani, in Masi von Eles 1981, p. 368 (type 8)
3 8	Savignano sul Rubicone			X	Miari, 2003
3 9	Castrocaro				Miari, 1997, n. 7, p. 155
40	Villanova			X	Miari, 2000, p. 343

Nr.	Site	V	s	m	References
41	S. Zaccaria – Maiano			X	Miari et al., 2008, p. 32
42	Covignano			X	Masi von Eles, 1981; Miari, 2000, pp. 325-326
43	Spina			X	Miari, 2000, p. 288
44	Pasano		X		SV7, Cardarelli and Malnati, 2009, p. 173
45	Palazzina di Sopra			X	Von Eles and Forte, 1994, p. 30
46	Campazza		X		CE392, Cardarelli and Malnati, 2009, p. 62
47	Rastellino		X		CE 146, Cardarelli and Malnati, 2009, pp. 56-57
48	Castelfranco Emilia				Buoite and Zamboni, 2008, n. 990, p. 101. Fig. 20
49	Baggiovara			X	Miari, 2000, p. 145
50	Corlo		X		FO3, Cardarelli and Malnati, 2009, p. 261
5 1	Canneti	X			CR9, Cardarelli and Malnati, 2009, pp. 270-271
52	Magreta	X	X		FO900, Cardarelli and Malnati, 2009, pp. 270-271
5 3	Cacciola di Scandiano			X	Miari, 2005, pp. 427-428
54	Ca' Bertacchi			X	Miari, 2005, pp. 427-428
5 5	S. Polo d'Enza, Servirola			X	Miari, 2000, pp. 90-92
56	Monte Menegosa	X			Poggiali, 2017
57	Tesa della Mirandola			X	Malnati and Miari 2008, p. 68
5 8	Barchessone		X		MI130, Cardarelli and Malnati, 2003, p. 68
59	Pompeano	X			Malnati in Cardarelli and Malnati, 2006, p. 72

Table. 2: Finding places of vacuolated (v), strigilated (s) and miniature (m) pottery in the northern Apennines.

of the kilns and of the products, it is possible to observe a spread of technical knowledge and skills along the northern Apennines affecting some specific forms of pottery production, such as miniature pottery (Da Vela, 2022a; Zamboni, 2012; Miari, 2000), vacuolated pottery (Serafini, 2019; Poggiali, 2017), and strigilated ollae (Buoite and Zamboni, 2008, p.73 Type 1) (Fig. 6).

The distribution patterns of the objects, as well as the kiln- and workshop design at certain sites, indicate that the spread of this knowledge was not random or casual, but rather followed specific patterns linked to the artisans' mobility and economic motives or purposes. In a few contexts it is also possible to prove how specific religious practices accompanied the introduction of this knowledge: for example, a single miniature pot was deposited as a ritual offering upon the disposal of the workshop in Savignano sul Rubicone and another in San Zaccaria-Maiano (Miari, 2003; Miari et al., 2008, p.32), near Cesena in the foot-hill plain northern of the Apennines, as well as in the kiln of a workshop at Trebbio (Da Vela, 2022a, p.286) in the south. Knowledge of this ritual was probably restricted to a specific group of actors, artisans, and other people involved in ceramic production, and thus helped shape the identities of this group within the local communities.

The limited 'community of practice' that this shared knowledge formed amongst these particular potters was then a specific group within the broader community of potters on both sides of the Apennines. This exclusivity implies a restriction in the transmission of knowledge within local communities (Hasaki and Pont, 2019, pp.298-300; Hasaki, 2012, pp.186-187, 194). Moreover, the presence of this knowledge across the Apennines in

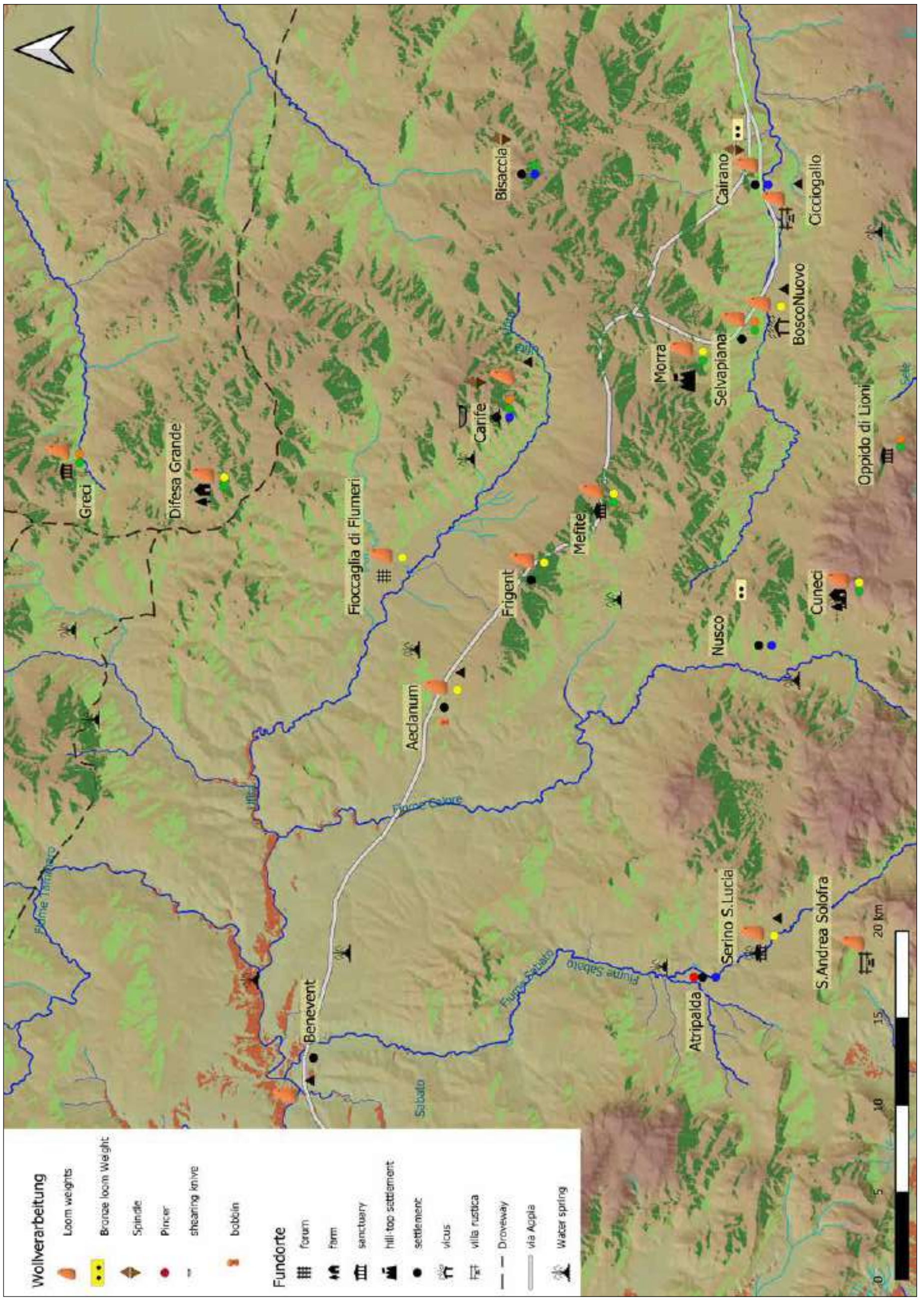

Figure 7: Distribution of objects linked to animal breeding in context in Hirpinia (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1, vector data references see text).

different cultural regions should not be thought of as a form of 'acculturation', but rather as the formation of a transcultural community of practices in the field of pottery production. This formation process was enhanced by the mobility of people, objects and skills between regions, and the transfer of information to new generations of potters, who may well have belonged to different cultural traditions and geographic regions (Boix, 2022; Stapfer, 2017, p.150).

In the second case study set in the southern Apennines in Hirpinia, a different kind of local knowledge concerning resources reached a broad diffusion. This was the above-mentioned one relating to the practice of mobile pastoralism. Although the archaeological traces of transhumance activities in Iron Age Hirpinia are very few and mostly indirect, the probability that these activities had already been practiced in the region during the prehistorical period is significant (Busino, 2008, pp.131-132). To recall the principal elements which support the existence of this form of pastoralism in the Iron Age of this region: there was a long continuity of settlements along the droveways, from the Iron Age up to the Imperial Age, wherein this activity is attested in both literary and epigraphic sources (Corbier, 2016; Pasquinucci, 2004; Corbier, 1991; Gabba and Pasquinucci, 1979); the cult places are mostly located in both rural and suburban areas along the same roads, and belong to deities linked to transhumance resources, such as Mephitis and Heracles (Da Vela, 2023, pp.192-196); the production of wool textiles is more broadly distributed and the working tools of both key activities for this production – animal breeding and weaving – have a particular value in the religious and funerary representation of both women and men (Da Vela, 2022b, p.274) (Fig. 7). Last but not least, the climatic conditions are not suitable for the sedentary breeding of ovicaprines. The short vertical form of transhumance would have proven a necessity, because the lowland pastures are too dry during the summer and the upper pastures are covered by snow during the winter.

The local knowledge of transhumant pastoralists can be considered a form of traditional ecological knowledge (T.E.K.). The current interpretation of this term in ethno-anthropological studies sees it as more static in comparison to the more general local knowledge (Antweiler, 1998, p.471). Nonetheless, this terminology, which is commonly used in transhumance studies (Tamou, et al., 2017; Oteros Rozas, et al., 2013), will be used here to define a network of theoretical cognition, skills, and expertise that is the result of dynamic evolution within a geographic context, becoming part of the cultural references of local societies or of specific groups within it (Berkes, 2018, pp.77-79). In our case study the specific group is constituted by the mobile herders and their families.

In the practice of transhumance, this knowledge belongs to the mobile shepherds and their families and is required to assure the maintenance and growth of the herds or flocks (Soma and Schlecht, 2018; Oteros-Rozas, et al., 2013; Al-Tabini, et al., 2012). In transhumance societies, the T.E.K. refers to the climatic conditions, seasons, and timing for different phases of animal and human mobility, as well as the position of water reserves and winter and summer pastures, specific expertise concerning animal breeding (especially as regards the sustainability of the herd or flock), including the animals' reproduction and their care, potential incentive-based hybridisation with the animals from different flocks/herds and from different regions, to improve resistance to parasites and productivity of milk and wool (Fre, 2018, pp.46-48).

This knowledge shaped the identities of the shepherds and marked the rhythm of life in settlements related to transhumance activities, based on climatic variations and on the needs of both the animals and their pastures (fallow periods and so on). Moreover, the need to move and manage agreements with other communities of shepherds and farmers in both the local and neighbouring regions would have required further cultural skills, perhaps even partial literacy and numeracy. This does not mean that transhumance practices were entirely and exclusively dependent upon ecological knowledge. There were other important parameters, such as the safety of flocks, herds, and shepherds, and the fair distribution of resources and grazing rights must have also been important factors. These would have been governed institutionally in the form of negotiations, agreements, laws, and controls (see Gonin, Filoche, and Lavigne Delville, 2011).

At the moment, we have very few indirect archaeological indicators of the transmission of knowledge within the transhumant communities of Hirpinia. Some of them practiced horizontal transhumance, which is linked with cultural contact and exchanges taking place along the droveways. It is also especially connected with contact to the neighbouring regions included in the network of pastures, and to the transformation of transhumance products such as milk and wool (for transhumance studies in the neighbouring regions: Heitz, 2022; Roubis, et al., 2015). We can find some suggestions of how knowledge transmission between shepherds functioned in the *de rustica* of Varro, although this is obviously a later literary work. In *de rustica*, Varro indicated intergenerational education (*rr* 2,10,1-3) as well as the written transmission (*rr* 2, 1, 23. 2, 10) as the main pathways to access this knowledge. Moreover, ethnological comparisons suggest that modern transhumant societies apply intergenerational transmission of knowledge and knowledge exchange between different groups of shepherds and different regions to maintain and improve the resources that are essential to transhumance (Oteros Rozas, et al., 2013).

Valuation and Sacralisation of Resources

The analysis of knowledge as an immaterial resource for the people of the Apennines has already underlined a strong link between this resource and one particular resource-related sociocultural dynamic, namely the sacralisation of resources. This term defines a process in which a society connects particularly valuable resources with the religious sphere, in the form of objects, rituals, festivals or sacred spaces (Schweizer, 2021 a, 2021a, pp.310-311; Bartelheim, et al., 2015, pp.41-42). Examples of such sacralisation include the above-mentioned offering of miniature pottery as part of an obliteration ritual for the kilns and clay pits, as well as the construction of cult places at the transhumance hubs. These two examples deserve a closer look, since they were part of a broader trend towards sacralisation of resources in the Apennines.

The northern case study provides relatively few examples of specific rituals linked to the disposal of production sites. These rituals, performed at the moment of the workshop's abandonment, are the last visible acts of the sacralisation process of pottery production (Denti, 2014). Comparison to other regions of the Mediterranean, for example in the Greek colony of Selinuous in Sicily (Bentz, et al., 2016, p.62), indicate the sacralisation of pottery-making, which was perceived as a creative performance able to transform clay, water, fire, air, minerals, and fuel into an object. This sacralisation involved different steps of the working process, as is also confirmed by the Greek archaic literary sources (*Homeric Hymn* 14). Nevertheless, the medium of the ritual in the Apennines, a miniature pot with an oval mouth profile, is associated with many other cult practices of that region. This association, rather than being casual and meaningless, seems to integrate the sacralisation

Figure 8: The sacred cave Grotta del re Tiberio in the karstic region of the Vena del Gesso Romagnola (author).

of pottery-making into the larger frame of religious practices, putting the resources directly under divine protection, and appropriating them through worship.

The same type of miniature pottery has thus also been used in foundation and abandonment rituals of huts and houses, as well as in communitarian cult places near settlements and in sacred caves dispersed across the mountains. Miniature pottery was used in household rituals in the Casentine hilltop settlement of Serelli (Fedeli, Incammisa and G.A.C., 2006; Incammisa, 2013). Here, four vases of this type were intentionally deposited in the corner of a room on a plate made of sandstone, before the building's reconstruction (Da Vela, 2022a, p.287). A similar ritual was performed south of the Apennines at Monte Giovi (Cappuccini, 2017, p.21) and on the plain north of the Apennines at Persolino di Faenza (Zamboni, 2010, p.21; Miari, 2000, p.242).

This widely distributed usage shows how these ceramic shapes were part of shared cult practices in domestic contexts with different architectural features, dependent upon different traditions and lifestyles. This fact suggests that shared material and immaterial resources constituted only one part of the life-worlds of the Apennines communities. The sociocultural dynamics linked to the ritual use of miniature pottery in foundation and abandonment rituals seem to function independently, unaffected by other factors such as the use of stone, wood, or clay in the building. These pragmatic choices could be on one hand linked to specific micro-local conditions, since stone was more easily available in the mountains, as at the site of Serelli and Monte Giovi (700-900 Mt.), while Persolino di Faenza located in the plains, in zones rich in lime and clay.

However, this does not explain why the same ritual practices took place recurrently in such different cultural and social contexts. The use of miniature pottery, as explained above, is also attested in communitarian cults within settlements. In that respect the case of

Figure 9: The sacred lake Lago degli Idoli (author).

Castelfranco Emilia, north of the Apennines, is quite enlightening, since the miniature pottery is offered together with animal bones, in particular wild game (Farello, 2008, pp.191-192). Since Castelfranco was an agricultural hub, as attested by the materials found in the excavation of the settlements, (Marchesini, et al., 2008, pp.206-207), the offering of wild game represents an evident reference to hunting and the animal resources available in the mountains. The use of miniature pottery and wild game in the ritual is evocative of the mountain landscape and is thus able to reinforce the symbolic relationship between the inhabitants of the foothills- and plains settlements and the ResourceComplex of the Apennines.

The third type of religious context found in the northern Apennines is perhaps best able to clarify the semantic value of the miniature pottery, providing the best example of the association between such pottery and the general sacralisation of natural reserves. A very large amount of miniature pottery dated between the Archaic and Hellenistic periods has been found in the Grotta del Re Tiberio (Cave of King Tiberius: Bertani, 1997) (Fig. 8), together with animal bones and grains of red ochre, contained within some of the small pots (Rondelli 2006/2007, p.103). Both the contextual associations and the key geographic position of this cave in the sacred landscape of the northern Apennines indicate its function as a temple of sacralised resources. This cave, located within a mineral-rich landscape where sulphureous fumaroles and gypsum mines were active for centuries, is also part of a wider network of natural groves, sacred caves, creeks, and springs (these play a particular role within the infrastructural hubs, as essential water reserves along long-distance routes).

Another famous example of these sacred hubs linked to resources and water reserve is the so-called Lago degli Idoli (Idols' Lake Fig. 9), which yielded several hundred bronze votive figurines, both anthropomorphic and zoomorphic. This lake was restored after being intentionally drained in 19th century (Bartolini, Miozzo and Toni, 2007).

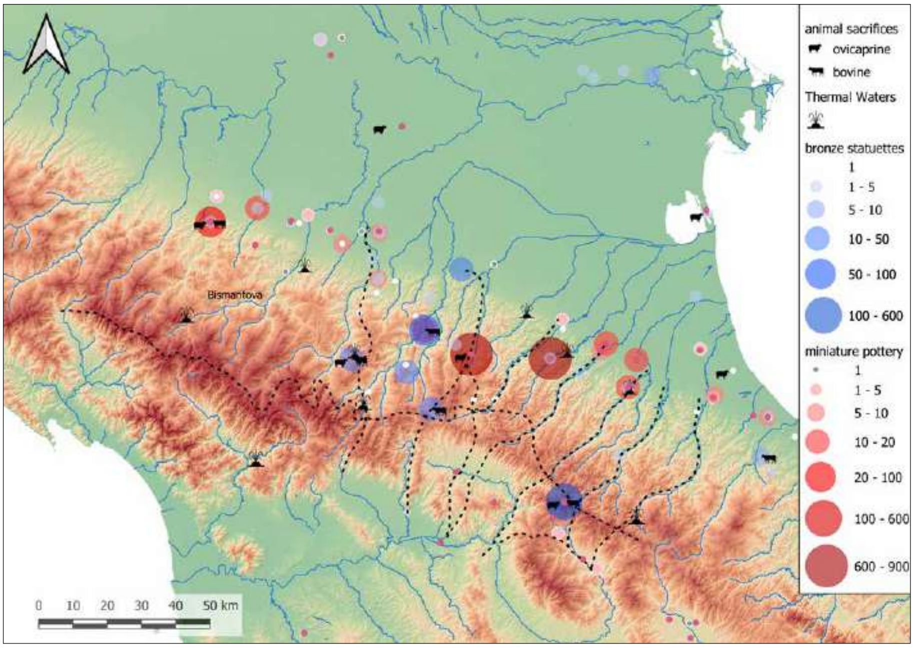

Figure 10: Religious infrastructure and sacralisation of natural reserves and connectivity on the Northern Apennine (GIS): distribution of miniature votive pots and bronze figurines (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1).

It was originally situated near the springs of the Arno River, the main river in northern Etruria, on Mount Falterona. The location of the sacred groves and caves in the Apennines indicate clearly how the natural reserves needed to survive long trips across and along the ridges of these mountains became sacralised. Moreover, the worshippers active in these cult places need to be individuated into different cultural areas on both sides of the Apennines, as the spread of cult objects in the foot-hills settlement and plains suggests (Fig. 10).

The second case-study in the southern Apennines presents some similarities with the first one, focussing instead on the sacralisation of the geographic hubs of mobile pastoralism, and the structural importance of raw materials. In Iron Age Hirpinia, the topographic distribution of cult places is strictly linked to two key resources essential for transhumance: springs and sulphureous fumaroles, such as those in the sacred grove of Mephitis in the Ampsanctus-Valley (Fig. 11) and the smaller one in Malvizza by Ariano Irpino. The animals being driven back and forth across the mountains obviously needed drinking water, but water is also necessary for the development and maintenance of good pastures (Gabba and Pasquinucci, 1979, pp.98-100), while sulphur was used to protect ovicaprines from certain parasites (Santillo Frizell 2004; Gallo, 2015, p.77 note 71). Water and sulphur are also both needed in the different steps of wool production (Flohr 2013, pp.117-118. 172). The cult places in question are mostly situated on the historic transhumance routes and droveways, which were probably continuously used from the Bronze Age on (Fig. 12).

The topographical distribution of cult places is not the only indicator of this sacralisation of resources. The divine actors of the cult, the typology of the ritual objects and their semantic associations all indicate the strong focus of both personal and communitarian

Figure 11: The sacred grove at the sulphoureous fumarole of Mephitis in Hirpinia (photo: author).

cult practices on transhumance resources. The two main deities worshipped in this region were Mephitis and Herakles (Scopacasa, 2015, pp.109-115). Mephitis was a goddess with functions in the chthonic and reproductive spheres, similar to other goddesses worshipped in the Apennines, such as Marica, Cupra and Feronia, also linked to successful animal breeding (Ferrando, 2017; Dionisio, 2013; Loffredo, 2012). Herakles, who was worshipped as a god rather than as a hero in many regions of Iron Age Italy, has also frequently been presented as having a close relationship with transhumance (De Vincenzo, 2015, p.75; van Wonterghem, 1999; Gros, 1995; Letta, 1992). Although there are several criticisms of this association (Stek, 2009, pp.55-58), the topographic distribution of Herakles' cult in Hirpinia and in the neighbouring regions near springs and along the connecting routes do not leave much doubt on his semantic closeness with mobile pastoralism, at least on the local scale.

A second form of sacralisation of resources, which can be structurally assimilated to the sacralisation of clay production in the northern Apennines, is the sacralisation of the creative transformation of animal-based resources, especially wool. The presence of textile tools, such as clay spindles, loom weights, and a few metal distaffs (Di Giuseppe, 2017, pp.269-274) in Hirpinian sanctuaries, as well as in grave contexts, indicates a sacralisation of the act of textile production, also known in other regions of the Iron Age Mediterranean (Quercia and Foxhall, 2014, pp. 75-76). This sacralisation is largely relevant to the sanctuaries at the key connecting hubs between the Apennines and the coast. The presence of stamps displaying dolphins, fibulas, and the flying Eros, as well as the presence of spikes on some of the loom weights confirm their integration into the semantics of cults related to the female sphere (Sofroniew, 2011). As well as the deposition of these objects in grave assemblages, their use as votives in sanctuaries indicates that wool, as an animal-based resource, as well as the creative act and the knowledge and skills linked to spinning and weaving wool, all functioned strongly in the representation of women, and carried a high social value within

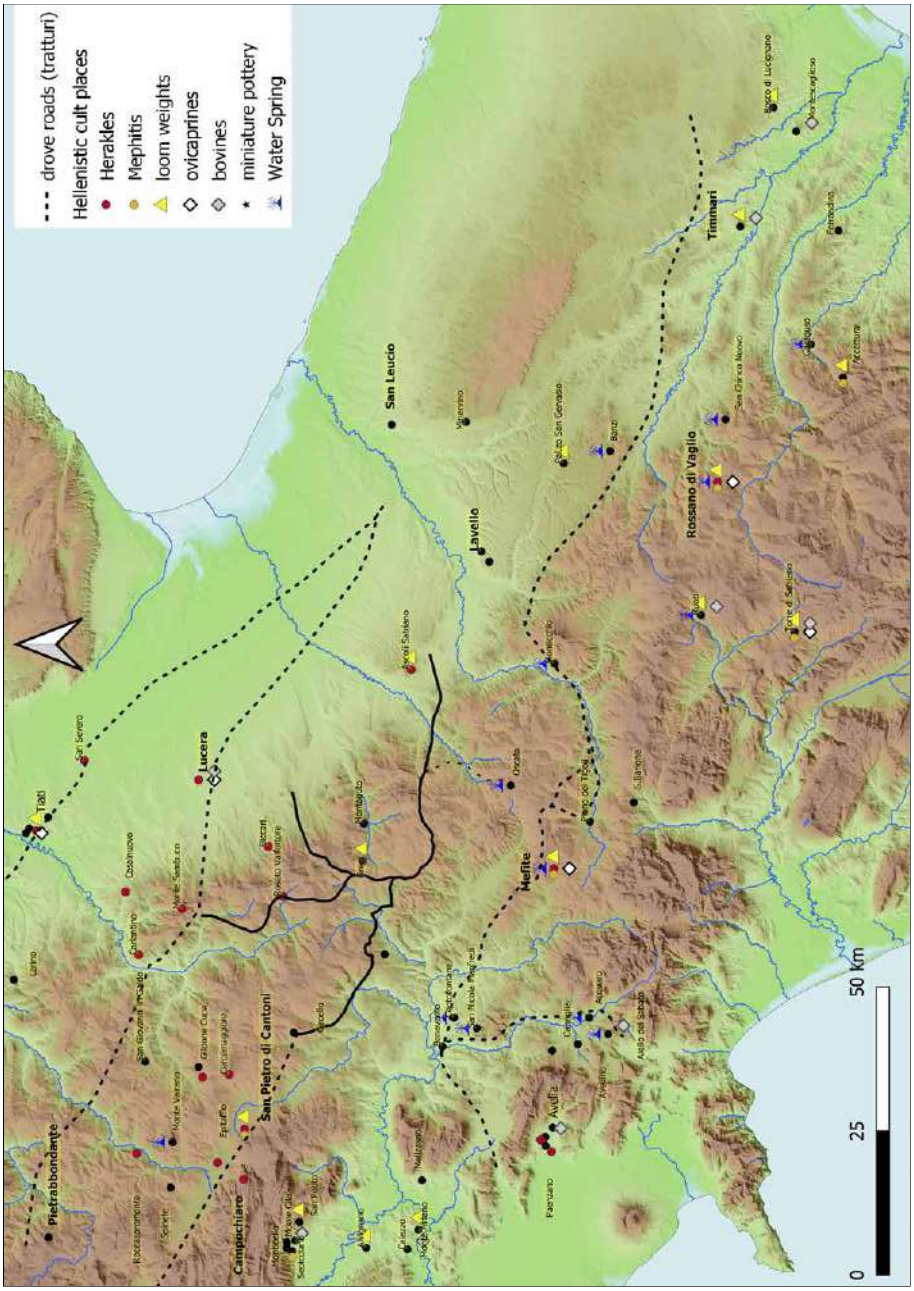

Figure 12: Religious infrastructure and sacralisation of natural reserves and connectivity on the Southern Apennine (author with QGIS 3.8 DEM ESRI 3035 Copernicus 1.1, vector data references see text).

Iron Age Hirpinian society. Moreover, the almost exclusive association of textile tools with the graves of adult women suggests that the acquisition of skills and (traditional) knowledge linked to spinning and weaving played an important role in the rite of passage to the adult world, and that this resource therefore also helped shape gender and age identities (Amann, 2000, pp.56-60).

The Temporal Dimension of Resources: The Apennines as ResourceAssemblage

The abovementioned ResourceComplexes of the Apennines were not static, but were rather shaped by a continuous mobility of human and non-human actors, by variable shifts of tangible and intangible resources, and by changes in the social consideration and value given to these resources. If the network is conceived of as a structure of nodes (resources) and edges (interconnections between them), it provides a useful empirical model for understanding the forms of interactions and social spaces of resources. However, a further step is required to capture the dynamics of the creation of value for resources, as well as their usage and disposal over a given period of time. The diachronic analysis of both the components of the abovementioned network and the interactions within the resulting ResourceComplexes aims to individuate the origins and catalysts of change within the network and also to detect which resources are more adaptable to changes, or responsible for the main changes occurring within the network structure. The diachronic approach to the networks of tangible and intangible resources, human and non-human agency, and resource-related sociocultural dynamics permits us to reframe the contingent aspects of the usage and social evaluation of resources. In conformity with the terminological framework of the present paper, the diachronic and contingent modelling of ResourceComplexes will be referred to as a ResourceAssemblage (Bartelheim, Hardenberg and Scholten, 2021, p.14; Bartelheim, García Sanjuán and Hardenberg, 2021, p.16). The impact of contingency and changes on the network has left some traces in the archaeological record, particularly in the diachronic distribution of materials and the visible sequence of cultural and religious practices attested in the archaeological contexts of the Iron Age Apennines.

In the northern Apennines, for example, a settlement's internal structure and territorial organisation underwent a shift in sensitivities around the middle of the 6th century BC, when the cities of Gonfienti (Poggesi and Pagnini, 2011) and Marzabotto (Govi, 2017, p.88) emerged as urban entities. These settlements comprised an area of almost 20 hectares and included houses with stone foundations in the form of standardised *insulae* within a regular street-network, as well as common infrastructures and communitarian spaces for various social activities. They can thus be properly considered as urban centres. These changes (the reasons for which cannot be deeply analysed here) were linked to a general transformation occurring in the Etruscan society, which corresponded to contemporary political restructuring, as well as personal mobility and changes in the economic system. These shifts had a strong impact on the available resources and resource-related sociocultural dynamics of the Apennines.

The first evident impact was the growing importance of vertical connections across the Apennines toward the Po-Valley and Bologna. In this case, there was variation in both the spatial distribution and mobility of objects and also in their perception and usage. Concerning the evaluation and sacralisation of resources, the urban centres (despite being very near to the mountains) seem to have sought for their sociocultural references in other geographical areas and distant cultural models, which were linked more closely to the dimension of commercial exchange. In Marzabotto (Sassatelli, 1991, pp.294-296) and Gonfienti (Piccioni, 2020, pp.52-54), the miniature pottery employed in communitarian and private cults are frequently bucchero *kyathoi*. In terms of cultural references, these vases were not associated with the sacred groves and caves of the Apennines, but rather with the well-integrated cult places in the core land of Etruria, such as the urban sanctuaries in Veio Campetti and Piazza d'Armi (Sciacca, 2010, p. 240 f. pp. 240-241; for a review of other examples in Etruria see also Zamboni, 2010, p. 13 note 25), as well as domestic cult settings (Piccioni, 2020, p.201-202; Giuntoli, 2018, pp.46-47). The semantic value of these miniature vases is linked to the consumption of wine and the cultural practice of the *symposion*, which was related to resources and the sacralisation of resources found in other geographic and climatic zones (see Schweizer, 2021a). These changes did not bring about a breakdown of the traditional networks, but rather displaced some elements within them from their previously central positions or roles.

Concerning the second case study, the changes within the Hirpinian Resource Assemblages originated from the infrastructural revolution linked to the rise of a new economic system, which affected the local management of resources. These changes were linked to two main events: the conversion of a group of longitudinal droveways into the Roman consular road known as the *via Appia* at the end of the 4th century BC, and the foundation of Roman cities in the form of *coloniae*, *municipia,* and *fora* during the 3rd and 2nd century BC (Da Vela, 2020; Nowak-Lipps, forthcoming). These external interventions accelerated the already increasing agricultural exploitation of the river valleys and contributed to the integration of local agricultural production into a supra-regional system. Several small and medium farms, as well as some rural agglomerates from this period are attested in the plains of the river Ufita, near the *colonia* of Beneventum (Tomay, 2012, pp.269-275) and the *municipium* of Frigentum (Pugliese, 2018; Carfora, Matalauna and Renda, 2014). Some of these farms and agglomerates were pre-existing Samnitic rural hubs and were now embedded in the new commercial infrastructure (Conte, forthcoming; Santoriello and De Vita, 2018). Others were founded to host new settlers, as in the case of Circello, where the epigraphic sources attest to the deportation of the community of Ligures Baebiani from the north-western Apennines (Scopacasa, 2015, pp.156-157; Johannowsky, 1991, pp.77-82).

Some of these new settlements were also conceived of as places of coexistence for locals and newcomers, like Fioccaglia di Flumeri (Colucci Pescatori, 2017, pp.150-152; Johannowsky 1991, pp.68-77). Consequently, the interaction between agricultural activities and (mobile) pastoralism, and the importance of the traditional foothill settlements decreased. Resources essential for transhumance and forestry were progressively appropriated by central administrations located in the cities, and the exploitation of these resources increased. From the 2nd century BC, the Roman administration (in which representatives of the local elite participated), was aimed towards a progressive commodification of these resources. This was especially true of water, which was channelled into aqueducts serving the main cities on the coasts (Colucci Pescatori, 1996, pp.129-144). In the meantime, legislative acts to maintain the small and middle-sized land holdings and control the use of pastures (*pascua*) were created and disseminated: such legislation is suggested by the wider distribution of boundary stones in the region (*limites Gracchani*: Camodeca, 2017, pp.110-117; Gallo, 2015, pp.77-78; Gabba and Pasquinucci, 1979, pp.39,104). This new form of resource-evaluation challenged the traditional forms of negotiation governing grazing rights in what were probably open-access pastures, thus also affecting the social relationships between local families, the organisation of the work within local communities (Da Vela, 2022b, p.286-287.), as well as the role of religious institutions as guarantors of fairness in the agreements on transhumance resources (La Regina, 2000). The sacralisation of resources was also involved in this shift, as shown by the progressive alteration of the symbols used in ritual practices requesting protection for agricultural activities and a good harvest. Likewise, most of the traditional shrines and sacred groves were restructured using monumental forms (Johannowsky, 2001, pp.234-239; see also for the analysis of this shift in the whole Samnium Scopacasa, 2015, pp.192-210).

In both case studies human mobility, political shifts, and economic rationale impacted upon the sociocultural dynamics linked to resources, and to the social evaluation of those resources. At the same time, the resources themselves were in fact the trigger for this mobility, as well as for political and economic changes. The key moments, time periods, modality, and consequences of these changes were different in Etruria and Hirpinia. The diachronic perspective shows how dynamic these ResourceComplexes were, underlining the importance of the second category, the ReourceAssemblages, in understanding changes in resources and their conception across space and time.

ResourceCultures of the Iron Age Apennines

In the first part of this contribution the resource landscape of the Apennines has been considered as a dynamic network of material and immaterial resources and resource-related sociocultural dynamics (ResourceComplex). Two connected aspects of this network, knowledge and sacralisation of resources, have been analysed in more depth, in two separate Iron age regions with differing political, social, and economic structures: The Etruscan Apennines in the north and the Hirpinian Apennines in the south. This comparison points out the impact of political and social frameworks on ResourceComplexes with similar ecological and climatic conditions. The reason for these differences is that resources have a strong societal impact, but are also shaped and evaluated differently by different groups, based on local tradition, socio-economic factors and selective choices. So e. g., the sacralisation of creative processes, which took place in both Iron Age societies (the Etruscan and the Hirpinian), is related to pottery production in the north and textile production in the south, even though both activities and the correspondent raw materials are present across the entirety of the Apennines. The reconceptualisation of resource landscapes into ResourceComplexes thus permits us to consider resources from a relational point of view, and to describe their evaluation in the form of a reciprocal interaction between resources and societies. Moreover, the diachronic study of these ResourceComplexes provides us with certain insights into the interaction between tangible and intangible resources and their social frame, since the choices made concerning the usage and evaluation of individual tangible and intangible resources provoke changes in the whole network. The growth of urban centres during the middle of the 6th century BC in Etruria, for example, had an impact on particular infrastructural resources, creating a shift in the relationships between religious practices and natural reserves of raw materials. In Hirpinia, the foundation of new settlements and the institution of Roman colonies, as well as the construction of the *via Appia*, increased the expansion of transhumance, bringing about a commodification of its resources and structures and consequently a new social value and use of traditional religious hubs. These changes were not directly aimed to the exploitation of traditionally valuable raw materials of the Apennines, but they nonetheless affected the immaterial resources connected to them, such as the transmission of knowledge and its social evaluation or sacralisation. The diachronic perspective also permits us to analyse the network of resources and resource-related sociocultural dynamics from an historical perspective. Therefore, the perspective given by ResourceAssemblages also considers the rebound effects of changes in the resources, looking at their agency in maintaining the network dynamic.

Thinking about the resource landscapes of the Iron Age Apennines as a dynamic network requires the use of a heuristic model, in which personal identities, and the identities of groups or of entire communities are seen as the result of a fluid interaction between resources, their function in society, and their evaluation. This understanding of the relationship between resources and life-worlds as a non-hierarchical interaction can be defined as ResourceCultures. ResourceCultures are dynamic models "connecting certain resources, social forms of use, social relations, units and identities in a contingent, yet meaningful way" (Hardenberg, Bartelheim and Staecker, 2017, pp.20-21). This new model gives us the chance to understand and view the social value and impact of resources on societies, as a reciprocal exchange in which the values given by a human group are able to determine what constitutes a resource, but the resources themselves (including their characteristics and their abundance or scarcity) possess independent agency in the re-shaping of the same society that originally determined their value (see also Hardenberg 2021, p.151).

From this perspective, local knowledge concerning resources, and the sacralisation of resources are both ResourceCultures of the Iron Age Apennines. Knowledge and its transfer are linked to geographical mobility, but also to intergenerational communication and educational processes, and social mobility. The sacralisation of resources from the mountains spreads into the foothills and plains, underlining the integration of the Apennines with these areas in a vertical resource landscape. This integration resulted in the mobility of people, animals, objects, ideas, and even deities. The mobility of Etruscan objects, people, and ideas north of the Apennines caused social development in the foothills and plains on both sides of the Apennines, with the structuring of key settlements as urban centres with a Mediterranean dimension (Marzabotto, Gonfienti, Bologna, Spina), which then became at their turn hubs for the mobility of people, objects, stylistic models, consumption behaviours, and lifestyles. This social development led in turn to a new evaluation of the resources of the Apennines, such as new expertise in pottery production, the use of stone foundations for private building, and the ritualised social use of wine and wine pots. In Hirpinia, the mobility of animals, people, objects, and ideas were all traditionally part of the seasonal activity of pastoralism and thus fully embodied in the life-worlds of local communities. This traditional mobility become progressively challenged by the social mobility introduced by the external actions of Roman power, with the involvement of local families and individuals in the management of farms on the plains and in the administrative structure of the new urban centres, as well as new forms of forced mobility (legionnaires, deported Ligurians, veterans).

The new infrastructure and organisation brought with them a new evaluation of the traditional resources of animal breeding and agriculture and contributed to their quantitative growth. The consequent social development replaced the traditional system based on political and religiously ruled agreements and transactions, with a systematisation of knowledge related to transhumance, and central regulation of land usage. The described development created a new segmentation in Hirpinian society and a stronger economic dependence on the coastal regions, integrating economic production into an 'imperial' system designed to support exportation and large urban centres. The results of the analysis of the two case studies, with their structural affinities and contingent divergences, show how the heuristic level of the ResourceCultures model gives access to new interpretative approaches to the interaction between resources and societies, and create a new understanding on the impact of the cultural definition of resources on the local identities of ancient communities (Bartelheim, Hardenberg, and Scholten, 2021, pp.9. 14-15).

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References

Al-Tabini, R., Al-Khalidi, K. and Al-Shudiefat, M., 2012. Livestock, medicinal plants and rangeland viability in Jordan's Badia: through the lens of traditional and local knowledge. *Pastoralism: Research, Policy and Practice* 2(1), e4. Available at: DOI: 10.1186/2041-7136-2-4 [Accessed 8 August 2021].

Amann, P., 2000. *Die Etruskerin. Geschlechterverhältnis und Stellung der Frau im frühen Etrurien (9.-5. Jh. v. Chr.).* Österreichische Akademie der Wissenschaften, Archäologische Forschungen 5. Wien: Verlag der Österreichischen Akademie der Wissenschaften.

Amann, P., 2010. Räumliche Verteilung und Bedeutung anthropoider Grabstelen und Grabstatuen im früheisenzeitlichen Italien und eventuelle Wechselwirkungen mit dem Raum nördlich der Alpen. In: B. Gediga and W. Piotrowski, eds., *Rola głównych centrów kulturowych… / Rolle der wichtigen Kulturzentren…* Oddział we Wrocławiu 18. Biskupin – Wrocław, pp.147-174.

Ammirati, A., 1990. La prima età del ferro. In: D. Vitali, ed., *Monterenzio e la Valle dell'Idice. Archeologia e storia di un territorio.* Exhibition catalogue, Monterenzio. Bologna: University Press Bologna, pp.75-82.

Arbeid, B., 2010. *Bronzi votivi etruschi a figura animale.* PhD thesis. Ferrara: Università degli Studi di Ferrara.

Antweiler, Ch., 1998. Local knowledge and local knowing: an anthropological analysis of contested "cultural products" in the context of development. *Anthropos* 93, pp.469-494.

Baldissara, L., 2018. Gotenstellung: linea del fronte, linea di confine, linea "mentale". In: M. Carrattieri and A. Preti, eds., *Comunità in guerra sull'Appennino: la Linea Gotica tra storia e politiche della memoria.* Rome: Viella, pp.39-63.

Badiali, F., 2013. Il Lago Bracciano di Montese: studio interdisciplinare di un'area sacra nell'Appennino modenese. In: A.M. Stagno, ed., *Montagne incise. Pietre incise. Archeo-*

logia delle risorse nella montagna mediterranea / Craved Mountains. Engraved Stones. Archeologia Postmedievale. Società Ambiente Produzione 17, pp.323-332.

Bartelheim, M., García Sanjuán, L. and Hardenberg, R., 2021. Human-made environments: the development of landscapes as resource assemblages. An introduction. In: M. Bartelheim, L. García Sanjuán and R. Hardenberg, eds., *Human Made Environments. The Development of Landscapes as Resource Assemblages.* RessourcenKulturen 15. Tübingen: Tübingen University Press, pp.7-22.

Bartelheim, M., Hardenberg, R. and Scholten, T., 2021. Ressourcen – RessourcenKomplexe – RessourcenGefüge – RessourcenKulturen. In: T. Schade et al., eds., *Exploring Resources. On Cultural, Spatial and Temporal Dimensions of ResourceCultures.* RessourcenKulturen 13. Tübingen: Tübingen University Press, pp.9-21.

Bartelheim, M., Hardenberg, R., Knopf, T., Scholz, A.K. and Staecker, J., 2015. 'ResourceCultures' – a concept for investigating the use of resources in different societies. In: A. Danielisová and M. Fernández-Götz, eds., *Persistent Economic Ways of Living.* Archaeolingua 35. Budapest: Archaeolingua Alapítvány, pp.39-49.

Bartolini, S., Miozzo, M. and Toni, C., 2007. Il progetto di recupero ambientale dell'area del Lago degli Idoli. In: S. Borchi, ed., *Gli scavi e le indagini ambientali nel sito archeologico del Lago degli Idoli.* Atti della giornata di studio, Poppi, 28 settembre 2006. Stia: Comunità Montana del Casentino, pp.133-143.

Bassani, M., 2019. Shrines and healing waters in ancient Italy: buildings, cults, deities. In: M. Bassani, M. Bolder-Boos and U. Fusco, eds., *Rethinking the Concept of 'Healing Settlements': Water, Cults, Constructions and Contexts in the Ancient World.* Oxford: Archaeopress, pp.9-20.

Battiloro, I., 2017. *The Archaeology of Lucanian Cult Places. Fourth Century BC to Early Imperial Age.* Basingstoke: Routledge.

Bentz, M., Adorno, L., Albers, J., Benz, A., Miß, A. and Müller, J.M., 2016. Das Handwerkviertel von Selinunt: Vorbericht zu den archaischen Strukturen der Kampagnen 2010-2016. *KuBA* 6, pp.59-74.

Berkes, F., 2018. *Sacred Ecology,* 4th ed. New York: Routledge.

Bertani, M.G., 1997. La Grotta di Re Tiberio. In: M. Pacciarelli, ed., *Acque, grotte e dei: 3000 anni di culti preromani in Romagna, Marche e Abruzzo.* Catalogo della mostra, Imola – Ancona 1997. Imola: Musei Civici di Imola, pp.78-90.

Boix, A., 2022. Migration of Athenian potters and painters in the late 5th century BC. In: R. Da Vela, ed., *The Economic Contribution of Migrants to Ancient Societies.* Vol. 2. Heidelberg: Propylaeum, pp.63-65.

Bonamici, M., 1991. Nuovi monumenti di marmo dall'Etruria settentrionale. *Archeologia Classica* 43, pp.795-817.

Bonifacio, R., 2001. I materiali votivi del santuario in località Macchia Porcara di Casalbore. *Ostraka* 10, pp.207-225.

Bosio, L. and Rosada, G., 2020. Le fonti della fonte: l'Italia fisica nella descrizione della Tabula Peutingeriana. In: D. Usai, S. Tuzzato and M. Vidale, eds., *Tales of Three Worlds…* Oxford: Archaeopress, pp.119-134.

Buoite, C. and Zamboni, L., 2008. Gli scavi di Castelfranco Emilia presso il Forte Urbano: un abitato etrusco alla vigilia delle invasioni celtiche. *Quaderni di Archeologia dell'Emilia-Romagna* 21. Florence: All'Insegna del Giglio.

Busino, N., 2008. L'alta valle del Cervaro fra tarda antichità e alto medioevo: dati preliminari per una ricerca topografica. In: C. Ebanista and M. Rotili, eds., *La Campania fra tarda antichità e alto medioevo.* Cimitile: Tavolario, pp.129-152.

Camodeca, G., 2017. Note sull'Irpinia in età romana. In: V. Franciosi, A. Visconti, A. Avagliano and V. Saldautti, eds., *Appellati nomine lupi…* Napoli: Università "Suor Orsola Benincasa", pp.97-128.

Cappuccini, L., ed., 2017. *Monte Giovi. "Fulmini e saette". Da luogo di culto a fortezza di altura.* Insediamenti di altura 2. Florence: All'Insegna del Giglio.

Cardarelli, A., 2006. L'Appennino modenese nell'età del Bronzo. In: A. Cardarelli and L. Malnati, eds., *Atlante dei beni archeologici della Provincia di Modena, II: Montagna.* Florence: All'Insegna del Giglio, pp.40-68.

Cardarelli, A. and Malnati, L., eds., 2003. *Atlante dei beni archeologici della Provincia di Modena, I: Pianura.* Florence: All'Insegna del Giglio.

Cardarelli, A. and Malnati, L., eds., 2006. *Atlante dei beni archeologici della Provincia di Modena, II: Montagna.* Florence: All'Insegna del Giglio.

Cardarelli, A. and Malnati, L., eds., 2009. *Atlante dei beni archeologici della Provincia di Modena, III: Collina e alta pianura.* Florence: All'Insegna del Giglio.

Carfora, P., Mataluna, S. and Renda, G., 2014. Il territorio di Sturno. Fascicolo 8: Comuni di Bellona, Marcianise e Sturno. *Atlante tematico di Topografia Antica,* suppl. 15, pp.227-396.

Cerchiai, L., 2017. Urban civilization. In: A. Naso, ed., *Etruscology.* Boston/Berlin: De Gruyter, pp.617-644.

Colucci Pescatori, G., 1996. *Abellinum romana I.* In: G. Colucci Pescatori, ed., *Storia illustrata di Avellino e dell'Irpinia. L'Irpinia antica 1.* Avellino: Sellino & Barra, pp.97-128.

Colucci Pescatori, G., 2017. Per una storia archeologica dell'Irpinia… In: V. Franciosi et al., eds., *Appellati nomine lupi…* Napoli: Università "Suor Orsola Benincasa", pp.131-206.

Conte, G., forthcoming. Dal contesto all'organizzazione del territorio nella Benevento preromana: la fattoria sannitica in loc. Acquafredda.

Corbier, M., 1991. La transhumance entre le Samnium et l'Apulie… In: *La romanisation du Samnium aux IIe et Ier siècles av. J.-C.* Bibliothèque de l'Institut Français de Naples 9. Naples: Centre Jean Bérard, pp.149-176.

Corbier, M., 2016. Interrogations actuelles sur la transhumance. *Mélanges de l'École française de Rome* 128(2), pp.269-286.

Costello, E. and Svensson, E., eds., 2018. *Historical Archaeologies of Transhumance Across Europe.* Themes in Contemporary Archaeology 6. London: Routledge.

Da Vela, R., 2019. L'officina ceramica etrusca nel centro di Firenze… In: M. Denti and M. Villette, eds., *Fouiller et comprendre les gestes de potiers.* Monographie d'Archéologie Méditerranéenne, Hors-Série 9. Lattes: ADALR, pp.33-41.

Da Vela, R., 2020. Thinking transhumance and agriculture in Hirpinia as dynamic networks of resources (5th century BCE-1st century CE). *Metalla* Sonderheft 10, pp.135-139.

Da Vela, R., 2022a. Le ceramiche miniaturistiche casentinesi e altovaltiberine… In: L. Cappuccini and A. Gaucci, eds., *Officine e artigianato ceramico nei siti etruschi dell'Appennino Tosco-Emiliano…* Pisa/Roma: Bretschneider, pp.281-300.

Da Vela, R., 2022b. Die Familie als soziale Ressource… In: P. Amann, R. Da Vela and R.P. Krämer, eds., *Familie und Gesellschaft bei den Etruskern und Italikern.* Wiener Beiträge zur Alten Geschichte Online.

Da Vela, R., 2023. Networks of cult practices as resources of cohesion… In: R. Da Vela, M. Franceschini and F. Mazzilli, eds., *Networks as Resources for Ancient Communities.* RessourcenKulturen. Tübingen: Tübingen University Press.
Denti, M., 2014. Rites d'abandon et opérations d'oblitération "conservative" à l'âge du Fer. *Revue de l'histoire des religions* 231(4), pp.699-727.
d'Ercole, V. and Cella, E., 2007. Il Guerriero di Capestrano. In: M. Ruggeri, ed., *Guerrieri e re dell'Abruzzo antico.* Pescara: Carsa, pp.33-44.
De Vincenzo, S., 2015. Etruskische Kultstätten in Berglandschaften. In: K. Sporn, S. Ladstätter and M. Kerschner, eds., *Natur – Kult – Raum.* Wien: Österreichisches Archäologisches Institut, pp.63-118.
Diana, B., 1997. Annibale e il passaggio degli Appennini. *Aevum* 61, pp.108-112.
Di Giuseppe, H., 2017. The female *pensum* in the archaic and Hellenistic periods… In: M. Gleba and R. Laurito, eds., *Contextualising Textile Production in Italy in the 1st Millennium BC. Origini* 49. Rome: Gangemi, pp.259-276.
Dionisio, A., 2013. Caratteri dei culti femminili a Corfino. *Archeologia Classica* 64, pp.223-262.
Ducci, C., Paoli, L. and Sarti, S., eds., 2015. *Museo Archeologico Comprensoriale del Mugello e della Val di Sieve a Dicomano. Revisione inventariale…* Florence: Soprintendenza Archeologia della Toscana.
Farello, P., 2002. I reperti ossei. In: J. Ortalli and L. Pini, eds., *Lo scavo archeologico di via Foscolo – Frassinago a Bologna. Quaderni di archeologia dell'Emilia-Romagna* 7, pp.93-104.
Farello, P., 2008. L'economia animale: allevamento, caccia e consumi carnei. In: L. Malnati and D. Neri, eds., *Gli scavi di Castelfranco Emilia… Quaderni di archeologia dell'Emilia-Romagna* 21, pp.183-197.
Fedeli, L., Incammisa, G. and Gruppo Archeologico Casentinese, 2006. Stia (AR)… *Notiziario della Soprintendenza Archeologica della Toscana* 2, pp.146-148.
Ferrando, S., 2017. Antichi riti purificatori dell'Italia preromana: il santuario di Mefitis nella Valle dell'Ansanto. *Otium. Archeologia e Cultura del Mondo Antico* 3, pp.1-18.
Flohr, M., 2013. *The World of the Fullo. Work, Economy, and Society in Roman Italy.* Oxford Studies on the Roman Economy 1. Oxford: Oxford University Press.
Franciosi, V., 2017. Alcune note sul grande *xoanon* della Mefite d'Ansanto. In: V. Franciosi et al., eds., *Appellati nomine lupi…* Napoli: Università "Suor Orsola Benincasa", pp.275-288.
Fre, Z., 2018. *Knowledge Sovereignty among African Cattle Herders.* London: UCL Press.
Gabba, E. and Pasquinucci, M., 1979. *Strutture agrarie e allevamento transumante nell'Italia romana (III – I sec. a.C.).* Biblioteca di Studi Antichi 18. Pisa: Giardini.
Gallo, A., 2015. L'Hirpinia fra III e I sec. a.C.: *agro pubblico*, assegni *viritani*, giurisdizione delegata, assetto istituzionale. *Quaderni Lupiensi di Storia e Diritto* 5, pp.65-96.
Giuntoli, S., 2018. Trent'anni di scavi all'Accesa… In: S. Bruni, ed., *Archeologia a Massa Marittima.* Pisa: ETS, pp.39-56.
Gleba, M., 2008. *Textile Production in Pre-Roman Italy.* Ancient Textile Series 4. Oxford: Oxbow.
Gleba, M., Heitz, C., Landenius Enegren, H. and Meo, F., 2018. At the crossroads of textile cultures: textile production and use at the South Italian archaic site of Ripacandida. *Journal of Mediterranean Archaeology* 31(1), pp.27-51.

Gonin, A., Filoche, G. and Lavigne Delville, P., 2011. Dynamics of access to pastoral resources in a farming area (western Burkina Faso): unveiling rights in open-access regimes. *International Journal of the Commons* 5(2), pp.1049-1061.

Gottarelli, A., ed., 2017. *Archaeology in the Upper Idice Valley. Archaeological and Naturalistic Tourist Guidebook.* Bologna: Te.m.p.l.a.

Govi, E., 2017. Kainua – Marzabotto: the archaeological framework. In: S. Garagnani and A. Gaucci, eds., *Knowledge, Analysis and Innovative Methods… Archeologia e Calcolatori* 28(2), pp.87-97.

Gros, P., 1995. Hercule à Glanum: sanctuaires de transhumance et développement "urbain". *Gallia* 52, pp.311-331.

Guidi, C., 2010. *Materiali lapidei in provincia di Bologna: studio sulle cave storiche e ipotesi di sostenibilità.* MA thesis. Bologna: Università di Bologna.

Harari, M., 2010. Gli Etruschi nella valle del Po. In: G. Bonini, A. Brusa and R. Cervi, eds., *Il paesaggio agrario italiano protostorico e antico.* Quaderni dell'Istituto Alcide Cervi 6, pp.51-57.

Hardenberg, R., Bartelheim, M. and Staecker, J., 2017. The "Resource Turn": a sociocultural perspective on resources. In: A.K. Scholz, M. Bartelheim, R. Hardenberg and J. Staecker, eds., *ResourceCultures…* RessourcenKulturen 5. Tübingen: Tübingen University Press, pp.13-23.

Hardenberg, R., 2021. The rise of a new millet assemblage in India. In: T. Schade et al., eds., *Exploring Resources…* RessourcenKulturen 13. Tübingen: Tübingen University Press, pp.141-156.

Hasaki, E., 2012. Craft apprenticeship in ancient Greece: reaching beyond the masters. In: W. Wendrich, ed., *Archaeology and Apprenticeship.* Tucson: University of Arizona Press, pp.171-202.

Hasaki, E. and Pont, D., 2019. Potters and their wheels in ancient Greece… In: M. Denti and M. Villette, eds., *Fouiller et comprendre les gestes de potiers.* Monographie d'Archéologie Méditerranéenne, Hors-Série 9. Lattes: ADALR, pp.293-314.

Heitz, C., 2015. Mobile pastoralists in archaic southern Italy? The use of social and material evidence for the detection of an ancient economy. *EAZ – Ethnographisch-Archäologische Zeitschrift* 56(1-2), pp.135-164.

Heitz, C., 2022. A mobile model of cultural transfer in pre-Roman southern Italy. In: J. Armstrong, S. Cohen and A. Rhodes-Schroder, eds., *Exchanging Ideas: Trade, Technology and Connectivity in Pre-Roman Italy.* London: Routledge, pp.224-225.

Incammisa, G., 2013. L'insediamento di Serelli… In: F. Trenti, ed., *Museo Archeologico Comprensoriale del Casentino "P. Albertoni".* Bibbiena: Fruska, pp.70-86.

Johannowsky, W., 1991. Circello, Casalbore e Flumeri… In: *La Romanisation du Samnium…* Bibliothèque de l'Institut Français de Naples 9. Naples: Centre Jean Bérard, pp.57-83.

Johannowsky, W., 2001. Ricerche sull'insediamento sannitico a Casalbore. *Ostraka* 10, pp.227-239.

Klocke-Daffa, S., 2017. ResourceKomplexes, networks, and frames: the Sambrata in Madagascar. In: A.K. Scholz et al., eds., *ResourceCultures…* RessourcenKulturen 5. Tübingen: Tübingen University Press, pp.253-270.

La Regina, A., 2000. Il trattato tra Abella e Nola… In: Soprintendenza Archeologica di Roma, ed., *Studi sull'Italia dei Sanniti.* Milano: Electa, pp.214-222.

Letta, C., 1992. I santuari rurali nell'Italia centro-appenninica: valori religiosi e funzione aggregativa. *Mélanges de l'École française de Rome* 104, pp.109-124.

Loffredo, F., 2012. La dea Mefítis: dalle mofete del Sannio ad Abano Terme. *Quaderni del Ramo d'Oro on-line* 5, pp.176-188. Available at: http://www.qro.unisi.it/frontend/sites/default/files/Loffredo_La_dea_Mefitis.pdf [Accessed 25 August 2021].

Malnati, L. and Cardarelli, A., eds., 2009. *Atlante dei beni archeologici della Provincia di Modena, III: Collina e alta pianura.* Florence: All'Insegna del Giglio.

Mader, C., 2020. *Sea Shells in the Mountains and Llamas on the Coast: The Economy of the Paracas Culture (800 to 200 BC) in Southern Peru.* Research into the Archaeology of Non-European Cultures 16. Wiesbaden: Harrassowitz.

Marchesini, L. and Marvelli, S., 2002. Il paesaggio vegetale e le testimonianze dell'attività antropica. In: J. Ortalli and L. Pini, eds., *Lo scavo archeologico di via Foscolo – Frassinago a Bologna. Quaderni di archeologia dell'Emilia-Romagna* 7, pp.105-108.

Marchesini, M., Marvelli, S., Gobbo, I. and Rizzoli, E., 2008. Risultati delle indagini archeobotaniche. In: L. Malnati and D. Neri, eds., *Gli scavi di Castelfranco Emilia… Quaderni di archeologia dell'Emilia-Romagna* 21, pp.198-216.

Marinković, D. and Ristić, D., 2019. Knowledge as identity: an essay in genealogy. *Society Register* 3(1), pp.73-86. Available at: DOI: 10.14746/sr.2019.3.1.04 [Accessed 25 August 2021].

Masi von Eles, P., ed., 1981. *La Romagna tra VI e IV sec. a.C. La necropoli di Montericco e la protostoria romagnola.* Bologna: Santerno.

Menozzi, O., 2020. Introduction… In: G. Adinolfi et al., eds., *Progetto ARS… Frankfurter Elektronische Rundschau zur Altertumskunde* 40, pp.1-52.

Miari, M., 2000. *Stipi votive dell'Etruria Padana.* Corpus delle Stipi Votive in Italia 11. Rome: Bretschneider.

Miari, M., 2003. Un impianto produttivo per ceramica a Savignano sul Rubicone (FO). In: IIPP, ed., *Le comunità della preistoria italiana…* Atti del XXXV Convegno IIPP. Florence: IIPP, pp.499-514.

Miari, M., 2005. Lo spazio del sacro… In: A.M. Comella and S. Mele, eds., *Depositi votivi e culti dell'Italia antica…* Bari: Edipuglia, pp.427-436.

Miari, M., Mazzoni, C., Gentile, C. and Rossi, T., 2008. San Zaccaria – Maiano (RA)… In: M. Ficara and B. Manzelli, eds., *Orme nei campi. Quaderni di archeologia dell'Emilia-Romagna* 20, pp.13-36.

Miller, P., 2017. *Continuity and Change in Etruscan Domestic Architecture: A Study of Building Techniques and Materials from 800-500 BC.* Oxford: Archaeopress.

Nannetti, M.C., Minguzzi, V., Zantedeschi, E. and Esquilini, E., 2010. Le analisi archeometriche. In: E. Govi and G. Sassatelli, eds., *Marzabotto. La casa 1 della Regio IV – Insula 2. I materiali.* Bologna: Ante Quem, pp.421-438.

Nowak-Lipps, C., forthcoming. Siedlungsdynamik und urbane Entwicklung in Hirpinien in republikanischer Zeit. In: F. Daubner, ed., *Italien in hellenistischer Zeit.* International workshop, Trier, 19-20 July 2019.

Oteros-Rozas, E., Ontillera-Sánchez, R., Sanosa, P., Gómez-Baggethun, E., Reyes-García, V. and González, J.A., 2013. Traditional ecological knowledge among transhumant pastoralists in Mediterranean Spain. *Ecology & Society* 18(3), e33. Available at: DOI: 10.5751/ES-05597-180333 [Accessed 8 August 2021].

Pallecchi, P., 2011. I caratteri fisici e l'antropizzazione del territorio. In: P. Perazzi and G. Poggesi, eds., *Carta Archeologica della Provincia di Prato.* Florence: All'Insegna del Giglio, pp.9-16.

Pasquinucci, M., 2004. Montagna e pianura: transumanza e allevamento. In: M. Clavel-Lévêque and E. Hermon, eds., *Espaces intégrés et ressources naturelles dans l'Empire romain.* Besançon: Presses Universitaires de Franche-Comté, pp.165-176.

Peinetti, A., Cattani, M. and Debandi, F., eds., 2019. *Focolari, forni e fornaci tra Neolitico ed Età del Ferro…* Firenze: Istituto Italiano di Preistoria e Protostoria.

Perazzi, P. and Poggesi, G., eds., 2011. *Carta Archeologica della Provincia di Prato. Dalla Preistoria all'età romana.* Florence: All'Insegna del Giglio.

Perkins, P., Nocentini, A. and Warden, P.G., 2020. Ricerca e scavi a Albagino (2017-2019). In: *Tutela & Restauro 2016-2019. Notiziario della Soprintendenza…* 2020, pp.414-416.

Piccioni, A., 2020. *Culti domestici in Italia meridionale ed Etruria.* Regensburg: Schnell & Steiner.

Poggesi, G. and Pagnini, L., 2011. Gonfienti I – IV. In: P. Perazzi and G. Poggesi, eds., *Carta Archeologica della Provincia di Prato…* Florence: All'Insegna del Giglio, pp.314-316.

Poggiali, L., 2017. La ceramica vacuolata dall'insediamento etrusco di Monte Giovi. In: G. Vannini, ed., *Florentia. Studi di Archeologia* 3. Florence: Florence University Press, pp.115-134.

Pugliese, A., 2018. Ricognizioni archeologiche nel territorio di Morra De Sanctis (AV)… *Atti e memorie della Società Magna Grecia* 2. Rome: Fabrizio Serra, pp.105-140.

Rainini, I., 2000. Modelli, forme e strutture insediative nel mondo sannitico. In: Soprintendenza Archeologica di Roma, ed., *Studi sull'Italia dei Sanniti.* Milano: Electa, pp.238-254.

Quercia, A. and Foxhall, L., 2014. Temporality, materiality and women's networks… In: K. Rebay-Salisbury, A. Brysbaert and L. Foxhall, eds., *Knowledge Networks and Craft Traditions in the Ancient World.* Routledge Studies in Archaeology 13. New York/London: Routledge, pp.62-82.

Ricciardi, S. and Calò, C., 2007. Le analisi palinologiche dei sedimenti del Lago degli Idoli. In: S. Borchi, ed., *Gli scavi e le indagini ambientali nel sito archeologico del Lago degli Idoli.* Stia: Comunità Montana del Casentino, pp.109-118.

Rondelli, B., 2006/2007. *Analisi del popolamento dell'Età del Bronzo in Romagna: proposta per un approccio regionale.* PhD thesis. Bologna: Università di Bologna.

Roubis, D., Sogliani, F., Masini, N., Vitale, V., Leucci, G. and Rizzo, E., 2015. Archeologia dei paesaggi montani in Basilicata… *Il Capitale Culturale* 12, pp.385-419. Available at: DOI:10.13138/2039-2362/1145 [Accessed 8 August 2021].

Salvini, M., 1994. L'intervento archeologico in loc. I Monti a San Piero a Sieve: Lo scavo – I materiali. In: Archeologia in Alto Mugello, Mugello, Val di Sieve e il Caso di S. Piero a Sieve. San Piero a Sieve: Il Torchio, pp. 25-38.

Salvini, M., 2009. L'orientalizzante in Mugello e nella Val di Sieve: Il sito etrusco I Monti a San Piero a Sieve. In: L. Cappuccini, C. Ducci, S. Gori and L. Paoli, eds., Museo Archeologico Comprensoriale del Mugello e della Val di Sieve. Florence: Aska, pp. 25-56.

Santillo Frizell, B., 2004. Curing the flock: the use of healing waters in Roman pastoral economy. In: B. Santillo Frizell, ed., *PECUS. Man and Animal in Antiquity.* Proceedings, Swedish Institute in Rome, 9-12 September 2002. Rome: Swedish Institute, pp.80-93.

Santoriello, A. and de Vita, C.B., 2018. Vivere in campagna lungo la via Appia… *Otium* 4. Online available at: http://www.otium.unipg.it/otium/article/view/60 [Accessed 18 December 2019].

Sassatelli, G., 1991. Nuovi dati epigrafici da Marzabotto e il ruolo delle comunità locali nella "fondazione" della città. *Archeologia Classica* 43, pp.693-715.

Schweizer, B., 2021a. Wine as a key resource in the fifth century BC… In: T. Schade et al., eds., *Exploring Resources…* RessourcenKulturen 13. Tübingen: Tübingen University Press, pp.307-328.

Schweizer, B., 2021b. Knowledge-scapes as resources… In: F. Jürcke, J. Montes-Landa and A. Ceccarelli, eds., '*Knowledge-scapes*' in archaeology: an introduction. *Archaeological Review from Cambridge* 35(2), pp.45-59.

Sciacca, F., 2010. Il bucchero. In: G. Bartoloni et al., *Veio: Piazza d'Armi. Materiali ceramici del VII e VI sec. a.C.* In: M. Rendeli, ed., *Ceramica, abitati, territorio…* Collection de l'École Française de Rome 4425. Rome: École Française, pp.215-266.

Scopacasa, R., 2015. *Ancient Samnium: Settlement, Culture, and Identity between History and Archaeology.* Oxford: Oxford University Press.

Seidel, U., 2017. From typo-chronology to inter- and intra-site variety: the 'Michelsberg' pottery of South Germany. In: C. Heitz and R. Stapfer, eds., *Mobility and Pottery Production.* Leiden: Sidestone Press, pp.89-114.

Settesoldi, R., 2013. La stipe votiva del Lago degli Idoli. In: F. Trenti, ed., *Museo Archeologico Comprensoriale del Casentino "P. Albertoni".* Bibbiena: Fruska, pp.97-126.

Serafini, M.A., 2019. Le ceramiche d'impasto vacuolare del sito di Pietramarina. *Florentia. Studi di Archeologia* 4, pp.143-159.

Sofroniew, A., 2011. Women's work: the dedication of loom weights in the sanctuaries of southern Italy. *Pallas* 86, pp.291-309.

Soma, T. and Schlecht, E., 2018. The relevance of herders' local ecological knowledge on coping with livestock losses during harsh winters in western Mongolia. *Pastoralism: Research, Policy and Practice* 8(1), e3. Available at: DOI: 10.1186/s13570-017-0108-y [Accessed 8 August 2021].

Sorrentino, C. and Landini, L., 2015. Una deposizione in contesto sacrificale di *Sus scrofa* da Podere Ortaglia, Peccioli (Pisa). *Annali dell'Università degli Studi di Ferrara. Museologia scientifica e naturalistica* 11, pp.97-100.

Stapfer, R., 2017. Special pottery in 'Cortaillod' settlements of Neolithic western Switzerland (3900-3500 BC). In: C. Heitz and R. Stapfer, eds., *Mobility and Pottery Production.* Leiden: Sidestone Press, pp.141-168.

Stek, T., 2009. *Cult Places and Cultural Change in Republican Italy: A Contextual Approach to Religious Aspects of Rural Society after the Roman Conquest.* Amsterdam Archaeological Studies 14. Amsterdam: Amsterdam University Press.

Stoddart, S., 2016. Etruscan Italy: physical geography and environment. In: S. Bell and A. Carpino, eds., *A Companion to the Etruscans.* Chichester: Wiley, pp.3-54.

Tamou, C., de Boer, I.J.M., Ripoll-Bosch, R. and Oosting, S.J., 2018. Traditional ecological knowledge underlying herding decisions of pastoralists. *Animal* 12(4), pp.831-843. Available at: DOI: 10.1017/S1751731117002130 [Accessed 8 August 2021].

Tomay, L., 2012. Processi di trasformazione dello spazio urbano a Benevento tra IV e III sec. a.C. In: *La Magna Grecia da Pirro ad Annibale.* Atti del LII Convegno, Taranto, 27-30 settembre 2012. Taranto: Istituto per la storia e l'archeologia della Magna Grecia, pp.264-285.

Trentacoste, A., Lightfoot, E., Le Roux, P., Buckley, M., Kansa, S.W., Esposito, C. and Gleba, M., 2020. Heading for the hills? A multi-isotope study of sheep management in first millennium BC Italy. *Journal of Archaeological Science: Reports* 29, e102036. Available at: DOI:10.1016/j.jasrep.2019.102036 [Accessed 25 August 2021].

Teuber, S. and Schweizer, B., 2020. Resources redefined: resources and ResourceComplexes. In: S. Teuber et al., eds., *Waters: Conference Proceedings for "Waters as a Resource"…* RessourcenKulturen 11. Tübingen: Tübingen University Press, pp.9-19.

Vanni, E., 2019. Sistemi agro-silvo-pastorali nella Toscana meridionale… In: S. Bertoldi, M. Putti and E. Vanni, eds., *Archeologia e storia dei paesaggi senesi…* Florence: All'Insegna del Giglio, pp.87-112.

van Wonterghem, F., 1999. Il culto di Ercole e la pastorizia nell'Italia centrale. In: E. Petrocelli, ed., *La civiltà della transumanza…* Isernia: Cosmo Iannone, pp.413-428.

Zamboni, L., 2010. Ritualità o riutilizzo? Riflessioni sul vasellame "miniaturistico" in Etruria Padana. *Pagani e Cristiani. Forme ed attestazioni di religiosità nel mondo antico in Emilia* 8, pp.9-46.

Zamboni, L., 2012. Testimonianze arcaiche in Emilia occidentale: una cultura di frontiera alla luce delle nuove indagini. In: M.P. Bologna and M. Ornaghi, eds., *Novissima studia. Dieci anni di antichistica milanese. Quaderni di Acme* 129. Milano: Cisalpino, pp.1-29.

Zamboni, L., 2018. *Sepolture arcaiche della pianura emiliana. Il riconoscimento di una società di frontiera.* Reditus. Rome: Quasar.

Urban Mining? A new look at taphonomic processes as key to the reconstruction of waste and resource management in Late La Tène society

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Waste is one of the most important sources of information for (prehistoric) societies. As part of an interdisciplinary research project on the Late La Tène period settlement at Basel-Gasfabrik (CH), ceramic sherds, animal bones, archaeological sediments as well as metal and glass objects from different archaeological features were examined for taphonomic alterations. Our results show significant differences between different features and materials. Furthermore, there is evidence of middens, which probably served as depots for certain materials. Our results suggest that waste was not simply seen as rubbish but was stored and reused or recycled. Thus, concepts of "waste" and "resource" can be entangled with each other and are determined by value concepts and social practices.

Statistical analysis, recycling, waste disposal practices, material stores, settlement, pit fillings, interdisciplinary research

1 Milena Müller-Kissing: Stratigraphy and Features; David Brönnimann: Geoarchaeology; Johannes Wimmer: Archaeological Finds; Barbara Stopp: Archaeozoology; Hannele Rissanen: Project Coordination and Data; Norbert Spichtig: Project Coordination and Data.

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Introduction

Uselessness, dirtiness or even danger are attributes that modern western society associates with waste. Even today a lot of what we perceive as trash is still considered taboo to reuse and will be disposed of permanently (Wimmer, et al., 2022).

However, in recent decades our attitude towards waste management and recycling has been challenged and changed. Concepts like resource recovery and waste minimisation have become more and more prevalent in everyday life (Cossu and Williams, 2015.). In view of the increasing competition for scarce natural resources, the use of secondary raw materials from domestic sources can help to conserve Earth's natural resources and thereby secure the life support systems of present and future generations.

Today the German Environment Agency defines Urban Mining as follows:

"*Urban Mining refers to the use not of only inner-city deposits but of the entire stock of long-lived goods in general. These goods include consumer products like electrical and electronic devices as well as infrastructures, buildings, and landfills. We are surrounded by a man-made warehouse which currently contains more than 50 billion tonnes of materials and is expected to continue to grow by another ten tonnes per capita every year.*" (Umweltbundesamt, 2017).

While "Urban Mining" is a fairly recent expression, the idea that materials that were no longer suitable to fulfil their primary functions nevertheless were not worthless but could be repurposed at any time and for a wide variety of uses is probably as old as the human experience. Furthermore, waste is without a doubt one of the most important sources of information for (prehistoric) societies and allows insights into crafts and subsistence as well as every day and ritual practices (Wimmer, et al., 2022).

In the Later La Tène settlement of Basel-Gasfabrik (CH) concepts of waste, waste disposal, resources and material recycling are closely interlinked in a complex pattern. To take a closer look at how waste was treated in the settlement, ceramic sherds, animal bones and archaeological sediments as well as metal and glass objects and other materials were examined as part of an interdisciplinary research project (Brönnimann, et al., 2020b; Wimmer, 2022; Wimmer, et al., 2022).

The Site Basel-Gasfabrik and the Study Area

The site of Basel-Gasfabrik is located on the Lower Terrace of the Rhine River, which is composed of Rhine gravel and an overlying silty loam (overbank deposit). The site was discovered in 1911 and is situated 2 km north of today's Basel city centre on the banks of the River Rhine (Fig. 1). Stretching over c. 17 ha, the unfortified settlement dates from the Later La Tène period (170/150 to 100/80 BC) (Wimmer, 2022; Brönnimann et al., 2022). Countless coins and Mediterranean wine amphorae emphasised its importance within a long-distance trade network (Nick, 2015; Martin-Kilcher, et al., 2013). Two associated cemeteries with about 200 known inhumations were situated north of the settlement (Rissanen, 2025). Large parts of the settlement have been excavated, with the bulk of the work taking place between the 1980s and 2010s. It has produced an extraordinary wealth of data and provided extensive archaeological, biological and geoarchaeological insight (Schaer and Stopp, 2005; Jud, 2008; Pichler, et al., 2015; Pichler, et al., 2017; Brönnimann, et al., 2020b ; Brönnimann et al., 2022). The features recorded over the years comprised almost 600 large pits, which had probably served mainly as silos and cellars and yielded a substantial amount of finds (Wimmer, et al., 2022); other features included a small number of wells and numerous sections of ditches and post pits. Remains of stratified archaeological layers only survived in natural depressions in the ground.

During the excavations at Basel-Gasfabrik, a research tradition focused on interdisciplinary cooperation has been established (Pichler, et. al., 2017). This tradition has been continued in the latest research project “Thinking Outside the Pits”. Its main objective was to combine the results of several different scientific disciplines to achieve an integrated understanding of a selected area of the settlement and to ultimately help better understand the settlement as a whole. To achieve this goal, different researchers contributed and shared their results from analyses of the archaeological finds, the stratigraphy and features, the animal bones and plant remains as well as the micromorphological examination of soil thin sections of various archaeological layers and structures within the selected area. Information from other disciplines like biological anthropology, material analysis and numismatics could also be integrated at various points.

A well-preserved section in the western part of the settlement was selected for the purposes of this project (Fig. 1). Located in an extended natural depression, it yielded a sequence of archaeological layers measuring a total of c. 50 cm in thickness (Rentzel, 1997; Brönnimann, et al., 2020b). Four archaeological horizons (aH1-aH4) extending over the entire section were identified during the excavations. Ditches, large pits and post pits were also recorded (Jud and Spichtig, 1995; Hecht, et al., 2004; Brönnimann, et al., 2020a).

In the scope of the research project, ceramic sherds, animal bones and archaeological sediments from one pit (pit 287), sections of two ditches (ditches 7 and 9) and the archaeological horizons aH1-aH4 of a selected area were closely examined for taphonomic alterations (Fig. 1C) (Brönnimann, et al., 2020b).

The Features

The stratigraphic sequence comprises four main archaeological horizons (aH1-aH4) that differ from each other both due to their characteristics as well as the sedimentation processes that led to their formation (Brönnimann, et al., 2020a; 2020b).

The oldest preserved archaeological horizon **aH1** formed after the ground had been artificially truncated in this part of the settlement, taking away parts of the natural loam as well as most traces of former settlement activities. It was most likely formed by repeated trampling and reinforcement of the surface and presents as a partially diffuse gravel horizon. The archaeological finds, animal bones and gravel that were included in this occupational layer were most likely intentionally deposited to pave the muddy surface (Brönnimann, et al., 2020a). No other settlement features could be associated with it.

Overlying aH1 was a layer of dark brown loam (**aH2**) comprised mostly of reworked local loam, coloured darker due to the presence of microcharcoal (Brönnimann, et al., 2020a). Embedded in the sediment was a considerable amount of archaeological finds and animal bones. The micromorphological examination revealed localised differences both with regard to its composition and formation processes (Brönnimann, et al., 2020b). It seems that in most parts of the study area aH2 accumulated over time, most likely due to repeated input of sediment and possible reinforcement with a mixture of ceramic shards, animal bones and other materials. There is however at least one part of the study area, where aH2 was homogenized and mixed with ashes, dung and faeces, which could be due to intense garden cultivation (tillage and manuring) (Brönnimann, et al., 2020a; 2020b).

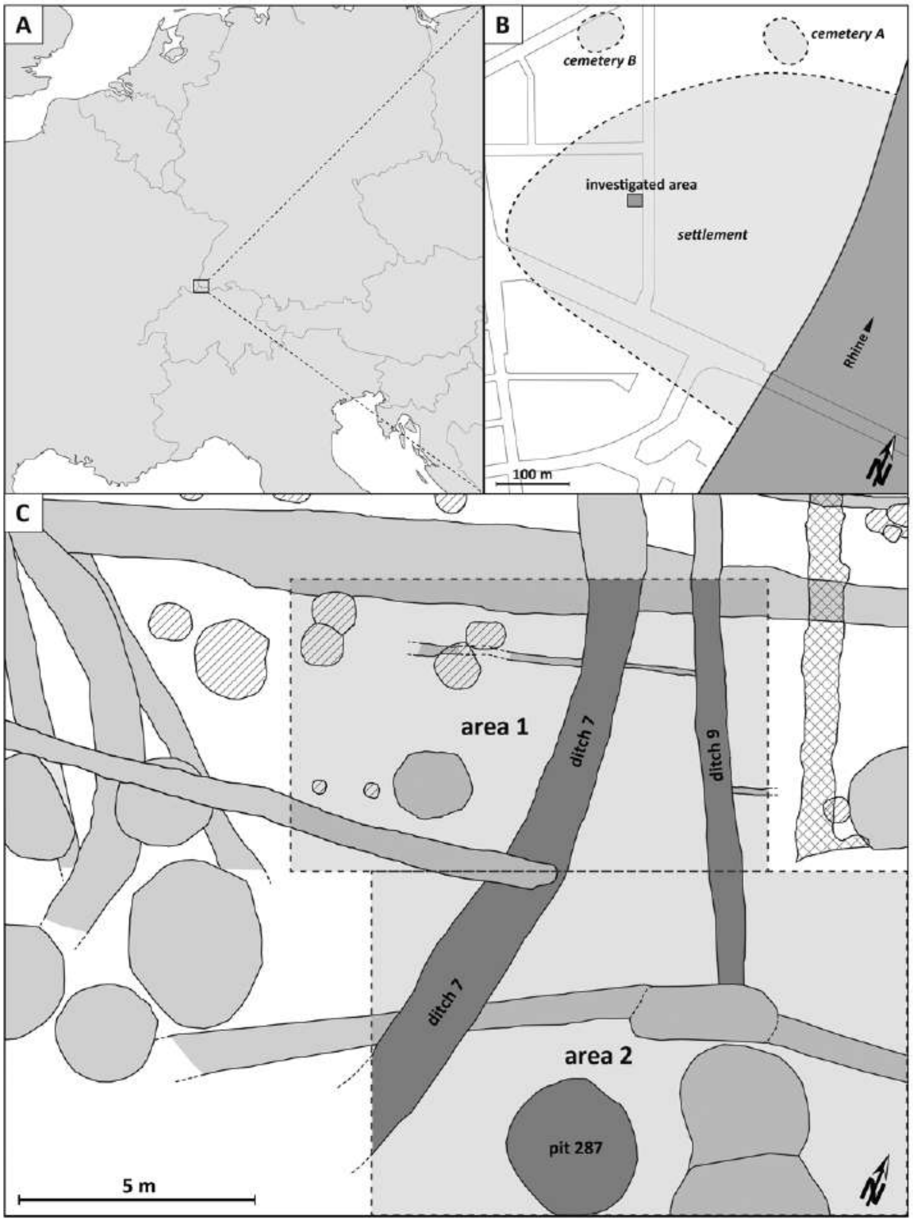

Figure 1: Location of the settlement of Basel-Gasfabrik in north-western Switzerland (A) on the left bank of the River Rhine in the city of Basel. The area examined (dark-grey zone) is situated in the western part of the settlement (B). Bottom (C): Plan of the examined areas and features. The ditch sections (ditch 7 and 9) and pit 287 are marked in dark grey. The finds from the archaeological horizons aH1-aH4 were examined in area 1, while in area 2 only those from aH1 were analysed. Hatching and cross-hatching denotes later intrusions and disturbances (from: Brönnimann, et. al., 2020b, Figure 2).

Both ditches as well as the pit that were selected for the presented study were dug from the surface of aH2.

Archaeological horizon **aH3** consisted mainly of pebbles from the Rhine gravel, which had been selected for their size (Brönnimann, et al., 2020a; 2020b). It seems to have been intentionally deposited over a wide area and signifies a break with the former internal settlement structure within the study area and maybe beyond.

The stratigraphic sequence ends with **aH4**, a modern-era plough horizon. The La Tène period finds in it suggest that the area continued to be settled after aH3 had been deposited, unfortunately not much is known about the settlement activities at that time due to intensive modern interference (Brönnimann, et al., 2020b).

Ditch 7 is a multi-phased ditch. In the bottom section, its walls were steep and clearly distinguishable from the base, suggesting that it had been lined. **Ditch 9** was shallower and trough-shaped in section. The bottommost ditch fill of both ditches consisted of microlaminated loam, which had gradually accumulated and washed in from the surrounding surface naturally. In both cases, it was overlain by one or two different intentional fills (Brönnimann, et al., 2020a; 2020b).

Pit 287 was round, had a maximum diameter of about 3 m and a depth of 2.2 m. Because its walls were vertical, it contained some kind of stabilising internal structure, since the pit walls in the unstable Rhine gravel would otherwise have collapsed within a short time. Its first fill after it had become redundant as a storage or cellar pit consisted of a sediment containing charcoal, large quantities of finds and a high proportion of gravel and debris. It then probably lay idle for a while, as indicated by a natural accumulation of amphibian remains. The internal structure was also removed at this time, which led to a partial collapse of the surrounding natural loam and Rhine gravel (Brönnimann, et al., 2020a). A microlaminated sequence of ash layers was identified in the middle section of the pit fill. Such well-preserved, finely layered deposits are usually found in roofed areas where they are associated with successive accumulation by repeated trampling – in the case of ashes and charcoal often in the context of craftworking (Brönnimann, et al., 2020b). The pit was then completely filled with loam containing charcoal, reworked ashes, coprolite fragments and numerous other (micro-) artefacts (Brönnimann, et al., 2020b).

A short while later, aH3 was deposited above it. The onset of compaction processes led to the layers subsiding, which in turn resulted in the formation of a shallow depression. This depression contained a coarsely bedded fill, which was interpreted as the result of the area being repeatedly levelled to counteract the subsidence (Brönnimann, et al., 2020b).

Material and Methods

The sediments, animal bones and ceramic sherds from these archaeological features in the selected areas of study (Fig. 1) were assessed in respect of 21 taphonomic proxies. These manifest themselves as changes on the artefact or sediment and allow us to draw conclusions concerning the way in which they were treated and what kinds of depositional, redepositional and postdepositional processes were involved. The aim was to determine which taphonomic features can be identified and which processes they can be linked to (Brönnimann, et al., 2020b).

To keep the database as large as possible, the study was supplemented by additional results of the micromorphological examination of thin sections from other pits, ditches and profile sections outside the selected areas of study (Brönnimann, et al., 2020a; 2020b).

Among the archaeological finds, pottery was chosen as the main focus due to the large number of available shards as well as its high susceptibility to taphonomic alteration and its rather quick progress through its life cycles (Brönnimann, et al., 2020b). However, several hundred metal and glass finds from the study area and beyond have since been analysed more closely (Wimmer, 2022) and can now be added to current analysis. As materials with harder surfaces, metal and glass retain taphonomic markers like scratches a lot less often than ceramic sherds and animal bones and corrosion, especially on iron artefacts, can additionally obscure other changes. Therefore, taphonomic alterations are much harder to detect on these materials. However, fragment size and weight still present two valuable markers for the state of preservation of those artefacts (Wimmer, 2022; Wimmer, et al., 2022).

The Taphonomic Processes

In order to be able to compare the formation of taphonomic features, each proxy was linked to one or more pre-defined processes, which could have been involved in the formation of the proxy concerned. Only those processes that tend to leave visible traces on the objects or sediments were assessed, like mechanical stress, redeposition, exposure, covering and postdepositional processes. The focus in defining these processes was not on an object's primary use but on what occurred after it had ceased to be used and before it was deposited in the ground (Brönnimann, et al., 2020b).

The next step involved estimating how much or how often each proxy recorded was impacted by each process. The weighting scale ranged from 1 (the proxy is only slightly/rarely impacted by the process) to 3 (the proxy is severely/often impacted by the process). Positive values indicate that a process supports or enables the formation of a proxy, whilst a negative value means that a process prevents a feature from developing. Weighting and linkage were largely based on experience and estimates because experimental archaeological studies are rare and very few include any quantitative specifications (Brönnimann, et al., 2020b).

Moreover, the intensity of the taphonomic processes is closely linked to site-immanent factors such as the hardness or permeability of the substrate or the quality of the pottery etc. Because of the lack of experimental data, the estimated weighting of the proxies was evaluated using statistical methods like confirmatory factor analysis (CFA). The test revealed that the weightings and the CFA loadings were congruent in most cases with two exceptions: impact of heat on animal bones differed from that on pottery and gnawing traces on animal bones did not appear to be synchronous with the other exposure proxies. In those cases, the behaviours of the proxies can be explained by a different (heat) source, time period or place, so that the discrepancies do not contradict the weighting of the proxies. Overall, the CFA confirmed the estimated weightings (Brönnimann, et al., 2020b).

Results

Comparing the proxies between the different feature types (pit, ditches and archaeological horizons) revealed significant differences in the taphonomic alteration of the animal bones, ceramic sherds and sediments (Fig. 2).

The artefacts and sediments in lower pit fills exhibited the least taphonomic alteration (= best state of preservation) and show distinct signs of covering and consequently less signs of exposure and mechanical stress (Brönnimann, et al., 2020b).

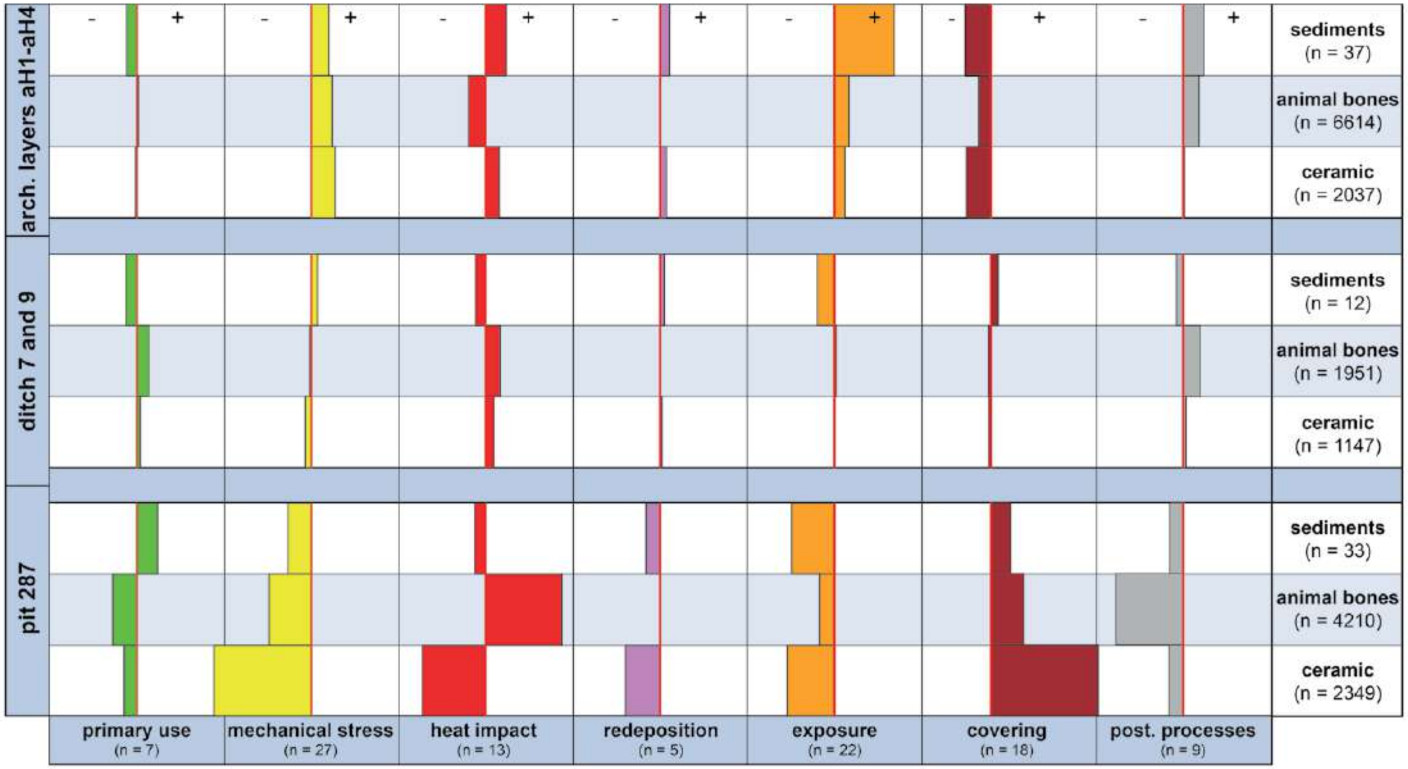

Figure 2: The seven taphonomic processes compared for pit 287, the two ditches and the four archaeological horizons, arranged by ceramic sherds, animal bones and sediments. Bars to the left (-) show slight/rare manifestation, whilst bars to the right (+) signify strong/frequent manifestation of the process. The axial red line marks the average manifestation. The sum of weighting marks for each process is given in brackets (from: Brönnimann, et. al., 2020b, Figure 7).

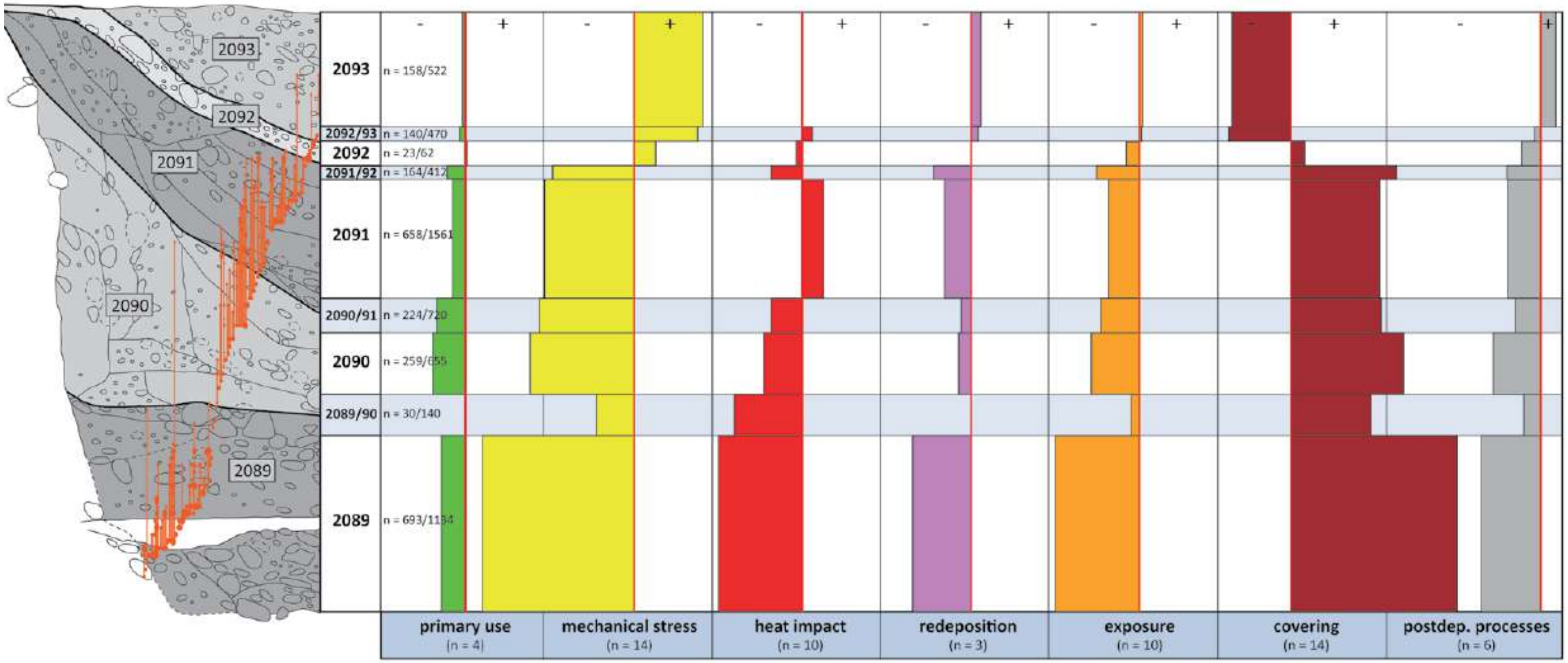

Figure 3: The impact of the taphonomic processes on the different fills (stratigraphic units) of pit 287 (pottery and animal bones combined). Bars to the left show slight/rare manifestation, whilst bars to the right signify strong/frequent manifestation of the process. The orange dots and lines in the image on the left denote joins between ceramic fragments (from: Brönnimann, et. al., 2020b, Figure 8).

The same materials from archaeological horizons provided the opposite picture, i.e. an intensive taphonomic alteration (= poor state of preservation).

Meanwhile, the materials from ditches bore average taphonomic alteration but showed significant differences between the two ditches 7 and 9 in regard to mechanical stress, exposure and heat impact. This clearly shows that ditches and ditch fillings are by no means homogenous features (Brönnimann, et al., 2020b).

Furthermore, the good state of preservation present in lower pit fills could not be observed in the uppermost part of the pit fills (Fig. 3). Those instead showed strong taphonomic alteration of the artefacts. This was probably due to gradual processes of subsidence and repeated levelling, which means that the objects in the topmost fills lay exposed and were trampled for certain periods of time. It is also possible that at least some of the material used to level and refill corresponding depressions above the pits was taken from other archaeological contexts like the archaeological horizons. Then the objects comprised therein would have already been exposed to taphonomic alteration before they became part of the topmost pit fills.

Although there were some discrepancies, animal bones, ceramic sherds and sediments reacted similarly in most processes. However, the pottery and bone fragments behaved differently concerning their use and the influence of heat or fire (Fig. 2). In case of pottery, various reuses in a craftworking or domestic context may be considered. Animal bones, on the other hand, may have been used as fuel (Brönnimann, et al., 2020a).

The strikingly good state of preservation observed in objects from the lower pit fills (Fig. 3) was because they were quickly deposited and covered and thus withdrawn from everyday use in the settlement (Brönnimann, et al., 2020b). Such intentional and rapid pit fillings were recorded in several instances on the site (Rentzel, 1998; Jud, 2008; Brönnimann and Rissanen, 2017; Brönnimann, et al., 2020b).

This required large amounts of material to be available at that particular time. We have therefore put forward the hypothesis that material deposits or middens existed where pottery sherds, animal bones and sediments but also other waste material from “daily life” like iron slag, hearth plates and oven fragments were stored together in a location that was only rarely exposed to settlement activities. The presence of gnawing marks on animal bones, however, indicates that these middens were at least temporarily accessible (Brönnimann, et al., 2020b).

Rather homogeneous mixing of the different materials was also observed in pit 287 and taken as an indication that these resources were not stored separately but intermixed without a discernible pattern (Brönnimann, et al., 2020b). The almost complete lack of conjoining sherds and slight differences in the taphonomic alteration between the bottommost and middle fills in the examined pit (Fig. 3) indicates that at least two different “material stores” were used to rapidly fill it in. This is further supported by the proposed short-term hiatus (see The Features: pit 287) in the filling process between those fills (Brönnimann, et. al., 2020b) and was observed for other pits as well (Brönnimann and Rentzel, in prep.).

In contrast to the animal bones and ceramic sherds, metal and glass objects have been found in much lower quantity. Furthermore, their fragmentation observed in the study area and other parts of the settlement was generally rather consistent and only minor differences in fragmentation occurred between objects from the lower pit fillings and from other types of archaeological features (Fig. 4). The only exceptions were 27 completely preserved fibulae, 24 of which were found in various pit fillings. Conjoining fragments can

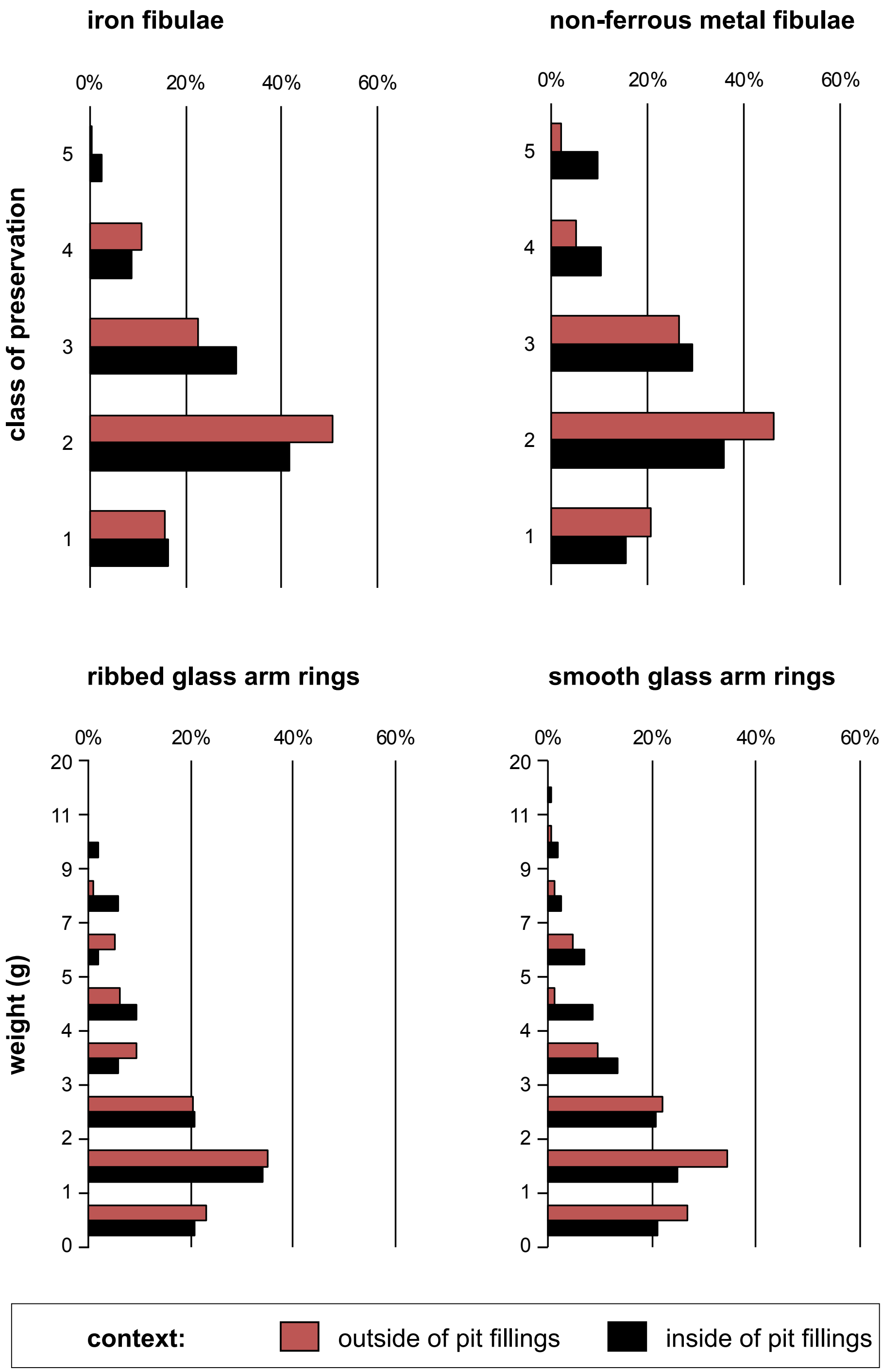

Figure 4: State of preservation of fibulae and glass arm rings found inside of pit fillings and outside of pit fillings. Class of preservation denotes how many parts of a fibula have been preserved (pin, head, bow and foot). Preservation class "5" comprises all completely preserved fibulae (from: Wimmer, et al., 2022).

be hard to detect due to corrosion (iron objects) and chipped edges (glass objects) but seem exceptionally rare nonetheless (Rissanen, 1999). It is therefore likely that the preserved fragments are all that remained of the individual objects. For the majority of glass arm rings for example only 20% of the original object remained (Wimmer, 2022; Wimmer, et al., 2022).

The materials used to produce metal and glass objects can be considered of comparatively higher value, since procuring, processing and transporting the necessary primary resources was a much more complex and time-consuming endeavour. And since said primary resources could not be sourced locally, the production was probably not (entirely) under local control. So, metal and glass objects were most likely present in smaller numbers than ceramic vessels and animal bones to begin with.

The differing patterns of taphonomic alteration across different features between animal bones and ceramic sherds on the one hand and glass and metal objects on the other hand may indicate that the latter were not placed in middens after they had outlived their primary uses by breaking. Instead, it is more likely that at least the bigger fragments were collected and recycled due to their material value and how inherently recyclable the materials are (Wimmer, et al., 2022). Therefore, usually only smaller fragments that might not have merited recycling ended up in the archaeological features. Rare bigger fragments might have been lost and must then have quickly been removed from the collective perceptual space (e.g. by covering) to not have been picked up again. In both cases, at least some of the fragments or even most of them were probably directly embedded in sediment. Then, as undetected parts of the sediment, some ended up in the archaeological features (Fig. 5). Consequently, the similar level of taphonomic alteration on metal and glass objects across different feature types can be explained by the similar paths they took before ending up in those features (Wimmer, et al., 2022). Notable exceptions are completely preserved objects that probably did not end up in pit fillings as part of regular waste disposal practices but are more likely connected to intentional deposits or funerary contexts (Wimmer, 2022).

Urban Mining in the Iron Age

Circling back to the initial question of this article, it is clear that the settlement of Basel-Gasfabrik could be "mined" for resources in different ways, starting with the procurement of raw materials.

A specialised use was observed in the naturally occurring loam (overbank deposit) and Rhine gravel (Brönnimann, et al., 2020b), great amounts of which came to light anytime the ground was broken. The calcareous loam (C horizon overbank deposit) was used as daub, whilst the decalcified, clayey loam (Bt horizon overbank deposit) was utilised in the production of pottery or in the construction of ovens or hearths (Brönnimann, et al., 2020b; Steiner, 2012). Rhine gravel was severely underrepresented and rarely occurred in the archaeological layers. One exception was layer aH3, which consisted of similar-sized large pebbles from the Rhine gravel. This suggests that the pebbles were preselected for their size, stored for a time and then used for specific purposes, for example to form this archaeological horizon (Brönnimann, et al., 2020b).

Apart from this type of Urban Mining, the settlement of Basel-Gasfabrik also shows Urban Mining in a way that more closely resembles today's definition especially in the form of materials recycling (Cossu and Williams, 2015).

On the one hand, the differences in the taphonomic alteration of the animal bones and ceramic sherds from the pit and the archaeological layers show that objects of the same

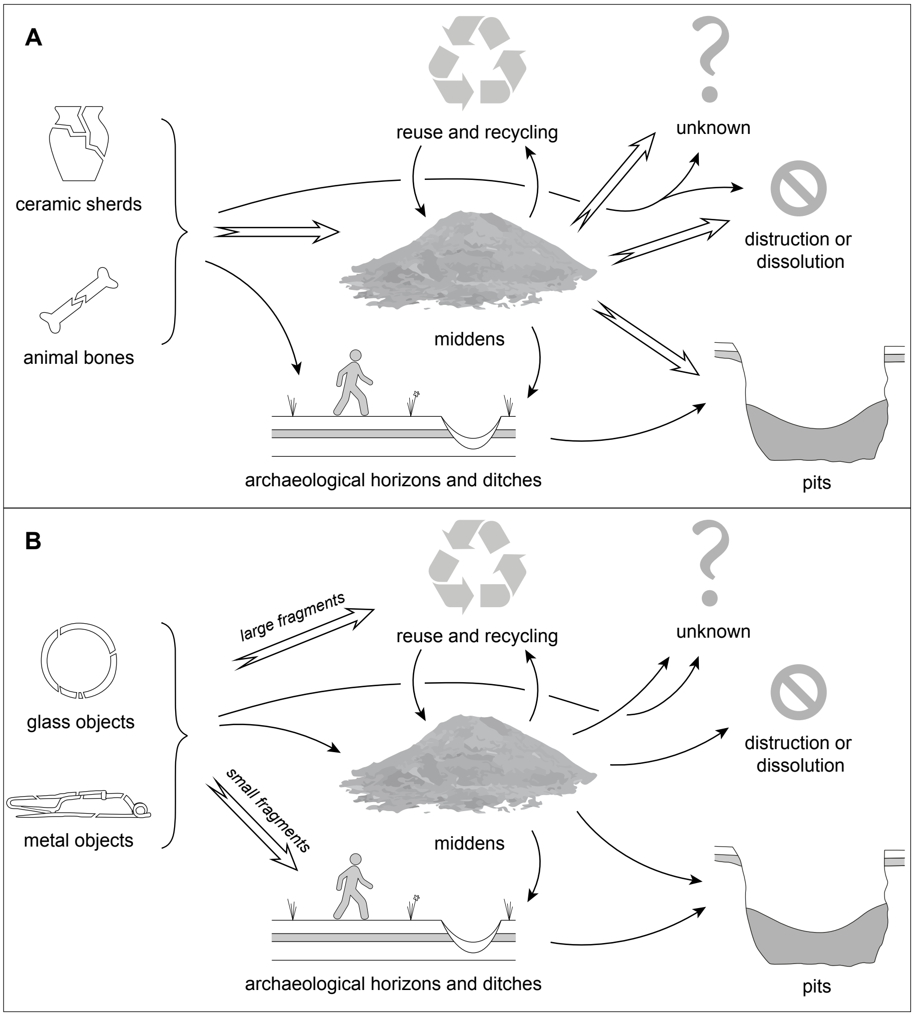

Figure 5: The different ways different objects and materials were treated after they outlived their primary uses. While a large number of ceramic sherds and animal bones (A) where at least temporarily placed in middens after they had outlived their primary usefulness, a lot of glass and metal objects (B) on the other hand seem to have been either recycled at once (especially large fragments) or ended up embedded in sediment (especially smaller fragments) (courtesy of Wimmer).

type may have taken different paths (Fig. 5A). On the other hand, the pattern of taphonomic alteration on metal and glass objects indicates the same path for different objects (Fig. 5B).

There is a wide variety of ways how objects and sediments were used and reused in the settlement and how they finally ended up in the ground or became undetectable (Brönnimann, et al., 2020b; Wimmer, et al., 2022).

One proportion of the pottery and animal bone fragments ended up directly in an active zone like trampled surfaces and was incorporated in the everyday life of the settlement. Whether the objects served a particular purpose (e.g. to pave a surface) or whether they “participated” in everyday life in another way, can no longer be ascertained.

All we can say is that they experienced severe taphonomic alteration (Brönnimann, et al., 2020b).

Another proportion of the artefacts was likely deposited in presumed material stores (middens), where they were accessible but did not go through any recognisable processes of transformation, unless they were retrieved for particular purposes and reused, for instance for household chores or craftworking (Brönnimann, et al., 2020b). At least some of these reused objects were subsequently deposited in the material stores for a second time and – along with material with hardly any taphonomic alteration – later used to (partially) fill a pit (Brönnimann, et al., 2020b). We can assume that whole material stores, or perhaps just parts of them, were "disposed of" and made inaccessible in pit 287. It is noteworthy, that by depositing the material this way, it fulfils yet another (probably final) purpose in filling the no longer used pit (Brönnimann, et al., 2020b).

Although most pits yielded several thousand ceramic fragments and many conjoining sherds were found within each pit, it was hardly ever possible to reconstruct whole vessels. The same can be said for the animal bones. Whilst the archaeological analyses showed that many pits yielded large minimum numbers of cattle, pig and sheep/goat individuals, each pit generally contained no more than 10% of an entire skeleton of a single individual. This means that only a remarkably small proportion of the original vessel or individual animal skeleton ended up in any one pit. This raises the question of what became of the remainder. In contrast to other organic material, neither the animal bones nor the pottery would have decayed completely (Brönnimann, et al., 2020b). In addition, the post-excavation work that has been carried out to date has rarely revealed conjoining sherds or fragments from different pits (Jud, 2008). While it cannot be definitely discarded as a possibility, distribution between various pits most likely cannot therefore have been the only reason for the absence of material. Another possibility is that parts of the vessel or carcass remained out in the open and were incorporated in the archaeological horizons. This theory is difficult to substantiate archaeologically since the large number and strong taphonomic alteration of ceramic sherds in the archaeological horizons including change of colour and rounding of edges makes the identification of conjoining sherds almost impossible.

Yet another possibility is that some of the ceramic sherds or animal bone fragments were reused as raw material and almost completely destroyed in the process. Ceramic fragments were used as grog in local pottery production (Steiner, 2012), whilst bone was probably used as fuel (Brönnimann, et al., 2020a; 2020b). This possible way of extracting energy from waste can be seen as yet another very old concept with important modern-day applications in the field or resource recovery (Cossu and Williams, 2015). Ultimately, we cannot exclude the possibility that some of the pottery or animal bones were disposed of in a manner that cannot be detected by archaeological means, for instance by dumping them in the Rhine (Brönnimann, et al., 2020b).

In contrast, metal and glass objects seem to have been recycled as well but have undergone a somewhat different journey from the moment their primary use was no longer possible. While animal bones and ceramic sherds were placed in middens, where they could be reused more or less spontaneously whenever they were needed, broken glass and metal fragments were collected almost systematically and mostly recycled to craft new objects (Fig. 5) (Brönnimann, et al., 2020b; Wimmer, et al., 2022). While the proposed middens were used like man-made raw material deposits, the treatment of

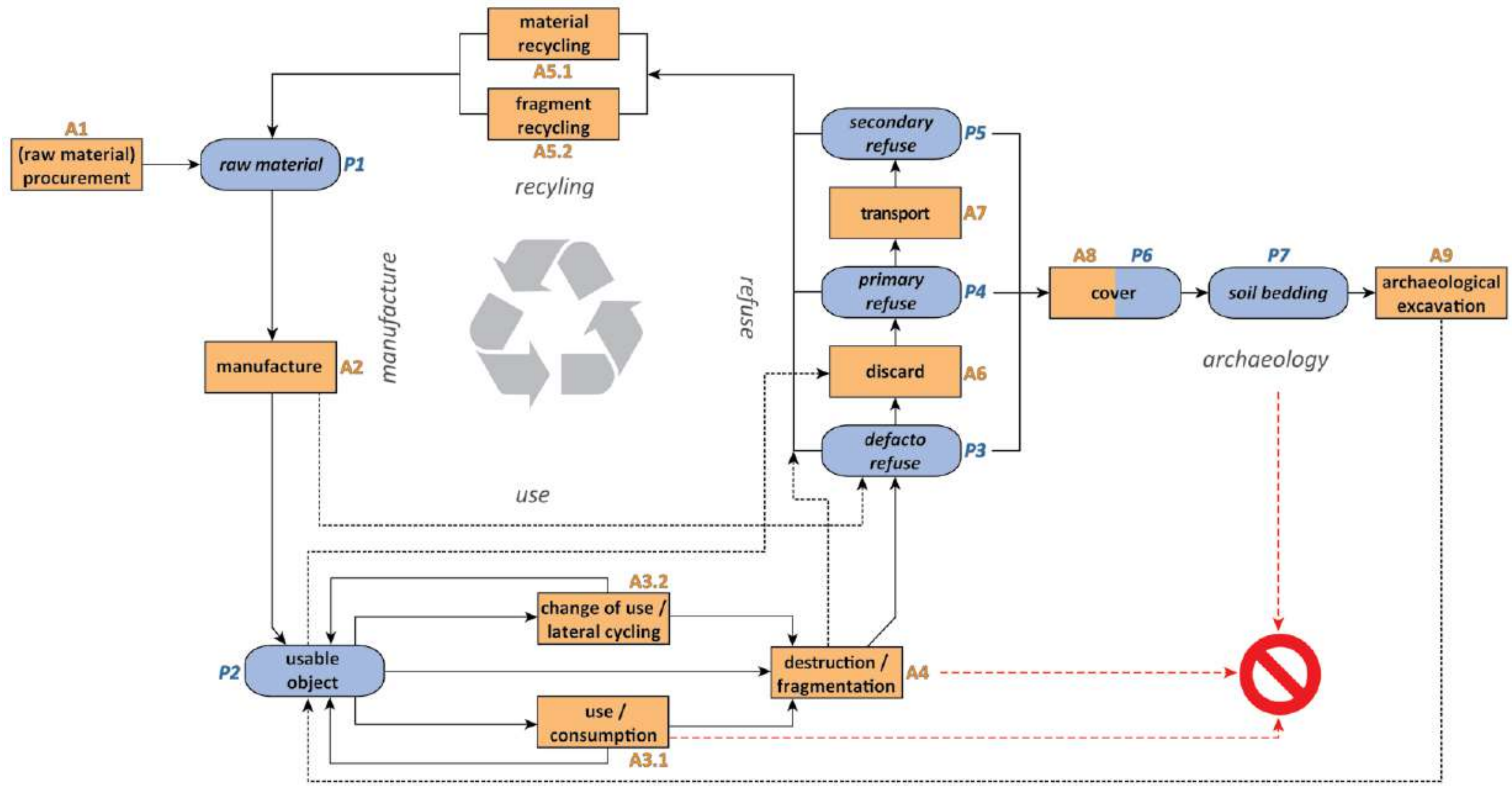

Figure 6: Flowchart based on Schiffer (1972) and extended to reflect in a somewhat simplified manner the genesis, use, re-use and recycling as well as the disposal, destruction and deposition of an object in the ground and to illustrate this as part of a partially closed cycle. "Passive phases" are marked in blue, the "activated phases" in orange. The red symbol signifies the destruction or dissolution of the object (from: Brönnimann, et. al., 2020b, Fig. 1).

glass and metal seems to have much more closely resembled the modern-day treatment of recyclable materials like glass and metal as well as electronic waste (Cossu and Williams, 2015), most likely due to the higher value of the used materials and the effective way they can and could be recycled.

Cycle of Life

All this shows that the life cycle of an object in the settlement didn't necessarily end with its primary usefulness. In fact, there is a wide variety of ways how ceramic sherds, animal bones and sediments, as well as metal and glass objects were used and reused in the settlement and how they finally ended up in the ground or became undetectable (Brönnimann, et al., 2020b; Wimmer, et al., 2022). While these materials were the main focus of the studies, the same can probably be said for others like amphora sherds that were reused as whetstones and timber that might have been reused as firewood etc.

After they had outlived their primary use, at least some objects and materials were kept in stores or middens. Even though they contained a variety of different materials, they can be compared to raw material deposits, only man-made instead of naturally occurring. They could then be "mined" for recyclable or reusable resources until they were disposed of permanently in one of the many pits in the settlement as secondary waste. Other objects were again integrated into everyday life and severely altered in the form of object recycling, stored as raw material and reused or else completely transformed like grog or destroyed as fuel or in the form of material recycling (Fig. 6) (Brönnimann, et al., 2020b; Wimmer, et al., 2022).

This multi-branched path appears to have been a regular pattern and points to a clearly defined treatment of "waste" and resources on the one hand and a complex and intricate cultural biography of objects on the other (Brönnimann, et al., 2020b).

This leads us to the conclusion, that "waste" was not just meant to be discarded, but has regularly been used as a resource in the settlement of Basel-Gasfabrik and probably in other settlements of the Later La Tène period.

Objects and materials were frequently and cyclically used, reused and recycled before they were disposed of, destroyed or deposited in the ground. Thus, concepts of "waste" and "resource" can be entangled with each other and are determined by value concepts and social practices.

References

Brönnimann, D., Portmann, C., Pichler, S.L., Booth, T.J., Röder, B., Vach, W., Schibler, J. and Rentzel, P., 2018. Contextualising the dead – combining geoarchaeology and osteo-anthropology in a new multi-focus approach in bone histotaphonomy. *Journal of Archaeological Science*, 98, pp.45-58.

Brönnimann, D. and Rentzel, P., in prep. Geoarchäologische Untersuchungen an zwei Siedlungsgruben sowie an Grabgruben und Gräben innerhalb der beiden Gräberfelder der spätlatènezeitlichen Siedlung Basel-Gasfabrik. In: Anon, ed., *Über die Toten zu den Lebenden. Interdisziplinäre Synthese. Materialhefte der Archäologischen Bodenforschung Basel-Stadt.* Basel: Archäologische Bodenforschung Basel-Stadt.

Brönnimann, D., Rentzel, P., Röder, B., Spichtig, N., Rissanen, H. and Lassau, G., 2020a. The hidden midden – geoarchaeological investigation of sedimentation processes, waste disposal practices and resource management at the Latène settlement

Basel-Gasfabrik (Switzerland). *Geoarchaeology: An International Journal*, 36(2), pp.151-168. Available at: DOI: 10.1002/gea.21787.

Brönnimann, D. and Rissanen, H., 2017. Vivre et mourir sur le site La Tène de Bâle-Gasfabrik (Suisse) – l'étude interdisciplinaire de structures d'habitat choisies et de deux nécropoles donne un aperçu de la société à la fin de l'âge du Fer. In: J. Wilczek, A. Cannot, T. Le Cozanet and J. Remy, eds., *Interdisciplinarité et nouvelles approches dans les recherches sur l'âge du Fer. Interdisciplinarity and new approaches in the research of the Iron Age. International Doctoral Conference 2015, Bibracte (France), 28-30 April 2015*. Brno: Masarykova univerzita, pp.93-97.

Brönnimann, D., Wimmer, J., Müller-Kissing, M., Stopp, B., Rissanen, H. and Spichtig, N., 2020b. One man's trash is another man's treasure: interdisciplinary examination of taphonomic aspects of ceramic sherds, animal bones and sediments from the La Tène period settlement at Basel-Gasfabrik. *PLOS ONE*, 15(7), e0236272. Available at: DOI: 10.1371/journal.pone.0236272.

Brönnimann, D., Rissanen, H., Spichtig, N. and Wimmer, J., 2022. Die jüngerlatènezeitliche Zentralsiedlung Basel-Gasfabrik im Fokus. Ausgewählte Ergebnisse der interdisziplinären Forschung. Jahresbericht der Archäologischen Bodenforschung Basel-Stadt, 2021, pp.116-152.

Cossu, R. and Williams, I.D., 2015. Urban mining: concepts, terminology, challenges. *Waste Management*, 45, pp.1-3.

Hecht, Y. and Niederhäuser, A., 2011. *Alltagskultur und Totenrituale der Kelten: ein Siedlungszentrum am Oberrhein um 100 v. Chr.* Basel: Merian.

Hecht, Y., Rissanen, H., Schaltenbrand, K., Spichtig, N., Stelzle-Hüglin, S. and Weber, E., 2004. Vorbericht über die Grabungen 2002 im Bereich der spätlatènezeitlichen Fundstelle Basel-Gasfabrik. *Jahresbericht der Archäologischen Bodenforschung Basel-Stadt*, 2002, pp.57-78.

Jud, P., 2008. *Die Töpferin und der Schmied: Basel-Gasfabrik, Grabung 1989/5. Dissertation 2004, Teil I: Text. Materialhefte zur Archäologie in Basel 20:1*. Basel: Archäologische Bodenforschung des Kantons Basel-Stadt.

Jud, P. and Spichtig, N., 1995. Vorbericht über die Grabungen 1992 in der spätkeltischen Siedlung Basel-Gasfabrik. *Jahresbericht der Archäologischen Bodenforschung Basel-Stadt*, 1992, pp.19-35.

Martin-Kilcher, S., Deschler-Erb, E., Roth-Zehner, M., Spichtig, N. and Thierrin-Michael, G., 2013. Les importations en amphores dans la civitas Rauracorum (IIe/Ier siècle av. J.-C. – Ier siècle apr. J.-C.): Bâle-usine à gaz, Sierentz, Sausheim, Bâle-colline de la cathédrale, Augst. In: F. Olmer, ed., *Itinéraires des vins romains au Gaule IIIe – Ier siècles avant J.-C. Confrontation de faciès. Actes du colloque européen organisé par l'UMR 5140 du CNRS, Lattes, 30 janvier-2 février 2007*. Lattes: Archéologie des Sociétés Méditerranéennes, pp.377-422.

Nick, M., 2015. *Die keltischen Münzen der Schweiz: Katalog und Auswertung. Inventar der Fundmünzen der Schweiz 12*. Bern: Schweizerische Akademie der Geistes- und Sozialwissenschaften.

Pichler, S.L., Rissanen, H. and Spichtig, N., 2015. Ein Platz unter den Lebenden, ein Platz unter den Toten – Kinderbestattungen des latènezeitlichen Fundplatzes Basel-Gasfabrik. In: R.W. Kory, ed., *Lebenswelten von Kindern und Frauen in der Vormoderne.*

Archäologische und anthropologische Forschungen in memoriam Brigitte Lohrke. Paläowissenschaftliche Studien 4. Berlin: curach bhán publications, pp.257-273.

Pichler, S.L., Röder, B., Brönnimann, D., Knipper, C., Kühn, M., Rentzel, P., Rissanen, H., Stopp, B., Vach, W., Warnberg, O., Alt, K.W., Schibler, J. and Lassau, G., 2017. The Basel-Gasfabrik research project: addressing complex topics by an integrative approach. In: V.I. Molodin and S. Hansen, eds., *Multidisciplinary approach to archaeology: recent achievements and prospects. Proceedings of the international symposium "Multidisciplinary Approach to Archaeology: Recent achievements and prospects", Novosibirsk, 22-26 June 2015*. Novosibirsk: IAET SB RAS Publishing, pp.240-247.

Rentzel, P., 1997. Geologisch-bodenkundliche Untersuchungen an den Niederterrassenfeldern bei Basel unter besonderer Berücksichtigung der spätlatènezeitlichen Fundstelle Basel-Gasfabrik. *Jahresbericht der Archäologischen Bodenforschung Basel-Stadt*, 1994, pp.31-52.

Rentzel, P., 1998. Ausgewählte Grubenstrukturen aus der spätlatènezeitlichen Fundstelle Basel-Gasfabrik. *Jahresbericht der Archäologischen Bodenforschung Basel-Stadt*, 1995, pp.35-79.

Rissanen, H., 1999. Die Glasfunde aus der spätlatènezeitlichen Siedlung Basel-Gasfabrik. *Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte*, 82, pp.149-161.

Rissanen, H., 2025. Umgang mit den Toten. Analyse der Bestattungspraxis in der jüngeren Latènezeit anhand des Fundortes Basel-Gasfabrik. *Materialhefte zur Archäologie in Basel 27*. Basel: Archäologische Bodenforschung des Kantons Basel-Stadt.

Schaer, N. and Stopp, B., 2005. Bestattet oder entsorgt? Das menschliche Skelett aus der Grube 145/230 von Basel-Gasfabrik. *Materialhefte zur Archäologie in Basel* 19. Basel: Archäologische Bodenforschung des Kantons Basel-Stadt.

Schiffer, M.B., 1972. Archaeological context and systemic context. *American Antiquity*, 37(2), pp.156-165.

Sommer, U., 1991. Zur Entstehung archäologischer Fundvergesellschaftungen: Versuch einer archäologischen Taphonomie. In: E. Mattheußer and U. Sommer, eds., *Studien zur Siedlungsarchäologie I. Universitätsforschungen zur prähistorischen Archäologie 6*. Bonn: Habelt, pp.51-174.

Steiner, S., 2012. Zur Keramikherstellung in der Spätlatènezeit: neue Forschungsansätze von Funden aus Basel-Gasfabrik, Schweiz. In: A. Kern, J.K. Koch, I. Balzer, J. Fries-Knoblach, K. Kowarik, C. Later, P.C. Ramsl, P. Trebsche and J. Wiethold, eds., *Technologieentwicklung und -transfer in der Hallstatt- und Latènezeit. Beiträge zur internationalen Tagung der AG Eisenzeit und des Naturhistorischen Museums Wien, Prähistorische Abteilung – Hallstatt 2009. Beiträge zur Ur- und Frühgeschichte Mitteleuropas 65*. Langenweißbach: Beier & Beran, pp.145-148.

Umweltbundesamt, 2017. Urban mining: raw materials sources on our doorsteps. Available at: https://www.umweltbundesamt.de/en/press/pressinformation/urban-mining.

Wimmer, J., 2022. *Wenn Fibeln sprechen könnten. Taphonomische und chronologische Untersuchungen anhand stratifizierter Fundinventare aus der jüngerlatènezeitlichen*

Siedlung Basel-Gasfabrik. Materialhefte zur Archäologie in Basel 25. Basel: Archäologische Bodenforschung des Kantons Basel-Stadt.

Wimmer, J., Brönnimann, D., Müller-Kissing, M., Stopp, B., Rissanen, H. and Spichtig, N., 2022. Wertlos? – taphonomische Untersuchungen zum jüngerlatènezeitlichen Umgang mit Abfällen und dessen Auswirkungen auf die Entstehung von Fundvergesellschaftungen. In: H. Wendling, M. Augstein, J. Fries-Knoblach, S. Gentner, M. Kirchmayr, M. Kohle, R. Schumann and J. Wiethold, eds., „Wert und Maß" – Systeme ökonomischer und sozialer Differenzierung in der Eisenzeit Beiträge zur Jahressitzung der AG Eisenzeit bei der gemeinsamen Tagung des WSVA und des MOVA vom 1.–5. April 2019 in Würzburg. Langenweißbach: Beier & Beran, pp.67-81.

Technology and Social Dynamics of Mining in Bronze Age China

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The Chinese Bronze Age (ca. 2000—250 BC) has been well-known for its exquisite bronze ritual vessels that display power, prestige, and influence of the owners of the early dynasties. Apart from their aesthetic and political value, these bronze artefacts reflect a particular social order shared by the elite groups who demonstrated their ability to acquire metals through vast exchange networks. Nonetheless, researchers have long been obsessed with the study of finished products but paying little attention to the fundamental mining history that underpins the important social and political conditions of the time. In this paper, we show how an investigation of mining techniques and mining communities of Bronze Age China could potentially address essential issues concerning the transfer of technology, the identity of mining practitioners, and the movement and network among Bronze Age societies. The timbering structures and pottery assemblages found in ancient copper mining sites along the middle and lower reaches of the Yangtze River provide evidence for the technological and social diversity of the engaged communities.

Timbering techniques; underground mining; social identity; transfer of technology

Introduction

The Bronze Age of China (ca. 2000—250 BC) is characterised by its extraordinary consumption of metals to fabricate a variety of bronze weapons, chariot fittings, and most importantly ritual vessels (Loewe and Shaughnessy 1999). A single royal tomb of the consort Fuhao at Anyang in the late-Shang Dynasty (ca. 1200 BC) yielded bronze artefacts that weigh 1.6 metric tons, a sign of the enormous demand for copper, tin, and lead to sustain the significant ritual system of the time (Liu, et al., 2020b). To untangle the mystery of this vast bronze industry, researchers have for decades been primarily focusing on the finished products and/or production debris as a proxy for the provenance, applied techniques, and social meaning of metals. The chemical and isotopic data from these materials have in recent years grown rapidly and made significant contributions to the reconstruction of

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 127-140.

the metal exchange network (Jin, et al., 2017; Chen, et al., 2019; Hsu, et al., 2021; Liu and Pollard, 2022). Nonetheless, the mining history of the Chinese Bronze Age has failed to keep up the same pace as the artefact studies, leaving a significant gap in understanding the organisation of primary production and mining infrastructures. The Bronze Age mining sites we have known of are mostly based on excavation in the 1970s and 1980s and have been primarily discussed in Chinese literature (see Han and Ke, 2007; Li, 2016 and references therein). Among the English literature, the most comprehensive overview of ancient Chinese mining activities was given by Peter Golas (Golas, 1999). However, his work mainly addresses technical aspects and lacks the nuanced discussions of the social context of mining communities. In recent years, an increased number of Bronze Age mining activities have been encountered in regional archaeological surveys (Liu, et al., 2020a) but no systematic investigation has been attempted. It is perhaps due to the destruction of old structures caused by the modern mining industry or the danger of working in the underground mines that requires the expertise of mining archaeologists. This specific archaeological discipline in China has unfortunately remained underdeveloped.

This paper aims to review previous mining archaeological works to develop new perspectives on the technological and social dynamics of the mining sector in Bronze Age China. It begins with an overview of the geographic and chronological background of mining sites dated mainly from 1500 to 100 BC, highlighting one of the most important ancient mining districts in the middle and lower Yangtze River Valley. It then discusses the development of timbering techniques used in different regions over time as a proxy for potential transfer of technology or the movement of people. Finally, pottery sherds found within the sites are used to characterise the mining communities and their interconnections, providing a new understanding for the mining practice and organisation of production.

Site Descriptions

Chinese Bronze Age mining sites can be geographically divided into five regions: Jinan 晋南, Liaoxi 辽西, Xinjiang 新疆, Hexi 河西, and the middle and lower reaches of the Yangtze River (Chen, 2014), as shown in Fig. 1. Only a few sites in these areas were provided with radiocarbon dates that suggested an active period of approximately between the 21st and 6th centuries BC (Fig. 2). They were mostly mined for copper, while tin and lead from some polymetallic ore deposits could have been also extracted as by-products. Sites at Xinjiang (e.g., Nurasai 奴拉赛) and Liaoxi (e.g., Xiquegou 喜鹊沟 and Dajing 大井) indicate some evidence of ore extraction (Mei and Li, 1998; Jilin University and Institute of Archaeology, 2014; Dong, 2012), yet they yield few remains of mining infrastructures and are situated further away from the Central Plains (the middle reach of the Yellow River). In contrast, sites at Jinnan and Yangtze, due to their geographic and cultural proximity are the most pertinent to the metallurgical development of the early dynasties at Erlitou, Zhengzhou, and Anyang where bronze ritual vessels are regarded as the most iconic symbol for the Chinese Bronze Age.

Zhongtiao Mountains 中条山

Jinnan is located in the southern part of Shanxi Province where the northern foothills of the Zhongtiao Mountains host abundant copper deposits that are situated in the vicinity of the settlements of the Erlitou (ca. 1900-1500 BC) and Erligang periods (ca. 1500-1300 BC). The entries of mines have been discovered in several localities, but the collapse of the

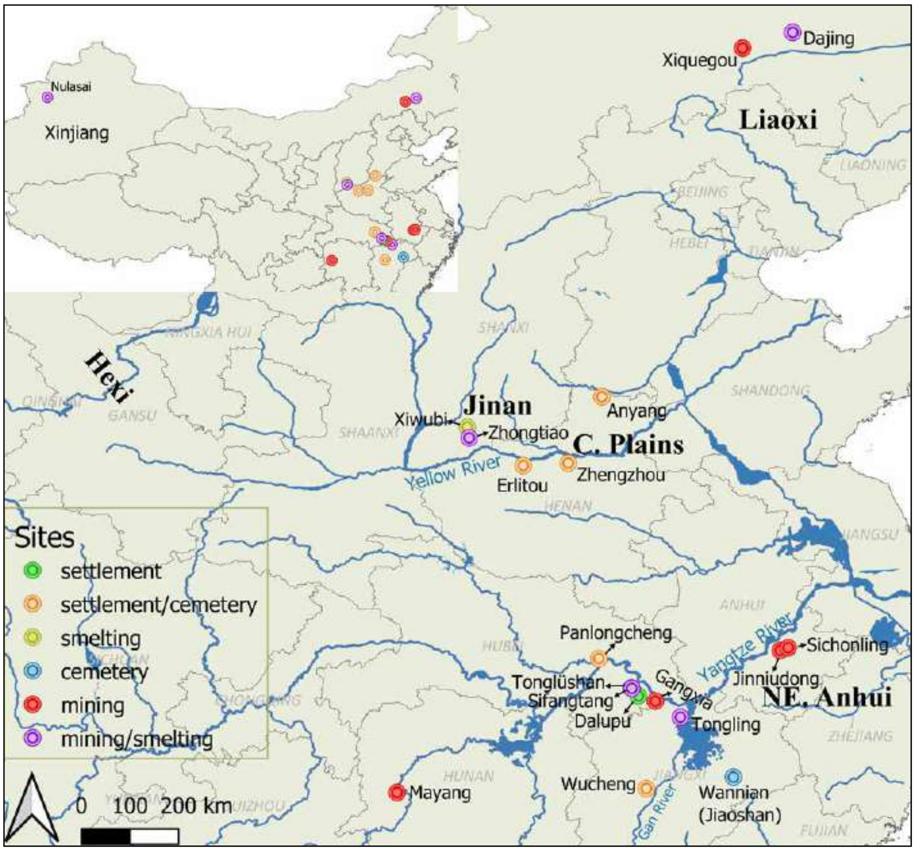

Figure 1: Map showing the geographic distribution of the sites discussed (authors).

entrances prevents further investigation. The most direct evidence for mining activity in this area is the collection of hammer stones scattered around the mining and smelting sites, presumably associated with ore extraction (Li, 1993). Recent archaeometallurgical studies on several smelting sites, including a large smelting installation at Xiwubi 西吴壁, indicate the primary use of copper oxide ores (Li, 2011; Cui, et al., 2022).

Tonglüshan mine 铜绿山

In this paper, we are particularly keen to explore the mining sites along the Yangtze River Valley due to their abundance of mining infrastructures, especially the wooden remains in shafts and galleries. The middle and lower reaches of the Yangtze River are situated along an important polymetallic mineralisation belt that extends over Jiangsu, Anhui, Jiangxi, and Hubei Provinces (Pan and Dong, 1999). Five Bronze Age mining districts, namely Tonglüshan, Tongling at Ruichang, Gangxia, southeast Anhui, and one from Mayang, Hunan Province, have yielded a variety of mining practices that articulate a rich mining history of Bronze Age China.

Located in the area of Daye County in Hubei Province, the Tonglüshan Bronze Age mine is by far the most well-studied and well-known site in Chinese mining archaeology (Tonglüshan Committee, 2013). Discovered in 1965 and excavated between 1974 and 1985,

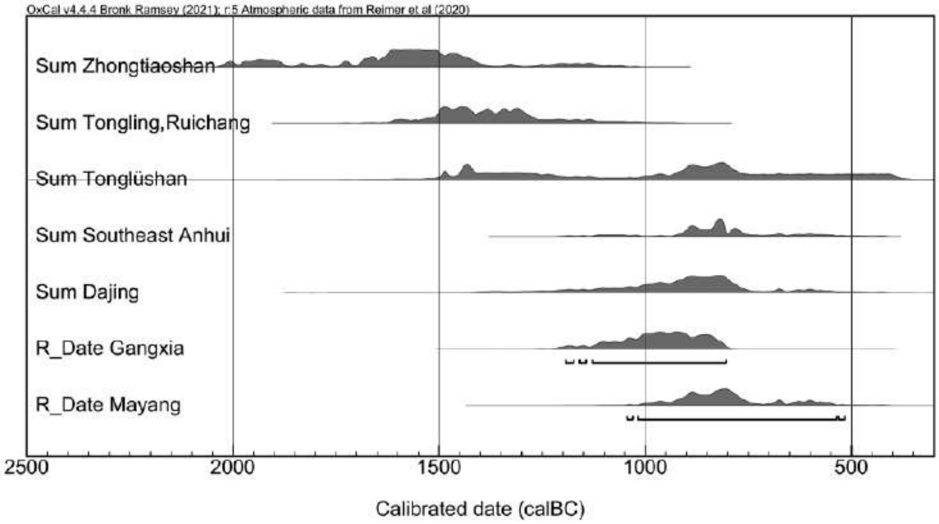

Figure 2: Radiocarbon chronology of Chinese Bronze Age mining regions (authors).

Tonglüshan consists of seven mining localities with enormous underground facilities, including 231 shafts as well as a large quantity of mining tools and equipment. Radiocarbon dates indicate the duration of Bronze Age mining from the Shang Dynasty to the Warring States period (ca. 15th—5th centuries BC). The mine contains rich secondary deposits of which the main copper minerals are chrysocolla ($CuSiO_3.2H_2O$), malachite [$Cu_2CO_3(OH)_2$], azurite $Cu_3(CO3)_2(OH)_2$, native copper (Cu), cuprite (Cu_2O) and tenorite (CuO). To extract these high-grade ores, ancient miners initially began with mining pits and shallow shafts that followed the outcrops. Later as the operation went deeper, vertical shafts and connecting underground tunnels were constructed. From 500 BC onwards, miners worked on the outcrop till the bottom of the mine with the assistance of stair-crosscut galleries.

Tongling mine at Ruichang 铜岭

Discovered in 1988, the Tongling mine at Ruichang is the earliest Bronze Age copper mine in the Yangtze area (Liu and Lu, 1998). According to unearthed pottery sherds, stratigraphic sequences, and radiocarbon dates, the mining operation began here at least by the 15th century BC, was intensified between the 10th and 6th centuries BC, and eventually ceased to develop by the 5th century BC. The ancient mining covers approximately an area of 70,000 square metres of which 1,800 square metres were excavated. A total of 103 shafts, nineteen drifts, three open-cast pits, two prospecting trenches were uncovered.

The orebodies at Tongling are hosted in the contact zone between dolomitic limestone and argillaceous siltstone where the friable rock enabled easy prospection for the ancient miners. The principal secondary minerals are malachite, azurite, and limonite, with the copper grade in the first two minerals averaging 10%. In addition to the mine, a smelting area of 200,000 square metres is located in the vicinity and contains slag layers with a thickness between 0.6 and 3.4 metres. Logistically speaking, Tongling has easy access to adjacent agriculture, rich forests, as well as convenient water transportation via the Yangtze River and its tributaries. These provided a favourable condition of food, timber, and trade necessary to sustain local mining communities.

Gangxia 港下 and Mayang 麻阳

The Gangxia mine is situated between the Tonglüshan and Tongling sites, covering an area of 170 square metres (Gangxia, 1988). By the time of excavation in 1986, it had been mined by manpower so that most of the ancient mining traces were preserved. A number of shafts and galleries were uncovered, especially the use of some timbering structures unique to the site. A single ^{14}C date places this site between the 12th and 9th centuries BC, corresponding to the late Shang and Western Zhou periods.

Located in western Hunan, Mayang is a Warring-States period (5th—3rd centuries BC) copper mine geographically distant from the sites mentioned above (Mayang Museum, 1985). The site yields a total of fourteen shafts that constitute an intricate underground structure. A unique characteristic of the mine lies in its rich native copper reserves, distributed in the sandstone and quartz. Furthermore, the presence of charred walls might indicate the use of fire setting, which has not been observed in other Bronze Age sites.

Mining sites in Southeast Anhui

The metallogenic district in Southeast Anhui contains a series of skarn ore deposits rich in copper, iron, gold, zinc, and sulphur. A cluster of ancient mines has been found in the mining regions of Tongguanshan 铜官山, Dagongshan 大工山, Shizishan 狮子山, and Fenghuangshan 凤凰山 (Wei, et al., 2019). These sites span a period from the 10th century BC to 10th century AD. While the Jiningdong mine 金牛洞 of the western Han period (206 BC—9AD) yielded two vertical shafts, four inclined shafts, and three galleries (Institute of Archaeology in Anhui, 1989), the rest of sites have never been subject to any systematic survey.

Timbering techniques for underground mining

Initially, those early mining sites in the Yangtze River region might have begun with surface mining that extracted ore minerals from the outcrop. At Tonglüshan, an open-pit mining operation with a depth of nineteen metres was uncovered, accompanied by two mounds of excavated waste on either side (Fig. 3A). In contrast, ancient miners at Tongling constructed a trench on the surface with both sides marked by lines of wooden stakes (Fig. 3B). The end of the trench led to a vertical shaft whose bottom was connected to a gallery. It might have been a later extension as a result of tracing the underground rich ores. Despite these interesting early finds of surface mining, what made Chinese Bronze Age mining truly magnificent was the complexity of underground mining infrastructure, namely shafts and galleries, which would require some degree of organisation and division of labour. One of the most characteristic infrastructures was the diversity of timbering practices applied to support the stability of mining structures. The adoption of a particular timbering technique might have not only manifested the need to adapt to various working environments, but also represented cultural characteristics of different mining communities.

In general, Chinese Bronze Age miners mainly adopted two techniques to reinforce the wooden supports for walls and roofs. The first method is known as “bowl-mouth joints” through which the crosspieces were installed into the indentations of connecting timbers, typically seen at Tongling and Gangxia (Fig. 4A). The ends of the timbers were carved into concave dents resembling the cross section of a bowl. As early as 1500 BC, miners at Tongling had started to apply this technique to the construction of both shaft and gallery supports. The example of the Tongling shaft might indicate some degree of standardisation

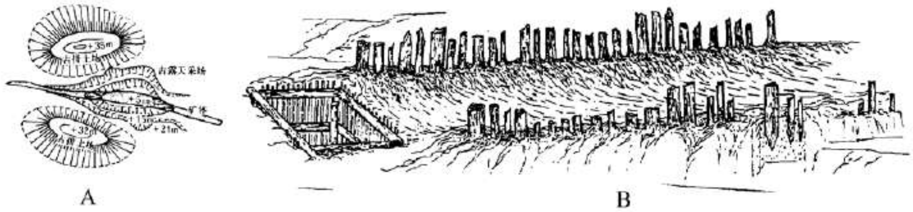

Figure 3: Examples of Bronze Age surface mining. A: Tonglüshan (from Yang, et al., 1980, p.88) and B: Tongling (from: Liu and Lu, 1998, p.475).

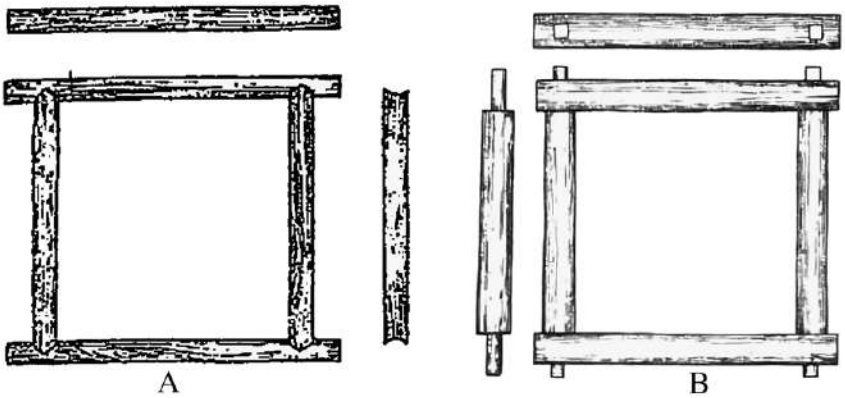

Figure 4: Two main types of timbering technique during the Chinese Bronze Age. A: bowl-mouth joints at Tongling (from: Han and Ke, 2007, p.30). B: mortie-and-tenon method at Tonglüshan (from: Tonglüshan Committee 2013, p.4).

in which miners prepared standardised timbers outside the mine and assembled them underground (Lu and Liu, 1993, p.35).

The other timbering technique is known as "mortise-and-tenon" fashion in which the ends of each timber were gouged out to form a hole or slot into which the tenon or peg of the other timber was inserted (Fig. 4B). This method had been a long-lasting feature of the underground structures at Tonglüshan (see the discussions below).

One of the most intriguing aspects of "bowl-mouth" and "mortise-and-tenon" techniques lies in their temporal and spatial development across the Bronze Age mining sites. The change and modification of wooden supports in different regions might hint at the transfer of technology associated with interactions between different mining communities or even the movement of miners during that time. The shift in timbering techniques is best demonstrated by the Tongling and Tonglüshan sites where the chronological sequence of underground structures has been well documented. As mentioned above, miners at Tongling initially used simple bowl-mouth joints for the wooden supports at ca. 1500 BC.

However, this technique was modified between 1200 and 1000 BC by adding extra timbers within the frame to increase the stability of the shaft (Fig. 5B-1). Meanwhile, for the first time at Tongling the mortise-and-tenon fashion was adopted to construct supporting frames for the gallery (Fig. 5B-2). During the Western Zhou period (ca. 10th to 8th

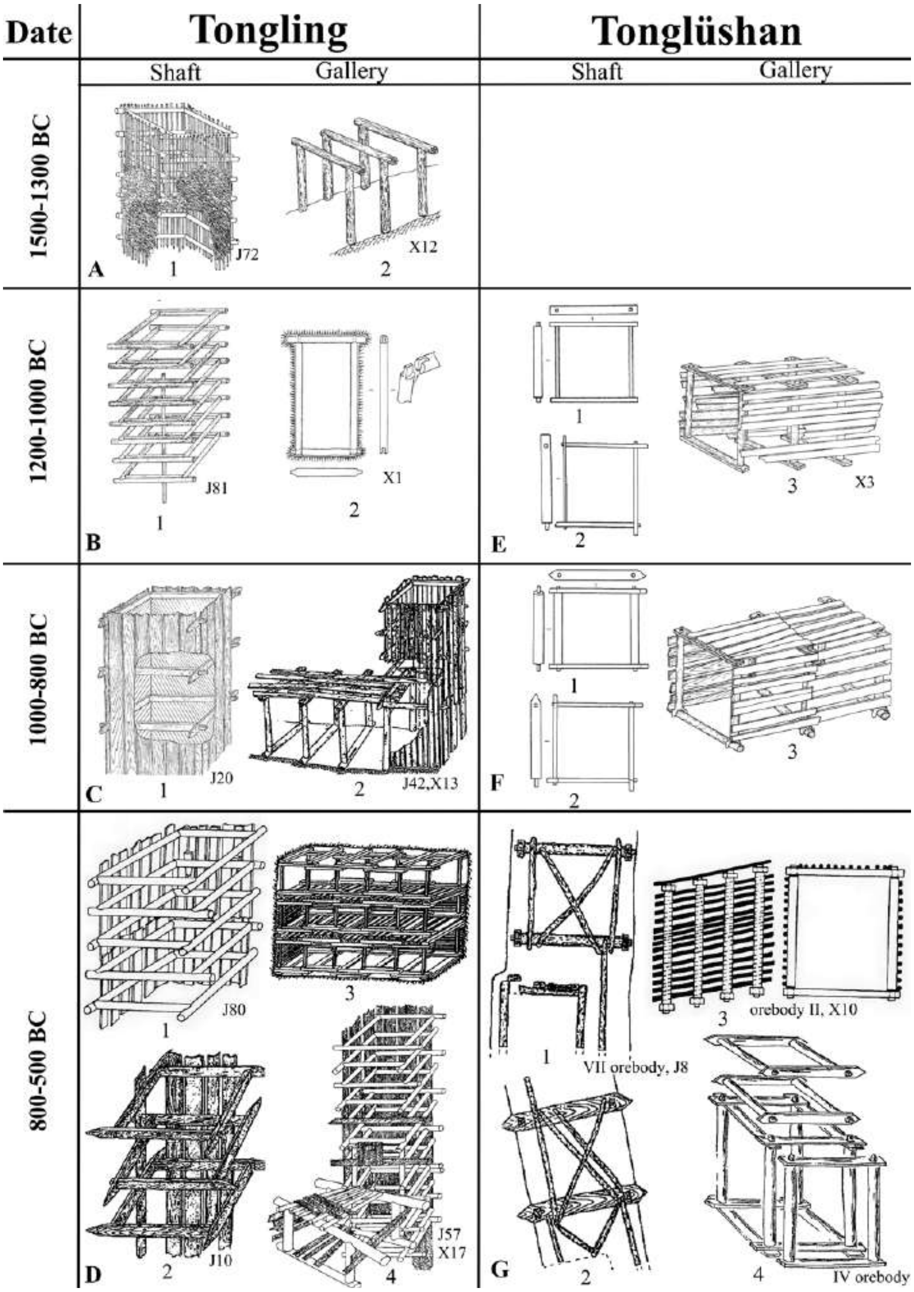

Figure 5: Timbering structures for shafts and galleries of Bronze Age mines from 1500 to 500 BC. Tongling: A1 (from: Liu and Lu, 1998, p.475); A2 (from: Liu and Lu, 1998, p.481); B1(from: Liu and Lu, 1998, p.478); B2 (from: Liu and Lu, 1998, p.481); C1(from: Liu and Lu, 1998, p.478); C2 (from: Han and Ke, 2007, p.54); D1 (from: Han and Ke, 2007, p.50); D2 (from: Han and Ke, 2007, p.49); D3: (from: Han and Ke, 2007, p.93); D4: (from: Liu and Lu, 1998, p.484). Tonglüshang: E1 (from: Li, 2016, p80); E2 (from: Li, 2016, p80); E3 (from: Han and Ke, 2007, p.35); F1 (from: Li, 2016, p80); F2 (from: Li, 2016, p80); F3 (from: Han and Ke, 2007, p.53); G1 and G2 (from: Han and Ke, 2007, p.88); G3 (from: Han and Ke, 2007, p.90).

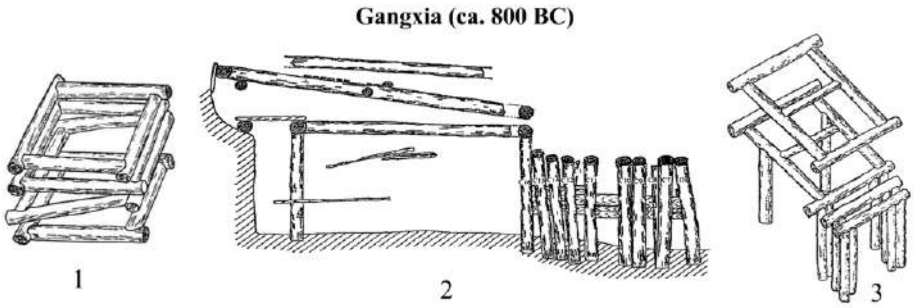

Figure 6: Timbering structures at Gangxia. 1: shaft (from: Gangxia, 1988, p.34); 2: gallery (from: Gangxia, 1988, p.40); 3: junctions between the shaft and gallery (from: Gangxia, 1988, p.40).

centuries BC), the traditional bowl-mouth technique was replaced by the mortise-and-tenon practice comparable to that used at Tonglüshan. Frames for both shafts and galleries were assembled with this new method and reinforced by wooden boards on the outside to withstand the pressure from the side and top walls (Fig. 5C). From the late Western Zhou to the Spring and Autumn period (ca. 8th to 5th centuries BC), Tongling was characterised by a mixed practice with both bowl-mouth and mortise-and-tenon techniques (Fig. 5D-1). Four timbers that formed a set were now interlocked alternately to increase the supporting points (Fig. 5D-2). Another new technique was also invented for the gallery where the horizontal timbers were "chained" together by the mortise-and-tenon method to avoid the slipping and loosening of the frames (Fig. 5D-3). Furthermore, the J57 shaft at Tongling was installed with an extra set of horizontal timbers at the juncture of the shaft bottom and gallery for additional support of the roof (Fig. 5D-4). A contemporary mine at Gangxia also exhibited similar bowl-mouth joints as Tongling (Fig. 6).

Unlike Tongling with its shifting practices over time, Tonglüshan remained fairly consistent by adopting the mortise-and-tenon method for the underground infrastructure. By the late Shang period (ca. 13th to 11th centuries BC), Tonglüshan had developed variations of timbering structures. The shaft consisted of both regular and alternating arrangements of wooden framework (Figs. 5E-1 and 5E-2). The gallery support was based on a set of timbers with two rounded posts connected to the flat boards through mortise-and-tenon joints (Fig. 5E-3). Tonglüshan during the Western Zhou period principally inherited the previous style but with some variations. Some timbers were carved into a cylindrical form instead of flat boards (Fig. 5F-1), and some were designed with pointed ends, which allowed for a better reinforcement against the wall (Fig. 5F-2). These pointed timbers were also observed at the contemporary Tongling site (Fig. 5C). Moreover, a new form of gallery support had emerged where one end of the timber was constructed with the mortise-tenon method, while the other end featured a forked timber with a bifurcated bottom (Fig. 5F-3). The subsequent phase from the 8th to 5th centuries BC displayed an even more diverse picture of timbering structures. Some timber frames were tied to each other through the bamboo ropes to increase their stability and could meanwhile also have been used as a ladder (Figs. 5G-1 and 5G-2). The inclined gallery was supported by a set of mortise-and-tenon timbers surrounded by a line-up of wooden sticks (Fig. 5G-3). The bottom of the shaft was reinforced by four round pillars to function as a "gateway" to the gallery (Fig. 5G-4).

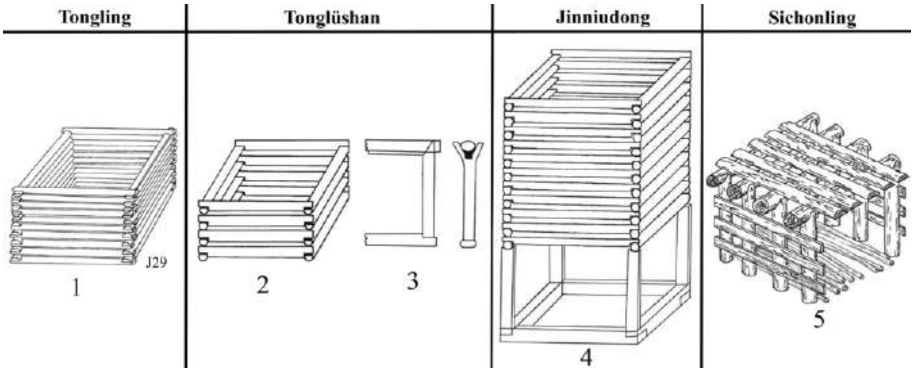

Figure 7: Timbering structures of mining sites during 500 to 100 BC. 1: Tongling (from: Liu and Lu, 1998, p.480). 2 and 3: Tonglüshan (from: Li, 2016, p.82). 4: Jinniudong (from: Institute of Archaeology in Anhui, 1989, p.913). 5: Sichonling (from: Institute of Archaeology in Anhui, 2002, p.50).

The final phase of the Chinese Bronze Age, roughly between the 5th and 1st centuries BC, showed a rather homogeneous timbering practice across the mining sites along the Yangtze River Valley. A new and more sophisticated shaft construction emerged at Tongling, Tonglüshan, and some sites in Southeast Anhui. It comprised a set of densely stacked timbers whose ends were half removed and assembled together by the upward facing and downward facing indentations to form a frame (Figs. 7-1 to 7-3). Furthermore, Tonglüshan miners invented a novel support for the gallery where the cap timber on the top was placed onto the forked post and the bottom was designed with a notch to fit into the other end of the post (Fig. 7-2). Another peculiar phenomenon during this period was the re-adoption of the bowl-mouth structure at several mining sites in Anhui (Fig. 7-4) and particularly in Hunan (Mayang), which is located at a remote distance from Tongling where this method might have originated from.

Identity of miners and its relationship with mining techniques

The conventional perspective on resource extraction held that mining sites along the middle and lower Yangtze River were under direct control of the Central Plains polity since the Erligang period. The discovery of a walled settlement at Panlongcheng on the Yangtze River was assumed to be an "outpost" built by the Shang polity, in order to obtain copper from the ore-rich Yangtze Valley for their enormous bronze-making industry of the Shang (Liu and Chen, 2001). This centre-periphery relation continued during the Western Zhou as inscriptions on the bronze vessels and textual evidence also described several military campaigns launched by the Zhou authorities to seize copper resources at the Yangtze (Chen and Wang, 2021). However, those cited texts were in fact written several hundred years later and military conflicts between the Central Plains and the South represented occasional events rather than a regular relationship with local Yangtze communities. In fact, recent excavations along the Yangtze River Valley have revealed several characteristic indigenous sites in the vicinity of the mines, which might indicate that copper resources were procured by local communities rather than by people from the Central Plains (Zou, 2019; Liu, et al., 2020a). One of the most direct pieces of evidence comes from the variety of pottery assemblages found in those mines that bear resemblance to their counterparts at the adjacent local settlements and cemeteries.

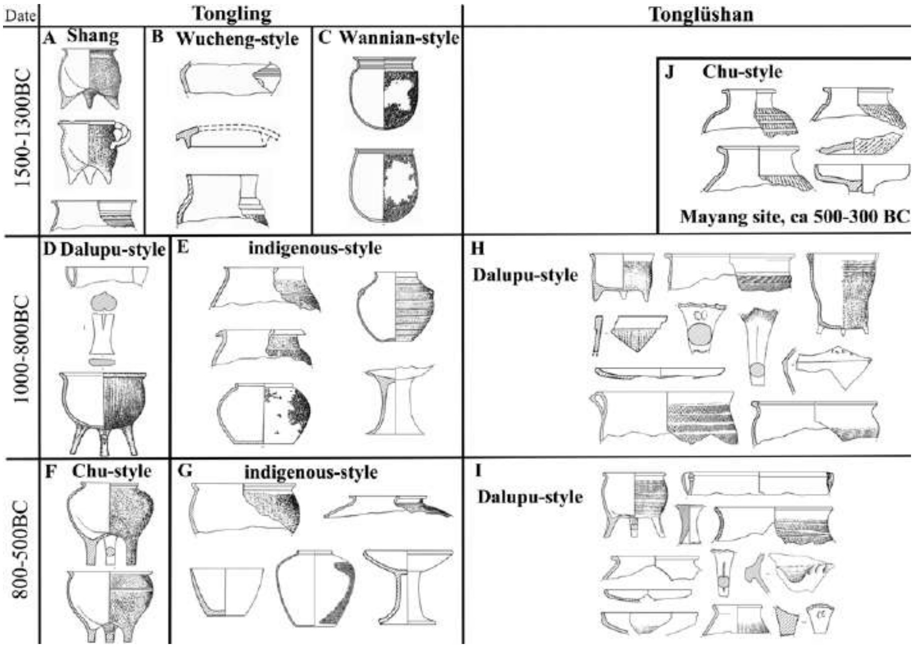

Figure 8: Pottery assemblages found in the Bronze Age mining sites (from: Li, 2016, figures 12-17).

Ceramic finds from the Tongling copper mine mostly exhibit mixed traits with an influx of external influence over time. During the Erligang period, Tongling yielded three distinct types of pottery remains. The first group consisted of *li*-tripods and *jia*-cups derived from the Shang culture in the Central Plains (Fig. 8A). The second category included the high-neck jar, lidded pot, and jar with the angular shoulder made of stoneware, also known as the so-called "hardware" in Chinese literature (Fig. 8B). These ceramic types are associated with the construction of the Wuchang 吴城 walled settlement located on the western bank of the Gan River 赣江, a tributary of the Yangtze River (Zhang, 2003). The final group is represented by jars imprinted with geometric designs, also made of stoneware (Fig. 8C). These finds could be attributed to the Wannian 万年 culture on the eastern bank of the Gan River (Zhang, 2003). The appearance of both Wuchang and Wannian potsherds suggests that a group of Tongling miners could have come from the local communities in the vicinity.

Although there has been so far no pottery dated to the late Shang period at Tongling, the subsequent Western Zhou period clearly shows the change in cultural outlook as evidenced by the emergence of new pottery assemblages. Notably, a foreign element known as the Dalupu 大路铺 culture entered this area with its diagnostic ceramic characteristics, such as the grooved foot, cooking vessel with ears, and perforated bowl (Feng, 2013). The first two variants have been observed at Tongling (Fig. 8D). Interestingly, the key site of the Dalupu community is only situated about 15 km southeast of the Tonglüshan mine and has been considered as the primary actor to extract copper from Tonglüshan from the 10^{th} to 5^{th} centuries BC (see the discussion below). It is likely that Tonglüshan miners travelled to Tongling and left their pottery assemblage behind. In addition to the Dalupan pottery, Tongling also yields a local pottery type, yet its precise origins remain uncertain due to the lack of archaeological record in this region. (Fig. 8E).

Beginning at around 8th/7th centuries BC, there was once again a change in pottery assemblage at Tongling. The emergence of tripods from the Chu state (a vassal state of the Zhou Dynasty) implies a return of influence from the Central Plains (Fig. 8f). Meanwhile, the continued use of local ceramics also suggests the engagement of indigenous communities with copper mining (Fig. 8G).

The pottery assemblage at Tonglüshan shows a strong affiliation with the Dalupu culture from the 10th to 5th centuries BC (Figs. 8H and 8I). This highly suggests that the mine was primarily exploited by the local communities before it was taken over by the Chu state after the 5th century BC. The Dalupu settlement nearby yields metallurgical remains of ores, smelting slags, furnaces, and moulds, which also consolidate the assumption of indigenous mining. A miner's cemetery at Sifangtang 四方塘 has been recently uncovered next to the VII orebody at the Tonglüshan mine (Chen and Chen, 2015) and most tombs are dated between the 8th and 5th centuries BC. The cemetery displays mixed cultural traits including the influence from the Central Plains and Dalupu. The former is marked by bronze artefacts such as the vessel, dagger-axe, and sword vessels, dagger-axes, and swords. The latter is reflected by the tripod's foot decorated with the grooved motif of Dalupu origin. From the 6th/5th century BC onwards, the Chu state was likely to dominate copper extraction along on the Yangtze River, as evidenced by the replacement of local pottery with the Chu style (Fig. 8J).

Based on the investigation of the pottery assemblage, it is highly likely that both Tongling and Tonglüshan were primarily operated by local communities before the 6th/5th century BC. The people from the Central Plains played a limited role in the direct control of mines. The distribution pattern of the Shang-related sites also shows this tendency as they are mostly located on the northern bank of the Yangtze River whereas the mining sites are on the south surrounded by indigenous cultures (Du, 2020). Although the presence of ceramics from the Central Plains at mines might have indicated the involvement of early dynasties in these areas, it is likely that the possession of exotic ceramic assemblages by indigenous groups was a means for the local elites to demonstrate their social status through their ability to maintain trade relationships with outsiders. On the other hand, those "super consumers" in the Central Plains, being geographically distant from the ore extraction sites, would likely have preferred to establish and secure the transportation routes of mine products rather than directly control the mine itself. Many Shang and Zhou sites found north of the Yangtze River might have acted as such trading nodes at the frontiers to organise the circulation of goods.

Apart from pottery sherds, the Chinese Bronze Age mines provide little information about other remains of material culture that could hint at the identity of the miners. The periodical switch to a new pottery assemblage at the mines does not necessarily advocate the "pots equal people" theory. Instead, the pottery evidence displays the interconnectivity between different communities (the Shang/Zhou, Dalupu, and Wuchang/ Wannian) who might have collectively engaged in ore extraction. One intriguing aspect is that the appearance of new pottery assemblage at mines the corresponded to the change in timbering techniques. At Tongling, the mortise-and-tenon method typical of the Tonglüshan mine made its first appearance at around 1200 BC and became the dominant technique between 1000 and 800 BC. This change coexisted with the influx of the Dalupu pottery at the site, which might have led to the appearance of the new timbering technique through the arrival of the Dalupu miners. Furthermore, the spread of the bowl-mouth technique of Tongling origin to Gangxia and Sichonling might also indicate the movement of miners. Ultimately, the timbering structure became unified across most mining sites along the Yangtze River after 500 BC due to the establishment of the Chu state that basically controlled the extraction of copper in this region. We argue that this diverse transfer of timbering technology was made possible through the movement of mining practitioners of different origins. Nonetheless, this interpretation should remain tentative as there is still a lack of more nuanced contextual information. The precise chronology of mining techniques and pottery traits, along with the DNA analysis of miners, and a nuanced study of pottery production would allow us to better reconstruct the social dynamics of Chinese Bronze Age mining.

Conclusions

This article is neither a comprehensive overview nor detailed investigation of all aspects of Bronze Age mining sites in China. Instead, we particularly focus on how a specific mining technique, namely the timbering support for shafts and galleries, had developed over time at Tonling and Tonglüshan. The shift in this mining practice could be linked with the emergence of a specific pottery assemblage that signified the movement of miners from other communities. An example of this phenomenon is shown by the presence of Dalupu pottery and the mortise-and-tenon technique of Tonlüshang origin at the Tongling mine from the 10th century BC. In addition, we assert that the actual ore exploitation was likely to be undertaken by the indigenous people who settled in the south of the Yangtze River Valley. This tendency towards resource procurement on a local scale has been foreseen by the Neolithic and Early Bronze Age communities at the Zhongtiao Mountains and Yangtze River Valley (Shi, 2021). At least before 5th century BC, the regimes in the Central Plains did not take direct control of mining activities but rather established a series of sites at the frontiers to secure the transportation routes for the mining products to the north. Furthermore, the sporadic appearance of Central Plains pottery at mines might suggest that the locals adopted these foreign goods to display their capability to maintain social or economic networks with the Central Plains. Resource procurement was probably largely based on peaceful trade rather than the violent military campaigns as described in the textual evidence.

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References

Chen, J., 2014. *New investigations of the metalworking civilizations in ancient China (中国古代金属冶铸文明新探).* Beijing: Kexue Chubanshe.

Chen, K., Mei, J., Rehren, T., Liu, S., Yang, W., Martinón-Torres, M., Zhao, C., Hirao, Y., Chen, J. and Liu, Y., 2019. Hanzhong bronzes and highly radiogenic lead in Shang period China. *Journal of Archaeological Science* **101**, pp.131-139. Available at: DOI: 10.1016/j.jas.2018.11.010 [Accessed 28 November 2024].

Chen, L. and Chen, S., 2015. A discussion on the characteristic of Sifangtang cemetery in Mt. Tonglu, Daye (试论大冶铜绿山四方塘墓地的性质). *Jianghan Kaogu* **5**, pp.95-102.

Chen, S. and Wang, D., 2021. Preliminary observation on the copper mining industry in Southeast Hubei during the Western Zhou Dynasty (西周时期鄂东南铜矿业初步观察). *Nanfang Wenwu* **3**, pp.19-28.

Cui, C., Dai, X., Tian, W. and Tang, Y., 2022. Copper smelting technology in the southern Shanxi during the Xia and early Shang Dynasties – an example from Xiwubi at Jiang County, Shanxi (夏及早商时期晋南地区的冶铜技术-以山西绛县西吴壁遗址为例). *Kaogu* **7**, pp.96-108.

Dong, L., 2012. Investigation on the mining and metallurgical sites of the Upper Xiajiadian culture (夏家店上层文化矿冶遗址的考察研究). PhD. University of Science and Technology Beijing.

Du, Y., 2020. Modes of resource control – Shang Dynasty's control over the copper mining regions in the middle and lower reaches of the Yangtze River (资源控制的通道模式-论商王朝对长江中下游铜矿区的控制). *Nanfang Wenwu* **6**, pp.95-101.

Feng, S., 2013. *Yangxin Dalupu (*阳新大路铺*).* Beijing: Wenwu Chubanshe.

Gangxi, 1988. A brief report on the excavation of the ancient mine at Gangxi, Yangxi, Hubei (湖北阳新港下古矿井遗址发掘简报). *Kaogu* **1**, pp.30-42.

Golas, P., 1999. *Science and civilisation in China. Vol. 5: Chemistry and chemical technology. Part XIII: Mining.* Cambridge: Cambridge University Press.

Han, R. and Ke, J., 2007. *History of science and technology in China – volume of mining and metallurgy (*中国科学技术史-矿冶卷*).* Beijing: Kexue Chubanshe.

Hsu, Y.-K., O'Sullivan, R. and Li, H., 2021. Sources of Western Zhou lead: a new understanding of Chinese Bronze Age supply networks. *Archaeological and Anthropological Sciences* **13**(2), p.30. Available at: DOI: 10.1007/s12520-021-01279-3 [Accessed 28 November 2024].

Institute of Archaeology in Anhui, 1989. Report of the ancient copper mining site at Jinniudong, Tongling, Anhui Province (安徽铜陵金牛洞铜矿古采矿遗址清理简报). *Kaogu* **10**, pp.910-919.

Institute of Archaeology in Anhui, 2002. Investigation and test excavation of ancient copper mining and smelting sites at Nanling County, Anhui Province (安徽南陵县古铜矿采冶遗址调查与试掘). *Kaogu* **2**, pp.45-54.

Jilin University and Institute of Archaeology, IM, 2014. Excavation report of the Xiquegou site in Hexigten Banner, Inner Mongolia (内蒙古克什克腾旗喜鹊沟遗址发掘简报). *Kaogu* **9**, pp.3-15.

Jin, Z., Liu, R., Rawson, J. and Pollard, A.M., 2017. Revisiting lead isotope data in Shang and Western Zhou bronzes. *Antiquity* **91**(360), pp.1574-1587. Available at: DOI: 10.15184/aqy.2017.149 [Accessed 28 November 2024].

Li, H., 2016. Research on mining sites in the Shang and Zhou Dynasties in the middle and lower reaches of the Yangtze River (长江中下游商周时期采矿遗址研究). *Kaogu* **10**, pp.78-88.

Li, J., 2011. Investigation on early copper mining and smelting sites in the south of Shanxi Province, central China (晋南早期铜矿冶遗址考察研究). MA. University of Science and Technology Beijing.

Li, Y., 1993. Preliminary investigation and research on ancient copper mining and smelting sites at Zhongtiaoshan (中条山古铜矿冶遗址初步考察研究). *Wenwu Jikan* **4**, pp.64-67.

Liu, H., Mei, H., Bai, G. and Chen, J., 2020a. A review of archaeometallurgical research on the copper ore belt of the middle and lower reaches of the Yangtze River in the pre-Qin period (综论长江中下游铜矿带先秦矿冶考古). *Journal of National Museum of China* 7, pp.17-34.

Liu, L. and Chen, X., 2001. Cities and town: the control of natural resources in early states. *Bulletin of the Museum of Far Eastern Antiquities* 75, pp.5-47.

Liu, R. and Pollard, A.M., 2022. Asking different questions: highly radiogenic lead, mixing and recycling of metal and social status in the Chinese Bronze Age. *Mineralogical Magazine* **86**(4), pp.1-11. Available at: DOI:10.1180/mgm.2022.32 [Accessed 28 November 2024].

Liu, R., Pollard, A.M., Cao, Q., Liu, C., Sainsbury, V., Howarth, P., Bray, P., Huan, L., Yao, B., Fu, Y. and Tang, J., 2020b. Social hierarchy and the choice of metal recycling at Anyang, the last capital of Bronze Age Shang China. *Scientific Reports* **10**(1), p.18794. Available at: DOI:10.1038/s41598-020-75920-x [Accessed 28 November 2024].

Loewe, M. and Shaughnessy, E.L., 1999. *The Cambridge history of ancient China: From the origins of civilization to 221 BC.* Cambridge: Cambridge University Press. Available at: DOI:10.1017/CHOL9780521470308 [Accessed 28 November 2024].

Lu, B. and Liu, S., 1993. A preliminary study of the technology for exploiting the Shang and Zhou copper mine at Tongling (铜岭商周铜矿开采技术初步研究). *Wenwu* 7, pp.33-38.

Mayang Museum, 1985. Report of a Warring States period copper mine at Mayang, Hunan (湖南麻阳战国时期古铜矿清理简报). *Kaogu* **2**, pp.113-124.

Mei, J. and Li, Y., 1998. Ancient copper mining and smelting at Nulasia, Xinjiang: preliminary research on smelting technology (新疆奴拉赛古铜矿冶遗址冶炼技术初步研究). *Studies in the History of Natural Sciences* **17**, pp.289-295.

Pan, Y. and Dong, P., 1999. The Lower Changjiang (Yangzi/Yangtze River) metallogenic belt, east central China: intrusion- and wall rock-hosted Cu – Fe – Au, Mo, Zn, Pb, Ag deposits. *Ore Geology Reviews* **15**(4), pp.177-242. Available at: DOI:10.1016/S0169-1368(99)00022-0 [Accessed 28 November 2024].

Shi, T., 2021. Copper mining and metallurgy in the Zhongtiao Mountains and Yangzi River Valleys in Early China. *Asian Perspectives* **60**(2), pp.382-416. Available at: DOI:10.1353/asi.2021.0005 [Accessed 28 November 2024].

Tonglüshan Committee, ed., 2013. *Archaeological discovery and research on the ancient mining site at Tonglüshan (*铜绿山古铜矿遗址考古发现与研究*).* Beijing: Kexue Chubanshe.

Wei, G., Yu, D., Zheng, X., Zhang, A. and Fang, Q., 2019. Ancient copper mining and smelting site in Tongling, Anhui Province: surveys and results in 2016 (安徽铜陵古铜矿冶遗址2016年调查及若干收获). *Nanfang Wenwu* **2**, pp.140-152.

Yang, Y., Li, Q. and Shouzhong, Z., 1980. A study of the mining methods at the ancient copper mine of Tonglüshan (铜录山古铜矿开采方法研究). *Youse Jinshu*, pp.84-92.

Zhang, L., 2003. Wucheng and Shang: a new history of a Bronze Age civilization in southern China. *Bulletin of the Museum of Far Eastern Antiquities* 78, pp.53-78.

Zou, G., 2019. Comprehensive research on archaeometallurgy of Shang Dynasty at Tongling site in Ruichang, Jiangxia Province (江西瑞昌铜岭遗址商代冶金考古综合性研究). PhD. University of Science and Technology Beijing.

Skill, embodiment and the growth of knowledge

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Materialized resources are a driving force for the transformation of societies. To understand their implication within these transformation processes, it is not enough to observe the large-scale patterns, the way resources are gained, exchanged or how their scales can be quantified. It is also necessary to understand their role in a qualitative way on a micro-scale. In this regard, the manufacturing processes, the way people are skillfully handling clay, metal, stone, wool, etc. throws light on the involved knowledge and meaning in crafting resources. While in anthropology these practices are for instance deducible from interviews with craftspeople and participatory observation, archaeological research gains evidence through the analysis of the involved materials such as fabrics, tools, working traces, and contextual settings, which is often combined with experimental reconstruction.

Somehow problematic is that research in the field of craft practices techniques has been long described in a rather technological and engineering-like way and thus as largely disembodied, mechanical sequences. The knowledge of these processes has been understood as externalizable, discursive scripts or representations similar to manuals or plans. A way of thinking or zeitgeist that has been described by Tim Ingold as a machine-theoretical cosmology (Ingold, 2011a, von Rüden 2015, pp.38-41; 2017). Such an approach does hardly describe the resource knowledge in crafts adequately as it acts from the assumption that a craft technique can be learned and spread through manuals or plan alone, while the incorporation of knowledge and thus the learning process with the resources and tools have been neglected.

André Leroi-Gourhan, in '*Le geste e la parole*,' in the 1950s surely was one of the first to focus on the relationship between the body, things and cognition (Leroi-Gourhan, 1988 [1964], pp.289-293; cf. von Rüden 2015, pp.36-37). His insights regarding body knowledge have been hardly picked up in the following years with an exception of an anthropological study by Marie-Noelle Chamoux in the 1970s with a strong emphasis on '*savoir-faire*' (1978), but she was long ignored by her mainly male, engineering-focused

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coevals. Only in the 1990s, Pierre Lemonnier picked up on some of Chamoux's ideas and at least enumerated the body as an element of the material on which the technique acts. Thereby he clearly addressed the know-how or manual skills of the actor (Lemonnier, 1992, pp.5-6), but following structuralist thinking this know-how remained solely anchored in the actor's perceived mental possibilities and choices.[1] As representations the knowledge was still separated from the body of the craftsperson as a layer of primary and amodal mental procedures whose bodily execution is subordinated (Lemonnier, 1992, pp.3-4). As with many contemporaneous approaches, the relation of the bodily experience and material in general with the articulated symbolic and ideological dimension remained a one-way street, in which the representation and ideas coined the bodily execution, whereas the body and the material have no real impact on the mental schema. Similar classical cognitive approaches based on structuralist thinking were also dominant in archaeology, for instance, the three-layered heuristic that Thomas Wynn introduced into lithic studies. Also, he describes a problem-solving/cognitive control layer that guides sequentially-structured actions and deploys them flexibly and intelligently into problems. Meanwhile, a biomechanical layer is underestimated and guides 'simple' behaviour like reaching and grasping (Wynn, 1993, p.390).

Only later did embodied cognition become a focal point of research, particularly in the field of the anthropology of craft.[2] For instance, Tim Ingold used Husserl's and Merleau Ponty's phenomenological concept of corporality to argue in a non-cartesian way that a technique is inseparable from the bodily experience of the human subject with other people, tools, raw materials, and the social and material environment in general (Ingold, 2011b, p.314-315; cf. 2011a; 2011c) and argues for a sensual entity between humans, tools and material. Only during the last ten years, the first ideas of this field have entered archaeology. For instance, Joanna Sofaer (2015; 2018) and Maikel Kuijpers (2019) emphasized materiality and its sensual experience using the idea that '[Y]*ou cannot make what you want, but what the material permits you to make*' (Pallasmaa, 2009, p.55, cf. Sofaer 2015, p.3.)[3] as their guidepost showing the importance of the sensual human-resource relation in crafts. Meanwhile, Lambros Malafouris (2004; 2016 [2013]) integrates insights from cognitive and psychological studies on how we engage with materials and develops it further within his project handmade (cf. Malafouris – Koukouti, 2022). Indeed, in the last years cognitive science (Varela, et al., 2017) is increasingly concerned with the embodied and situated character of action, perception, and cognition and recognizes the various ways the body can constitute or causally influence the execution of cognitive capacities. This extends to the sensual character of feedback from the things around us: the clay, the metal, the wood, potential tools, the floor we sit or stand on, the kiln, the wind and weather and of course other humans and animals – this sensual feedback is crucial for any learning process embodied in the course of thousands of repetitions necessary for learning a craft. Relational approaches emphasizing the interwovenness of materials, bodies and discursive aspects as practice theory can be therefore an adequate means to describe how resources are

1 Lemonnier, 1992, pp.5-6: he still considers mental abilities in the tradition of Durkheim as collective representations of ideas, beliefs, and values (Durkheim, 1912).

2 For instance, Downey, 2007; 2009; Downey andLende, 2012; Ingold, 2011a-c; Marchand 2001;, 2006; 2007; 2008; 2010; Marchand and Kresse, 2009; Pallasmaa ,2009; Sennett, 2009.

3 Similarly Sennett (2009).

caught up in craft practices. But this field is far from being explored from an archaeological perspective and the present book chapter wants to contribute in this regard.

Practice theory understands the social as initiated from the body and not from a mental-cognitive or discursive domain (Reckwitz, 2003, pp.287-288, 290; 2000) as it has been done in the technique studies by Lemonnier. In the sense of Theodore Schatzki, a practice emerges when material and the self are mediated through bodily knowledge (1996); a perspective, which is particularly fruitful for the understanding of crafts. To better understand this human-material entity of craft practices it is not only important to lay out the relationality of the practice particles (Hillebrandt 2023): the tools, the raw materials and the human bodies. The clue of the craft practice is that it is a sensual entity through gestures and routines. The major challenge for us is that it is difficult to verbally specify this (von Rüden, 2015; 2017).

Single gestures and routines can be traced in almost all the steps of a workflow – from the spotting of the resources, its preparation, and the shaping process until the final details and surface treatment. In archaeology, these gestures can be often reconstructed within the course of longer-lasting experimental studies. Then at least parts of the silent complexity of a skill can be captured through a thick description of the reconstructed gestures (Geertz, 1987). These descriptions accomplish our static categories in the archaeology of types and fabric which are only indirectly helpful to understand skills as they first need to be translated into processes and habitualised movements. This allows us to describe for instance the craftworker's awareness of the suitable humidity of clay when shaping a vessel, to feel the resistance of a tool during woodworking or to bodily sense the appropriate texture of a plaster surface to paint or burnish. In each case, sight alone – our usual scientific category – is not very helpful; it is the tactile experience, sensory feedback and memory that come to the fore as a primary source of knowledge. Without this, the mastery of a complex craft is often impossible. Such systematic integration of the so-called lower senses into the analysis of skill would also counteract the presentation of past people as *anaesthitoi* as Yannis Hamilakis (2013, p.6) has recently criticized.

Many interpretations in craft studies emphasise the continuity and repetitive character of practices and particularly when we are dealing with craft traditions. Indeed, they are reproduced in time and space through knowledgeable bodies, shaped through thousands of repetitions and the material facticity of artefacts – hence there is a certain stability. At the same time, there is always a tension between the routine of craft practices and the latter's openness to failure, misinterpretation, and conflict in their daily execution. The situatedness of craft practice leads to its context-related continuous reinterpretation which arises from confrontations with events, persons, artefacts or raw materials. The re-interpretation might be marginal, but is usual, and not exceptional (Reckwitz, 2003, p.294). So, in fact, we need to explain stability and not change.

There are several possibilities for how change can be provoked within craft practice. A possibility is through the emergence of new resources. Travelling craftspeople for instance are usually challenged by the different characteristics of their resources at different places. For instance, potters who are confronted with a new landscape will certainly try to choose the most suitable clay for their products. Nonetheless, the clay will differ to a certain degree from what they are used to. This will afford the adjustment of their workflow for instance by more intensive cleaning, additional temper or by adjusting the pot's sizes due to perhaps less plastic material. Another scenario would be the impact of new tools.

Staying with pottery production, the implementation of a throwing device needs not only an adjustment regarding the clay. It also needs a longer-lasting learning process as has been described by Loney for central Italy (2007). The necessary new gestures for throwing the pottery have to be incorporated by a body habitualised in the older techniques. As a result, the former embodied movements might merge with the new ones perhaps leading to a hybrid movement and techniques. And a last, but not least example, of course also discursive practices as ideologies and cosmologies have an impact on the practice bundle of pottery making.

However, the more usual source of change often neglected in archaeology is not coming from an external event, for instance, new tools, materials or ideas, instead, it is inherent in the practice itself. Using Wittgenstein's differentiation between the rules of written language and the physical language game (Wittgenstein, 1984, p.345), Jacque Derrida and, later, Theodore Schatzki stressed that practices can never be reduced to formal, normative rules (Derrida, 1976; Schatzki, 1996; 2002). Each new execution is rarely identical to the previous one. In contrast to the discursive scripts of technologies, in particular, the embodiment of craft practices has a high potential for a creative exploration of materiality and thus a lingering shifting of meaning, as Derrida revealed in his analysis of meaningful communication (1976). This fluidity is central to practice theory and particularly important when we are thinking about techniques and how they change.

These topics are addressed in this book section in three different papers focussing on three different crafts: metallurgy, ancient paintings and textiles. By using examples from the Aegean World, skills and their transmission as well as change are explored by Nikos Papadimitriou and Akis Goumas in the chapter 'Craft apprenticeship, craft innovation and the relational aspects of skill'. Here, skill is approached as a mixture of manual and mental competencies, whose meaning varies according to the context of practice. A relational approach, based on the concept of 'relational habitus', combined with contextual analysis, is used to understand better the character of skill and its mechanisms of transmission. While for apprentices, skill is perceived as an external set of dexterities that must be acquired through practice and repetition, for master artisans who focus on artistic innovation, skill is an internalized complex of thinking and doing. This difference in the meaning of skills derives from the kind of relations among the human agents, and among these and their tools. The relationship between master craftspeople and their tools is stronger and much more interactive with respect to apprentices.

Johannes Jungfleisch, in the Chapter 'Built from Paint: The Making of the Architectural Simulations in the Wall Paintings of Tell el-Daba', criticises approaches to ancient painting solely based on the visual fascination of imageries. On the contrary, it is argued that the fragmentary nature of ancient wall paintings should be embraced as an opportunity to investigate how they become in a material and technical way. Various stages of the past manufacturing process behind the Aegean-style wall paintings at Tell el-Dab^{c}a, Egypt, are analysed by using the example of the so-called architectural simulations from 'Palace G', which show building materials and techniques on a large scale. The craftspeople's material choices and technical actions are thus reconstructed, and their bodily and sensual engagement with the different materials during the production process is explained.

In the chapter "The Anatomy of a Tradition" Christopher Buckley examines what a 'tradition' consists of, using ethnographic examples, arguing that slow-changing and fast-changing aspects are both essential to understanding how traditions have evolved. By focusing on the weaving cultures of Southeast Asia, compared with the traditions of Tibetan Buddhism, it is shown how key features and processes spread. Both traditional weaving and Buddhist sects have at their core a kernel of knowledge that is passed on from generation to generation, as both weaving traditions and religious orders have 'technologies' at their core, and that, despite a huge difference in content, they have evolved in broadly similar ways.

Hence, the focus of this session is how resources can be sensually experienced, and how raw materials and tools are bodily incorporated within the skillful task of a craft. We touch on the topic of how these practices are transformed if one of the skill's ingredients- the raw materials, the tools, the body of the craftsperson, environmental or social aspects – changed or has been even replaced. The session further considers how such a problem-solving process or in general learning triggers creativity.

Moreover, in the field of craft, the term resources can be tackled in a two-folded way: it can be referred to as raw materials, and to what has been described in a traditional Marxist sense as productive resources and their knowledge, too. At first glance, the latter seems to be not directly tangible, however, at a second glance, it becomes obvious that this resource is far from being a-material. Knowledge is largely incorporated within the body and stretches into the world through what is today described as an extended mind. To reach from this micro-level to a larger scale, we observe how these practices are entangled also beyond the situations described above – within societies and their wider environment. Additionally, we observe who is involved in these tasks and if we can integrate these tasks into taskscapes or similar into interrelated bundles of practices according to praxeological approaches. These are just some ideas that will probably not even represent the tip of the iceberg and our contributors hi-jack us to much more exciting ways of seeing and approaching the topic.

References

Becker, J., Jungfleisch, J. and von Rüden, C., eds., 2018. *Tracing technoscapes: the production of Bronze Age wall paintings in the Eastern Mediterranean.* Leiden: Sidestone Press.

Bender Jørgensen, L., Sofaer, J. and Stig Sørensen, M.L., 2018. *Creativity in the Bronze Age: understanding innovation in pottery, textile, and metalwork production.* Cambridge: Cambridge University Press.

Bergson, H., 1986. *Matière et mémoire.* Reprint 1968. Paris: P.U.F.

Botwid, K., 2013. Evaluation of ceramics: professional artisanship as a tool for archaeological interpretation. *Journal of Nordic Archaeological Science*, 18, pp.31-44.

Botwid, K., 2017. *Understanding Bronze Age life: Pryssgården (LBA) in Sweden from an artisanal perspective.* Report Series of the Department of Archaeology and Ancient History Lund 102. Lund: Department of Archaeology.

Bourdieu, P., 1977. *Outline of a theory of practice.* Cambridge: Cambridge University Press.

Budden, S., 2008. Skill amongst the sherds: understanding the role of skill in the early to late Middle Bronze Age in Hungary. In: I. Berg, ed., *Breaking the mould: challenging the past through pottery. International Conference on Prehistoric Ceramics, Manchester 2006.* BAR International Series 1861. Oxford: Archaeopress, pp.1-17.

Chamoux, M.-N., 1978. La transmission des savoir-faire: un objet pour l'ethnologie des techniques? *Techniques et Culture*, 3, pp.46-83.

Clark, A., 2010. *Supersizing the mind: embodiment, action, and cognitive extension.* Oxford: Oxford University Press.

Clark, A., 2015. *Surfing uncertainty: prediction, action, and the embodied mind.* Oxford: Oxford University Press.

Deleuze, G. and Guattari, F., 1992. *Tausend Plateaus.* Berlin: Merve.

Derrida, J., 1976. *Of grammatology.* Baltimore, MD: Johns Hopkins University Press.

Downey, G., 2007. Seeing with a 'sideways glance': visuomotor 'knowing' and the plasticity of perception. In: M. Harris, ed., *Ways of knowing: anthropological approaches to crafting experience and knowledge.* New York/Oxford: Berghahn Books, pp.222-244.

Downey, G. and Lende, D.H., 2009. The encultured brain: why neuroanthropology? why now? Available at: https://neuroanthropology.net/2009/10/08/the-encultured-brain-why-neuroanthropology-why-now/ [Accessed 8 October 2017].

Downey, G. and Lende, D.H., 2012. Neuroanthropology and the encultured brain. In: D.H. Lende and G. Downey, eds., *The encultured brain: an introduction to neuroanthropology.* Cambridge, MA: MIT Press, pp.23-66.

Durkheim, E., 1912 [2014]. *Les formes élémentaires de la vie religieuse. Le système totémique en Australie.* Paris: CNRS, coll. « Biblis ».

Gallagher, S., 2017. *Enactivist interventions.* Oxford: Oxford University Press.

Gauß, W., Klebinder-Gauß, G. and von Rüden, C., eds., 2015. *The transmission of technical knowledge in the production of ancient Mediterranean pottery. Proceedings of the International Conference held at the Austrian Archaeological Institute at Athens, 23rd-25th November 2012.* Sonderschriften des Österreichischen Archäologischen Institutes 54. Vienna: Österreichische Akademie der Wissenschaften.

Geertz, C., 1987. *Dichte Beschreibung: Beiträge zum Verstehen kultureller Systeme.* Frankfurt a.M.: Suhrkamp.

Haider, H., Eichler, A. and Lange, T., 2011. An old problem: how can we distinguish between conscious and unconscious knowledge acquired in an implicit learning task? *Consciousness and Cognition*, 20, pp.658-672.

Hall, E.T., 1969. *The hidden dimension.* London: Anchor Books.

Hamilakis, Y., 2013. *Archaeology and the senses: human experience, memory, and affect.* New York: Cambridge University Press.

Hillebrandt, F., 2014. *Soziologische Praxistheorien: eine Einführung.* Wiesbaden: Springer.

Hillebrandt, F., 2019. Popmusik und Gesellschaftskritik: praxissoziologische Überlegungen. In: Th. Alkemeyer, N. Buschmann and Th. Etzemüller, eds., *Gegenwartsdiagnosen: kulturelle Formen gesellschaftlicher Selbstproblematisierung in der Neuzeit.* Bielefeld: Transcript, pp.xx – xx.

Høgseth, H.B., 2012. Knowledge transfer: the craftsmen's abstraction. In: W. Wendrich, ed., *Archaeology and apprenticeship: body knowledge, identity, and practice.* Tucson: University of Arizona Press, pp.61-78.

Howes, D. and Classen, C., eds., 2014. *Ways of sensing: understanding the senses in society.* London: Routledge.

Husserl, E., 1973. *Cartesianische Meditationen und Pariser Vorträge.* Husserliana 1. Den Haag: Martinus Nijhoff.

Ignatov, G., 2007. Theories of embodied knowledge: new directions for cultural and cognitive sociology? *Journal for the Theory of Social Behaviour*, 37(2), pp.115-135.

Ingold, T., 2011a. Tools, minds and machines: an excursion to the philosophy of technology. In: T. Ingold, ed., *The perception of the environment: essays on livelihood, dwelling and skill* (reissued). London: Routledge, pp.295-311.

Ingold, T., 2011b. Society, nature and the concept of technology. In: T. Ingold, ed., *The perception of the environment: essays on livelihood, dwelling and skill* (reissued). London: Routledge, pp.312-322.

Ingold, T., 2011c. Of string bags and birds' nests: skill and the construction of artefacts. In: T. Ingold, ed., *The perception of the environment: essays on livelihood, dwelling and skill* (reissued). London: Routledge, pp.349-361.

Ingold, T., 2013. *Making: anthropology, archaeology, art and architecture.* Abingdon: Routledge.

Joyce, R.A., 2005. Archaeology of the body. *Annual Review of Anthropology*, 34, pp.139-158.

Kuijpers, M.H.G., 2018. *An archaeology of skill: metalworking skill and material specialization in Early Bronze Age Central Europe.* London: Routledge.

Latour, B., 2007. *Eine neue Soziologie für eine neue Gesellschaft: Einführung in die Akteur-Netzwerk-Theorie.* Frankfurt a.M.: Suhrkamp.

Lave, J. and Gomes, A.M.R., 2019. *Learning and everyday life: access, participation, and changing practice.* Cambridge: Cambridge University Press.

Lemonnier, P., 1992. *Elements for an anthropology of technology.* Ann Arbor: Museum of Anthropology, University of Michigan.

Leroi-Gourhan, A., 1964. *Hand und Wort. Die Evolution von Technik, Sprache und Kunst.* Reprint 1988. Frankfurt a.M.: Suhrkamp.

Loney, H., 2000. Society and technological control: a critical review of models of technological change in ceramic studies. *American Anthropologist*, 65, pp.646-668.

Malafouris, L., 2004. The cognitive basis of material engagement: where brain, body and culture conflate. In: E. DeMarrais, C. Gosden and C. Renfrew, eds., *Rethinking materiality: the engagement of mind with the material world.* Cambridge: McDonald Institute for Archaeological Research, pp.217-238.

Malafouris, L., 2008. At the potter's wheel. In: C. Knappett and L. Malafouris, eds., *Material agency: towards a non-anthropocentric approach.* New York: Springer, pp.19-36.

Malafouris, L., 2013. *How things shape the mind: a theory of material engagement.* Cambridge, MA: MIT Press.

Marchand, T.H.J., 2001. *Minaret building and apprenticeship in Yemen.* Richmond, Surrey: Curzon.

Marchand, T.H.J., 2006. Endorsing indigenous knowledge: the role of masons and apprenticeship in sustaining vernacular architecture – the case of Djenné. In: L. Asquith and M. Vellinga, eds., *Vernacular architecture in the twenty-first century: theory, education and practice.* London: Taylor & Francis, pp.46-62.

Marchand, T.H.J., 2007. Crafting knowledge: the role of "parsing and production" in the communication of skill-based knowledge among masons. In: M. Harris, ed., *Ways of knowing: anthropological approaches to crafting experience and knowledge.* Oxford: Berghahn, pp.173-193.

Marchand, T.H.J., 2008. Muscles, morals and mind: craft apprenticeship and the formation of person. *British Journal of Educational Studies*, 56, pp.245-271.

Marchand, T.H.J., 2010. Making knowledge: explorations of the indissoluble relation between mind, body and environment. In: T.H.J. Marchand, ed., *Making knowledge. Journal of the Royal Anthropological Institute, Special Issue.* Oxford: Berghahn, pp.1-21.

Marchand, T.H.J. and Kresse, K., eds., 2009. *Knowledge in practice: expertise and the transmission of knowledge. Africa, Journal of the International African Institute, Special Issue,* 79(1), pp.1-16.

Mauss, M., 1973 [1935]. Techniques of the body. *Economy and Society*, 2(1), pp.70-88.

Merleau-Ponty, M., 1966. *Phänomenologie der Wahrnehmung.* Berlin: de Gruyter.

Meskell, L., 1996. The somatization of archaeology: institutions, discourses, corporeality. *Norwegian Archaeological Review*, 29(1), pp.1-16.

Noë, A., 2004. *Action in perception.* Cambridge, MA: MIT Press.

Newen, A., de Bruin, L. and Gallagher, S., eds., 2018. *The Oxford handbook of 4E cognition.* Oxford: Oxford University Press.

Pallasmaa, J., 2009. *The thinking hand: existential and embodied wisdom in architecture.* Chichester: Wiley.

Pettinen, K., 2012. From habits of doing to habits of feeling: skill acquisition in Taijutsu practice. In: D.H. Lende and G. Downey, eds., *The encultured brain: an introduction to neuroanthropology.* Cambridge, MA: MIT Press, pp.23-66.

Polanyi, M., 2009 [1966]. *The tacit dimension.* Chicago: University of Chicago Press.

Pye, D., 1968. *The nature and art of workmanship.* Cambridge: Herbert Press.

Reckwitz, A., 2000. *Die Transformation der Kulturtheorien: zur Entwicklung eines Theorieprogramms.* Weilerswist: Velbrück.

Reckwitz, A., 2003. Grundelemente einer Theorie sozialer Praktiken: eine sozialtheoretische Perspektive. *Zeitschrift für Soziologie*, 32(4), pp.282-301.

Reckwitz, A., 2016. *Kreativität und soziale Praxis: Studien zur Sozial- und Gesellschaftstheorie.* Bielefeld: Transcript.

Roux, V. and Jeffra, C., 2015. The spreading of the potter's wheel in the ancient Mediterranean: a social context-dependent phenomenon. In: W. Gauß, G. Klebinder-Gauß and C. von Rüden, eds., *The transmission of technical knowledge in the production of ancient Mediterranean pottery. Proceedings of the International Conference held at the Austrian Archaeological Institute at Athens, 23rd-25th November 2012.* Sonderschriften des Österreichischen Archäologischen Institutes 54. Vienna: Österreichische Akademie der Wissenschaften, pp.165-182.

Rudolph, C., Storck, T. and Sandamirskaya, Y., 2015. Learning to reach after learning to look: a study of autonomy in learning sensorimotor transformations. *Proceedings of the International Joint Conference on Neural Networks*. Available at: DOI:10.1109/IJCNN.2015.7280733 [Accessed 6 November 2024].

von Rüden, C., 2015a. Transmediterranean knowledge and Minoan-style reliefs in Tell el-Dab'a: an attempt at paradigm shift. In: S. Cappel, U. Günkel-Maschek and D. Panagiotopoulos, eds., *Minoan archaeology: perspectives for the 21st century.* Louvain, pp.355-366.

von Rüden, C., 2015b. Approaching ancient techniques: from technology to bodily learning and skill. In: W. Gauß, G. Klebinder-Gauß and C. von Rüden, eds., *The distribution of technical knowledge in the production of ancient Mediterranean pottery.* Vienna: Akademie Verlag, pp.35-39.

von Rüden, C., 2016. The ivory deposit. In: C. von Rüden, A. Georgiou, A. Jacobs and P. Halstead, eds., *Feasting, craft and depositional practice in Late Bronze Age Palaepaphos: the well fillings of Evreti.* Rahden: Leidorf, pp.291-368.

von Rüden, C., 2017. From mechanics to embodiment: some theoretical considerations on techniques. In: P. Eisenach, T. Stöllner and A. Windler, eds., *The RITaK (Raw Materials, Innovation, Technology of Ancient Cultures) conferences 2013-2014.* Bochum: Deutsches Bergbau-Museum, pp.71-79.

von Rüden, C., 2022. Making landscape: exploring a praxeological approach to landscape archaeology. In: T. Kienlin, ed., *Sociality – materiality – practice.* Bonn: Habelt, pp.163-175.

von Rüden, C. and Skowronek, T., 2018. Between common craft tradition and deviation: the making of stucco reliefs in the Eastern Mediterranean. In: J. Becker, J. Jungfleisch and C. von Rüden, eds., *Tracing technoscapes: the production of Bronze Age wall paintings in the Eastern Mediterranean.* Leiden: Sidestone Press, pp.213-231.

Schäfer, F., Daniel, A. and Hillebrandt, F., eds., 2015. *Methoden einer Soziologie der Praxis.* Bielefeld: Transcript.

Schatzki, T.R., 1996. *Social practices: a Wittgensteinian approach to human activity and the social.* Cambridge: Cambridge University Press.

Schatzki, T.R., 2002. *The site of the social: a philosophical account of the constitution of social life and change.* University Park, PA: Pennsylvania State University Press.

Skowronek, T., Hauptmann, A. and von Rüden, C., 2020. Using spinel chemistry to characterise archaeological steatite found in the wall paintings of Tell el-Dab‘a, Egypt. *Journal of Archaeological Science*, 118, 105137.

Sofaer, J.R., 2006. *The body as material culture: a theoretical osteoarchaeology.* Cambridge: Cambridge University Press.

Sofaer, J., 2015. *Clay in the Age of Bronze: essays in the archaeology of prehistoric creativity.* New York: Cambridge University Press.

Sofaer, J., ed., 2018. *Considering creativity: creativity, knowledge and practice in Bronze Age Europe.* Oxford: Archaeopress.

Stanley, J., 2011. *Know how.* Oxford: Oxford University Press.

Schatzki, T., Knorr-Cetina, K. and von Savigny, E., eds., 2001. *The practice turn in contemporary theory.* New York/London: Routledge.

Sennett, R., 2009. *The craftsman.* London: Penguin.

Tilley, C., 2008. *Body and image: explorations in landscape phenomenology 2.* Walnut Creek, CA: Left Coast Press.

Varela, F.J., Thompson, E. and Rosch, E., 2017. *The embodied mind: cognitive science and human experience.* 3rd ed. Cambridge, MA: MIT Press.

Wilkinson, L. and Shanks, D.R., 2004. Intentional control and implicit sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30, pp.354-369.

Wendrich, W., 2006. Body knowledge: ethnoarchaeological learning and the interpretation of ancient technology. In: B. Mathieu, D. Meeks and M. Wissa, eds., *L’apport de l’Égypte à l’histoire des techniques.* Cairo: IFAO, pp.267-275.

Wendrich, W., 2012. Archaeology and apprenticeship: body knowledge, identity, and communities of practice. In: W. Wendrich, ed., *Archaeology and apprenticeship: body knowledge, identity, and communities of practice.* Tucson, AZ: University of Arizona Press, pp.1-19.

Whitehead, A.N., 1925. *Science and the modern world.* New York: The Macmillan Company.

Craft apprenticeship, craft innovation and the relational aspects of skill

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In archaeological literature, craft skill is often treated as a standard set of (primarily manual) dexterities, which can be acquired with varying degree of success by individual artists. Particular emphasis is laid on the practical aspects of craft learning, and the embodied/implicit character of technical knowledge. This, however, may oversimplify the meaning of skill. In this paper, we examine skill as a mixture of manual and mental competences, whose meaning varies according to the context of practice. We propose that a relational approach, based on the concept of "relational habitus", combined with contextual analysis, can help us understand better the character of skill and its mechanisms of transmission. Using archaeological examples from the Aegean world, we examine how the notion of skill is perceived in two different types of working environment: (a) training areas for apprentices, and (b) workshops with master artisans who focus on artistic innovation. It is argued that in the former case skill is perceived as an external set of dexterities, which is bounded in character, and must be acquired through practice and repetition, whilst in the latter case it is an internalized complex of thinking and doing, whose limits must be explored and tested. It is argued that this difference in meaning derives from the kind of relations that develop among the human agents in each context, and between the craftspeople and their tools (the latter relation being stronger and much more interactive in the case of master artisans).

Implicit knowledge, habitual learning, relational habitus, technical affordances, Aegean archaeology

Commonly, discussion about craft knowledge revolves around the notion of "skill". Yet, the term is rather vaguely defined: some scholars use it in plural ("skills") to describe a number of technical competences (e.g. various papers in Oleson, 2008 and Bruun et al. 2022; Wilson

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 151-172.

and Flohr, 2016; Miniaci, et al., 2018; see also Roux and Courty, 2019), while others prefer the singular to denote the competitive advantages that distinguish "skillful" from "less skilled" craftspeople (e.g. Bleed, 2008; Kuijpers, 2018).

An idea that seems to underlie a number of these approaches is that skill is a self-contained (*i.e.* context-free) entity, a standard set of dexterities, which can be acquired with varying degree of success by different craftspeople. Despite the efforts of specialized technological studies to demonstrate the *contextual* nature of craft knowledge (e.g. Pfaffenberger, 1992; Lemonnier, 1992; Costin, 1998; Dobres, 2000; 2010; Schiffer, 2001), the idea that "skill" is a given set of bodily capacities is still quite widespread. This topic deserves further discussion.

In the present paper we explore the character of skill acquisition in different contexts of practice and argue that the notion of "skill" as a standard set of dexterities is meaningful only (or mainly) in the learning stages of a craft, when apprentices are trained in the proper use of tools, the tolerances of materials, and the basic principles of composition.

However, when it comes to creative work, skill becomes a more fluid notion. In contexts that favor innovation, craftspeople tend to experiment with novel techniques, new combinations of materials and new tool-types. Sometimes, these innovations create new technical affordances, which open previously unimaginable paths of work and make earlier working methods look insufficient or redundant. This suggests that skill has a strong relational element, which needs to be explored in depth. It also raises interesting questions about the nature of skill: is a craftsperson who makes an innovation "more skillful" than before? If yes, where does skill lie? Is it in the mental capacity, the manual dexterity or the ability to exploit the new technical affordances?

Approaches to skill

In a paper written 70 years ago, W.M. Macqueen described craft skill as "a complex of mental and physical achievements, in which manual skill plays only a part" (1951, p.34). Using examples from industry, he likened "manual skill" to the work of a machine-operator, which consists of the precise repetition of specific movements, and "craft skill" to the work of a tool-setter, which requires the efficient combination of various technical elements so that the machine can produce the desired results. Macqueen emphasized the cognitive dimension of skill and the problem-solving mentality that must characterize a craftsperson. He stressed that craftspeople continuously encounter new situations and challenges; to respond to these challenges, they have to acquire "a propensity for meeting changing situations adequately, … the power to translate ideas into…own manual expression, and … the ability to apprehend the different elements which combine to make up the total of [their] skills" (Macqueen, 1951, p.36).

Recent research has paid less attention to the close interweaving between the mental and the physical aspects of skill. Many studies have focused on making as a form of *practice*, often drawing on P. Bourdieu's notion of *habitus* (1980) and on M. Mauss' earlier work on the same concept and the "techniques of the body" (1934). By emphasizing the habitual or "embodied" elements of skill and the subconscious elements of craft working (*i.e.* the "motor know-how", Pelegrin, 1991; 1993), scholars have tried to illuminate the subtle mechanisms of acquiring and transferring technical knowledge. This emphasis has improved our understanding of craft skill, but at the same time has created a virtual split between the mental and the manual. So strong is this split that some scholars have felt the need to criticize the "reduction of the technical to the mechanical" (Ingold, 2000, p.352; cf. Burke and Spencer-Wood, 2019, pp.8-9), and urged to abandon oppositional dichotomies between cognitive and "bodily" processes (e.g. Knappett, 2004, pp.43-44; Spencer-Wood and Burke, 2019, pp.262-265) or between discursive and non-discursive knowledge in crafting (Kuijpers, 2012, pp.138-139; 2017, pp.81-82), and to reinstate the structural relation between mind and body in craft-working (Ingold, 2018).

Other scholars have gone further and challenged the distinction between cognitive and embodied forms of knowledge altogether (e.g. Marchand, 2007; 2010; von Rüden, 2017; see also Downey, 2010). Introducing a phenomenological approach, they propose a shift towards the study of the sensorial and intersubjective elements of skill, as well as an understanding of embodied experience as interaction among different knowledge domains. Unfortunately, there is not yet a clear methodology that would allow such theories to be used widely. In that direction, we believe that a relational approach can be helpful. Already in the 1990s theories of situated learning demonstrated the importance of social contexts (especially "communities of practice") for acquiring practical knowledge and discussed the relational character of knowledge in general (e.g. Lave and Wenger, 1991; Wenger, 1998). In archaeology, relational approaches have been used primarily for analyzing craft organization and production (e.g. Duistermaat, 2016; Roux, 2019; various papers in Knappett and Malafouris, 2008; Gauss, et al., 2015). Skill has been also examined as a relational concept, with emphasis being placed on its contextual and technological facets (e.g. Apel, 2006, pp.209-210). In this paper, we wish to draw on the importance of habitual learning in craftwork and try to integrate the aforementioned approaches with the notion of "relational habitus", which was originally developed in the field of educational psychology (Stone, et al., 2012).

Relational habitus refers to the production of knowledge in a learning environment and is defined as the ensemble of relations that develop among individuals, tools, tasks and others, who interact in the service of a goal-directed activity. Interaction takes place through repeated embodied actions (*i.e.* actions without reflection), which generate "intersubjective processes of meaning making" (Stone, et al., 2012, pp.66. 72). In these intersubjective processes, "tools are not simply given but take on meaning in the context of relationships with others as part of routine practices and this meaning continually develops" (Stone, et al., 2012, p.74). In other words, the kind of habitus that develops in a learning environment depends on – and is signified by – the context and form of interaction among agents. Interestingly, agency is not ascribed only to teachers and trainees but also to tools and technical processes as dynamic elements in the production of knowledge. This is a fascinating idea, which has not been sufficiently explored in archaeology (e.g. Knappett and Malafouris, 2008).

In the following section, we use a combination of archaeological and experimental data to explore how these ideas can be applied to the ancient world. We present "training pieces" and technically-advanced artefacts from different periods of Aegean archaeology, and argue that the meaning of skill varied according to the context of work. We discuss the differences and try to explain how the notion of skill was formed in contexts of apprenticeship, and in the workshops of master artisans.

Case-Studies[1]

Apprenticeship and training

The role of apprenticeship in craft-learning has received considerable attention by anthropologists, educational theorists, and archaeologists alike (Coy, 1989; Roux and Corbetta, 1989, pp.12-29; Lave and Wenger, 1991, ch.3; Brill and Roux, 2002; Marchand, 2008; Bourgeois and Durant, 2012; Wendrich, 2013a; Downey, et al., 2015; Freu, 2016; Martin, 2021). In the Aegean, there is sufficient archaeological, textual and iconographic evidence to suggest that apprenticeship was the primary method of craft learning both in prehistory and in Classical antiquity (e.g. Hasaki, 2013; Berg, 2015). However, training pieces are hard to identify in the archaeological record, for a number of reasons. Firstly, such pieces are to be found in workshops or artist's studios, which are rarely discovered in archaeological excavations. Secondly, in certain crafts (e.g. metallurgy) objects used for practice were often recycled after use; therefore, training pieces are likely to be found in non-recyclable materials, such as stone, bone or ceramic (i.e. fired clay), but not in metal or glass. Thirdly, there is not yet detailed methodology for their identification (cf. Hasaki, 2013, 174. pp.194-195; Wendrich, 2013b). It is not clear for example, how we can distinguish a training piece from an artifact which was simply not finished. Finally, and related to the last point, whilst scholars sometimes identify apprentices on the basis of the quality of work (e.g. for artifacts which resemble the style of a given "artist" but are of "lower" quality, see Hasaki, 2013, pp.194-195) this is related to finished works and not to practice pieces.

Despite such difficulties there are cases where training pieces can be safely identified on the basis of contextual and technical evidence. In a 18th century BC seal-engraving workshop at the Minoan port of Malia, Crete, a number of crudely carved sealstones have been identified as "trial" or "practice" pieces associated with apprentices (Poursat, 1996, p.110; Anastasiadou, 2011, pp.48-49. 77-78). This attribution has been based primarily on stylistic traits, i.e. their typological divergence from – and lower quality than – the majority of the production. A technological analysis would probably result in more sealstones being classed as "training" pieces. For example, among several seals depicting ships, Anastasiadou has considered only the crudely engraved seal CMS II.2 147b (Fig. 1a) as a practice piece (Anastasiadou, 2011, p.48, fig.16a. pp.235-237). From a crafting point of view, there are more seals with ships, which could be classed as "practice pieces", such as seal S2646 (Fig. 1b), which was found in the vicinity of the workshop (Poursat, 1996, p.104; Anastasiadou, 2011, p.557, cat. no. 239). It has only one of its three sides engraved, and a large break along the string-hole. Given that string-holes were usually made before the engraving (because of the risk of breakage during the engraving process, see Younger, 1981; Evely, 1993, p.154-157), the ship motif must have been carved *after* the seal was broken, therefore, the seal, although stylistically more advanced, may have not been meant for use but was more likely a practice piece. Similar breaks along the string-hole can be seen in a number of semi-worked stones from the site, which have been shaped as three-sided prisms but left unengraved (Fig. 1c-d). The breaks are crude and very unlikely to have been made by experienced craftspeople.

1 The following abbreviations are used in the figure captions: AMH = Archaeological Museum of Herakleion, Crete; CMS = Corpus der minoischen und mykenischen Siegel, Heidelberg; NAM = National Archaeological Museum, Athens; NMD = National Museum of Denmark, Copenhagen. We are grateful to all these institutions for allowing us access to their collections. Please see captions and acknowledgements for detailed references.

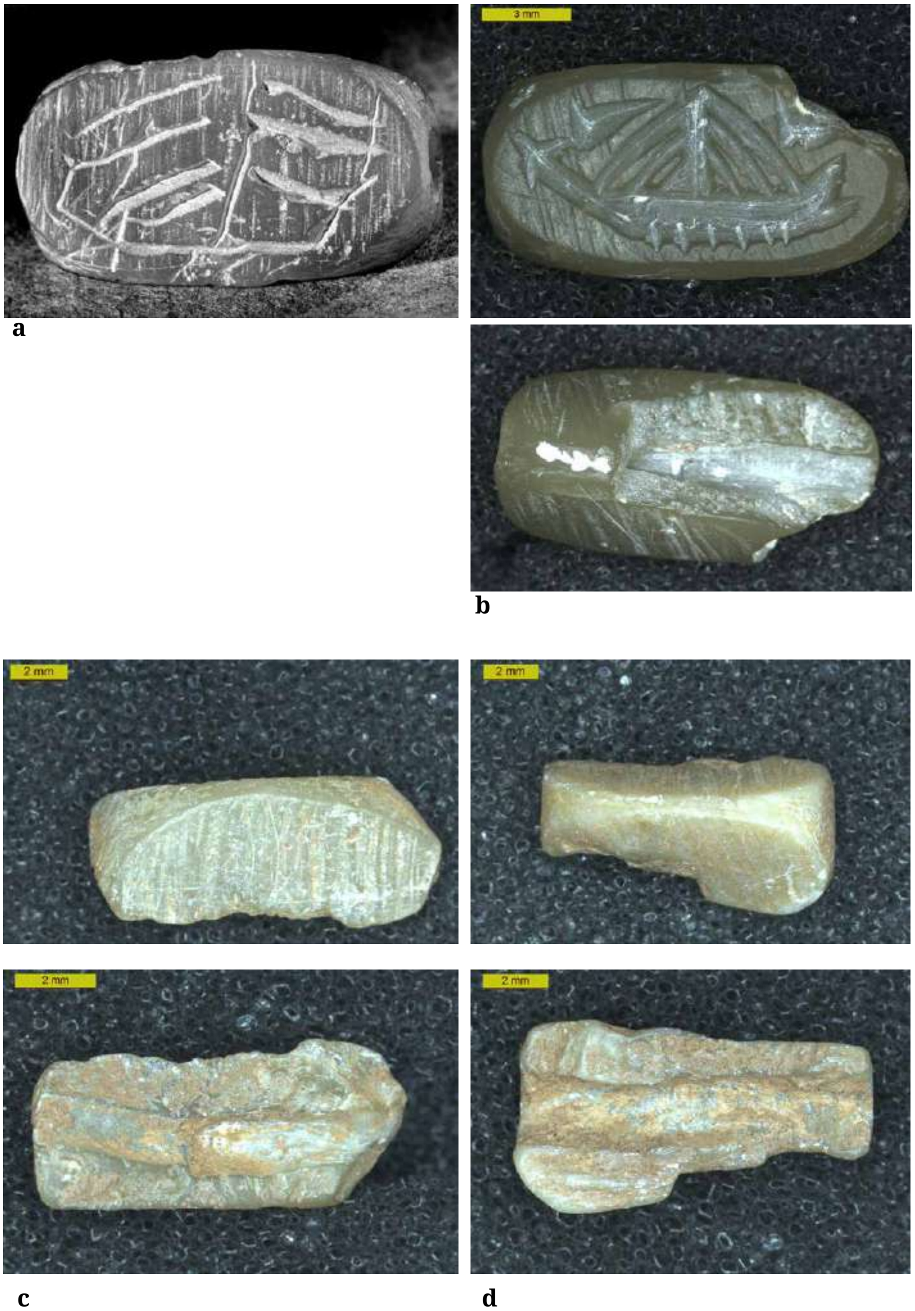


Figure 1: Possible training pieces from the 18th century BC seal-cutting workshop (and environs) of Malia Crete: a) steatite 3-sided prism with crude rendering of the ship-motif, AMH S1819 (CMS II.2, 147b); b) steatite 3-sided prism with engraved ship-motif in one side (the other sides are undecorated) and extended breakage along the string-hole, AMH S2646; c-d) undecorated steatite prisms with breakages along the string-hole (AMH S4615, S4616) (a, Corpus der minoischen und mykenischen Siegel, Heidelberg University; b-d, authors with the kind permission of the Archaeological Museum of Heraklion).

a

Figure 2: Marble training pieces from Aphrodisias, Caria: a) a statue of Poseidon from the Sculptor's Workshop, which was very probably used for practice (van Voorhis, 2018, pl.36); b) two right feet at the base of Poseidon's statue (van Voorhis, 2018, pl.37); c) practice pieces with sculpted feet from other parts of Aphrodisias (van Voorhis, 1998, figs.12-17) (a, b, New York University Excavations at Aphrodisias (G. Petruccioli); c, New York University Excavations at Aphrodisias) (continued next page).

b

c

For that reason, we argue that these nodules were more probably practice pieces used by apprentices who were learning the drilling technique, as well as for testing the tolerance of the raw materials.

The next example relates to the crafting of sculptures at a late Hellenistic/Roman marble workshop in Aphrodisias, Caria (Asia Minor). Here the excavators found several unfinished statues in different phases of the carving process (van Voorhis, 2018). Some of them were interpreted as training pieces because the tool-marks observed on their surfaces were so mixed and varied that they did not correspond to a given stage of the marble-carving chaîne opératoire. Most likely they were sculptures that had been abandoned at some stage of the carving process (perhaps due to failure of the material), and then used by apprentices for testing tools and techniques (van Voorhis 2018, pp. 44-45). Particularly interesting is a statue of Poseidon, which had all kinds of tool-traces on its surface, as well as two right feet (Fig. 2a-b) (van Voorhis, 2018, p.45 and cat. no. 26). Many more practice pieces with carved feet (mostly right ones, and a few left ones) have been found all over Aphrodisias (Fig. 2c), suggesting a special insistence by masters on that feature and its correct execution by apprentices (van Voorhis, 1998, figs.12-17). The precise carving of feet may have been "a standard exercise in an apprentice's curriculum in different workshops" of the city (van Voorhis, 1998, p.183).

In these cases, the artistic result was of little importance, instead what mattered was the acquisition of technical competence in the handling of tools, and an understanding of materials and their limits. This was achieved through repetitive trial-and-error actions, most probably under the close supervision of masters. Repetition is crucial in training as it is through sustained practice and the replication of movements that apprentices can translate external knowledge (i.e. what they are told and shown by their teachers) into personalized experience and embodied skill (cf. von Rüden, 2017, p.76). A craftsperson (quite like a musician or an athlete) has to repeat a movement thousands of times until it becomes almost "natural". In psychology, this process is described as the transition from explicit to implicit knowledge, the former referring to "facts and rules we are aware of and, therefore, able to articulate", the latter referring to things "we 'know' yet are not aware of, and thus, cannot articulate" (Masters, 1992, p.3). Learning starts with a *cognitive* phase (in which information comes mostly as explicit verbal instructions), goes through an *associative* stage (in which information and instructions are gradually encoded and movements become procedural through practice) and ends up in an *autonomous* phase, in which skill becomes implicit and movements almost automatic (Fitts, 1964; Anderson, 1982; 1987; Davids, et al., 2008, pp.8-9).

Logan has described how automaticity is born as the body learns to respond to specific stimuli:

> "*... novices begin with a general algorithm that is sufficient to perform the task. As they gain experience, they learn specific solutions to specific problems, which they retrieve when they encounter the same problems again. Then, they can respond with the solution retrieved from memory or the one computed by the algorithm. At some point, they may gain enough experience to respond with a solution from memory on every trial and abandon the algorithm entirely. At that point, their performance is automatic. Automatization reflects a transition from algorithm-based performance to memory-based performanc*e" (Logan, 1988, p. 493).

The mechanism mobilized in this process is known as “non-declarative” or “procedural/ habitual” memory. This type of memory is responsible for performing tasks and movements without conscious reflection – although perceptual processes, like priming, are also involved (e.g. Squire et al., 1993, pp. 275-278; Baddeley 1999, pp. 16-17, 81-85; see also Apel 2006, pp. 214-215). Habitual memory takes form through practice, and accounts for all motor skills and automatizations of the body (hence it is sometimes described as “bodily memory”).

It would be erroneous, however, to consider craft skill as a series of automatized bodily actions. As Logan explains, automaticity cannot account for an entire set of movements, instead it concerns individual instances of stimuli and responses, which are encoded separately and accumulated with time in procedural memory (Logan, 1988, p.493). The movements needed for using different tools become automatized, but the decision of how to combine a hammer with a chisel remains in the conscious part of the brain and continues to be a cognitive function (cf. Marchand, 2007, pp.186, 195-197 analyzing the concept of parsing; Ingold, 2018, pp.160-161). In other words, the body learns to respond automatically to specific stimuli, but the orchestration of stimuli is controlled by cognition. In the learning stages of a craft, developing such automatizations and the ability to control them (i.e. acquiring a *habitus* related to the specific task) is a primary goal.

What comes out of the above analysis is that, in training contexts, the notion of craft skill has specific *standards* (and limits), which are defined by instructors/masters and must be attained by apprentices. These standards are primarily technical (*i.e.* the proper handling of tools and the correct execution of techniques) and secondarily conceptual (how to use or to combine tools in order to create a design).[2] Apprentices have to learn and embody these standards in order to be accepted as craftspersons. This creates a strong bias in the intersubjective process: the flow of information is uni-directional from the part of the masters towards the apprentices – and, as we learn from archaeological and ethnographic sources, the relation to apprentices can be very disciplinary (e.g. Hasaki, 2013, pp.185-186; Downey, et al., 2015, pp.184-185).[3] As for the relation between apprentices and their tools, it is also conditioned by the expectations of masters. Students have little space to improvise, and if so, only at the last stages of their training period. This might help to explain how artistic “traditions” emerge. Apprentices spent so much time and effort trying to adjust their bodily postures, hand movements and thought according to their masters’ instructions that it is very difficult later to diverge from this way of “doing things”.

Creative work and innovation

When it comes to innovative work, things function in a different way, which can be understood if we approach a demanding technical process. Among the most demanding metal-working techniques in ancient Greece was so-called “gold-embroidery” (Konstantinidi-Syvridi, et al., 2022; Papadimitriou, et al., 2021; 2024).[4] This was a method for decorating the hilts and pommels of prestigious weapons in the Late Bronze Age. The technique consisted in the application of minute L-shaped gold bars (< 1 cm in length) on the organic hilt-plates

2 Of course, these standards may vary according to the cultural or social context.

3 Apprenticeship has also been seen as a form of horizontal division of labour, e.g. Goody, 1982, esp. pp.26-27.

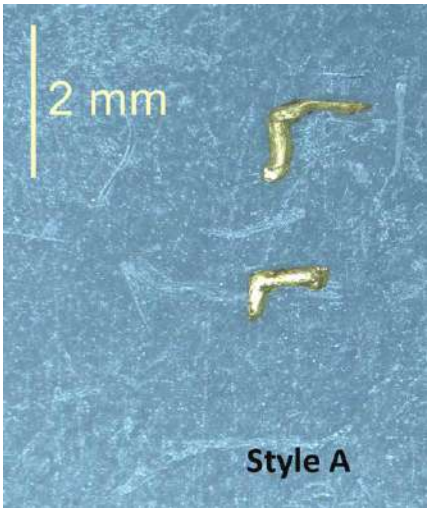
4 The study of gold-embroidery is made in collaboration with Dr Eleni Konstantinidi-Syvridi, Curator of the Prehistoric Collection at the National Archaeological Museum of Athens, and Mrs Maria Kontaki, Metal Conservator at the National Archaeological Museum.

Style A
17th/ 16th c. BC

a **b**

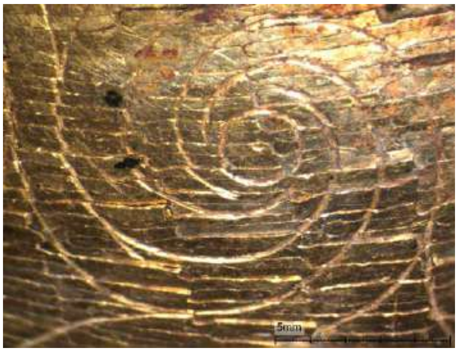
Figure 3: Gold embroidery, examples of the two styles of decoration. Style A: a) sword from Shaft-Grave IV of Mycenae, NAM 435; b) dagger from Shaft Grave IV of Mycenae, NAM 396; Style B: c) dagger from chamber tomb 81 at Mycenae, NAM 3111; d) ivory pommel of a sword probably from chamber tomb 12 at Dendra, AMD 14417. At the bottom (e) gold bars of Style A (left, unknown provenance, NAM 23328) and Style B (right, Dendra tholos tomb, NAM 7349) (a-c, e, authors with kind permission by the National Archaeological Museum of Athens; d, National Museum of Denmark, Copenhagen).

e



Style B
16th/ 15th c. BC

c



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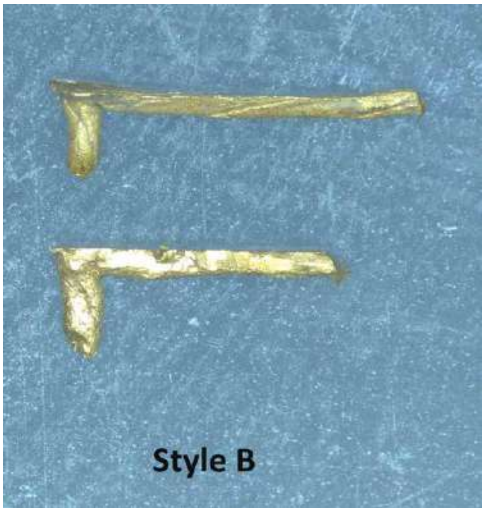

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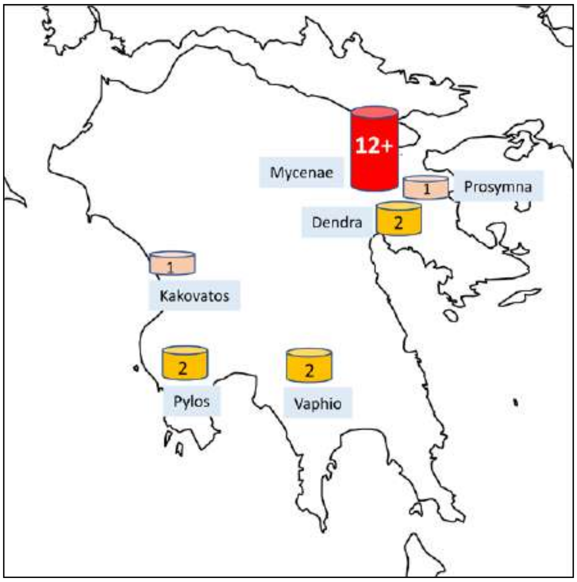


Figure 4: The geographical distribution of weapons decorated with gold-embroidery (authors).

of swords and daggers (Fig. 3). The bars either formed decorative motifs themselves (Style A) or created a solid gold surface which was then decorated with engraving (Style B).

The technique is encountered almost exclusively in "royal/princely" graves of the Early Mycenaean period (17th to 15th centuries BC), including Shaft Graves IV and V at Mycenae, the Dendra and Vaphio tholos tombs, and the recently excavated Griffin Warrior grave at Pylos (Konstantinidi-Syvridi, et al., 2022) (Fig. 4). Several facts suggest that objects decorated in that technique were manufactured in one or perhaps two workshops located at Mycenae: (a) the overall rarity of "gold embroidered" objects (ca. 20 examples identified so far, distributed in 6 sites, Fig. 4); (b) their impressive technical homogeneity (Fig. 3); (c) that Mycenae has yielded more than half of the known examples (Fig. 4); (d) that the technique occurs earlier at Mycenae (17th century) than in other places (16th/15th centuries); and finally (e) that gold-embroidery often co-exists with another demanding technique, metal-inlay decoration, which seems to have originated also at the workshops of Mycenae (Laffineur, 1974, pp.27-28; Xenaki-Sakellariou and Chatziliou, 1989, p.14).

Thus, contextual analysis suggests that gold-embroidery was an exclusive technique, which was only applied to weapons destined for individuals of very high, perhaps "princely", status. This means that a craftsperson did not have the chance to practice the technique very often – only when a ruler or another high-official of a major Mycenaean center passed away (or assumed office). Yet, the technique survived for 2-3 centuries, which means that knowledge was transmitted over several generations of artisans. Moreover, microscopic study reveals that considerable changes and technical innovations took place over time. For example, in the earliest weapons (17th-16th centuries BC) the tiny gold bars were used to create decorative motifs themselves (Fig. 3, Style A), while in the most advanced pieces (16th-15th centuries BC) the bars were used to create a gold plateau, upon which spiral motifs were engraved (Fig. 3, Style B). Moreover, in the early stages of the technique (Style A) the gold bars varied considerably in form and size, while later (Style B) they became highly standardized (Fig. 3e). Finally, in the chronologically

Figure 5: Detached piece of gold embroidery from the hilt of a sword found at the tholos tomb of Dendra, NAM 7439: a) front side with perfectly burnished surface and engraved decoration; b) side-view; c) the back side showing the "brickwork" method of placement of the gold bars (authors with kind permission by the National Archaeological Museum of Athens).

later examples (Style B), the gold bars were placed on the organic surface according to a sophisticated "brickwork" pattern, and then burnished to perfection – sometimes resembling gold sheet (Fig. 5) (for a detailed description of technical advances, see Konstantinidi-Syvridi, et al., 2022; Papadimitriou, et al., 2024).

What may have motivated these developments? Demand by the commissioners is not very likely: the differences between Style A and B were obvious on the surface, but, on a technical level it was impossible to perceive changes in the form of the gold bars or the system of placing – these details are accessible only to the modern researcher through microscopic examination of partly damaged pieces. Competition among different workshops is possible, although the known examples show remarkable technical homogeneity perhaps suggesting manufacture in a single workshop – but, of course, the possibility of more centers cannot be excluded. Another reason might have been competition with *tradition* – *i.e.* the personal need of a skilled artist to test his/her own limits and surpass the work of predecessors/teachers. A final reason may have been "peer-competition". Early Mycenaean workshops produced elaborate weapons for elite burials, combining a variety of materials and demanding techniques such as the decoration of blades with incision or metal-inlay, the gold-sheathing of handles, the carving of pommels made of ivory, alabaster and other materials, the decoration of wooden or ivory hilt-plates with gold-embroidery, cloisonné, glass-enameling and other specialized techniques. Several experts must have worked together for the manufacture of such a weapon, a situation which may have created an environment of artistic emulation and competition.

But how was innovation achieved in practice? What did cause changes in the approach of artisans? Was it improvements in their manual abilities, a shifting perception of the objects, or something else? To find answers to these questions, we decided to experiment ourselves. Akis Goumas (an accomplished goldsmith) started working on gold-embroidery, conducting experiments which lasted for approximately two years. The full experimental results have been presented elsewhere (Papadimitriou et al., 2024) so we will summarize the most important findings here.

1. The most serious challenge was the scale of work: the tiny size of gold bars (1-8 mm in length, Fig. 3e) made handling and even seeing them extremely difficult (Fig. 6). Akis Goumas worked with magnifying glasses, and recording was made mostly with microscopic cameras[5]. In reproducing the technique, Akis Goumas had to work first with larger pieces of gold and gradually diminish the size until he reached the dimensions of the originals.
2. Manual abilities were refined with time (e.g. in handling increasingly smaller pieces of gold), but this was not crucial. An accomplished craftsperson has sufficient manual dexterity and knowledge to easily adapt his/her gestures and overall bodily posture to new conditions of work.
3. What increased substantially with each effort was the visual perception of the artist. Through practice, Akis Goumas could see the surface of the objects and the various elements on it in far greater detail. This applied both to experimental pieces and to the originals. For example, only at an advanced stage of the study did he realize that the Mycenaean artisans used additional strips of gold bars in order to correct small mistakes and gaps (Fig. 7).
4. In general, Goumas' work was governed by the desire to solve problems. Such problems could be technical (e.g. how to reproduce the form of a gold bar) or related to design (e.g. how to best arrange gold bars on the organic surface). Particularly useful was the identification of errors visible on Mycenaean artifacts (e.g. the aforementioned example with the additional strips) or in earlier experimental pieces. These errors dictated the need for changes in the technical process, and often opened new paths of thought (cf. Marchand, 2016, pp.10-14; Fregni, 2019, 38-39).
5. Very often, technical advances were made possible with the creation of *new tools* (Fig. 8). The need for custom-made implements was realized from the beginning, as standard tools were not efficient at the minute dimensions of gold embroidery. Later in the process, Goumas met various difficulties, which necessitated a retouching of the tools (or sometimes a change in the copper alloy) to improve the results. For example, to be able to grasp the tiny gold bars tightly – without rolling around – he had to create tweezers with small grooves in the pincers (Figs. 6c-d, 8c), as well as a pressing tool with concave end that helped him press the bars in place (Fig. 8d) The efficiency of the new tools (made specifically to solve a technical problem) simplified the process of setting the bars in place, and showed that earlier methods used by Goumas or proposed by other scholars were not as effective and should, consequently, be abandoned (for more details, see Papadimitriou et al., 2024; for the importance of tool adaptation in general, see O'Connor, 2006). Thus, increasing visibility, refined tools and a problem-solving mentality were the most crucial elements of the experimental process, and those that allowed for technical advances to be made. Increased visibility and refined tools improved the artist's command over his materials and technique, and sometimes opened new, previously unimaginable paths of work. The whole process was driven by a problem-solving mentality, which drew on previous errors and inefficiencies and sought for solutions to problems. We should stress, however, that what the artist perceived as "problem" and "solution" changed over time together with refined tools and increased visibility. Each advance created *new technical affordances*, which made previous working methods to look inadequate or redundant (for the notion of *affordances*, see Knappett, 2004; Groth and Kimmel 2025).

5 The possible use of magnifying lenses in antiquity has been extensively discussed by Plantzos, 1997.

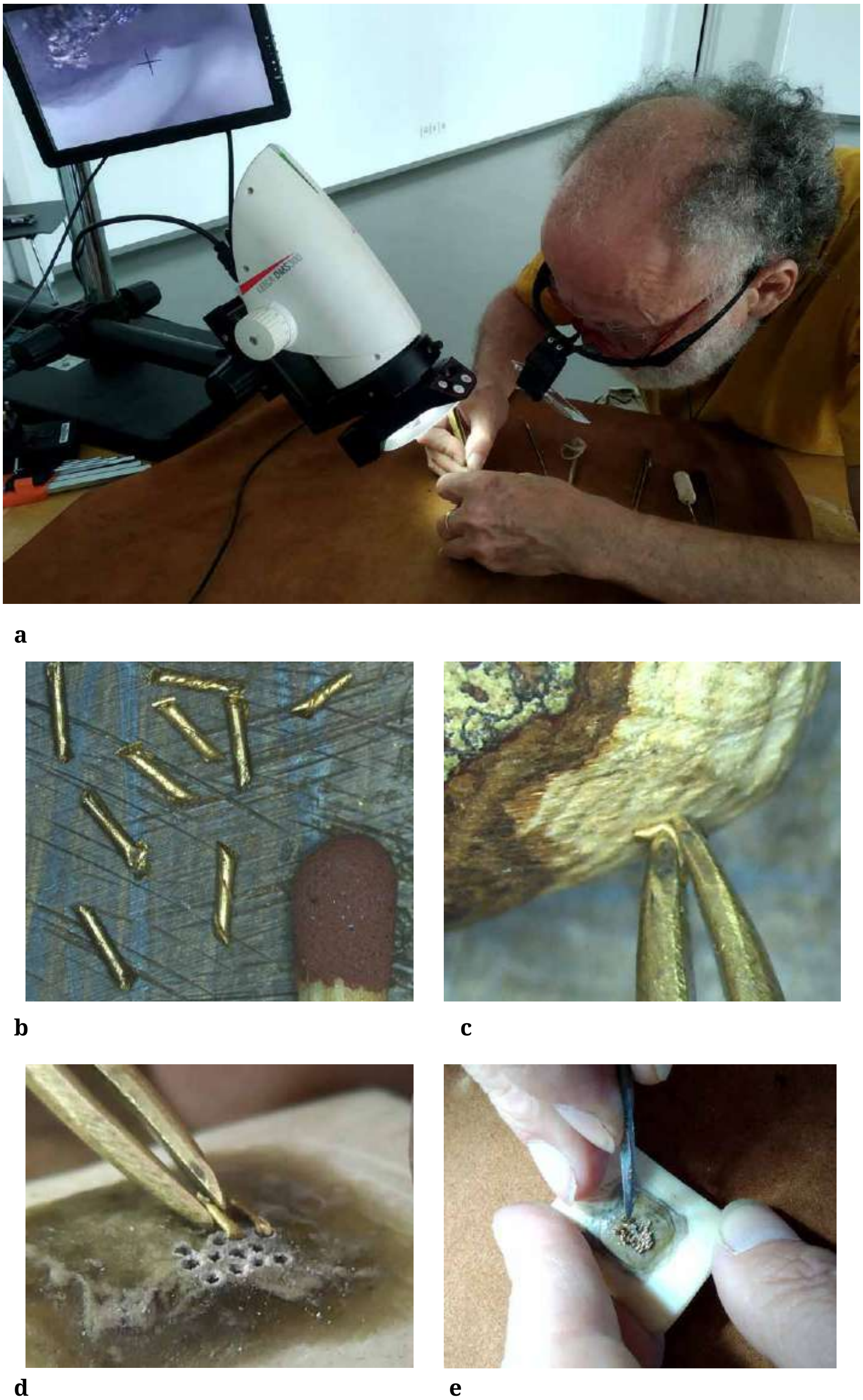


Figure 6: Experimental working by Akis Goumas: a) general view of the setup showing the scale of work; b) the size of gold bars; c) bending the gold bars; d) placing a gold bar in a pre-drilled hole on the organic surface; e) filling the space with gold bars (authors).

Figure 7: Detail of gold embroidery decoration on the ivory pommel of a sword from Dendra chamber tomb 12, NMD 14417; yellow arrows indicate "inset" gold bars, which have been added to correct small mistakes and gaps (authors).

This suggests that skill at the highest level of craftsmanship is closely linked to innovation. But innovation is by definition relational, as it is based on a "dialogue with tradition" (cf. Girard, 1990, p.18-20). This relational-dialogic process has a profoundly cognitive character. For an artist to innovate, automized movements and sensorial perception are of course important. Yet what blends these elements together is their desire to solve what they perceive as a "problem", and their ability to adjust their tools so that they can create new technical affordances. This justifies Macqueen's thesis that craft skill is "a complex of mental and physical achievements, in which manual skill plays only a part" (1951, p.34).

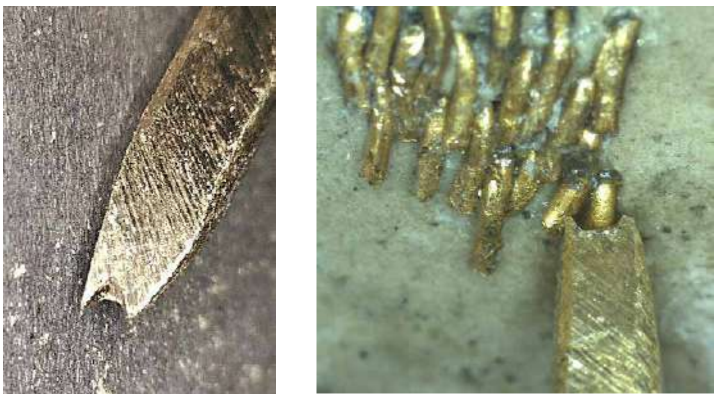
As for the concept of "relational habitus", it has a very different application here than it had in the apprenticeship case. Instead of being dominated by master-student relations, the intersubjective framework, in which a master Mycenaean goldsmith operated, included peer-relations with other expert craftspeople (their "community of practice"), a dialogic relation with tradition and past achievements, as well as a strong, interactive relation to his/her media of work, *i.e.* the tools. These differences explain why skill in archaeology can only be understood if grounded in sound contextual analyses.

Figure 8: Tools made by Akis Goumas to fit the scale of gold embroidery: a) cutting chisel (bronze with ca. 15% tin), L. 10.8 cm; b) drill (bronze with ca. 15% tin), L. 9.3 cm, L. point 1.4 cm; c) tweezers (bronze), L. 8.4 cm; d) pressing tool (bronze), L. 10.1 cm (authors) (on the right).

a

b

c



d

Concluding remarks

In this paper, we have explored the relational aspects of craft skill. We have argued that skill acquires different meaning according to the context of practice. It means different things to students/apprentices and to professional artisans. To the former it is an external set of dexterities, which seems bounded in character, and which has to be acquired through training; to the latter it is an internalized complex of thinking and doing, whose limits must be explored and tested. Students/apprentices learn from their teachers and try to imitate them, thus becoming unconsciously part of an artistic tradition or "school". Accomplished artisans refer to their peers and to previous masters and often try to get beyond the constraints of existing traditions through innovations. Their relation to tools also varies considerably: students/apprentices try to adjust their hands and bodily posture to the requirements of the tools; accomplished artisans try to adjust the tools to the needs of the work, if necessary, by reshaping them.

The merits of relational approaches have been appreciated in recent years by students of ancient technology and crafts (see Duistermaat, 2016, for a useful overview). A relational approach combines contextual, technological and archaeometric data, to reconstruct entire processes of making and to shed light on the relationships among the people involved in the process, as well as between them, their materials and tools. It is an approach that can be used in a synchronic way (e.g. for cross-examining contexts of the same period) and diachronically (e.g. for examining different stages in the development of a technique). As such, it can provide fresh insights into the complex issue of artistic skill in the past. We hope that our paper has made a contribution in that direction.

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References

Anastasiadou, M., 2011. *The Middle Minoan three-sided soft stone prism: a study of style and iconography.* CMS Beiheft 9. Darmstadt/Mainz: Akademie der Wissenschaften und der Literatur.

Anderson, J.R., 1982. Acquisition of cognitive skill. *Psychological Review*, 89, pp.369-406.

Anderson, J.R., 1987. Skill acquisition: compilation of weak-method problem solutions. *Psychological Review*, 94, pp.192-210.

Apel, J., 2006. Skill and experimental archaeology. In: J. Apel and K. Knutsson, eds., *Skilled production and social reproduction.* SAU Stone Studies 2. Uppsala: Societas Archaeologica Upsaliensis, pp.207-218.

Baddeley, A.D., 1999. *Essentials of human memory.* Hove: Psychology Press.

Berg, I., 2015. Potting skills and learning networks in Bronze Age Crete. In: W. Gauss, G. Klebinder-Gauss and C. von Rüden, eds., *The transmission of technical knowledge in the production of ancient Mediterranean pottery.* Österreichisches Archäologisches Institut Sonderschriften 54. Vienna: Österreichisches Archäologisches Institut, pp.17-34.

Bleed, P., 2008. Skill matters. *Journal of Archaeological Method and Theory*, 15, pp.154-166.

Bourdieu, P., 1980. *The logic of practice.* Stanford: Stanford University Press.

Bourgeois, É. and Durant, M., eds., 2012. *Apprendre au travail.* Paris: Presses Universitaires de France.

Brill, B. and Roux, V., 2002. Les "programmes" d'apprentissage comparables pour des actions techniques différentes. In: B. Brill and V. Roux, eds., *La geste technique: réflexions méthodologiques et anthropologiques.* Ramonville Saint-Agne: Éditions érès, pp.231-241.

Bruun, M.H., Wahlberg, A., Douglas-Jones, R., Hasse, C., Hoeyer, K., Kristensen, D.B., Winthereik, B.R., eds, 2022. The Palgrave Handbook of the Anthropology of Technology. Singapore: Palgrave Macmillan.

Burke, C. and Spencer-Wood, S.M., eds., 2019. *Crafting in the world: materiality in the making.* Cham: Springer Verlag.

Costin, C.L., 1998. Introduction: craft and social identity. In: C. Costin, R. Wright and E. Brumfiel, eds., *Craft and social identity.* Archaeological Papers of the American Anthropological Association 8 (Special Issue). Arlington, VA: American Anthropological Association, pp.3-16.

Coy, M.W., ed., 1989. *Apprenticeship: from theory to method and back again.* Albany: SUNY Press.

Davids, K., Button, C. and Bennet, S., 2008. *Dynamics of skill acquisition: a constraints-led approach.* Champaign: Human Kinetics.

Dobres, M.-A., 2000. *Technology and social agency.* Oxford: Blackwell.

Dobres, M.-A., 2010. Archaeologies of technology. *Cambridge Journal of Economics*, 34, pp.103-114.

Downey, G., 2010. Practice without theory: a neuroanthropological perspective on embodied learning. *Journal of the Royal Anthropological Institute*, 16, pp.22-40.

Downey, G., Dalidowicz, M. and Mason, P.H., 2015. Apprenticeship as method: embodied learning in ethnographic practice. *Qualitative Research*, 15, pp.183-200.

Duistermaat, K., 2016. The organization of pottery production: toward a relational approach. In: A. Hunt, ed., *The Oxford handbook of archaeological ceramic analysis.* Oxford: Oxford University Press, pp.114-147.

Evely, R.D.G., 1993. *Minoan crafts: tools and techniques. An introduction.* Vol. 1. Studies in Mediterranean Archaeology 92(1). Göteborg: Paul Åströms Verlag.
Fitts, P.M., 1964. Perceptual motor-skill learning. In: A.W. Melton, ed., *Categories of human learning.* New York: Academic Press, pp.243-285.
Fregni, E.G., 2019. Looking over the shoulder of the Bronze Age metalsmith: recognizing the crafter in archaeological artefacts. In: C. Burke and S.M. Spencer-Wood, eds., *Crafting in the world: materiality in the making.* Cham: Springer Verlag, pp.37-49.
Freu, C., 2016. Disciplina, patrocinium, nomen: the benefits of apprenticeship in the Roman world. In: A. Wilson and M. Flohr, eds., *Urban craftsmen and traders in the Roman world.* Cambridge: Cambridge University Press, pp.183-199.
Gauss, W., Klebinder-Gauss, G. and von Rüden, C., eds., 2015. *The transmission of technical knowledge in the production of ancient Mediterranean pottery.* Österreichisches Archäologisches Institut Sonderschriften 54. Vienna: Österreichisches Archäologisches Institut.
Girard, R., 1990. Innovation and repetition. *SubStance*, 62/63, pp.7-20.
Goody, E., 1982. Introduction. In: E. Goody, ed., *From craft to industry: the ethnography of proto-industrial cloth-production.* Cambridge: Cambridge University Press, pp.1-37.
Groth, C. and Kimmel, M., 2025. Dynamic affordances in human-material 'dialogues'. In: N. Nimkulrat and C. Groth, eds, Craft and design practice from an embodied perspective. London: Routledge, pp. 17-29.
Hasaki, E., 2013. Craft apprenticeship in ancient Greece: reaching beyond the masters. In: W. Wendrich, ed., *Archaeology and apprenticeship: body knowledge, identity and communities of practice.* Tucson, AZ: University of Arizona Press, pp.171-202.
Ingold, T., 2000. *The perception of the environment. Essays on livelihood, dwelling and skill.* London: Routledge.
Ingold, T., 2018. Five questions about skill. *Cultural Geographies*, 25, pp.159-163.
Knappett, C., 2004. The affordances of things: a post-Gibsonian perspective on the relationality of mind and matter. In: E. DeMarrais, C. Gosden and C. Renfrew, eds., *Rethinking materiality: the engagement of mind with the material world.* Cambridge: McDonald Institute for Archaeological Research, pp.43-51.
Knappett, C. and Malafouris, L., eds., 2008. *Material agency: towards a non-anthropocentric approach.* New York: Springer.
Konstantinidi-Syvridi, E., Papadimitriou, N., Goumas, A. and Kontaki, M., 2022. Gold embroidery: a sophisticated technique for Early Mycenaean swords and daggers. *Archäologischer Anzeiger*, 2022, 11-81. https://doi.org/10.34780/da2b-d3ef
Kuijpers, M., 2012. The sound of fire, taste of copper, feel of bronze, and colours of the cast: sensory aspects of metalworking technology. In: M.L.S. Sørensen and K. Rebay-Salisbury, eds., *Embodied knowledge: perspectives on belief and technology.* Oxford: Oxbow, pp.137-150.
Kuijpers, M., 2017. *An archaeology of skill: metalworking skill and material specialization in Early Bronze Age Central Europe.* London: Routledge.
Kuijpers, M., 2018. The Bronze Age: a world of specialists? Metalworking from the perspective of skill and materials specialization. *European Journal of Archaeology*, 21, pp.550-571.
Laffineur, R., 1990-91. L'incrustation à l'époque mycénienne. *L'Antiquité Classique*, 43, pp.5-37.
Lave, J. and Wenger, E., 1991. *Situated learning: legitimate peripheral participation.* Cambridge: Cambridge University Press.

Lemonnier, P., 1992. *Elements for an anthropology of technology.* Anthropological Papers Museum of Anthropology 88. Ann Arbor: University of Michigan Press.

Logan, G.D., 1988. Towards an instance theory of automatization. *Psychological Review*, 95, pp.492-527.

Macqueen, W.M., 1951. What is craft skill? *The Vocational Aspect of Secondary and Further Education*, 3(6), pp.34-37.

Marchand, T.H.J., 2007. Crafting knowledge: the role of 'parsing and production' in the communication of skill-based knowledge among masons. In: M. Harris, ed., *Ways of knowing: anthropological approaches to crafting experience and knowledge.* Oxford: Berghahn Books, pp.173-193.

Marchand, T.H.J., 2008. Muscles, morals and mind: craft apprenticeship and the formation of person. *British Journal of Educational Studies*, 56, pp.245-271.

Marchand, T.H.J., 2010. Making knowledge: explorations of the indissoluble relation between mind, body and environment. In: T.H.J. Marchand, ed., *Making knowledge: explorations of the indissoluble relation between mind, body and environment. Journal of the Royal Anthropological Institute, Special Issue* 5. Chichester: Wiley-Blackwell, pp.1-21.

Marchand, T.H.J., 2016. Introduction: craftworks as problem solving. In: T.H.J. Marchand, ed., *Craftwork as problem solving: ethnographic studies of design and making.* Burlington: Ashgate, pp.1-32.

Martin, T., 2021. *Craft learning as perceptual transformation: getting "the feel" in the wooden boat workshop.* Cham: Macmillan.

Masters, R.S.W., 1992. Implicit knowledge, stress and skill failure. PhD thesis. University of York.

Mauss, M., 1934. Les techniques du corps. *Journal de psychologie normale et pathologique*, 32, pp.271-293. Reprinted in: Mauss, M., 1968. *Sociologie et anthropologie.* 4th ed. Paris: PUF, pp.364-386.

Miniaci, G., Moreno García, J.C., Quirke, S. and Stauder, A., eds., 2018. *The art of making in ancient Egypt: voices, images and objects of material production, 2000-1550 BC.* Leiden: Sidestone Press.

O'Connor, E., 2006. Glassblowing tools: extending the body towards practical knowledge and informing a social world. *Qualitative Sociology*, 29, pp.177-193.

Oleson, J.P., ed., 2008. *The Oxford handbook of engineering and technology in the ancient world.* Oxford: Oxford University Press.

Papadimitriou, N., Konstantinidi-Syvridi, E. and Goumas, A., 2021. A demanding gold-working technique attested in Armorican/Wessex and Early Mycenaean funerary contexts. *Bulletin de l'Association pour la Promotion des Recherches sur l'Âge du Bronze (APRAB)*, 19, pp.26-33.

Papadimitriou, N., Konstantinidi-Syvridi, E., Goumas, A., Kontaki, M. and Filippaki, E., 2024. Mycenaean 'gold-embroidery' and questions of craftsmanship: a combined archaeological, archaeometric and experimental approach. *Archaeological and Anthropological Sciences,* 16, 84. doi.org/10.1007/s12520-024-01980-z

Pelegrin, J., 1991. Les savoir-faire: une très longue histoire. *Terrain*, 16, pp.106-113.

Pelegrin, J., 1993. A framework for analysing prehistoric stone tool manufacture and a tentative application to some early stone industries. In: A. Berthelet and J. Chavaillon, eds., *The use of tools by human and non-human primates.* Oxford: Oxford University Press, pp.302-317.

Pfaffenberger, B., 1992. Social anthropology of technology. *Annual Review of Anthropology*, 21, pp.491-516.

Plantzos, D., 1997. Crystals and lenses in the Graeco-Roman world. *American Journal of Archaeology*, 101, pp.451-464.

Poursat, J.-C., 1996. *Fouilles exécutées à Mallia. Le Quartier Mu, III. Artisans minoens: les maisons-ateliers du Quartier Mu.* Paris: Boccard.

Rosenbaum, D.A., Carlson, R.A. and Gilmore, R.O., 2001. Acquisition of intellectual and perceptual motor-skill. *Annual Review of Psychology*, 52, pp.453-470.

Roux, V., 2019. Modelling the relational structure of ancient societies through the chaîne opératoire: the Late Chalcolithic societies of the southern Levant as a case study. In: M. Saqalli and M. Vander Linden, eds., *Integrating qualitative and social science factors in archaeological modelling.* Berlin: Springer, pp.163-184.

Roux, V. and Corbetta, D., 1989. *The potter's wheel: craft specialization and technical competence.* New Delhi: Oxford and IBH Publishing.

Roux, V. and Courty, M.-A., 2019. *Ceramics and society: a technological approach to archaeological assemblages.* Cham: Springer Verlag.

Schiffer, M.B., ed., 2001. *Anthropological perspectives on technology.* Albuquerque, NM: University of New Mexico Press.

Spencer-Wood, S.M. and Burke, C., 2019. Epilogue: the future of craft research. In: C. Burke and S.M. Spencer-Wood, eds., *Crafting in the world: materiality in the making.* Cham: Springer Verlag, pp.255-287.

Squire, L.R., Knowlton, B. and Musen, G., 1993. The structure and organization of memory. *Annual Review of Psychology*, 44, pp.453-495.

Stone, L., Underwood, C. and Hotchkiss, J., 2012. The relational habitus: intersubjective processes in learning settings. *Human Development*, 55, pp.65-91.

van Voorhis, J., 1998. Apprentices' pieces and the training of sculptors at Aphrodisias. *Journal of Roman Archaeology*, 11, pp.175-192.

van Voorhis, J., 2018. *Aphrodisias X. The sculptor's workshop.* Wiesbaden: Reichert.

von Rüden, C., 2017. From mechanics to embodiment: some theoretical considerations on techniques. In: P. Eisenach, T. Stöllner and A. Windler, eds., *The RITaK (Raw Materials, Innovation, Technology of Ancient Cultures) conferences 2013-2014.* Bochum: Leidorf, pp.69-78.

Xenaki-Sakellariou, A. and Chatziliou, C., 1989. 'Peinture en métal' à l'époque mycénienne: incrustation, damasquinage, niellure. Athens: Ekdotike.

Younger, J.G., 1981. Creating a sealstone: a study of seals in the Greek Late Bronze Age. *Expedition*, 23(4), pp.31-38.

Wendrich, W., ed., 2013a. *Archaeology and apprenticeship: body knowledge, identity and communities of practice.* Tucson, AZ: University of Arizona Press.

Wendrich, W., 2013b. Recognizing knowledge transfer in the archaeological record. In: W. Wendrich, ed., *Archaeology and apprenticeship: body knowledge, identity and communities of practice.* Tucson, AZ: University of Arizona Press, pp.255-262.

Wenger, E., 1998. *Communities of practice: learning, meaning and identity.* Cambridge: Cambridge University Press.

Wilson, A. and Flohr, M., eds., 2016. *Urban craftsmen and traders in the Roman world.* Oxford: Oxford University Press.

The Anatomy of a Tradition

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In this chapter I will examine what a 'tradition' consists of, using ethnographic examples. My main focus is the weaving cultures of Southeast Asia, which I will compare with the traditions of Tibetan Buddhism, in order to show how widespread key features and processes are. Traditions are amalgams of parts, including conservative elements that change very slowly, and aspects that change more quickly: I will illustrate this by teasing apart some of the components and describing their evolution over time, looking in particular at how inventions and innovations arise and spread. Consideration of both slow-changing and the fast-changing aspects are essential to understanding how traditions have evolved.

Both traditional weaving and Buddhist sects have at their core a kernel of knowledge that is passed on from generation to generation. Both possess lineages that are resolvable by different methods: in the case of Buddhist sects these lineages are directly accessible via historical records, while in the case of weaving there are few historical accounts and other methods must be used, amongst which I will focus on the use of long-lived aspects of material culture (such as weaving looms) to trace the histories of craft traditions. I will argue that both weaving traditions and religious orders have 'technologies' at their core and that, despite a huge difference in content, they have evolved in broadly similar ways.

Cultural evolution, cultural transmission, lineages, GRP plot, innovation

Introduction

Traditions are a prominent, perhaps defining feature of human culture. For this essay I will adopt a definition of a tradition similar to that used by Wenger (1998): a tradition consists of group of people (sometimes called the 'community of practice') who share a common goal, together with a body of knowledge that is passed from generation to generation. They are thus coherent sets of knowledge and practices that endure over time. There are many kinds, such as agriculture, tool manufacture (crafts), trade guilds, organizations, companies, and religions. Their universality means that describing and explaining their existence and persistence must form a central part of any investigation of culture.

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 173-202.

Why do traditions exist? Human activities and societies retain and process complex information. This is compartmentalized and distributed in a modular way, a manner of organization that seems to give rise to robust, durable systems while minimizing transaction costs (Simon, 1962). Viewed in this light, traditions are stable modules within societies.

When we identify a tradition empirically, whether in a living society or in the archaeological record, we are stating that something that can be seen in individual behaviours or in artifacts is part of a process that exists at a larger scale and persists over time. This implies that to understand traditions we will need to look at culture at a range of scales, both spatial and temporal, ranging from the experiences of individuals to large scale patterns (i.e. traditions) that persist for centuries.

Culture 'evolves' in the broadest sense of the word, meaning that it changes gradually over time. Knowledge and skills are passed from one generation to the next in modified form, so that each succeeding generation is similar to, but not exactly the same as the previous one. For example, the sarongs made by present-day weavers in the Indonesian archipelago are recognisable as being similar to ones collected by Dutch colonists in the same locations in the nineteenth century. There are differences however: some new motifs, for example, have been invented or introduced in the past 100 years (Buckley, 2012; 2021).

Transmission of knowledge that occurs predominantly from an older to a younger generation is usually called 'vertical transmission'. Knowledge can also be exchanged between communities or brought in by traders from further afield. These kinds of processes are known as 'horizontal transmission', or 'blending'. The enthusiastic adoption of European-made synthetic dyes by many rural communities of weavers during the late 19th and early 20th century (discussed below) is an example of blending, a process that tends to reduce differences between traditions.[1]

Processes of the first kind (vertical transmission) tend to preserve the continuity of cultures over time, and produce well-defined lineages, whereas processes of the second kind (horizontal transmission) tend to blur the distinctions between cultures, or to create new ones from amalgams of old ('ethnogenesis'): real-world traditions are the result of both kinds. This is apparent from the fact that the pattern of human traditions (and in fact, of cultures in general) is that of a 'patchwork' that includes some common elements, but also distinct boundaries. For example, in their investigation of African crafts, Roux and colleagues (Roux, et al., 2017) found separate, coherent traditions existing in the same region, using similar materials but distinct techniques and designs. The barriers to blending were not lack of awareness, since the products were all sold in the same marketplaces and all understand the differences, but cultural conservatism at a fundamental level. On the other hand, there are some inventions that have proved so useful or compelling that they have spread far from their points of origin, such as iron making, which originated in what is now northern India and was subsequently transmitted along the Silk Roads (Turner, 2020).

The consequences of vertical transmission were investigated by Darwin (1859), who showed (in a biological context) that this process gives rise to an endlessly branching and diversifying family tree of entities. Darwin's tiny sketch (the sole illustration in his 'Origin of Species') of branching descent is also a useful model for the extraordinary diversity

1 Some researchers distinguish 'vertical' (parent to child) and 'oblique' (other kin to child) transmission styles. For my purposes, I will define all kinds of transmission that occur *within the community of practice*, in other words that retain knowledge within the community, as 'vertical'.

Figure 1: Bedcovering made by a Buyi weaver from Qiannan, Guizhou province, China. Three strips of woven cloth, decorated with silk supplementary weft and joined together. This kind of bedcovering is typical of trousseau items woven by young women before marriage and displayed at wedding ceremonies. 88 × 105cm (excluding border) [author].

of world cultures, particularly as this diversity is difficult to explain by other processes such as ethnogenesis (cultural blending), genetic predisposition or local responses to the environment. The evolutionary process that Darwin identified is open-ended, generates diversity rather than uniformity, and can accommodate random change (drift) and human agency. Crucially, it can explain why two or more traditions co-existing in the same environment can nevertheless be quite different, such as the African craft traditions investigated by Roux and colleagues.

The view that culture in the broadest sense is shaped, over time, by a mixture of such vertical and horizontal transmission processes might have become uncontroversial, were it not for a lengthy theoretical detour that began in the nineteenth century. This was the view that originated in the writings of Herbert Spencer, that the evolution of cultures, rather than being an open-ended process, was a march of progress towards the highest, 'most evolved' form. This is the teleological error, the mistaken view that evolution has a destination, with the writer's culture (or an idealized view of it) placed at the pinnacle.[2] This assumption underlies the writings of many early twentieth century anthropologists, as well Karl Marx's theories of social progression. Its influence is still felt today: in popular imagination societies pass through 'stages': Paleolithic, Mesolithic, Neolithic, Bronze age, Iron age. In fact, these stages have little validity outside of a European context, and there is in any case nothing inevitable about them. As these issues gradually became apparent during the second half of the twentieth century, the result was a backlash against all things evolutionary (Carneiro, 2018).

Despite misunderstandings and detours, the usefulness of Darwin's branching model in the field of culture remains. It was recast in more rigorous form by Cavalli-Sforza and Feldmann (1981) and Boyd and Richerson (1988), who used mathematical models to explore the idea that culture forms a parallel system of inheritance, complementing genetic inheritance. As might be expected from the history of evolutionary ideas, this work met with some scepticism, typified by Terrell's commentary (1987) on phylogenetic work on Polynesian traditions. There were also more measured critiques, including one by Terrell himself.[3] Temkin and Eldredge noted that human culture 'undeniably evolves', but pointed out that a reticulated (blended) pattern rather was more appropriate for some types of material culture, such as their study of the evolution of musical instruments (2007, p.146).

Recent thinking reflects a growing appreciation that cultural traditions are shaped by multiple processes (Collard, et al., 2006 ; Whiten, et al., 2011, Mesoudi, 2016), and that the most constructive approach to such questions is not to impose an *a priori* view but to tease out processes on a case-by-case basis (O'Brien, et al., 2013; Buckley, 2023), with a shift in emphasis towards data quality rather pointing out theoretical flaws (Lukas, et al., 2021). Acceptance of models that incorporate evolutionary thinking continues to be held back, however, by the historical taint surrounding 'evolution', and continuing resistance amongst some socio-cultural anthropologists of the use of models in general.[4]

In the remainder of this section I will discuss my research on the weaving traditions of Southeast Asia, carried out over the past two decades, examining on how and why change has occurred over time. In broad terms my approach is 'evolutionary' since it deals with gradual change, though without preconceptions about which particular model(s) (Darwinian or otherwise) are useful for each particular cultural feature. This research has included study of the evolution of motifs (Buckley, 2012; 2021b), the development of loom technology (Boudot and Buckley, 2015; Buckley and Boudot, 2017; Buckley, 2018), cultural transmission (Buckley, 2016), and the links between the patterns of weaving and historical migrations and trade in the region (Buckley, 2017). I will focus here on the development

2 This is sometimes called the 'unilinear' view of evolution.

3 'It is good common sense to think that one generation is descended from the one before it, that migrations of one sort or another can and do happen [...] and that things today are not as they used to be, so over time things become modified, or change. The idea of descent, therefore, expresses something real about the world and how it works.' (Terrell ,1988, p.647).

4 As Maurice Bloch (2005) lamented in the introductory chapter to his book on cultural transmission, some students have been taught that 'the very attempt to generalize … was, in and of itself, wrong'.

Figure 2: Bridewealth sarong from Lembata, Indonesia. This textile is given by the bride's family to the groom's family during marriage gift exchange rituals, gifts of other kinds passing in the opposite direction. The sarong is left unfinished at the back and is never worn. 60 × 200cm (author).

Figure 3: Detail of Tai Lao tube-skirt from northern Laos, made during the first half of the 20th century. The intense purple shade is synthetic dye that was popular with Tai weavers for a few decades (author).

Figure 4: A master thangka painter supervises an apprentice at a painting studio in Lhasa, Tibet (author).

of the repertoire of techniques, tools and motifs used by weavers in Island Southeast Asia (ISEA) since it illustrates a key aspect of traditions: they consist of an amalgam of parts that change at varying rates. I will compare the findings with other traditions in East Asia, in particular the transmission and lineages of Tibetan Buddhism. This may seem, at first sight, to be an unlikely comparison, but there are deep similarities.

Figure 5: Gilt copper statue of the protector god Acala, Tibet, around 1400 CE (author).

Weaving traditions in the Asia region are mainly (but not exclusively) rural. A range of technologies is used which are distinct and culture-specific, but which also have features in common. Weaving and the display of textiles is linked with ceremonial occasions marking life transitions, including birth, marriage, and death. There is an extensive literature on the ethnography of weaving, ranging from monographs on individual cultures to regional surveys (for a general introduction see Maxwell, 2012).

Weaving is not purely, perhaps not even mainly, about making items for practical use. Many useful items are made, such as clothing, slings for carrying babies, tents, and blankets, but more effort is expended on making and decorating textiles than can be explained by strictly utilitarian needs. In many cultures the largest part of a weaver's effort goes into making elaborately decorated items for dowry use (Fig 1) or bride-wealth exchange. This is a common pattern in craft goods that require skill and investment of

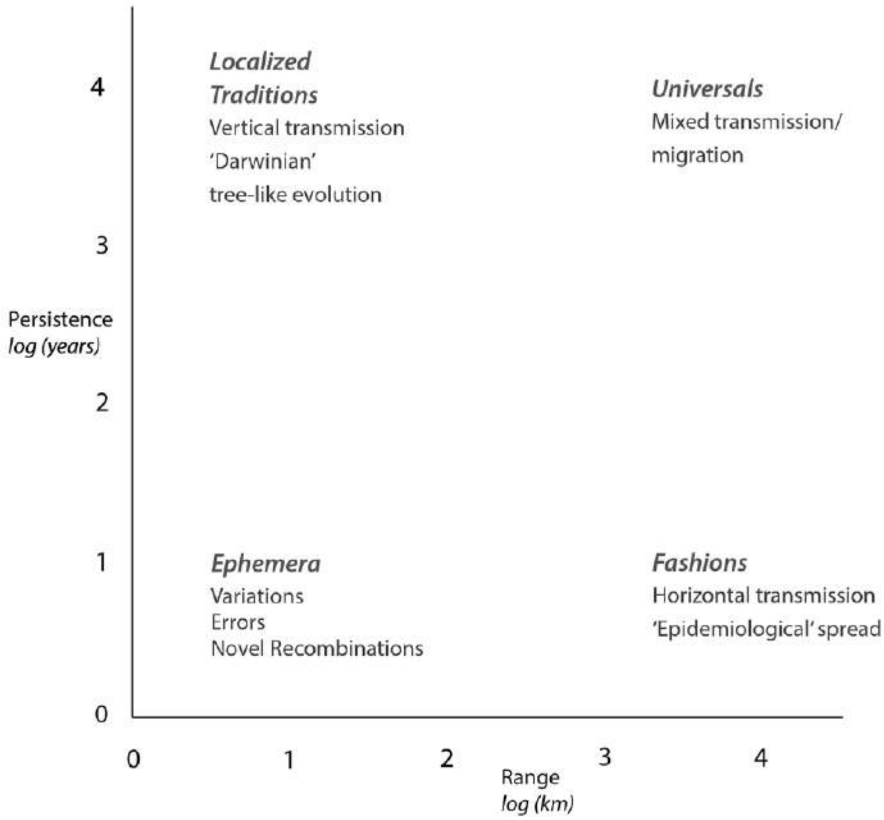


Figure 6: Geographical range vs persistence plot, with four limiting cases (author).

time.[5] Traditional weaving practice is also accompanied by ritual, for example it is usual to make offerings to local gods before warping a loom, and certain prohibitions must be observed, for example not beginning new weavings during the New Year festival.

Teasing a 'tradition' apart

There are distinct activities involved in making cloth, which form a sequence of operations (*chaîne opératoire*). These include cultivating fibre, which is typically cotton but can also be hemp, ramie or leaf fibres such as banana, or silk; processing it into yarn by splicing, twisting or spinning, dyeing the yarn, mounting the warp on the loom, weaving, removing the finished cloth and tailoring into its final form. Many activities are seasonal and the entire process from start to finished textile usually takes a minimum of a year. In the Indonesian archipelago dyeing with the highly valued red shade obtained from mengkudu (*Morinda citrifolia*) for ceremonial textiles involves multiple mordanting and dyeing steps on the same cloth, sometimes twenty or thirty times. As a result, some bride-wealth textiles

5 For example, Hampton investigated the stone tools of the Dani people of Papua, Indonesia and found that around half of the tools that the Dani possessed were actually wealth items, ritual gift exchange items, healing stones and good-luck talismans (Hampton, 1999).

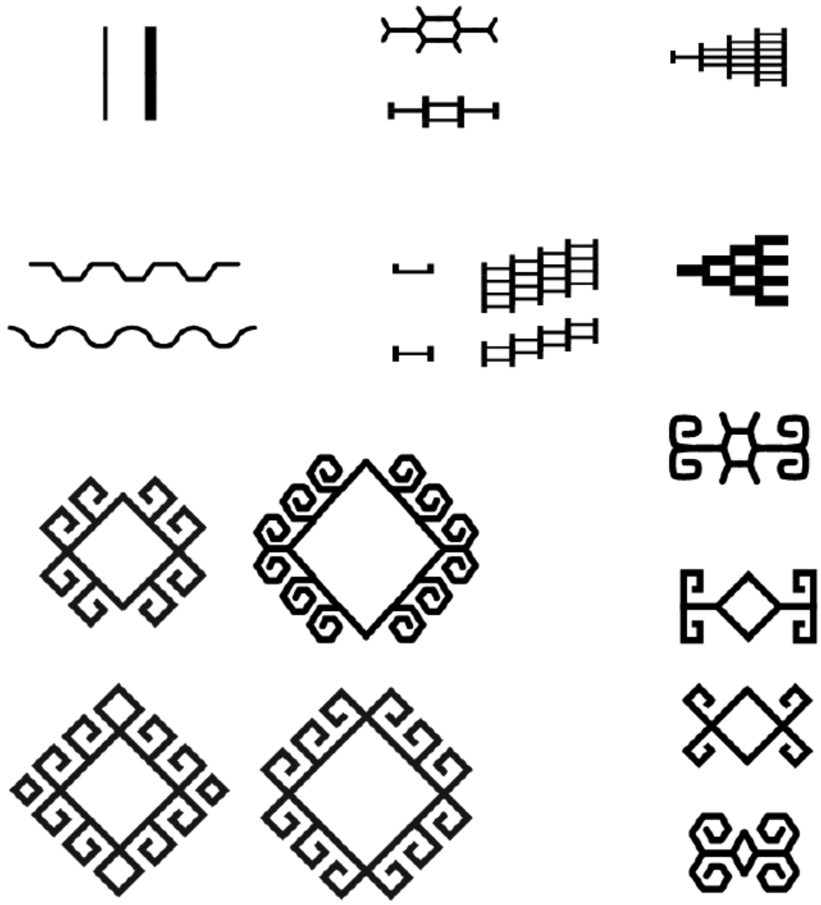


Figure 7: Ancestral motifs found on warp ikat weavings in Southeast Asia (ISEA and mainland SEA) (after: Buckley, 2012).

may take more than a decade to complete (Fig 2), an astonishing effort on the part of the maker for a cloth that will never be worn.

Since I will look at how aspects of a tradition are transmitted and if/how they persist over time, a short digression is necessary, to define some basic terms.

Cultural transmission, apprenticeships and apprenticeship-like processes

The transmission of culture from one generation to the next is an important field of study in its own right, described in several recent surveys (Bloch, 2005; Stark, Bowser and Horne, 2008; Ellen, Lycett and Johns, 2013). As noted, knowledge and skills can be passed vertically within a community, or horizontally between communities. For craft skills, a key mode of cultural transmission is the apprenticeship. Classical apprenticeships, as described by Lancy (2021), consist of a formal arrangement (sometimes expressed as a written contract) between apprentice and master. Learning takes place by observation and repetition, with little or no formal teaching. Apprenticeships are a remarkably general phenomenon, being found in craft traditions around the world as well as religious orders and other settings.

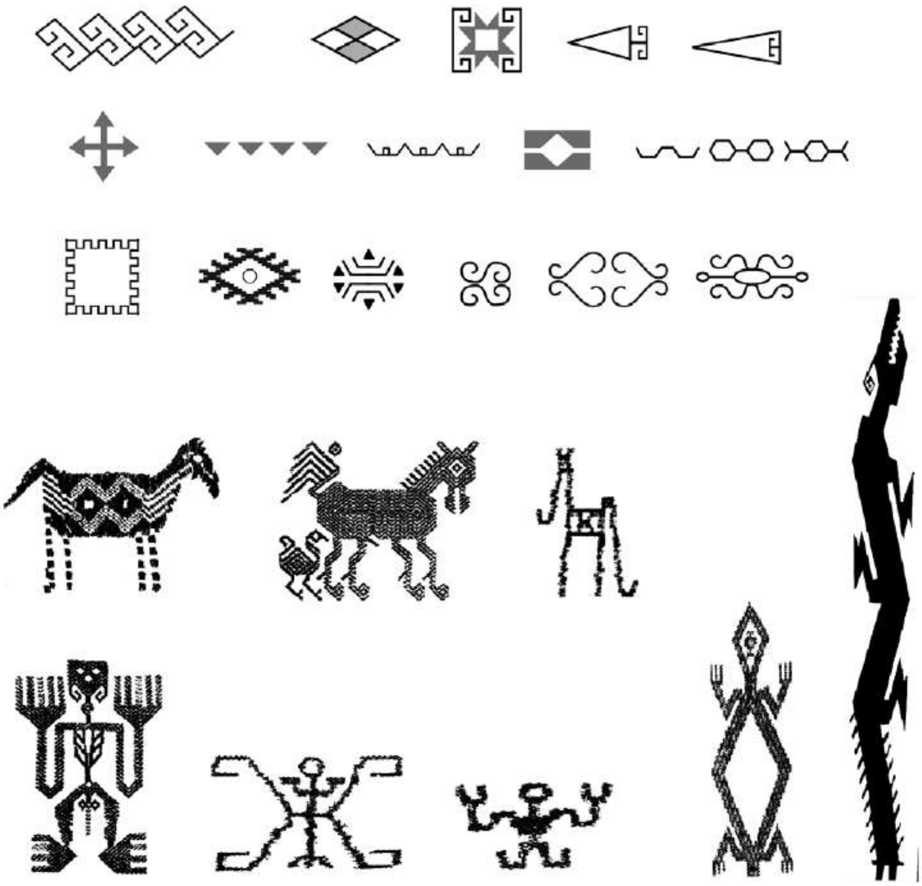


Figure 8: Ancestral motifs for weavings in ISEA (author).

Formal apprenticeships are but one type of a more general set of cultural transmission arrangements that I call apprenticeship-like processes (ALPs), in which complex skills are passed from one generation to the next via an extended learning process. In a domestic setting there is an unspoken understanding rather than a formal agreement, for example between mother (or grandmother or aunt) and daughter.

The transmission of weaving

My fieldwork on the transmission of weaving cultures in Southwest China and in East Nusa Tenggara (ENT) in Indonesia shows that weaving is transmitted in these regions by typical ALPs (Buckley, 2015; 2016). Novice weavers learn by observation and imitation, beginning at a young age (usually around 7 or 8 years old in ENT), with simple tasks such as winding yarn, gradually moving on to more complex tasks. There is no formal teaching: verbal instruction is confined to pointing out and correcting mistakes. The apprentice is expected to carry out routine tasks such as winding yarn and pounding dyestuffs. The relationship is a deferential one and continues long after the novice has attained mastery. Similar patterns have been found in weaving traditions as diverse as Turkomen tribes in Iran (Tehrani and Collard, 2009), Tibetan nomads (Ahmed, 2002), Batak

Figure 9: Silk patola, made in Gujarat for the Indonesian market, around 1800 CE (author).

weavers in Sumatra (Niessen, 2009), and Zincatan weavers in Mexico (Greenfield and Lave, 1982; Greenfield, 1999).

Novices are discouraged from altering practices; for example, during her apprenticeship to a Batak weaver, Sandra Niessen (2009) found that even details that had no effect on the result, such as the side of the loom from which the weft was thrown-in, were determined by tradition. Similarly, motif choices and arrangements are dictated by tradition, though there is a difference between items for ritual or ceremonial use, where the weaver's choices are tightly constrained, and items for daily use, where there is more freedom to experiment (see also Barnes, 1989, pp.69-72).

Some aspects are passed horizontally between unrelated peers, such as dye and colour choices for informal, daily-use items, and aspects of dress such as ways combining clothing items, and hair styling and ornamentation. These can spread rapidly over a wide area but tend to last a relatively short time: such things are usually called 'fashions'. Other significant changes have occurred in the past 100 years: commercial dyes have been adopted by many weaving communities, and novel colours have come and gone. For example, a distinctive synthetic purple shade was characteristic of many Tai weavings in the first half of the 20th century but is rarely seen in contemporary weavings (Fig 3).

Figure 10: Ibu Anastasia Bataona, a weaver on the Indonesian island of Lembata, with a sarong she has woven. She calls the geometric motif in the centre of the cloth *patola*, inspired by imported Indian textiles such as the one in Fig 9 (author).

One might object that such fashions, by definition, cannot be considered part of a tradition. The reasons for their inclusion in my discussion are twofold. Firstly, they are an integral part of the participant's experience of a cultural tradition. Secondly, there is no dividing line between short-lived and long-lived (persistent) parts of a tradition: they are part of a continuum. Most importantly, if we wish to understand invention and innovation (which have short histories, by definition), we must also consider short-lived aspects of the complex whole that is a 'tradition'.

The transmission of Tibetan Buddhism

Comparing of the transmission of weaving cultures with that of Tibetan Buddhist sects may seem odd at first sight, but in fact there is overlap between traditional crafts and religions, and deep similarities in the way in which they are passed from generation to generation. Most craft traditions include ritual aspects: e.g. Klaas Ruitenbeek has written on the magico-religious foundations of traditional Chinese carpentry, centred around sacred texts such as the Lu Ban Jing: the 'Classic of Lu Ban', that are passed down and revered as holy objects:

'The book, which was tightly wrapped in red paper, was said to contain the whole wisdom of Lu Ban *pusa*, 'Saint Lu Ban'. Before opening the book it was necessary … to clean one's body, burn incense and make a sacrifice, only then might one hope to be able to read it' (Ruitenbeek, 1996, p.1, quoting Jiang Shan).

Figure 11: Motif of an eagle (of relatively recent origin) on a tubeskirt from Pulau Buayah, Indonesia (author).

Traditional building construction in China is governed by magical rites and formulae. The rule used by carpenters is divided into ten inches associated with colours: five of these are regarded as favourable, the rest are to be avoided when setting the dimensions of a new building. Amongst minaret builders in Yemen, Marchand (1999) similarly found spells and benedictions in routine use alongside practical skills. He noted parallels between religious education and that of a builder: in both cases the emphasis is first and foremost on 'correct actions', which are learned by observation and imitation, with conscious reflection and intentionality following later.

Tibetan Buddhist orders are organized into monastic lineages in which teachings are passed from masters (lamas) to novice monks. The notion of an unbroken transmission of teachings, expressed as a lineage of masters, is central to the legitimacy of an order, and each order traces its teachings back to specific masters in northern India (Snellgrove and Richardson 1968, Snellgrove 1987).

In a monastic setting, novices are not usually related to masters, and transmission is one-to-many rather than the one-to-one pattern found in traditional crafts. Aside from these differences, the novice monk experiences a type of apprenticeship. Instruction is based upon imitation and repetition: novices recite and memorize sutras and prayers, observe and reproduce ritual practices (Cabezón, 1997). A form of ritualized 'debate', consisting of codified questions-and-responses sessions, is employed in some orders. Strict hierarchy and discipline are maintained, and novices carry out menial domestic tasks within the monastery. Questioning one's masters or the teachings is not encouraged. Knowledge is retained and passed within the monastic order, and novice monks rarely switch from one order to another.

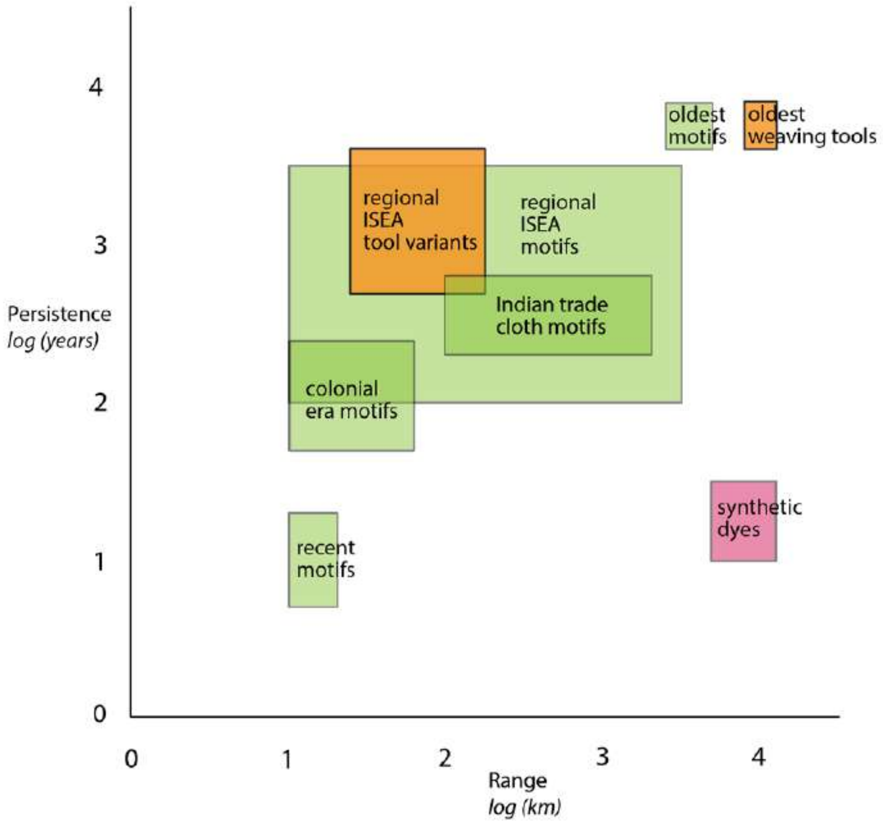


Figure 12: Geographical range vs persistence plot for components of Southeast Asian weaving traditions (author).

Three distinct strands of transmission can be discerned: oral, textual and visual. The oldest form is oral: at the outset Tantric teachings and meditative practices were communicated by word of mouth, and oral transmission is still central today.

Oral teachings were eventually written down in the form of sutras (texts) that constitute the second strand. Sutras were initially copied by hand; later they were reproduced by means of wooden printing blocks. Reading and memorizing texts forms a second component of transmission within monastic orders.

The production of paintings and sculpture grew as newly founded Tibetan sects developed from the tenth century onwards (Snellgrove and Richardson, 1968). The visual arts became a third, parallel strand of transmission. Painting studios, sometimes attached to particular monastic orders, developed and maintained their own styles of depicting deities and other devotional imagery.

While working for an NGO (The Tibet Poverty Alleviation Fund) and a weaving workshop (The Tibet Tanva Weaving Workshop, now closed) in Lhasa during 2000-2010, I had the opportunity to research traditional workshops making Buddhist paraphernalia within the old city (Buckley, 2005a; 2011), including thangka (sp) painters, furniture makers (Buckley, 2005b), mask makers and repoussé production. Amongst thangka painters, proportions of deities were laid down precisely in collections of sketches

Figure 13: Lineage portrait of an Abbot, Tibet, around 1350. This thangka depicts the head of a Kagyu order from central Tibet, painted during his lifetime or shortly after. The lineage of the order is depicted around the edges, beginning near the top left with Indian tantric sages, through the figure of Phakmo Drupa directly above the abbot's portrait and continuing down the right hand side. 77 × 60cm (after: Metropolitan Museum of Art 1991.304, Open Access).

owned by each workshop (Pal, 1990, pp.60-61). Painters consult with senior lamas on the iconographic program of certain works (particularly complex sequences in temple murals), but the details of their craft are maintained by the lineage of painters and are transmitted within the setting of the workshop (Fig 4). Portable paintings of common deities are produced without outside input. The same is true of makers of statues of cast copper, repoussé work, and clay, as well mask-makers. Moulds that have been in use for

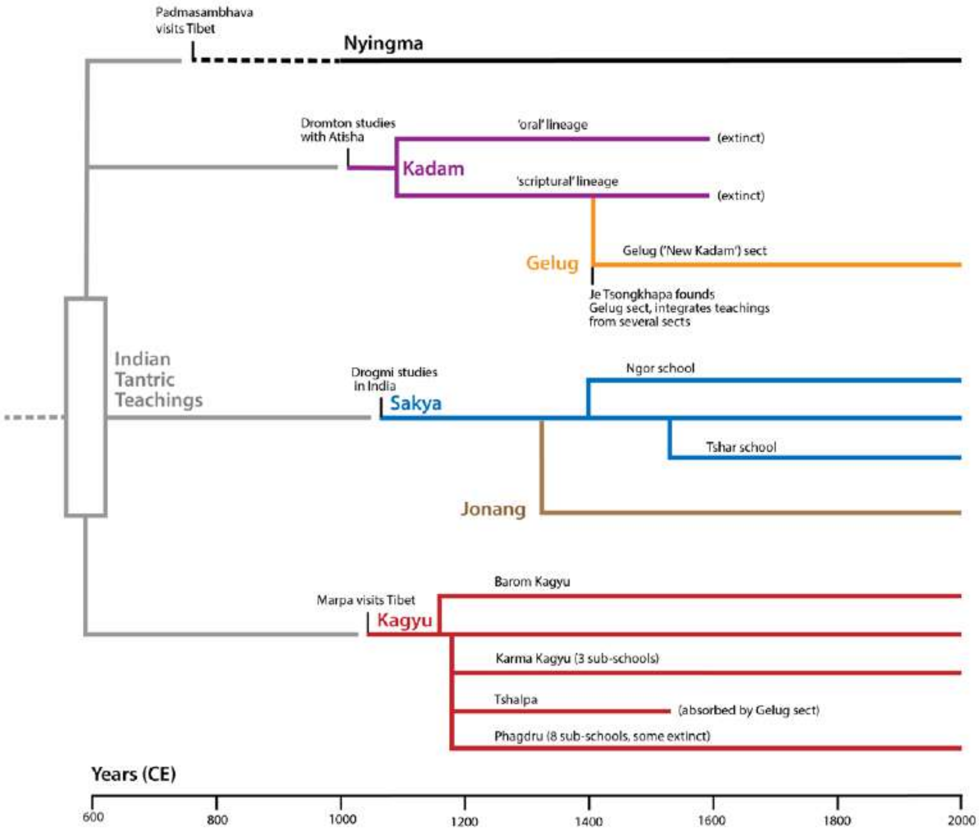


Figure 14: Phylogeny and time chart showing the origins and development of Tibetan Buddhist orders. This chart was inspired by the timeline of successive religious schools in Snellgrove and Richardson's account (1968, p.290).

generations are carefully preserved, and distinctive styles and techniques are maintained and passed down within workshops.

These three modes of transmission continue to this day, separate but inter-twined. They are not necessarily congruent: deviations from texts (for example) are common in traditional paintings, which may also incorporate purely local elements such as pre-Buddhist protector gods that are absent from the textual tradition.

As with weaving traditions, some aspects of Buddhist traditions have endured for more than a millennium while other aspects have proved less durable. For example, Linrothe (1999) has traced how certain wrathful protector gods such as Acala (Fig 5) rose to prominence from the eighth century, only to fade from view as gods associated with the newly dominant Gelug sect were promoted from the fifteenth century onwards.

Geographical range vs persistence (GRP) plot

Traditions, therefore, are made up of a mixture of traits, some of which endure over time and can be said to be the 'core' of the tradition, others of which have shorter lifetimes and trajectories. To examine traits in a more systematic way I will focus on two characteristics: their geographical range (how widespread they are) and their persistence (how old they are). These characteristics are related to the rates and fidelity of horizontal and vertical transmission, respectively.

Assuming we can determine, or at least estimate, these quantities, they can be used as the basis for a classification scheme. This is illustrated in a conceptual way in the plot in Fig 6. The horizontal axis represents geographical range, defined as the maximum spread in terms of distance of a given trait in kilometres, while the vertical axis shows the persistence of the trait, in years. Logarithmic scales are used since we are dealing with differences spanning orders of magnitude.

At the corners of the plot are four 'idealized' behaviours, representing limiting cases. Things that spread rapidly between peers (horizontally transmitted) and persist a short time are 'fashions'. Things that are passed on within families or villages from generation to generation (vertical transmission), but not shared with outsiders, are 'culture-specific traditions'. Things that are both persistent and shared widely can be called 'universals'. Things that are localized and of short duration, such as variations made by an individual weaver that have not (yet) been copied by her peers or passed on to her descendants are 'ephemera'. Real cultural phenomena occupy the continuum between these four cases: the challenge is to characterize the various components of a tradition within this continuum and to understand their behaviours.

I will illustrate this by constructing the plot for the motifs, weaving tools and dyes for traditions in Southeast Asia, comprising the island archipelago (ISEA) and the mainland. The data I will use is based on a study of ikat motifs (Buckley, 2012), a survey of looms in the region (Buckley and Boudot, 2017), and a recent survey of a large group of Indonesian textiles in a private collection (Buckley, 2021b). I have observed weaving at first-hand at most of the locations across the archipelago where weaving is still carried out. The large corpus of art historical analysis of textile production and trade around the archipelago and with India and China has also been helpful in identifying the sources of motifs and techniques (surveys and bibliographies can be found in Maxwell, 2003; Barnes and Kahlenberg, 2012).

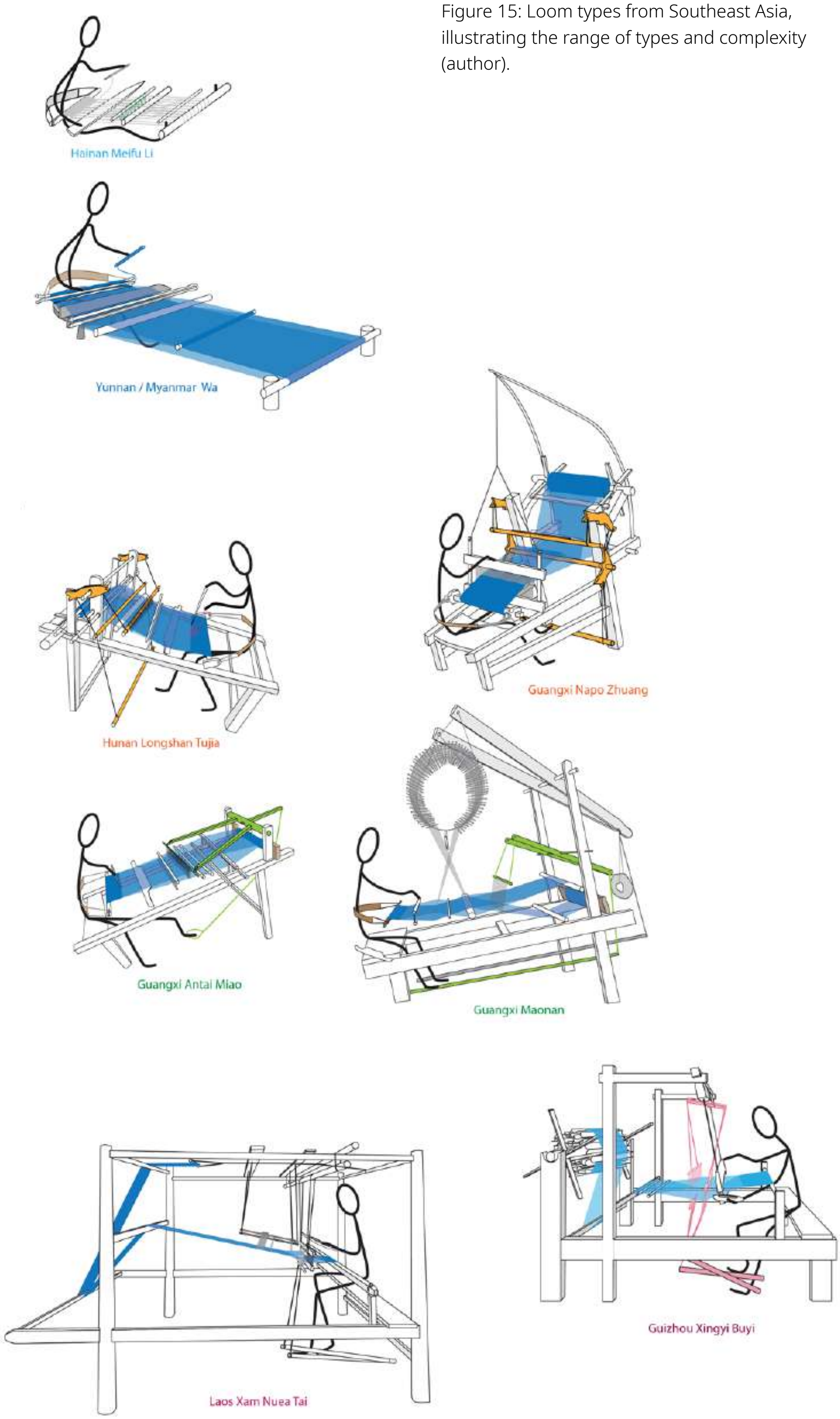
Motifs in ISEA weavings

Motifs on traditional cloths can be grouped into five categories.

The oldest and most widespread category is a group of geometric motifs that are woven by speakers of Austronesian and Tai languages and which are found across the island archipelago, as well as parts of the mainland, a geographical range of at least five thousand kilometres. These motifs post-date the origins of weaving at around 7000-8000 years ago but predate the migration of Austronesian speakers into ISEA and are thus at least 4000 years old (Fig 7). They have distinct and resolvable lineages (Buckley, 2012).

The second, and largest, group consists of motifs that are unique to sub-regions. For example, motifs that are unique to ISEA (Fig 8) must have been added by weavers to their repertoire subsequent to their arrival in the archipelago, setting an upper limit of around 4000 years on their ages. The majority of these are probably local inventions, though there are no records to confirm this. Museum examples of cloths that were collected between 150 and 100 years ago show largely the same set of motifs as present-day cloths (with a few exceptions), establishing a lower limit on their ages. Some motifs are unique to individual dialect groups, and thus have a range of a few tens of kilometres. Others (presumably older) are more widespread, appearing in weaving traditions in widely separated parts of the archipelago several hundred or thousand kilometres apart.

Figure 15: Loom types from Southeast Asia, illustrating the range of types and complexity (author).



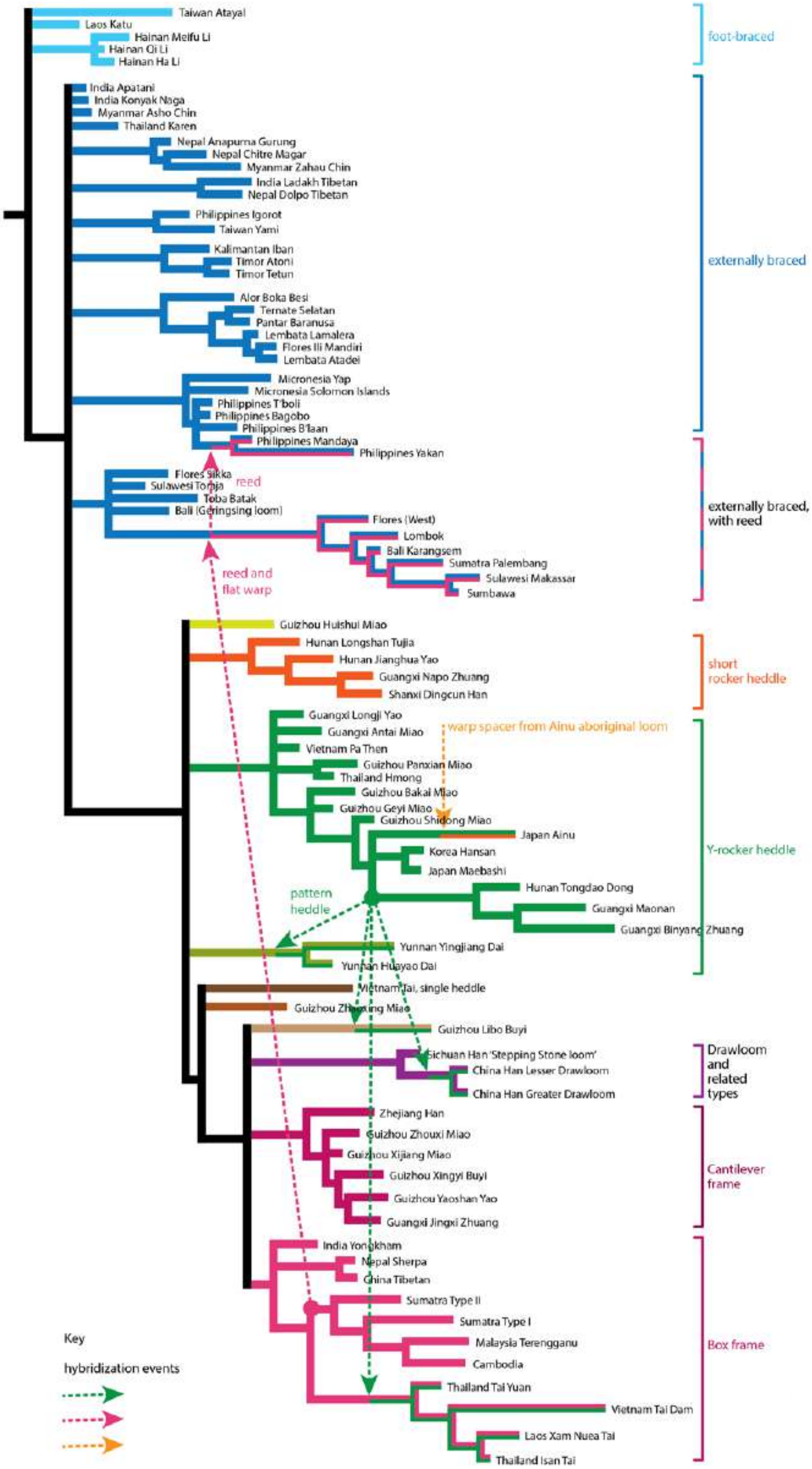


Figure 16: Phylogeny of looms in East and Southeast Asia. Hybridization events are shown with dotted lines between lineages (after: Buckley and Boudot, 2017).

On occasions it is possible to be more precise: depictions of horses (a status symbol) on Indonesian textiles are probably a local invention and post-date the introduction of the horse into the archipelago between the seventh and the thirteenth century (Clarence-Smith, 2015).

The third group consists of motifs derived from Indian cloths traded within the archipelago during the last 500 years, particularly those copied from silk *patola* (Maxwell, 2003, pp.149-237, Barnes, 1989, pp.72-73), luxurious cloths associated with wealth and prestige (Figs 9 and 10). These motifs, which are innovations acquired from outside sources, with some local re-interpretation, have more limited ranges within the archipelago, as well as parts of the mainland (Thailand and Cambodia). They have been integrated into local traditions for hundreds of years, yet weavers are (for the most part) still aware of their foreign origins, referring to their local versions as 'patola'. Cloths with designs influenced by imports from China are also known, such as batik designs produced in ports frequented by Chinese traders along the north coast of Java, with a probable history of around 200-500 years. In terms of age this group overlaps with the following group (colonial era imports), since in later years Indian cloths were brought to the region by the trading vessels of the Dutch East India company.

The fourth group consists of motifs that have been copied from colonial era imports from Europe during the last 250 years, or influenced by recent Christian missionary work, such as the 'heraldic' lions found on cloths on the island of Sumba, and floral designs and written inscriptions in Roman alphabet incorporated into ikat cloths on the island of Flores[6] and Lembata (Barnes, 1989, pp.72-73). Like the patola designs, these are innovations since they are based on outside sources. Most of these motifs have ranges of a few tens of kilometres.

In recent years I have observed a fifth group, consisting of novel motifs such as fish and butterflies, invented recently by some groups of weavers, for example in the islands between Pantar and Alor (Fig 11), to make their cloths more attractive to tourists. It is an open question whether they are a passing phenomenon or whether they will survive in the longer term and become part of the 'canon' of accepted motifs.

Weaving tools

As with motifs, weaving tools can be divided into groups. Some items such as the weaver's sword, the cloth beam (on which the finished cloth is wound) and the heddle (a device that helps separate warps for weft insertion) are found across the entire region. Archaeological remains from the Asian mainland show that these tools were present during the late Neolithic period around 7000-4000 years ago and may be considerably older (Boudot and Buckley, 2015, Buckley and Boudot, 2017, Zhao, et al., 2019). As with the oldest motifs, these tools were carried into the archipelago by migrants from the Asian mainland within the last 4000 years. Other features of looms, such as certain types of patterning system and distinctive designs for cloth beams have more localized distributions and seem to be later developments. Museum examples of looms and early photographs of weaving suggest that these tools have remained essentially unchanged over the last 150 years.

6 Lewis illustrates a type of sarong from the Sikka region of Flores called *kélang suster*, 'sarong of the nuns' with European style floral motifs (Lewis, 1994, p.169).

	Geographical range of trait (km)	Estimated longevity of trait (years)
Oldest weaving tools	10000+	5000-8000
Regional ISEA tool variants	50-500	4000-400
Oldest motifs	4570-2700	4000-8000
Regional ISEA motifs	2900-10	100-4000
Indian trade cloth motifs	1800-100	200-500
Colonial era motifs	60-10	50-250
Recent motifs	20-10	5-30
Synthetic dyes	6000-10000+	50-10

Table 1: Geographical ranges and persistence of weaving culture characters in Southeast Asia (data plotted in Fig 12). References are given in the text.

Dyes

Traditional dyeing methods, such as indigo vats, are widely distributed and thus probably very ancient, though to date no systematic study has been done. In the case of synthetic dyes the evidence is clearer. The first synthetic dyes, imported from Europe, became available in the region after 1870. Their intense and vibrant shades made them attractive to traditional weavers, who incorporated them rapidly (but selectively) into their repertoires (Hamilton, 1994, p.54, Maxwell, 2003, p. 370).[7] The first such dyes turned out to have poor lightfastness and were replaced by better dyes by around 1900. As noted, colours are fashion choices and commercial dyes tend to have lifetimes of a few decades before they are supplanted by new shades.

The traits mentioned above are summarized in Table 1 and plotted in Fig 12, which illustrates some general aspects of cultural traditions. Firstly, they are not homogeneous but are made up of many elements that have differing histories. Even though a tradition is characterised by persistence, some important parts of it have fleeting existences.

Secondly, there is no clear dividing line between different kinds of behaviour: they exist on a continuum. Motifs, for example, incorporate a range of histories ranging from a few decades to millennia.

Thirdly, it is possible to discern trajectories within the GRP plot. Novel traits, consisting of modifications (inventions) made by individual weavers, plus traits recently copied from neighbouring traditions or from trade goods (innovations) are found at the bottom left corner of the plot. Most of these will be lost or forgotten within a few years. A few will be copied by the weaver's peers and become fashions. A small number will be passed on to the weaver's descendants and will become part of the core tradition, moving gradually towards the top of the plot.

7 Ruth Barnes (1989, pp.69-72) notes how outside influences in the form of aniline dyes and European-derived motifs made their way into festive (ie informal) sarongs made on the Indonesian island of Lamalera, while the *adat* (traditional) sarongs were left largely unchanged.

Lineages

The lineage is an important concept both for craftspeople[8] and religious orders, and they are often remembered and celebrated in the Asia region. Tibetan Buddhist orders trace their teachings back to Indian gurus who lived more than a millennium ago, and the unbroken chain of transmission is central to the legitimacy of each order (Snellgrove and Richardson, 1968; Snellgrove, 1987). Lineages were depicted in paintings as successions of masters (Jackson, 2005) (Fig 13). In some cases, paired images of masters-and-pupils conversing represent the chain of oral transmission in a graphic manner.

The histories of Tibetan religious orders can be expressed in diagrammatic form as a tree (Fig 14), similar to the one employed by historians Snellgrove and Richardson to summarize the growth and diversification of schools of Tibetan Buddhism (Snellgrove and Richardson, 1968, p.290). Like the tree diagrams constructed by biologists that illustrate the evolution of species, these diagrams include branching events (schisms and breakaway sects), hybridization (reform and recombination, such as the founding of the Gelug order) and extinctions.

Rural craft traditions lack written histories, their lineages being preserved mainly through oral traditions.[9] To identify lineages we can sometimes use phylogenetic comparative methods to investigate the histories traits, supplemented with information from other sources such as archaeology. The assumption is that the phylogenies of core elements of a tradition reflect that of the tradition as a whole.[10]

With this in mind, my colleague Eric Boudot and I surveyed the looms used across the East Asian region (Boudot and Buckley, 2015, pp.400-421; Buckley and Boudot, 2017): These are extremely diverse (Fig 15), though they share some common characteristics such as horizontal orientation and body-tensioning. Certain types are associated with particular ethnolinguistic groups: complex patterning systems that record designs are a characteristic feature of Tai weaving, for example. We examined 86 localized weaving traditions with their distinctive looms and created a table of ethnolinguistic group versus loom characteristics, each trait being listed as 'present' or 'absent' for each group. We employed a Bayesian phylogenetic approach to construct a model for the descent of this group of looms. The resulting phylogeny (Fig 16) is a hypothesis for the evolution of looms in the Asia region, and by extension, for the evolution of the traditions themselves. The tree is well resolved, in other words, branches of the lineage appear to have remained separate and distinct over a long period. As noted, this is because of the conservatism of transmission of looms, a complex technology that weavers are reluctant to alter.

A key feature of this phylogeny is its diversity. Some lineages based around simple body-tensioned looms have remained virtually unchanged for four millennia, other lineages produced extremely complex looms with thousands of individual parts. An outstanding example is the Chinese drawloom: based on textual evidence, this loom seems to have

8 Roy Dilley (1989, p.10), apprenticed to a Tukolor weaver in Senegal, found that he had joined a 'clan' (*mabube*) who traced their ancestry to a founder figure called Juntel Jabali. His first task was to memorize all 16 masters in the lineage (*asko*).

9 Batak weavers on the island of Sumatra formerly recounted a legend called the Rangsa ni tonun ('account of weaving'), which was preserved in written form as a result of missionary interest during the 19th century. This legend links Batak weaving to a primordial weaver Si Boru Hasagian (Niessen, 2013).

10 Not all shared traits are examples of cultural transmission and thus ancestry. Some are shared because they are solutions that have been rediscovered multiple times (convergent evolution).

appeared by the Song Dynasty (960-1279 CE), perhaps earlier. At that time, it was probably the most complex technology in existence. It was used for making intricate silk lampas weaves in reproducible patterns and colours, primarily for court use and for diplomatic gifts (Boudot and Buckley, 2015, pp.422-426). Technological progress (increased complexity) is therefore not inevitable, but depends on factors such as environment and economy. 'Cultural evolution' may on occasions be cumulative, but this is not a necessary or inevitable feature.

Blending

There are two clear instances of technology transfer (blending) between lineages of looms. One concerns the development and spread of patterning systems amongst Tai looms. Similar patterning systems appear across several lineages that are otherwise only distantly related. The most parsimonious explanation is that these systems were transferred horizontally between lineages. This would have been made easier by the fact that the patterning systems are modules that are designed to be re-used, so transferring this technology between lineages is relatively straightforward. The mostly likely vectors for this transfer were intermarriage between dialect groups, and the practice of slave-taking during warfare.[11]

Related patterning systems are also found on the Chinese drawloom, a predominantly Han Chinese tradition that is ethnically and geographically distant from the Tai groups. There are no precedents for such patterning systems elsewhere in China, so adaptation from Tai patterning systems seems likely. In this case the likely vector is imperial edict: court records show that in 966CE several hundred weavers were relocated from Sichuan province to the imperial capital in Kaifeng. This would not have been a voluntary move on the part of the weavers concerned, nor was it a unique event. The motivation for taking weavers from such a distant part of the empire was undoubtedly to acquire their weaving skills, and possibly their technology.[12]

A third example from weaving concerns the adoption of the reed (a comb-like device for ordering and spacing warps) from mainland frame looms into body-tensioned looms in Java and Sumatra, producing a novel, hybrid loom (Buckley and Boudot, 2017).

Religious technology vs weaving technology

How does the evolution of Tibetan religious sects compare with that of weaving traditions? There is no need for a phylogenetic study of Tibetan sects because their histories are recorded in detail. A key formative period occurred during the 11th and 12th centuries, a period referred to as the Second Diffusion. This was a period of rapid development, during which many new 'religious technologies' were imported from India and Nepal and adapted and extended in the new environment in Tibet. These included temple building,

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11 A depiction of a weaving scene on a bronze cowrie container from the Dian culture in southern China (around 200-100 BCE) has been interpreted by Rawson as an overseer with a group of enslaved weavers. She notes that similar scenes on other bronzes also seem to show enslaved individuals, and that slave-taking was an important source of labour in south China at least until the Tang dynasty (618-907 BCE). Rawson 1983, pp.219-220.

12 Dieter Kuhn (2012, pp.11-12) records this 'technology transfer', as well as several other instances of movement of weavers from the countryside to the capital as a result of imperial edict.

the painting of religious scrolls (thangkas),[13] the casting of copper statues and their gilding and decoration, the writing (and later, printing) of sutras, and the development of large monastic orders, supported by almsgiving and by taxation. My characterisation of these crafts as 'religious technologies'[14] encompasses both technical aspects of their production (for example, the printing of sutras) and the conventions surrounding their use in promulgating and transmitting the doctrine. Most were in place by around 1200, and relatively few new aspects were added after this time, though a great many fashions and variations came and went.

Tibetan sects were political as well as faith-based institutions and were major forces in Tibetan society. They were sometimes in direct competition with each other: at times, wars were fought, and monasteries maintained armouries (Pal, 1990, p.26). This competition seems to have led to the emergence of a dominant monastic 'model', with a certain uniformity in terms of the structure of these institutions, how they were organized and financed, and what they offered to their adherents (both in terms of inducements and sanctions). Today, the temples and monasteries of different Buddhist sects are quite similar in terms of their underlying structure and basic features.[15] To discern differences, one must look at subtle clues such as the deities represented on paintings and sculptures, though even here there is considerable overlap. Even Tibet's native (non-Buddhist) Bon religion, which was initially of a quite different character, has come to resemble the Buddhist sects, apparently exchanging ideas with Buddhists in order to compete.[16] The monasteries were notably successful social and political institutions that survived almost unchanged until the 20th century.

A similar pattern of important but infrequent 'technology transfer' to that which occurred between certain weaving groups is found amongst Tibetan Buddhist sects. For the most part, sects remained separate, guarding their texts and traditions jealously, but at certain times, such as the period during which the reformer Je Tsongkhapa (1357-1419) and his disciples were active, teachings were combined and reformed, leading to the rise of the Gelug order that is pre-eminent in Tibet today (Snellgrove and Richardson, 1968, pp.180-183). This kind of reform movement is a feature of religious traditions: prime examples can also be found in the history of European Christianity.

In contrast to Tibetan Buddhist orders, the traditional weavers of Southeast Asia do not, for the most part, compete with each other. Most weavers pay little attention to the traditions or techniques of their neighbours and they are not greatly concerned with the speed or efficiency of the methods they use, nor with attracting 'converts' outside of their own communities. The separate evolution of countless rural traditions has led to a diverse landscape, with simple and complex technologies co-existing within a few kilometres of each other. There is evidence for competition and accelerated change in commercial

13 'Art functioned actively for the practitioners of Esoteric Buddhism both as visual triggers of integrated states of realization and as expressions of those states' (Linrothe 1999, p.3).

14 compare Alfred Gell's characterization of art: as 'a technical system [] oriented towards the production of [] social consequences' (Gell, 1992, p.44).

15 'Although there are four major sectarian schools and many sub-schools of Tibetan Buddhism, from a technical standpoint there is actually very little difference between them.' (Huntington and Bangdel, 2003, p.39).

16 'To the casual observer, Tibetans who follow the tradition of Bon and those who adhere to the Buddhist faith can hardly be distinguished.' (Kvaerne, 1995, p.12; see also Pal, 1990, p.38).

weaving workshops in urban areas, however. Commercial pressures or imperial demands probably accelerated the development of the Chinese drawloom discussed above.

In popular imagination, biological evolution is accompanied by competition between species, but this is by no means a necessary feature. Gradual change also takes place because of environmental change, and 'drift' (Mesoudi, 2016; see also Hahn and Bentley (2003) for an example of drift as a key factor in cultural change). These forces can also be seen at work in the evolution of weaving traditions. Some differences can be explained by differing access to resources, which are also evident in the textiles that are produced. Other differences seem to be of the 'contingent' and 'path dependent' type: they are not mandated by environmental conditions, rather they are the result of the histories of individual lineages (Buckley and Boudot, 2017).

Invention and Innovation

Invention is usually taken to mean the creation of new things, whereas innovation means their adoption. This aspect is one of the most important but also the most difficult to study in the context of traditions, which are by nature conservative and resistant to change. As regards weaving traditions, I have noticed weavers producing some novel motifs (as noted above), but I have not observed any changes in loom technology, since these are by nature infrequent. I have investigated two claimed cases of recent 'inventions' in traditional looms, but in both cases, I found that these were better classified as innovations, i.e. the reapplication of technologies from one lineage of looms to another (which in no way diminishes their usefulness). Both concerned patterning methods, which are by their nature relatively easy to move between looms. This illustrates a general point: true inventions are rare: most changes in lineages are of an incremental kind. Douglas Brooks, who apprenticed to Japanese master boatbuilders, in order to study their traditions, found that his masters were proud of the improvements they had made, but these were modest: changes to the stern of boats to accommodate outboard motors, changes to the shape of a scoop for bailing water from the boat (Brooks, 2015).

As regards fundamental changes to loom design, Buckley and Boudot (2017) estimated that such changes only need occur once in a generation to account for the entire evolution of loom designs in southeast Asia, and much less frequently than this (if at all) in the case of the simplest and most conservative looms. Invention and innovation are more common in motifs and designs, however, which can change at faster rates.

When examined closely in the context of weaving, the distinctions between 'invention' and 'innovation' tend to blur. For example, as described, Indian trade textiles, particularly the coveted silk *patola*, were a key source of design inspiration in ISEA. In some cases, designs were copied in a literal fashion, such as the case of batik (wax-resist) cloths produced in Java in close imitation of *patola*. This could be called innovation. In other cases, such as the inspired-by-*patola* motifs found on some Timor textiles the *patola* designs served as little more than a starting point (Barrkman, 2006). This is closer to invention: the recombination of ideas from ideas from more than one source. In Indonesian textiles all variations between these two extremes can be found.

Buddhist religious orders are also highly conservative by nature. 'New' ideas are generally unwelcome since (by definition) they do not originate from the approved source. How then can religious teachings adapt, and yet retain the credibility afforded by the 'lineage'? The Tibetan tradition of *terma* represents a remarkable solution to this problem. *Terma* are religious teachings ('treasure') that are said to have been hidden by early teachers such as Padmasambhava (active during the 8th century), awaiting re-discovery at the appropriate time. When this occurs, the treasure reveals itself to a finder (*terton*). Sometimes a text is found, sometimes a sacred object that triggers a revelation in the mind of the *terton*. In either case, the newly discovered teaching is understood not as a novelty, but as something that has been temporarily hidden from view. Such teachings are more likely to be accepted into the canon than material that is regarded as having been written recently.

New ideas are essential for the long-term survival of traditions, but the bar is set high, so that existing information is transmitted reliably from one generation to the next. There is a strong parallel with biological evolution: a source of variation (novelty, whether random or directed) forms an essential part of the evolutionary process. The sources of variation do not derive from within evolutionary theory, however: Darwin assumed variation existed within species, but he had no explanation for it, since he knew nothing of genes or mutations. Variation and invention are similarly assumed by cultural evolutionary models but are not explained by them.

The process by which inventions arise in human culture consists in part of random variations and accidents (which are conceptually similar to genetic mutations), and in part of directed problem-solving by participants. An important type of invention consists of the recombination of existing elements to create something new (Arthur, 2009). The process of invention of seems to be facilitated by the presence of transposable modules, such as the patterning systems discussed above. True novelty arises when modules are transposed across lineages to make new looms, or elements of religious teachings are synthesized across lineages. The presence of modules that can be recombined means that the potential for invention (via recombination) exists even in mature lineages.

These recombinative processes are essential for the operation of Darwin's model of evolutionary change, but they are not in any sense predicted by it.[17] New ideas and increased complexity arose in both weaving and Tibetan religious traditions when technology modules (loom technologies, doctrinal teachings) were shuffled and recombined across lineages. Such developments are not inevitable but are dependent upon chance and individual intervention.

Summary

In this contribution I have described how aspects of two cultural traditions in the Asia region evolve and change over time. Some aspects that form the core of these traditions are highly conserved and evolve in a tree-like (Darwinian) way, while other aspects that are equally important may change rapidly and may be swapped between lineages. The processes that generate variation operate via a mixture of incremental change (minor modifications) and more profound but infrequent changes that result from recombination across lineages.

Darwin's mechanism provides a useful model for how diversity arises and cultural 'solutions' are discovered and maintained, but it does not describe the solutions themselves, or where novel insights come from. Other processes, such as recombination and horizontal exchange between lineages (blending) must be considered, in order to account for invention and innovation, and to make sense of the patterns of culture that we observe.

17 Darwin's most famous work is mis-titled: his book describes the *continuation* of species, not their origin.

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References

Arthur, W.B., 2009. *The Nature of Technology: What It Is and How It Evolves.* New York: Simon & Schuster.

Barnes, R., 1989. *The Ikat Textiles of Lamalera: A Study of an Eastern Indonesian Weaving Tradition.* Leiden: Brill.

Barnes, R. and Hunt Kahlenberg, M., eds., 2012. *Five Centuries of Indonesian Textiles: The Mary Hunt Kahlenberg Collection.* New York: DelMonico Books/Prestel.

Barrkman, J., 2006. *Entwined: The Influence of Indian Patola and Trade Cloths on the Ritual Practices and Textile Motifs of the Atoin Meto People of West Timor.* MA thesis. Darwin: Charles Darwin University.

Bloch, M., 2005. *Where Did Anthropology Go? Or the Need for "Human Nature". Essays on Cultural Transmission.* Oxford: Berg.

Boudot, E. and Buckley, Chr., 2015. *Roots of Asian Weaving.* Oxford: Oxbow Books.

Boyd, R. and Richerson, P.J., 1988. *Culture and the Evolutionary Process.* Chicago: University of Chicago Press.

Brooks, D., 2015. *Japanese Wooden Boatbuilding.* Warren: Floating World Editions.

Buckley, Chr., 2011. *Living Hands: Tibetan Arts and Artisans.* (1st ed. 2005.) Hong Kong: Torana Publications.

Buckley, Chr., 2005b. Contemporary traditional furniture making in Lhasa. Unpublished report for the Tibet Poverty Alleviation Fund.

Buckley, Chr., 2012. Investigating cultural evolution using phylogenetic analysis: the origins and descent of the Southeast Asian tradition of warp ikat weaving. *PLoS ONE*, 7(12), e52064.

Buckley, Chr., 2016. A cultural inheritance: the transmission of traditional ikat weaving in the islands of Indonesia. In: *Proceedings of the 10th International Shibori Symposium*, 15-20 November.

Buckley, Chr., 2017. Looms, weaving and the Austronesian expansion. In: A. Acri, ed., *Spirits and Ships: Cultural Transfers in Early Monsoon Asia.* Singapore: ISEAS Publishing.

Buckley, Chr., 2018. Connecting Tai, Kam and Li peoples through weaving techniques. *Journal of the Siam Society*, 106, pp.73-108.

Buckley, Chr., 2021a. First migrants, first textiles. In: D. Shaffer, ed., *Textiles of Indonesia.* Munich: Prestel.

Buckley, Chr., 2021b. Motifs, meaning and madness. In: D. Shaffer, ed., *Textiles of Indonesia.* Munich: Prestel.

Buckley, Chr., 2023. Craft traditions. In: *The Oxford Handbook of Cultural Evolution.* Oxford: Oxford University Press.

Buckley, Chr. and Boudot, E., 2017. The evolution of an ancient technology. *Royal Society Open Science*, 4(5), 170208.

Bühler, A. and Fischer, E., 1979. *The Patola of Gujarat: Double Ikat in India.* 2 vols. Basel: Krebs AG.

Cabezón, J.I., 1997. The regulations of a monastery. In: D.S. Lopez, ed., *Religions of Tibet in Practice.* Princeton: Princeton University Press.

Collard, M., Shennan, S.J. and Tehrani, J.J., 2006. Branching, blending, and the evolution of cultural similarities and differences among human populations. *Evolution and Human Behavior*, 27(3), pp.169-184.

Carneiro, R.L., 2018. *Evolutionism in Cultural Anthropology: A Critical History.* New York and London: Routledge.

Cavalli-Sforza, L.L. and Feldman, M.W., 1981. *Cultural Transmission and Evolution: A Quantitative Approach.* Princeton: Princeton University Press.

Clarence-Smith, W.G., 2015. Breeding and power in Southeast Asia: horses, mules and donkeys in the longue durée. In: *Environment, Trade and Society in Southeast Asia*, pp.32-45. Leiden: Brill.

Darwin, Ch., 1859. *On the Origin of Species.* London: John Murray.

Dilley, R., 1987. Myth and meaning and the Tukolor loom. *Man*, 22, pp.256-266.

Ellen, R., Lycett, St.J. and Johns, S.E., eds., 2013. *Understanding Cultural Transmission in Anthropology: A Critical Synthesis.* Vol. 26. New York and Oxford: Berghahn Books.

Gell, A., 1992. The technology of enchantment and the enchantment of technology. In: J. Coote and A. Shelton, eds., *Anthropology, Art and Aesthetics.* Oxford: Oxford University Press, pp.40-63.

Greenfield, P.M. and Lave, J., 1982. Cognitive aspects of informal education. In: D.A. Wagner and H.W. Stevenson, eds., *Cultural Perspectives on Child Development.* San Francisco: W.H. Freeman, pp.181-207.

Greenfield, P.M., 1999. Cultural change and human development. *New Directions for Child and Adolescent Development*, 83. Available at: DOI: 10.1002/cd.23219998305 [Accessed 17 December 2024].

Hahn, M.W. and Bentley, R.A., 2003. Drift as a mechanism for cultural change: an example from baby names. *Proceedings of the Royal Society B: Biological Sciences*, 270(Suppl. 1), pp.S120-S123.

Hamilton, R.W., 1994. *Gift of the Cotton Maiden: Textiles of Flores and the Solor Islands.* Los Angeles: Fowler Museum.

Hampton, O.W., 1999. *Culture of Stone: Sacred and Profane Uses of Stone among the Dani.* College Station: Texas A&M University Press.

Huntington, J.C. and Bangdel, D., 2003. *The Circle of Bliss: Buddhist Meditational Art.* Chicago: Serindia Publications.

Jackson, D., 2005. Lineages and structures in Tibetan Buddhist painting: principles and practices of an ancient sacred choreography. *Journal of the International Association of Tibetan Studies*, 1, pp.1-40.

Kuhn, D., 2012. Reading the magnificence of ancient and medieval Chinese silks. In: D. Kuhn, ed., *Chinese Silks.* New Haven: Yale University Press, pp.1-64.

Kværne, P., 1995. *The Bon Religion of Tibet: The Iconography of a Living Tradition.* Chicago: Serindia Publications.

Lancy, D.F., 2012. "First you must master pain": the nature and purpose of apprenticeship. *Anthropology of Work Review*, 33(2), pp.113-126.

Lewis, E.D., 1994. Sikka Regency. In: R.W. Hamilton, ed., *Gift of the Cotton Maiden: Textiles of Flores and the Solor Islands.* Los Angeles: Fowler Museum.

Linrothe, R.N., 1999. *Ruthless Compassion: Wrathful Deities in Early Indo-Tibetan Esoteric Buddhist Art.* Chicago: Serindia Publications.

Lukas, D., Towner, M. and Borgerhoff Mulder, M., 2021. The potential to infer the historical pattern of cultural macroevolution. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 376(1828), 20200057.

Marchand, T.H.J., 1999. *Moulding Minaret Makers: A Study of Apprenticeship and Spatial Cognition with Traditional Builders in Sana'a, Yemen.* PhD thesis. London: SOAS, University of London.

Maxwell, R., 2003. *Textiles of Southeast Asia: Trade, Tradition and Transformation.* North Clarendon: Tuttle Publishing.

Mesoudi, A., 2016. Cultural evolution: a review of theory, findings and controversies. *Evolutionary Biology*, 43(4), pp.481-497.

Niessen, S., 2009. *Legacy in Cloth.* Leiden: KITLV Press.

Niessen, S. and Nashir, M.I.A., 2013. *Rangsa ni Tonun.* Film.

Pal, P., 1990. *Art of Tibet: A Catalogue of the Los Angeles County Museum of Art Collection.* Expanded ed. Berkeley, Los Angeles and London: University of California Press.

Rawson, J., 1983. *The Chinese Bronzes of Yunnan.* London: Sidgwick & Jackson; Beijing: Cultural Relics Publishing House.

Roux, V., Bril, B., Cauliez, J., Goujon, A., Lara, C., Manen, C., De Saulieu, G. and Zangato, E., 2017. Persisting technological boundaries: social interactions, cognitive correlations and polarization. *Journal of Anthropological Archaeology*, 48, pp.320-335. Available at: DOI: 10.1016/j.jaa.2017.09.004 [Accessed 17 December 2024].

Ruitenbeek, K., 1996. *Carpentry and Building in Late Imperial China: A Study of the Fifteenth-Century Carpenter's Manual "Lu Ban Jing".* Leiden: Brill.

Simon, H.A., 1962. The architecture of complexity. *Proceedings of the American Philosophical Society*, 106(6), pp.467-482.

Snellgrove, D.L., 1987. *Indo-Tibetan Buddhism: Indian Buddhists and Their Tibetan Successors.* London: Serindia Publications.

Snellgrove, D.L. and Richardson, H.E., 1968. *A Cultural History of Tibet.* New York: Frederick A. Praeger.

Stark, M.T., Bowser, B.J. and Horne, L., eds., 2008. *Cultural Transmission and Material Culture: Breaking Down Boundaries.* Tucson: University of Arizona Press.

Tehrani, J. and Collard, M., 2009. On the relationship between inter-individual cultural transmission and population-level cultural diversity: a case study of weaving in Iranian tribal populations. *Evolution and Human Behavior*, 30, pp.286-300. Available at: DOI: 10.1016/j.evolhumbehav.2009.03.002 [Accessed 17 December 2024].

Tëmkin, I. and Eldredge, N., 2007. Phylogenetics and material cultural evolution. *Current Anthropology*, 48(1), pp.146-154.

Terrell, J.E., 1987. Comment on "History, phylogeny, and evolution in Polynesia" by P.V. Kirch and R.C. Green. *Current Anthropology*, 28, pp.447-448.

Terrell, J.E., 1988. History as a family tree, history as a tangled bank. *Antiquity*, 62, pp.642-657.

Turner, E.A.L., 2020. Anvil age economy: a map of the spread of iron metallurgy across Afro-Eurasia. *Cliodynamics*, 11(1), pp.21-40. Available at: DOI:10.21237/C7clio11145895 [Accessed 17 December 2024].

Wenger, E., 1998. *Communities of Practice: Learning, Meaning, and Identity.* Cambridge: Cambridge University Press.

Whiten, A., Hinde, R.A., Laland, K.N. and Stringer, C.B., 2011. Culture evolves. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1567), pp.938-948.

Zhao, F., Sardjono, S. and Buckley, Chr., eds., 2019. *A World of Looms: Weaving Technology and Textile Arts.* Hangzhou: Zhejiang University Press.

Built from Paint: The Making of the Architectural Simulations in the Wall Paintings of Tell el-Dabᶜa/Egypt

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The colourful imageries of ancient wall paintings frequently cast a spell over modern beholders and take them into the realm of possible meanings they may have had for people of the past. At the same time, the impressiveness and attraction of these murals, often reconstructed from a myriad of fragments, tend to make us forget the dynamic processes of their production. Rather than succumb to the visual fascination of imageries, this paper embraces the fragmentary nature of ancient wall paintings as an opportunity to investigate how they become in a material and technical way. A particular group of highly fragmented Aegean-style wall paintings in a palace district of the 18th dynasty at Tell el-Dabᶜa/Egypt serves as a starting point. Using the example of the so-called architectural simulations from 'Palace G', which show building materials and techniques on a large scale, I seek to set the various stages of the past manufacturing process in motion again. In this way, I first attempt to reconstruct the craftspeople's material choices and technical actions. Second, I demonstrate how the craftspeople might have bodily and sensually engaged with the different materials during the production process.

Egypt; Tell el-Dabᶜa; Aegean-style; wall paintings; architecture; simulation; technique; chaîne opératoire

Introduction: From Static Images to Wall Paintings in Motion

Despite their often fragmented and poorly preserved condition, wall paintings belong to the most spectacular remains of ancient material cultures. Their imagery offers colourful impressions of the past and may even provide vivid glimpses into people's lives and beliefs, seen from the craftsperson's or patron's perspective. At the same time, these colourful images tend to conceal important aspects of the wall paintings from the modern beholder, namely the versatile and complex processes of their production. Once pieced together,

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 203-224.

wall paintings or their reconstructions look desperately static at first glance. Their making, however, was far from motionless: Their 'coming-into-being' occurred in a dynamic, continuous flow of transformations, which emerged from the situational entanglement of materials, things, and human bodies in a specific environment.

Although these dynamics are beyond recovery, the very physical existence of the wall paintings might shed some light on the various aspects of the production processes in the past. This is especially true if the wall paintings are only fragmentarily preserved. Along these lines, Mark Cameron, a specialist in Bronze Age Aegean wall paintings, understood the fragmented condition of these murals as an opportunity or even a requirement to study them from a technical point of view. "Ancient damage to these beautiful paintings", as M. Cameron (1976, p.274) put it, "for all its unfortunate consequences, provides considerable technical and architectural information if we know how to 'read' the broken pieces aright."

Therefore, the careful examination and description of the material characteristics and details of plaster fragments is an important precondition for a better understanding of the various technical stages of production. In combination with the analytical tool of the *chaîne opératoire* or operational sequence, these data enable us to set the past manufacturing processes in motion again.[1] Archaeologists mostly use the *chaîne opératoire* approach to study lithics or pottery. Several researchers, however, have recently shown its potential to analyse ancient wall paintings. Besides reconstructing past workflows and transformations, it is even possible to address the question of the craftspeople's technical knowledge and their bodily and sensuous involvement with materials and things (see, e.g., Brysbaert, 2008b; von Rüden, 2015; Becker, 2018; von Rüden and Skowronek, 2018; Becker 2024). Especially in the latter case, it is necessary to give the *chaîne opératoire* approach a "sensory update", as Maikel Kuijpers called it (2018, see also von Rüden, 2017, p.77).

With this new focus on sensual aspects of manufacturing, this paper examines the lime plaster fragments of a specific group of Late Bronze Age Aegean-style wall paintings: the so-called architectural simulations. Although this type of painting is common in Bronze Age sites of the Aegean, the murals discussed here emerged in a palace district of the 18th dynasty at ^{c}Ezbet Helmi/Tell el-Dab^{c}a in Egypt's eastern Nile Delta. They reproduce the appearance of various building materials and techniques on a large scale, giving the walls the distinctive impression of architectural designs. Following M. Cameron's approach, I provide a detailed account of the physical characteristics of the lime plaster fragments and reconstruct the operational sequence of these paintings. In this way, I follow the craftspeople's material choices and technical actions from the beginning to the end of the production processes within the context of the specific environmental conditions in Egypt. In addition, I explore and highlight the craftspeople's sensual and bodily engagement with the materials used in the making.

The Architectural Simulations from 'Palace G' at Tell el-Dab^{c}a

During the early 1990s, an Austrian excavation team made an astonishing discovery in Egypt's eastern Nile Delta. At the site of ^{c}Ezbet Helmi/Tell el-Dab^{c}a, ancient Avaris, they

1 Based on André Leroi-Gourhan's first conceptualisation (Leroi-Gourhan, 1988, pp.150-151), Robert Cresswell defined the *chaîne opératoire* as a series of operations that transform raw materials into objects (Cresswell, 2010, p.26). Since then, various scholars have elaborated on this definition. Therefore, there are different conceptions of the *chaîne opératoire* today (for an overview, see Martinón-Torres, 2002).

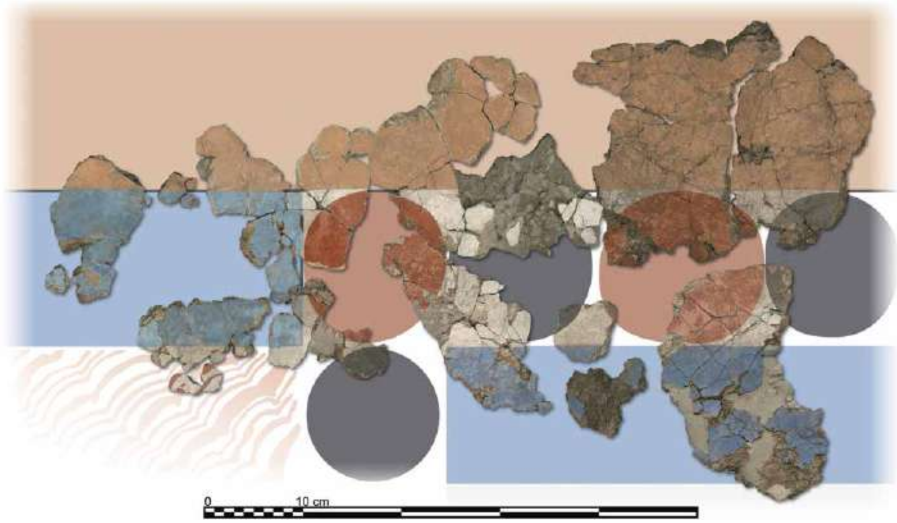

Figure 1: Reconstruction of fragments simulating roof beams ('beam-end'-frieze) (author).

uncovered thousands of painted lime plaster fragments within a palatial district of the 18th dynasty. The fragments were found in extensive deposits, apparently dumped in front of the two main buildings of the complex, 'Palace F' and 'Palace G' (Bietak, Marinatos and Palyvou, 2007, pp.26-40). In the case of 'Palace G', the plaster adhered to several walls in situ. The façade of the building, the inner side of the enclosure wall, and the walls of the former entrance gate that led to the palace precinct were covered in parts with lime plaster (with further references, see Jungfleisch, 2016, pp.39-42). It is precisely this entrance area from which almost 1,500 fragments of the so-called 'architectural simulations' and 200 ceiling plaster fragments originate (Bietak, et al., 2012/2013, pp.136-139; Jungfleisch, 2016; 2018; Jungfleisch, in press). Based on this finding, the murals might have decorated the gate or a hypothetical upper room of the entrance portico (Jungfleisch, 2016, p.42; Jungfleisch, in press; see also Bietak, Dorner and Jánosi, 2001, pp.87-88).

At first sight, the architectural designs from 'Palace G' at Tell el-Dabᶜa appeared somewhat enigmatic (Fig. 1, 2). However, I could identify several motifs compared to Bronze Age Aegean wall paintings: Aegean craftspeople used similar designs to reproduce the material appearance of various architectural elements nearly to scale. Following these similarities, it can be assumed that the murals from 'Palace G' at Tell el-Dabᶜa simulated different types of veined stone slabs, ashlar walls, and wooden structural components such as timber masonry reinforcements and the circular ends of ceiling beams (Bietak, et al., 2012/2013, pp.136-139; Jungfleisch, 2016; 2018, pp.200-203; Jungfleisch, in press). Thus, the painted architectural simulations changed the materiality of the mud-brick architecture of 'Palace G' to a great extent. But how was this painted architecture built from lime plaster and paint? Since a complete discussion of all fragments lies beyond the scope of this article, I summarise the technical characteristics of the architectural simulations and explore the transformative stages of their making (for a detailed discussion, see Jungfleisch, in press).

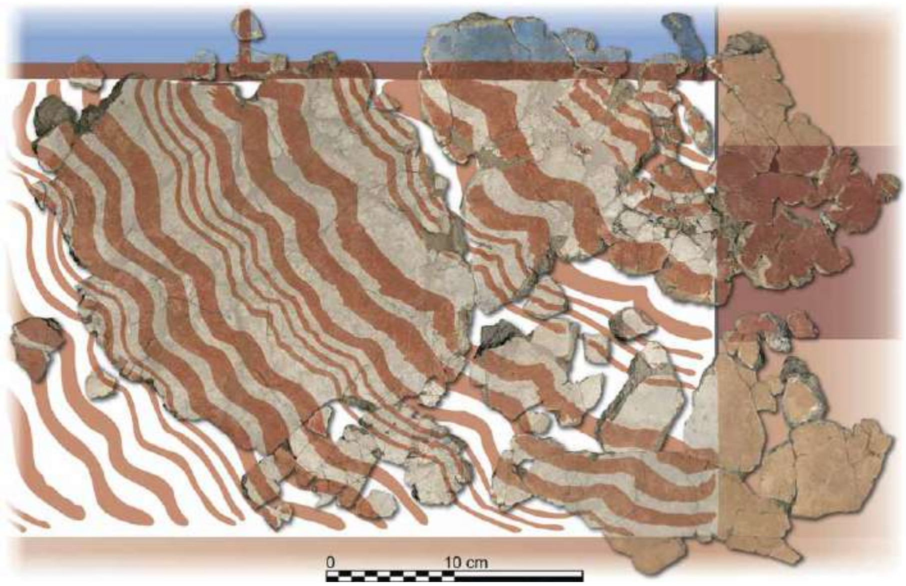

Figure 2: Reconstruction of fragments simulating a wooden framework, veined stone slabs and ashlar blocks (author).

The Making of the Architectural Simulations

Creating Stone: The Production of the Lime Plaster

One of the first steps within the production sequence of the carbonation-based wall paintings from Tell el-Dab^{c}a was probably the acquisition of raw materials such as limestone or some other source of calcium carbonate, e.g., marble or seashells. Moreover, fuel for the lime burning needed to be procured. Although the material characteristics of the lime plaster fragments do not give direct insights into the past procurement of these resources, some general observations can be made based on archaeological correlates and analogies to the lime-burning craft in later times.

According to Alexandra Winkels' plaster analysis (2007, pp.286-287), the craftspeople at Tell el-Dab^{c}a used different types of limestone for plaster production. These ranged from fine-crystalline and coarse-grained types to shell limestone and dolomitic limestone.[2] There were no limestone deposits in the eastern Nile Delta near Tell el-Dab^{c}a (Winkels, 2007, p.286). Instead, the nearest quarries were over 100 km away in the area of present-day Cairo.[3] In later times, the reduction of limestone to quicklime often occurred in the

2 The use of dolomitic limestone is surprising. Modern conservation studies consider this type of rock unsuitable for the production of lime plaster: Remaining unslaked magnesia particles can delay the hydration and lead to expanding surfaces (Elert, et al., 2002a, p.503). However, keeping the lime covered with water for some time solves this problem (Wingate, 1985, p.18).

3 For an overview of the limestone deposits and pharaonic quarries in Egypt, see Klemm and Klemm, 1993, pp.26-197; for the ancient quarries of Tura and Maasara near Cairo, see Klemm and Klemm, 1993, pp.65-71.

quarrying sites.[4] As the rare finds of lime-based plaster suggest,[5] lime burning was unusual in Egypt before the Ptolemaic Period (see Lucas, 1962, p.76; Nicholson, 2010). Consequently, the quarries on both sides of the Nile likely lacked the necessary infrastructure for this task during the 18th dynasty. However, craftspeople used simple pit kilns to burn lime at Qantir/Per-Ramesses, a 19th dynasty site only a few kilometres away from Tell el-Dabᶜa.[6] It can therefore be assumed that, firstly, limestone and fuel had to be transported to Tell el-Dabᶜa and, secondly, that the limestone was burned there on site.

Most probably, the very first procurement steps, namely prospection, required experienced lime burners. Only some raw sources of calcium carbonate were equally suitable for producing high-quality quicklime. The calcium carbonate content must be above 90 % and ideally around 98 % (Wingate, 1985, p.18; see also Brysbaert, 2007b, p.33). Furthermore, in the case of limestone, many physical characteristics such as surface area, porosity, pore size distribution, and crystallite size affect the later properties of the quicklime to a great extent (Elert, et al., 2002b, p.64). Today, modern measuring methods facilitate the identification of calcium carbonate sources that exhibit all relevant physical properties. In the past, however, assessing these properties without the help of modern technical instruments required a high degree of experience. The craftspeople had to make an almost intuitive choice of stone based solely on their bodily senses. To learn how a particular type of rock would respond to the calcination and subsequent slaking, they had to experience these spectacular processes countless times. For the lime burners, it was equally important to know where they could find deposits of suitable types of limestone. Therefore, they might have collaborated with other specialists who were well-informed about Egypt's geography and geology.[7]

In Tell el-Dabᶜa, there is no evidence for the kiln type that the craftsperson used for quicklime production (Winkels, 2007, p.286). Interestingly, modern practices of lime burning show how artisans rely on their sensory experiences during this process. The burning procedure can last several days, depending on the used rock type (Elert, et al., 2002b, p.63). In this context, a German documentary film of the 'Landschaftsverband Rheinland' about traditional lime burning in Gransdorf, an Eifel village in southwestern Germany, is of interest (Simons, Grunsky-Peper and Heizmann, 1979a; Simons, Grunsky-Peper and Heizmann, 1979b). According to this documentary, the colour of the smoke rising from the flare kiln gave the craftspeople hints about the moisture content of the limestones right at the beginning of the burning process. Occasionally, the lime burner took a piece of stone with the hand and examined if it was still 'sweating'. Based on the visual and haptic

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4 Since the resulting quicklime is lighter than its primary materials, lime burning in quarries can facilitate transportation. Nevertheless, for large building projects stretching over several years, it can be advantageous to integrate lime burning into the general workflow on the construction site, especially if the fuel is locally available (Wingate, 1985, p.128).

5 For lime-based plaster finds from various sites in Egypt from the Old Kingdom to the New Kingdom period, see, e.g., Noll, 1981, pp.417-422 (Giza); Bietak, Dorner and Jánosi, 2001, pp.48-50 (Tell el-Dabᶜa); Weatherhead, 2007, pp.361-367; Winkels, 2014, p.23 (Tell el-Amarna); Kahl, 2016, pp.15-16 (Assiut); Lacovara and Winkels, 2018, pp.164-165 (Malqata); Franzmeier, 2019, pp.21-23 (Qantir).

6 The excavators based this hypothesis on slag finds smelted with pieces of limestone and kiln fragments (Pusch and Rehren, 2007a, p.16; Pusch and Rehren 2007b, p.874, cat. no. PA 043).

7 The objectification of geological knowledge in ancient Egypt finds expression in the 'Turin Papyrus Map', which dates back to the 20th dynasty. The detailed illustration of this map shows topographic and geological features in the ancient mining area of Wadi Hammamat in the Eastern Desert of Egypt. For the 'Turin Papyrus Map', see, e.g., Harrell and Brown, 1992.

perception, they adjusted the firing accordingly since too high temperatures would have caused the stones to burst at this stage. When the kiln operator noticed that all the moisture had vaporised, they accelerated the fire to reach the required temperatures of above 900 °C. Nonetheless, they had to carefully control the temperature even at this stage because the calcination at lower temperatures ensured higher reactivity and a higher quality of the quicklime (Elert, et al., 2002a, p.503, p.507; Elert, et al., 2002b, pp.63-64). Therefore, they also paid close attention to the external conditions, for example, magnitude and direction of the wind. The shape and colour of the flames shooting out the holes of the kiln signalled to the craftsperson whether the fire was burning evenly. Towards the end of the calcination process, the lime burner determined the condition of the limestone. For this purpose, they inserted a metal rod into the blowholes of the kiln. If this procedure resulted in a soft, dull sound, they could hear that the limestone was 'baked'. Next, they examined the colour and weight of the burnt lime. In this way, the craftspeople verified their sound-based evaluation visually and haptically. From this account of traditional lime burning, it is clear that as late as in the 1970s, workers based many of their technical actions in the calcination process on sensory cues. It is likely that a similar process was followed in the Late Bronze Age when the lime burners did not have measuring devices to obtain information about the burning process. Instead, the workers had learned to read the sensory cues during a lifelong bodily engagement with the craft of lime burning.

In contrast to the calcination of the limestone, there is direct archaeological evidence at Tell el-Dab^ca for the next step of the plaster production: the slaking of the burnt lime. Excavations revealed several mud-brick basins directly outside the palace district of the 18th dynasty (Fig. 3) on the eastern bank of the former Pelusiac Nile branch (Jánosi, 2002, pp.203-210). The basins contained slaked lime and loamy earth alternating in layers. A. Winkels argued that this evidence is typical for the dry-slaking method (2007, p.283 fig.16, p.287).[8] During dry-slaking, the craftsperson poured just enough water over the layered quicklime and soil to ensure the hydration of the former. This action immediately causes a violent reaction that releases intense heat and steam. The course of the reaction depends on various factors: the ratio of quicklime to water, the properties of the quicklime, and the quantity, purity, and temperature of the water (Elert, et al., 2002b, pp.64-65). As a consequence, it is a challenging and complex task to keep the reaction under control and predict its outcome. In the past, the craftspeople relied only on their experience and judgment, which made things even more difficult.[9] In addition, A. Winkels (2007, p.279 fig. 7, p.282) identified so-called lime pops in the plaster matrix of the examined fragments. 'Lime pops' are small particles of only partially slaked burnt lime that remain in the plaster after dry-slaking. Owing to these 'lime pops', dry-slaked lime possesses a high water-retention capacity, considerably slowing down the setting process. As a result, the formation of shrinkage cracks is reduced to a minimum during the drying process. At the same time, the calcium carbonate content of the plaster can be as high as required

8 It should be mentioned that during recent excavations at Qantir/Per-Ramesses, a pit was discovered, that may have been used for the preparation of lime plaster (Franzmeier, 2019, pp.21-23).

9 It is interesting to note that there are many different views on the parameters of the slaking process in modern science, e.g., the amount or temperature of the water and their effects on the reaction and the quality of the lime plaster. Despite the possibilities of modern analyses, the slaking of lime remains an incompletely understood process until today. For a summary of diverging opinions, cf. Elert, et al., 2002b, pp.64-65.

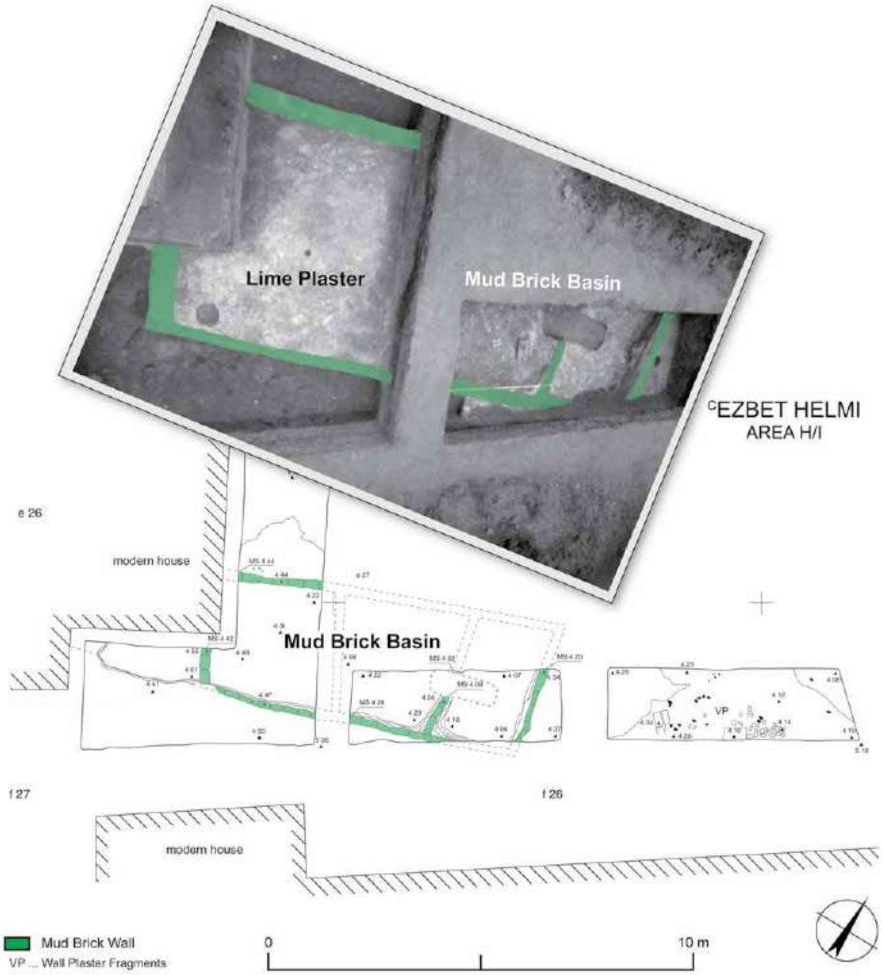

Figure 3: Plan and photograph of the mud-brick basins with lime mortar, which were found directly outside the palace district of the 18th dynasty on the bank of the former Pelusiac Nile branch at ᶜEzbet Helmi/Tell el-Dabᶜa (modified after: Jánosi, 2002, p.205 pl. 4, p.206 fig. 7).

for carbonation-based wall paintings (for these advantageous properties of dry-slaked lime, see, e.g., Kenter, n.d.). Accordingly, in the X-ray diffraction-analysis of some plaster samples from Tell el-Dabᶜa, Ann Brysbaert (2007a, p.153) identified very high proportions of calcium carbonate, varying from 86 to 100 %, and very small amounts of dolomite as well as moderate amounts of quartz.[10] Considering these properties, the dry slaking technique may have been a deliberate choice for producing wall paintings under hot climatic conditions, such as those in the eastern Nile Delta.

10 In recent but unpublished analyses, Tobias Skowronek also identified calcium carbonate as the main mineral in plaster samples from 'Palace G' at Tell el-Dabᶜa, including fragments of the architectural simulations (Skowronek, 2017).

What method craftspeople used for slaking in the Bronze Age Aegean and how they prepared the lime plaster is still unclear (Cameron, 1976, p.276). Noel Heaton claimed that they used a saturated, wet 'lime putty' that had previously aged over a long period (1911, p.700; 1912, pp.213-214). If this assumption is correct, Aegean craftspeople may have generally favoured a technique other than dry-slaking. Therefore, it is conceivable that the craftspeople at Tell el-Dab^ca not only mastered the complex and dangerous material transformations of dry-slaking but could also have adapted or even developed this technical process to meet the specific climatic conditions of the eastern Nile Delta.

The use of additives and aggregates for the lime plaster production at Tell el-Dab^{c}a supports this hypothesis. Based on the macro- and microscopical examination of plaster samples, it was suggested that the craftspeople used organic materials such as straw, hay, flax fibres, or hair in the plaster preparation (see, e.g., Brysbaert, 2007a, p.155; Winkels, 2007, p.281 fig. 10-13, 285). The proportion of organic additives could be as much as 5 to 15 % of the plaster, as A. Winkels estimated (2007, p.285). Fine impressions of slightly curved shapes in the matrix (Fig. 4) and even on the surface of the plaster (Fig. 5) indicate that organic additives, possibly hair, are also an essential part of the plaster composition of the architectural simulations and the ceiling plaster from 'Palace G'. The reasons for this distinct use may lie in the specific material interactions between the lime plaster and the organic additives: Organic fibres store water in the plaster and release it gradually. They thus act analogously to the 'lime pops' mentioned above and slow down the setting process. In this context, Constance von Rüden and Tobias Skowronek (2018, p.217) called attention to plaster 'recipes' handed down from Byzantine times, in which chopped ropes, animal hair, and straw are mentioned for precisely this purpose (see also Knoepfli, et al., 1990, p.23, p.30, p.32, p.65; Doerner, 2001, p.235). Aegean craftspeople probably also knew this effect (see, e.g., Cameron, 1976, p.277; Asimenos, 1978, p.573; Photos-Jones, 2005, p.225; Brysbaert, 2008b, p.114 tab. 6.1) but may have avoided organic materials as additives to the finer top layers (see, e.g., Heaton, 1911, p.699; Duell and Gettens, 1942, p.218; Shaw, 2009, p.144). In contrast, the high proportion of organic additives in the lime plaster of Tell el-Dab^{c}a suggests a plaster 'recipe' adjusted to the particular climatic conditions of the Nile Delta.

The moderate to small quantities of quartz and dolomite mentioned above point in a similar direction. Generally, mineral aggregates or fillers reduce shrinkage and stabilise the plaster but increase its porosity. This results in a thorough but accelerated carbonation process that shortens the time interval in which the craftsperson can apply and finish the plaster or paint its surface with a carbonation-based painting technique (see, e.g., Kühn, 1981b, p.350; Ling, 1991, p.199; Doerner, 2001, p.235). Given the climatic conditions, the craftspeople responsible for the plaster preparation may have aimed to extend the setting time, using a plaster mixture with fewer mineral fillers than usual. It is interesting to note that the artisans probably did not add them as inorganic fillers. Instead, A. Winkels concluded that they were remains of incompletely burnt limestone (2007, p.279 fig. 8; pp.282-284).[11] The quartz originated from local deposits of river sand (Winkels, 2007, p.284). It is precisely this material that modern artists such as Max Doerner (2001, p.235)

11 Ann Brysbaert also identified primary calcite in the plaster matrix. She attributed those particles to crushed raw limestone added as an inert filler (Brysbaert, 2007a, p.155, p.156 pl. 6). However, their rounded shape casts doubt on whether these particles are 'lime pops' rather than mineral fillers.

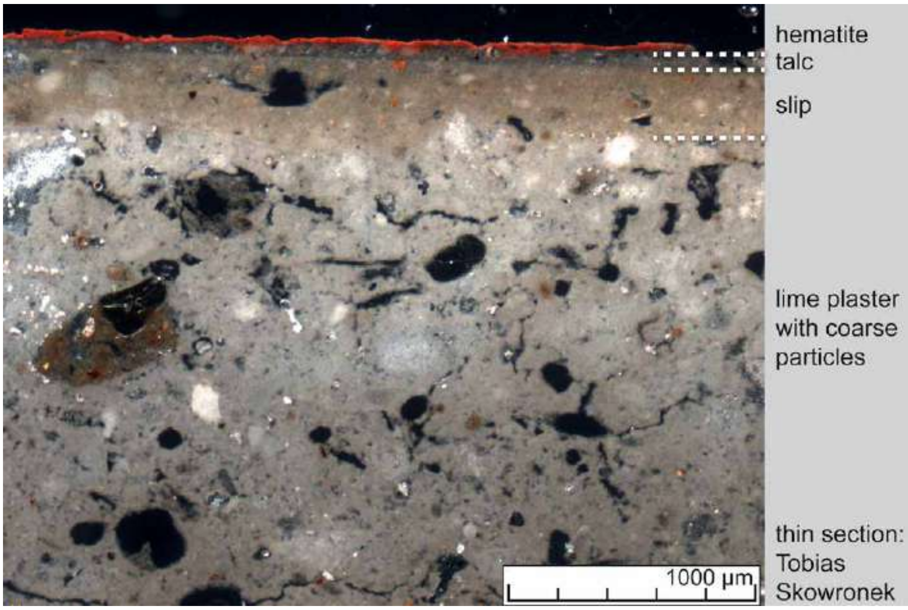

Figure 4: Thin section of a fragment belonging to the 'beam-end'-frieze. The sequence of layers shows, from bottom to top, the coarse lime plaster with decayed organic materials, the slip, the talc layer and the hematite layer (photograph: T. Skowronek).

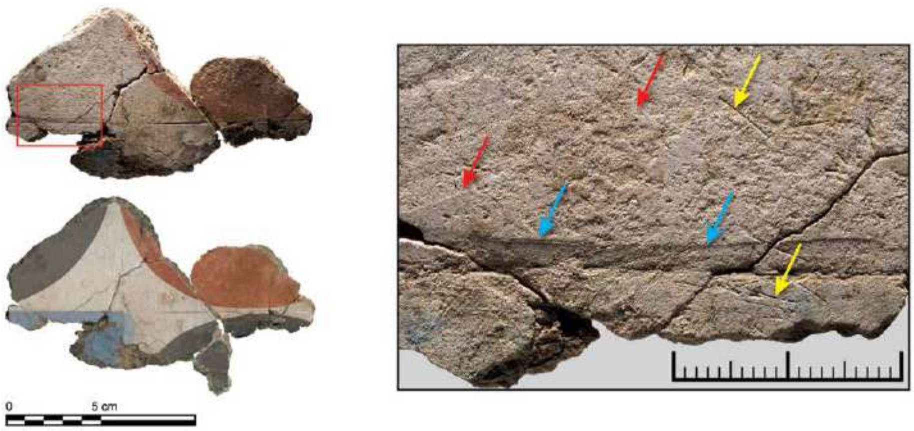

Figure 5: Obverse of a fragment belonging to the 'beam-end'-frieze (F06231+F06277+F06279), photograph (top) and digitally enhanced image (bottom). In the detailed view (right), the surface shows impressions of organic fibres (yellow arrows), polishing marks (blue arrows) and the indented surface of the former motif (red arrows) (author).

advised as filler for the lime plaster of fresco paintings. In addition, the craftspeople at Tell el-Dab[c]a added coarse aggregates such as old recycled plaster fragments (Brysbaert, 2002, p.98 pl. 4, p.99, pp.103-104; 2007a, p.155; von Rüden and Skowronek, 2018, pp.216-217) and crushed seashells, possibly of the murex species (Brysbaert, 2002, p.99, p.104; 2007a, p.155), to the plaster mixture.

Whether organic additives or mineral aggregates, it was far from trivial to manage the effects of these materials on the lime plaster. Recent research in experimental archaeology (Vlavogilakis, 2017) has shown that various factors, for example, the preparation of the aggregates or the timing of their addition to the mixture, strongly affect plaster properties.

To conclude this section, the composition of the lime plaster from Tell el-Dab[c]a reveals how the craftspeople carefully chose the different ingredients to manipulate the mortars' properties. The possible adjustments of the plaster properties to the specific environmental and climatic conditions of Egypt's Nile Delta indicate the craftspeople's sound knowledge and comprehensive understanding of the mutual interactions between the materials used.

Constructing the Walls: The Application of the Lime Plaster

In the next step of the production sequence, the artisanal specialists applied the plaster to the walls. In the case of the architectural simulations from 'Palace G' at Tell el-Dab[c]a, they first covered the mud-brick walls with a rough mud backing plaster, which contained plant fibres and presumably small pieces of wood and pottery sherds as reinforcement and temper (Fig. 6). This mud plaster functioned as a levelling coat that reduced the mechanical tensions between the 'moving' mud-brick walls and the rigid lime plaster cover (Jungfleisch, 2018, pp.204-207). The craftspeople likely applied the lime plaster only after the mud plaster had entirely set and its rough surface provided a suitable base for receiving the lime coating

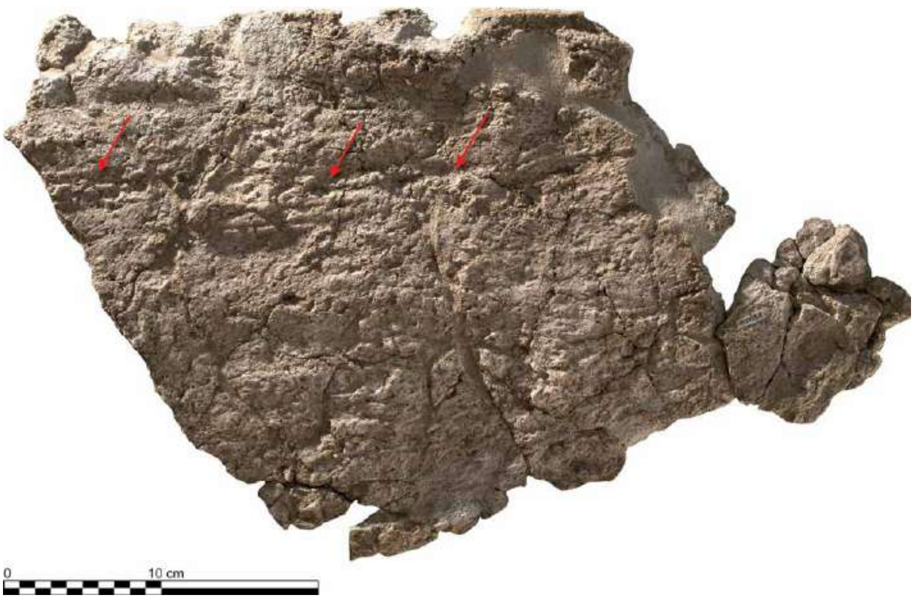

Figure 6: Reverse of a fragment belonging to the 'beam-end'-frieze. The rough reverse shows faint imprints of a mud-brick wall and impressions of organic materials belonging to the temper of the mud-backing plaster (red arrows) (author).

(Brysbaert, 2008a, p.2764). Since modern painters and conservators recommend pre-wetting the walls before applying the lime plaster (see Wehlte, 2000, pp.464-465; Dorner, 2001, pp.238-239; Kenter, n.d.), in particular, if the building materials absorb water, this may also have been the case at Tell el-Dab^{c}a.

The craftspeople might have used their hands to spread the plaster, which was common both in the Aegean (Cameron, Jones and Philippakis, 1977, p.153; Shaw, 2009, p.273 fig. 127, p.304 fig. 248) and Egypt (MacKay, 1921, p.162; Winkels, 2007, p.289 fig. 19). Tools comparable to the stone float found in a palatial building of the 13th dynasty at Tell el-Dab^{c}a (Bietak, 1984, pp.331-332 with fig. 8) or the various trowels and floats known from Bronze Age Crete (Evely, 2000, pp.474-477) could have also been used.

The fragments of the architectural simulations from 'Palace G' generally show two or three thicker layers of lime plaster and a thin lime plaster slip with a thickness of 0.35-0.57 mm (Fig. 4). While the initially applied layers evened out irregularities of the rough mud plaster and built up the main plaster body, the final slip provided the actual painting surface. Eventually, the craftspeople thoroughly floated this last plaster layer to enrich the surface with calcium hydroxide and to give it a smooth finish (see, e.g., Fig. 5, 7).

Applying the lime plaster to the wall surface required dexterity, fast work, and good timing: On the one side, the plasterers had to spread the layers wet-on-wet and on time so that the applied layer did not soak up the water of the previous one (see, e.g., Kühn, 1981a, p.11; Wehlte, 2000, p.464; Doerner, 2001, p.235). On the other side, it was essential to wait for the right moment when the slightly advanced setting process of the already applied plaster layers allowed to carry the weight of the subsequent layers (for this aspect, see also von Rüden, 2015, pp.360-361; von Rüden and Skowronek, 2018, pp.217-221).

The timely application of the plaster layers worked very well in the case of the architectural simulations since it is rather difficult to differentiate between single layers macroscopically. The thin sections of some fragments, however, show a fine line between the main body plaster and the final slip (Fig. 4). The slip of some fragments even flaked off (Fig. 7). Both observations indicate that the workflow was shortly interrupted. The setting process of the main plaster body began before the craftsperson applied the last layer of fine plaster. What appears as

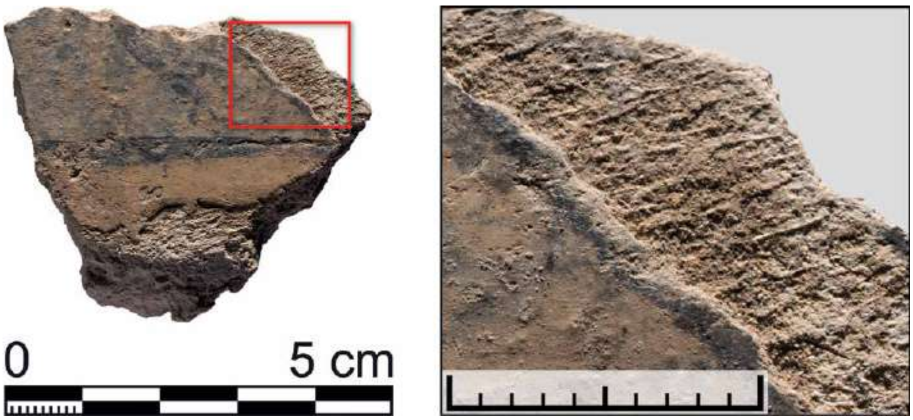

Figure 7: Obverse of a fragment belonging to a painted simulation of veined stone (F06932). The detailed view shows that the slip has flaked off in parts. Underneath, the surface of the plaster is only roughly trowelled (author).

a mistake may have been part of the craftspeople's plastering technique. For example, the modern painter and conservator Kurt Wehlte (2000, p.465) recommended an analogous method for applying lime plaster suitable for fresco paintings.

Architectural Drafting: Planning of the Architectural Paintings

Following the application of the plaster, the craftspeople planned the design of the architectural simulations. For this purpose, they used drafting tools such as strings. Pulled taut and snapped back, the string strokes left straight impressions in the damp, malleable surface of the lime plaster. Similar to the application of the plaster, the execution of string impressions required a good sense for the right moment: If the plaster was too fresh and damp, its elasticity would have absorbed the impression of the string. At the same time, the plaster had to contain sufficient moisture to allow the carbonation of the subsequently applied paint. In some examples of the architectural simulations, the craftspeople conducted the string impressions not only before, but in alternation with the paint application, which required them to work quickly, efficiently and precisely (Fig. 8). As a result, imprinting these guidelines – especially over larger areas or more than one wall – required some skill, as Maria Shaw (2003, p.181) rightly commented.

According to the identified string impressions, the craftspeople used only cords for the architectural simulations at Tell el-Dab^{c}a that showed an identical plying direction, namely in the S-direction (Fig. 9).[12] The twist of a cord is normally inverse to the spinning direction of the yarn used, meaning that a z-spun yarn normally shows an S-direction. The direction of the yarn depends on several parameters. In discussing the spinning direction in the prehistory of Europe and Egypt, Elizabeth Barber emphasized that Egyptian spinners tended to twist linen fibres in the s-direction. Following E. Barber, this homogeneity resulted from the properties of the fibres and the tools used but also from the specific context of learning in a particular craft tradition (Barber, 1991, p.42 fn. 1, pp.65-68). With this in mind, the consistent S-twist of the cords used for the string impressions of the architectural simulations from 'Palace G' at Tell el-Dab^{c}a opens an interesting interpretative approach: If the craftspeople produced the strings themselves, they might have belonged to the same community of practice (Lave and Wenger, 1991). An alternative explanation could be that the cords were acquired centrally.

Beyond Tell el-Dab^{c}a, strings as drafting devices were commonly used in the Aegean, Western Asia and Egypt (for the Aegean, see, e.g., Shaw, 2000; 2003; 2016; for Western Asia, see, e.g., von Rüden, 2011, pl. 40 a-b; von Rüden and Jungfleisch, 2017, pp.71-72). In the latter case, however, workers generally took a different approach than in the palace district of the 18th dynasty in Tell el-Dab^{c}a: Before releasing the strings upon the fully hardened plaster surface, they dipped them into red paint. This action resulted in red-painted guidelines, contrasting with the physical but colourless imprints known from Tell el-Dab^{c}a and the Aegean (see, e.g., Robins, 1994, p.26).[13]

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12 S-direction means that the twisted strings, when held vertically, slope in the same direction as the middle part of the letter 'S'. A second way of plying results in a twist with a reverse direction, similar to the middle part of the letter 'Z'. In this context, capitals ('Z', 'S') refer to the plying direction and lowercases ('z', 's') to the spinning direction (Barber, 1991, pp.65-66).

13 In Tell el-Amarna, however, the plaster was not only lime-based but showed, in rare cases, string impressions without red paint (Weatherhead, 2007, p.369, col. pl. 21).

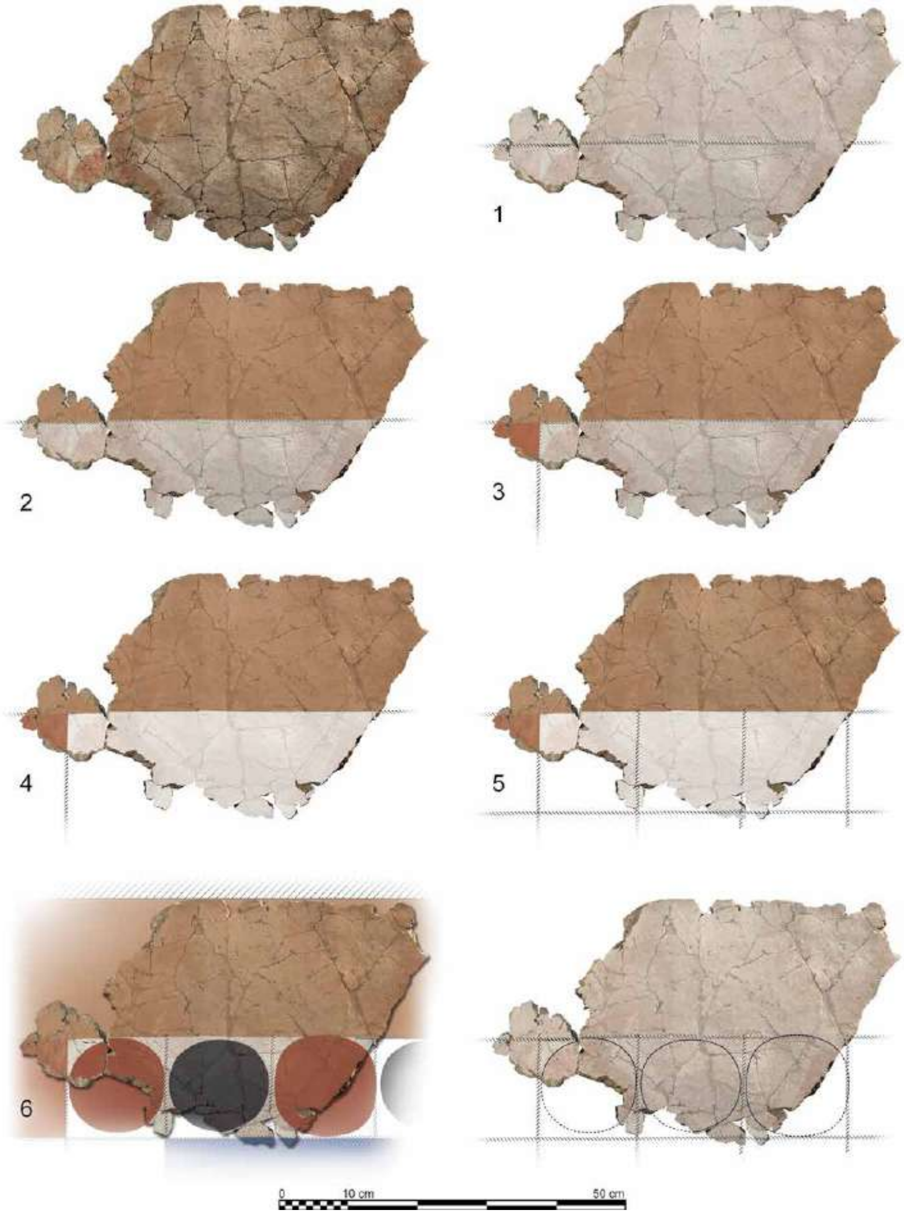

Figure 8: Reconstructed sequence of the execution of string impressions and the application of paint in the production of the 'beam-end'-frieze, scale 1:8. The final image illustrates the relationship between the impressed grid and the circles (author).

Building with Paint: Execution and Finish of the Paintings

After the planning process, the craftspeople started colouring the previously marked areas. In this work step, they employed different mineral pigments such as red and yellow ochre for red, orange and beige paint applications, Egyptian Blue and manganese black (Seeber, 2000, p.95, pp.98-99 tab. 2; Brysbaert, 2007a, pp.155-160). As C. von Rüden and T. Skowronek have recently argued (2018, pp.222-224; see also Skowronek, Hauptmann and

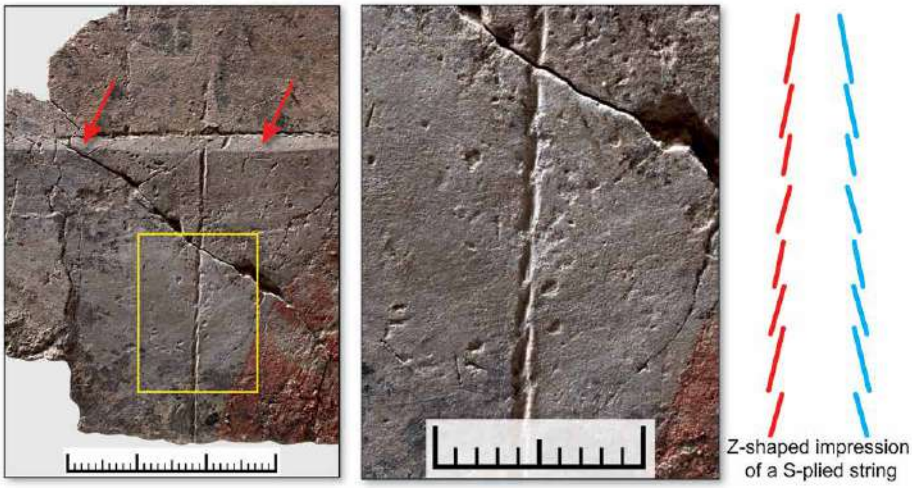

Figure 9: Photograph of a fragment of the 'beam-end' frieze (F08102+F08195) showing orange and white areas, scale 1:1. The white area consists of a thick white paint layer (talc?) and displays a polishing mark (red arrows). Two vertical and one horizontal string impressions are visible. In the detailed view, the Z-shaped impression of an S-twisted string can be observed (author).

von Rüden, 2020), the use of talc white is of special interest. This pigment was not only applied as a background colour for specific areas of the architectural simulations (Fig. 4, 9),[14] but also as a base coat and motif colour for other paintings from Tell el-Dabᶜa, for example, the 'labyrinth floor' and the stucco reliefs (von Rüden and Skowronek, 2018; Skowronek, Hauptmann and von Rüden, 2020). Talc white was never detected in Egyptian wall paintings. However, it was found in different regional pottery styles and wall paintings of the Aegean. Therefore, C. von Rüden and T. Skowronek concluded that "talc has been used in the wall paintings from Tell el-Dabᶜa in a very similar manner as on Cycladic pottery" (von Rüden and Skowronek, 2018, pp.223-224). Interestingly, the raw material for the talc white was obtained locally as a secondary product of gold mining in the Eastern Desert of Egypt (Skowronek, Hauptmann and von Rüden, 2020).

When painting the designs of the architectural simulations, the craftspeople generally followed the boundaries of the motifs. In this way, the brush strokes gave the painted areas a regular appearance. Depending on the intended motif, the specialists adjusted their painting style. They applied the paint in several layers to achieve an opaque, deep colour effect. For a slightly translucent impression, as in the case of the stone veining, they used just enough paint to execute the motif. Applying the paint required precise timing: If the lime plaster was too fresh, the brush strokes could disturb its surface; if they waited too long, the chemical reaction of the carbonation would not have fixed the pigments on the plaster (Knoepfli, et al., 1990, p.61).

In addition, the craftspeople took different approaches in the process of painting. The overlay of colours of some architectural simulations implies a workflow similar to

14 In the case of the architectural simulations, the painters applied talc white as the background for the black and red circles of the 'beam-end'-frieze from 'Palace G' at Tell el-Dabᶜa (for this design, see Bietak, et al., 2012/2013, pp.138-139; Jungfleisch, 2016, pp.45-46; Jungfleisch, 2018, pp.200-203; Jungfleisch, in press).

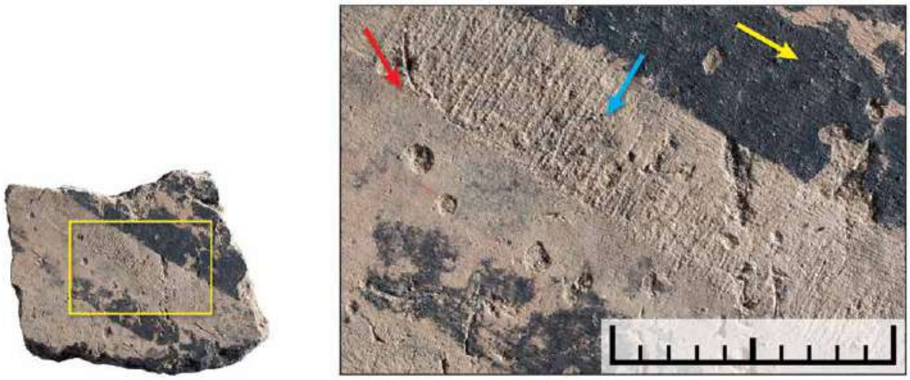

Figure 10: Obverse of a fragment belonging to a painted simulation of veined stone (F06600). First, the detailed view shows the indented polishing mark along a faint black motif element (red arrow). Second, the texture of the smoothed surface is recognisable (blue arrow). Third, it indicates the direction of the brushstroke (yellow arrow) (author).

the one recently identified by Johannes Becker (2018, pp.177-184; Becker 2024) in the mural of a large-scale griffon from 'Palace F' at Tell el-Dab^{c}a. In the case of the 'beam-end'-frieze, for instance, the craftspeople organised the working process in consecutive horizontal registers, which corresponded with the general composition of the design (Fig. 8). While the craftspeople processed these horizontal sections from the top of the wall downwards, they completed the technical actions within each register by working in a lateral direction. Interestingly, the workers did not execute all string impressions for these sections in advance but alternated between the design process and the painting of the motifs in their general workflow. Accordingly, the artisans were able to perform both tasks, or different groups of specialists worked closely together.[15]

In other designs, however, such as the blue ashlar masonry with red-painted joints (Jungfleisch, 2016, pp.42-44), the painters used a technique M. Cameron (1976, p.282) called "reserved spacing" in the context of Aegean wall paintings. Guided by the string impressions, the craftspeople in Tell el-Dab^{c}a first filled in the marked 'front sides' of the 'ashlar blocks' with blue colour. In the process, they left out the horizontal and vertical interstices between the 'ashlars' for the moment. Only then were the 'joints', which had previously been blocked out, painted red.

The treatment of the surface of the plaster formed an essential part of the production of the architectural simulations. The artisans dealt with this task at different stages of the production process. Some fragments of the architectural simulations have a distinct textured surface in spots where the slip has flaked off (Fig. 7). Apparently, the plasterers only roughly trowelled the last plaster layer before applying the final lime slip. This action was possibly intended to create a suitable substrate for the slip.

In many cases, the slip and the coats of paint show working traces, such as long, slightly elevated ridges related to the smoothing of the surface (Fig. 9, 10). Since the

15 A similar approach can be found in the 'Procession Fresco' from Knossos, as the filling of the background may have occurred before the execution of the string impressions (cf. Cameron, 1976, p.283; Shaw, 2000, p.53).

artisans trowelled the plaster before and after painting, additional lime enriched the surface and improved the fixation of the colours (see, e.g., Cameron, Jones and Philippakis, 1977, p.168; Knoepfli, et al., 1990, p.23; Doerner, 2001, p.261). In correspondence with external conditions such as humidity or temperature and also with the material itself, the craftspeople had to bodily know how much pressure they should exert on the plaster surface. If the artisan compressed the slip a little too much, the brought-up lime might have obscured the paint.[16] At worst, a calcite crust would have formed, making the subsequent painting impossible (Weyer, et al., 2016, p.358).

In addition, indented surface marks give evidence that the craftspeople polished certain areas in a pronounced manner (Fig. 5, 9, 10). They followed the course of string imprints or painted motifs with a pebble or polisher (for possible polishers found on Crete, see, e.g., Evely, 2000, p.477). Because the artisans did so after the painting process, a sense of the right moment was essential. They had to wait until the applied coats of paint were already partially fixed but not too long so that the plaster was still malleable. Otherwise, the polishing could have blurred the motifs in both cases. The surface treatment was thus a highly complex task that demanded a high skill level and experience from the craftspeople.

Conclusions

The lime plaster fragments of the architectural simulations presented in this paper provide detailed information about their technical characteristics. Based on archaeological correlates and analogies with modern crafts, the material properties and work traces give a vivid idea of the manufacturing processes. Step by step, the making of the architectural simulations is set in motion, connecting the plaster pieces' physicality with gestures and the sensual engagement of the craftspeople. The seemingly static broken pieces transform into traces, informing us about the dynamic processes of making in the past.

In this way, it becomes clear that from the very beginning of the production, the craftspeople relied heavily on their experience and senses in the material choices and technical actions, especially without the measuring methods and knowledge of modern science. For example, the knowledge of the suitable types of limestone probably arose from the direct bodily interaction with the materials during the various stages of lime plaster production. The workers may have developed a sense of the interplay of the perceived qualities of the raw materials and their later effects on the transformation processes of production through numerous repetitions of this engagement. Similarly, some of the actions during lime burning and dry-slaking were possibly guided by the perception of specific sensory cues. 'Reading' the colour of smoke and flames from the pit kiln and interpreting the released heat and rising steam during the slaking were both skills that could have been acquired only by experiencing these sensual spectacles through one's own body. In addition, the plaster preparation required a good sense of how the slaked lime, organic additives, and mineral aggregates would react with each other under specific environmental conditions. The workers may have mastered this complex procedure to such an extent that they were

16 A. Brysbaert (2008b, p.117; 2011, p.259) argued that this was certainly the case if the polishing took place after the paint was applied. However, working traces of the wall paintings from Tell el-Dab^{c}a indicate the artisans polished the surface after the painting process. Therefore, the formation of a white veil was probably a matter of the pressure applied to the surface rather than the timing of the work process.

able to make situational changes and adapt both slaking method and plaster recipe to meet the particular requirements of the eastern Nile Delta. Finally, the application of the plaster layers, the drafting of the designs, the execution of the paintings, and the treatment of their surfaces point to a very skilful handling of the specific material properties of the lime plaster. In these various bodily engagements with building materials, plaster, pigments, and tools, the craftspeople frequently depended on their experience and senses. In direct contact with the plaster's physicality, the sense of touch gave them an impression of the right moment in which they had to perform a particular gesture.

The reconstructed operational sequence of the architectural simulations demonstrates that the craftspeople required particular sensual and bodily skills at most stages of making. Some of these abilities were probably situated on the preconscious level of embodied knowledge which was part of the artisan's body and muscles. Therefore, it is highly likely that the craftspeople at Tell el-Dabᶜa had incorporated this form of knowledge through a lifetime of practice in making lime-based wall and floor paintings. Paintings based on the carbonation of lime were scarce in Egypt until the Ptolemaic Period. The appearance of this painting type at Tell el-Dabᶜa points to the involvement of craftspeople who were trained in a craft tradition of a region other than Egypt.

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References

Asimenos, K., 1978. Technological observations on the Thera wall-paintings. In: Chr. Doumas, ed., *Thera and the Aegean World I. Papers presented at the Second International Scientific Congress, Santorini, Greece, August 1978*. London: Thera and the Aegean World, pp.571-578.

Barber, E.J.W., 1991. *Prehistoric textiles. The development of cloth in the Neolithic and Bronze Ages*. Princeton: Princeton University Press.

Becker, J., 2018. How to paint a landscape: technical perspectives on the 'Aegean'-style landscape paintings from Tell el-Dabᶜa. In: J. Becker, J. Jungfleisch and C. von Rüden, eds., *Tracing technoscapes. The production of Bronze Age wall paintings in the Eastern Mediterranean*. Leiden: Sidestone Press, pp.173-190.

Becker, J., 2024. Ägäische Wandmalereien aus dem Tuthmosidenpalast von Tell el-Dabʿa I. Die großformatigen Greifen- und Landschaftsdarstellungen. Technik, Ikonographie und Rekonstruktion der Kalkputzmalereien im überregionalen Vergleich. Contributions to the Archaeology of Egypt, Nubia and the Levant, 18(1). Wiesbaden: Harrassowitz.

Bietak, M., 1984. Eine Palastanlage aus der Zeit des späten Mittleren Reichs und andere Forschungsergebnisse aus dem östlichen Nildelta (Tell el-Dabᶜa 1979-1984). *Anzeiger. Österreichische Akademie der Wissenschaften, Philosophisch-Historische Klasse*, 121, pp.312-349.

Bietak, M., Dorner, J. and Jánosi, P., 2001. Ausgrabungen in dem Palastbezirk von Avaris, Vorbericht Tell el-Dabᶜa/ᶜEzbet Helmi 1993-2000. *Egypt and the Levant. International Journal for Egyptian Archaeology and Related Disciplines*, 11, pp.27-120.

Bietak, M., Marinatos, N. and Palyvou, C., 2007. *Taureador scenes in Tell el-Dabᶜa (Avaris) and Knossos*. Untersuchungen der Zweigstelle Kairo des Österreichischen Archäologischen Institutes, 27. Vienna: Verlag der Österreichischen Akademie der Wissenschaften.

Bietak, M., von Rüden, C., Becker, J., Jungfleisch, J., Morgan, L. and Peintner, E., 2012/2013. Preliminary report of the Tell el-Dabᶜa Wall Painting Project – season 2011/2012. *Egypt and the Levant. International Journal for Egyptian Archaeology and Related Disciplines*, 22/23, pp.131-147.

Brysbaert, A., 2002. Common craftsmanship in the Aegean and East Mediterranean Bronze Age: preliminary technological evidence with emphasis on the painted plaster from Tell el-Dabᶜa, Egypt. *Egypt and the Levant. International Journal for Egyptian Archaeology and Related Disciplines*, 12, pp.95-107.

Brysbaert, A., 2007a. Technological approach to the painted plaster of Tell el-Dabᶜa, Egypt: microscopy and scientific analysis. In: M. Bietak, N. Marinatos and C. Palyvou, eds., *Taureador scenes in Tell el-Dabᶜa (Avaris) and Knossos*. Untersuchungen der Zweigstelle Kairo des Österreichischen Archäologischen Institutes, 27. Vienna: Verlag der Österreichischen Akademie der Wissenschaften, pp.151-162.

Brysbaert, A., 2007b. Murex and marine shell use for lime production and in plaster surfaces in the Aegean and Eastern Mediterranean Bronze Age. *Mediterranean Archaeology and Archaeometry*, 2, pp.29-51.

Brysbaert, A., 2008a. Painted plaster from Bronze Age Thebes, Boeotia (Greece): a technological study. *Journal of Archaeological Science*, 35, pp.2761-2769.

Brysbaert, A., 2008b. *The power of technology in the Bronze Age Eastern Mediterranean. The case of the painted plaster*. Monographs in Mediterranean Archaeology, 12. London: Equinox.

Brysbaert, A., 2011. Appendix I. The painted plaster from Qaṭna: a technological study. In: C. von Rüden, *Die Wandmalereien aus Tall Mišrife/Qaṭna im Kontext überregionaler Kommunikation*. Qaṭna-Studien, 2. Wiesbaden: Harrassowitz, pp.249-269.

Cameron, M.A.S., 1976. A general study of Minoan frescoes with particular reference to unpublished wall paintings from Knossos. PhD thesis. Newcastle University. Available at: http://hdl.handle.net/10443/302 [Accessed 21 April 2022].

Cameron, M.A.S., Jones, R.E. and Philippakis, S.E., 1977. Scientific analyses of Minoan fresco samples from Knossos. *The Annual of the British School at Athens*, 72, pp.121-184.

Cresswell, R., 2010. Techniques et culture: les bases d’un programme de travail. *Techniques & Culture*, 54/55, pp.23-45. Available at: DOI:10.4000/tc.4979 [Accessed 17 December 2024].

Doerner, M., 2001. *Malmaterial und seine Verwendung im Bilde*. 19th ed. Revised and supplemented by T. Hoppe. Berlin: Seemann.

Duell, P. and Gettens, R.J., 1942. A review of the problem of Aegean wall painting. *Technical Studies in the Field of the Fine Arts*, 10, pp.179-223.

Elert, K., Cazalla, O., Rodriguez, C., Hansen, E. and Sebastian, E., 2002a. Über das Einsumpfen von Kalk: warum sind historische Kalkmörtel so unterschiedlich erhalten?

Restauro. Zeitschrift für Kunsttechniken, Restaurierung und Museumsfragen, 108, pp.502-508.

Elert, K., Rodriguez-Navarro, C., Sebastian Pardo, E., Hansen, E. and Cazalla, O., 2002b. Lime mortars for the conservation of historic buildings. *Studies in Conservation*, 47, pp.62-75.

Evely, D., 2000. *Minoan crafts. Tools and techniques. An introduction II*. Studies in Mediterranean Archaeology, 92(2). Göteborg: Åström.

Franzmeier, H., 2019. Farbenprächtige Überraschungen: Bericht von den Grabungen in Qantir-Piramesse in den Jahren 2016 und 2017. *aMun. Magazin für die Freunde Ägyptischer Museen und Sammlungen*, 58, pp.20-23.

Harrell, J. and Brown, V., 1992. The oldest surviving topographical map from Ancient Egypt (Turin Papyri 1879, 1899, and 1969). *Journal of the American Research Center in Egypt*, 29, pp.81-105.

Heaton, N., 1911. Minoan lime-plaster and fresco painting. *Journal of the Royal Institute of British Architects*, 18, pp.697-710.

Heaton, N., 1912. On the nature and method of execution of specimens of painted plaster from the Palace of Tiryns. In: G. Rodenwaldt, *Tiryns. Die Ergebnisse der Ausgrabungen des Instituts II. Die Fresken des Palastes*. Athens: Eleutheroudakis und Barth, pp.211-216.

Jánosi, P., 2002. Bericht über die im Frühjahr 2001 erfolgten Sondagen im Dorf ^{c}Ezbet Helmi (Grabungsfläche H/I). *Egypt and the Levant. International Journal for Egyptian Archaeology and Related Disciplines*, 12, pp.195-210.

Jungfleisch, J., 2016. When Aegean wall paintings meet Egyptian architecture: simulations of architecture from 'Palace G' at Tell el-Dab^{c}a/Egypt. In: R. Stucky, O. Kaelin and H.-P. Mathys, eds., *Proceedings of the 9th International Congress on the Archaeology of the Ancient Near East, June 9th-13th, 2014, University of Basel. Volume II*. Wiesbaden: Harrassowitz, pp.37-50.

Jungfleisch, J., 2018. For further information please see the back of the plaster: architectural impressions in the 'Aegean'-style wall paintings from Tell el-Dabca. In: J. Becker, J. Jungfleisch and C. von Rüden, eds., *Tracing technoscapes. The production of Bronze Age wall paintings in the Eastern Mediterranean*. Leiden: Sidestone Press, pp.191-211.

Jungfleisch, J., in press. *Ägäische Wandmalereien aus dem Tuthmosidenpalast von Tell el-Dab^{c}a II. Architektursimulationen aus Palast G und ihre Wahrnehmung im ägyptischen Kontext.* Contributions to the Archaeology of Egypt, Nubia and the Levant, 18(2). Wiesbaden: Harrassowitz.

Kahl, J., 2016. *Ornamente in Bewegung. Die Deckendekoration der Großen Querhalle im Grab von Djefai-Hapi I. in Assiut*. The Asyut Project, 6. Wiesbaden: Harrassowitz.

Kenter, W., n.d. Trockengelöschte Kalkmörtel: das Verfahren. Available at: https://www.kalk-laden.de/Beschreibungen-und-Anleitungen [Accessed 21 April 2022].

Klemm, R. and Klemm, D.D., 1993. *Steine und Steinbrüche im Alten Ägypten*. Berlin: Springer.

Knoepfli, A., Emmenegger, O., Koller, M. and Meyer, A., 1990. *Wandmalerei, Mosaik*. Reclams Handbuch der künstlerischen Techniken, 2. Stuttgart: Reclam.

Kühn, H., 1981a. *Erhaltung und Pflege von Kunstwerken und Antiquitäten I*. 2nd ed. Munich: Keyser.

Kühn, H., 1981b. *Erhaltung und Pflege von Kunstwerken und Antiquitäten II*. Munich: Keyser.

Kuijpers, M.H.G., 2018. A sensory update to the chaîne opératoire in order to study skill: perceptive categories for copper-compositions in archaeometallurgy. *Journal of Archaeological Method and Theory*, 25, pp.863-891.

Lacovara, P. and Winkels, A., 2018. Malqata – the painted palace. In: J. Becker, J. Jungfleisch and C. von Rüden, eds., *Tracing technoscapes. The production of Bronze Age wall paintings in the Eastern Mediterranean*. Leiden: Sidestone Press, pp.149-172.

Lave, J. and Wenger, E., 1991. *Situated learning. Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Leroi-Gourhan, A., 1988. *Hand und Wort. Die Evolution von Technik, Sprache und Kunst*. Frankfurt am Main: Suhrkamp.

Ling, R., 1991. *Roman painting*. Cambridge: Cambridge University Press.

Lucas, A., 1962. *Ancient Egyptian materials and industries*. 4th ed. Revised and enlarged by J.R. Harris. London: Arnold.

Mackay, E., 1921. The cutting and preparation of tomb-chapels in the Theban necropolis. *The Journal of Egyptian Archaeology*, 7, pp.154-168.

Martinón-Torres, M., 2002. Chaîne opératoire: the concept and its applications within the study of technology. *Gallaecia*, 21, pp.29-44.

Nicholson, P.T., 2010. Kilns and firing structures. In: W. Wendrich, ed., *UCLA Encyclopedia of Egyptology*, 1(1). Available at: https://escholarship.org/uc/item/47x6w6m0 [Accessed 21 April 2022].

Noll, W., 1981. Zur Kenntnis altägyptischer Pigmente und Bindemittel. *Neues Jahrbuch für Mineralogie. Monatshefte*, 1981/9, pp.416-432.

Photos-Jones, E., 2005. Appendix. The examination of some Minoan fresco fragments with the scanning electron microscope (SEM). In: L. Morgan, ed., *Aegean wall painting. A tribute to Mark Cameron*. British School at Athens Studies, 13. London: British School at Athens, pp.199-228.

Pusch, E.B. and Rehren, T., 2007a. *Hochtemperatur-Technologie in der Ramses-Stadt. Rubinglas für den Pharao – Teil 1. Text*. Forschungen in der Ramses-Stadt. Die Grabungen des Pelizaeus-Museums Hildesheim in Qantir – Pi-Ramesse, 6(1). Hildesheim: Gerstenberg.

Pusch, E.B. and Rehren, T., 2007b. *Hochtemperatur-Technologie in der Ramses-Stadt. Rubinglas für den Pharao – Teil 2. Katalog*. Forschungen in der Ramses-Stadt. Die Grabungen des Pelizaeus-Museums Hildesheim in Qantir – Pi-Ramesse, 6(2). Hildesheim: Gerstenberg.

Robins, G., 1994. *Proportion and style in Ancient Egyptian art*. London: Thames and Hudson.

von Rüden, C., 2011. *Die Wandmalereien aus Tall Mišrife/Qaṭna im Kontext überregionaler Kommunikation*. Qaṭna-Studien, 2. Wiesbaden: Harrassowitz.

von Rüden, C., 2015. Transmediterranean knowledge and Minoan style reliefs in Tell el-Dab^{c}a: an attempt at paradigm shift. In: S. Cappel, U. Günkel-Maschek and D. Panagiotopoulos, eds., *Minoan archaeology. Perspectives for the 21st century. Proceedings of the International PhD and Post-Doc Conference at Heidelberg, 23-27 March 2011*. Aegis, 8. Louvain-la-Neuve: UCL Presses Universitaires de Louvain, pp.355-365.

von Rüden, C., 2017. From mechanics to embodiment: some theoretical considerations on techniques. In: P. Eisenach, T. Stöllner and A. Windler, eds., *The RITaK conferences 2013-2014. Raw materials, innovation, technology of ancient cultures, 1*. Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, 219. Anschnitt Beiheft, 34. Bochum: Verlag Marie Leidorf, pp.71-79.

von Rüden, C. and Jungfleisch, J., 2017. Incorporating the other: a transcultural perspective on some wall painting fragments from Hattusha. In: A. Schachner, ed., *Innovation versus Beharrung. Was macht den Unterschied des hethitischen Reichs im Anatolien des 2. Jahrtausends v. Chr.? Internationaler Workshop zu Ehren von Jürgen Seeher, Istanbul 23.-24. Mai 2014*. Byzas, 23. Istanbul: Ege Yayınları, pp.61-83.

von Rüden, C. and Skowronek, T., 2018. Between common craft tradition and deviation: the making of stucco reliefs in the Eastern Mediterranean. In: J. Becker, J. Jungfleisch and C. von Rüden, eds., *Tracing technoscapes. The production of Bronze Age wall paintings in the Eastern Mediterranean*. Leiden: Sidestone Press, pp.213-232.

Seeber, R., 2000. The technique of plaster preparation for the Minoan wall paintings at Tell el-Dab[c]a, Egypt – preliminary results. In: S. Sherratt, ed., *Proceedings of the First International Symposium 'The Wall Paintings of Thera', Petros M. Nomikos Conference Centre, Thera, Hellas, 30 August – 4 September 1997*. Athens: Pergamos S.A., pp.91-102.

Shaw, J.W., 2009. *Minoan architecture. Materials and techniques*. Studi di Archeologia Cretese, 7. Padova: Bottega d'Erasmo.

Shaw, M.C., 2000. Anatomy and execution of complex Minoan textile patterns in the Procession Fresco from Knossos. In: A. Karetsou, ed., *Κρήτη – Αίγυπτος. Πολιτισμικοί δεσμοί τριών χιλιετιών. Μελέτες*. Athens: Kapon Editions, pp.52-63.

Shaw, M.C., 2003. Grids and other drafting devices in Minoan and other Aegean wall painting: a comparative analysis including Egypt. In: K. Polinger Foster and R. Laffineur, eds., *METRON. Measuring the Aegean Bronze Age. Proceedings of the 9th International Aegean Conference/9e Rencontre égéenne internationale, New Haven, Yale University, 18-21 April, 2002*. Aegaeum 24. Liège: Université de Liège, Histoire de l'art et archéologie de la Grèce antique, pp.179-189.

Shaw, M.C., 2016. String lines, the artist's grid, and the representation of textiles in fresco. In: M.C. Shaw and A.P. Chapin, eds., *Woven threads. Patterned textiles of the Aegean Bronze Age*. Ancient Textiles Series, 22. Oxford: Oxbow Books, pp.183-204.

Simons, G., Grunsky-Peper, K. and Heizmann, B., 1979a. Bäuerliche Kalkbrennerei. Teil 1. Setzen des Feuerungsgewölbes und Füllen des Ofens. Video. Available at: https://commons.wikimedia.org/wiki/File:B%C3%A4uerliche_Kalkbrennerei._Teil_1_Setzen_des_Feuerungsgew%C3%B6lbes_und_F%C3%BCllen_des_Ofens.webm [Accessed 21 April 2022].

Simons, G., Grunsky-Peper, K. and Heizmann, B., 1979b. Bäuerliche Kalkbrennerei. Teil 2. Brennen des Kalks und Austragen des Ofens. Video. Available at: https://commons.wikimedia.org/wiki/File:B%C3%A4uerliche_Kalkbrennerei._Teil_2_Brennen_des_Kalks_und_Austragen_des_Ofens.webm [Accessed 21 April 2022].

Skowronek, T., 2017. „Sourcing steatite". Zur Provenienz weißer Pigmente in der Wandmalerei von Tell el-Dab[c]a. MA thesis. Ruhr-University Bochum.

Skowronek, T., Hauptmann, A. and von Rüden, C., 2020. Using spinel chemistry to characterise archaeological steatite found in the wall paintings of Tell el-Dabᶜa, Egypt. *Journal of Archaeological Science*, 117, p.105137. Available at: DOI: 10.1016/j.jas.2020.105137 [Accessed 17 December 2024].

Vlavogilakis, A., 2017. Painting Bronze Age plaster from Thebes, Boeotia. *EXARC Journal*, 2017/1. Available at: https://exarc.net/ark:/88735/10280 [Accessed 21 April 2022].

Weatherhead, F., 2007. *Amarna palace paintings*. Egypt Exploration Society Excavation Memoir, 78. London: Egypt Exploration Society.

Wehlte, K., 2000. *Werkstoffe und Techniken der Malerei*. Ravensburg: Ravensburger Buchverlag.

Weyer, A., Roig Picazo, P., Pop, D., Cassar, J., Ösköse, A., Vallet, J.-M. and Srša, I., 2016. *EwaGlos. European illustrated glossary of conservation terms for wall paintings and architectural surfaces*. Series of Publications by the Hornemann Institute, 17. 2nd ed. Petersberg: Michael Imhof Verlag. DOI: 10.5165/hawk-hhg/300.

Winkels, A., 2007. Restauratorisch-naturwissenschaftliche Untersuchung von tuthmosidischen Putzen aus ᶜEzbet Helmi/Tell el-Dabᶜa: ein Beitrag zur Erforschung altägyptischer Kalkputztechnik. *Egypt and the Levant. International Journal for Egyptian Archaeology and Related Disciplines*, 17, pp.273-293.

Winkels, A., 2014. Further analysis of Amarna's mortars and plasters. In: B.J. Kemp, *Tell el-Amarna, 2014*. *The Journal of Egyptian Archaeology*, 100, pp.22-23.

Wingate, M., 1985. *Small-scale lime-burning. A practical introduction*. London: Intermediate Technology Publications.

Resources and complex systems: Introduction

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Complex systems science is an interdisciplinary field that studies systems composed of many interacting components (complex systems). These systems often exhibit collective behaviour and emergent properties, and are characterized by self-organization, adaptation, evolution, and nonlinearity. All human social systems are complex adaptive systems. In archaeology, the organization of human societies can be fruitfully studied from a complex systems perspective, as shown by Daems (2021). Archaeology asks a series of high-level questions aimed at understanding the broader aspects of human behaviour and social evolution within their specific spatiotemporal contexts. In addition to societal organization and development, such high-level questions relate to human-environment interaction, human migration, cultural and technological evolution, economic systems and trade, social inequality and power structures, cognitive and symbolic development, or the question of long-term societal resilience and collapse. These questions go beyond the analysis of individual artifacts or specific events to explore the complex interactions and dynamics that have shaped human history over long periods and across large regions. Answering these questions requires interdisciplinary approaches and the integration of different types of data, including material culture, environmental records, and ethnographic analogies, to construct comprehensive narratives and models of past human behaviour and societal development. In addition, the availability of resources, whether material or culturally produced and accumulated, is an important consideration in trying to understand such higher-order questions. The distribution and availability of resources (including, e.g., knowledge) structure and constrain the potential activities of humans who lived in the specific spatiotemporal context. Thus, a resource-based view is most helpful in selecting the elements in the model or in making unavoidable assumptions about past human societies, be it individual behaviour or social processes.

With roots in physics, nonlinear mathematics, and computer and information science, complex systems science often employs computational simulation methods. In particular, agent-based models (ABMs) are ideal for simulating the emergent outcomes of interactions between individual agents equipped with specific behavioural rules and learning

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algorithms. Computer simulation has been used in archaeology since the late 1960s (see Lake, 2014). In this early phase, from the late 1960s to the early 1980s, simulation methods were applied to diverse topics such as demographic development, settlement patterns, human-environment interactions, or trade and exchange (see Hodder, 1978; Renfrew and Cooke, 1979; Sabloff, 1981).

During the 1980s, there was a hiatus in archaeological simulation for several reasons. Early models were criticized for their technical complexity, requiring skills that many archaeologists did not possess. The lack of expertise in simulation methods made the models inaccessible to the broader archaeological community. Other technical problems were the oversimplification of many early models, the lack of adequate data to validate the models, and the problem of equifinality, i.e., the fact that the same results can be produced by many different mechanisms, which limits the explanatory power of the models. Perhaps even more important was the theoretical shift away from the positivist and systemic approach of the 1970s and the rise of post-processual archaeology. Post-processual archaeology focuses on the subjective and interpretive aspects of human societies and thus places considerable emphasis on human agency, symbolism and meaning, and contextual analysis. The approach advocates a more interpretative and reflexive methodology, recognizing that the archaeologist's own perspectives, biases, and cultural background influence the interpretation of the archaeological record, and critiques the notion of scientific objectivity in archaeology, arguing that all knowledge is socially constructed. From this perspective, simulation and other quantitative methods were seen as reductionist.

The 1990s saw a renewed interest in simulation, driven by the development of new methodologies and the publication of influential edited volumes such as "Dynamics in Human and Primate Societies" by Kohler and Gumerman (2000). This period marked the emergence of agent-based modelling and a focus on simulating long-term societal change and human-environment interactions. Since 2000, there has been a significant increase in the number of simulations developed, with applications in fields as diverse as human evolution, cultural transmission, and socio-ecological dynamics (see Wurzer, et al., 2015). Agent-based modelling has become a prominent method that allows the simulation of individual agent behaviour and interactions in a virtual environment, facilitating the study of complex social processes and emergent phenomena. Recent simulations demonstrate a balance between methodological rigor and substantive research conclusions, indicating that simulation has become a more integrated and accepted tool in archaeological research. While scepticism remains in the field and old criticisms are still voiced, Ceglielski and Rogers (2016) argue that methodological progress has been made in the ABM community and that ABM therefore has significant potential to transform archaeological analytical practice. Barton (2013) takes a similar position.

The use of simulation methods, particularly agent-based modelling, in archaeology has generated considerable debate within the field. While these methods offer innovative ways to explore and understand past human behaviour and social systems, they also face significant criticisms and challenges. The debate over the use of simulation and ABM in archaeology highlights both the potential and the challenges of these approaches. While criticisms regarding complexity, validation, and theoretical fit persist, methodological advances and a growing understanding of the benefits of simulation are leading to their increasing acceptance. By addressing these challenges and integrating diverse theoretical perspectives, ABM can become a valuable tool for exploring and understanding the complexity of past human societies. In fact, ABM is increasingly being adopted for its ability to model complex systems and emergent behavior. It allows archaeologists to simulate interactions in virtual environments, providing insights into how individual actions can lead to large-scale social patterns. The session "Resources and Complex Systems" at the ReSoc conference discussed both the challenges and presented a number of fascinating applications of ABM to archaeological topics related to resources.

The paper by Dries Daems and Stef Boogers presents an agent-based modelling framework to study the year-to-year effects of resource exploitation strategies in the area of Sagalassos, southwestern Anatolia, from the Iron Age to the early Hellenistic period (1000-200 BC). Understanding the sustainability of resource exploitation strategies is crucial because these strategies determine the long-term resilience and sustainability of human societies. The model uses a semi-realistic GIS environment with characteristics related to resource availability and accessibility. Settlement households alternate between agriculture and resource exploitation (wood or clay) to meet basic needs. The authors simulate three resource categories: agricultural products (subsistence, renewable), wood (fuel for subsistence and production, renewable), and clay (production, non-renewable). The model incorporates spatially explicit data on soil fertility, forest growth, and clay sources, with parameters adjusted based on real archaeological data. The simulations show that continued timber exploitation without conservation measures leads to resource depletion. Agricultural productivity also declines over time, indicating the potential unsustainability of intensive exploitation strategies. By simulating the interactions between settlements and their environment, the model helps to better understand the long-term dynamics of human-environment interactions and the factors that contribute to societal resilience and sustainability. Dries Daems and Stef Boogers' work on the simulation of resource exploitation strategies in Iron Age to Hellenistic communities represents a significant advance in archaeological research. Their innovative use of agent-based modelling, combined with a rigorous empirical foundation and interdisciplinary approach, provides profound insights into the complex dynamics of ancient human-environment interactions. The research has broader implications for the study of human-environment interactions and resource management strategies. By providing a detailed case study, the paper sets a precedent for similar studies in other regions and time periods, contributing to a more comprehensive understanding of historical sustainability practices.

Edmund Chattoe-Brown argues for the development of ABM as a distinctive and interdisciplinary methodology in archaeology and other social sciences. His paper highlights the risk of ABM reinforcing disciplinary silos and argues for its potential to promote interdisciplinarity. ABM should be seen not only as a technology, but as an innovative methodology that promotes interdisciplinarity. Conceptual developments in ABM offer clear benefits to archaeological research by suggesting theoretical and empirical improvements. However, interdisciplinarity is challenging because different disciplines have different methodologies, theoretical approaches, and thematic foci. The paper illustrates how different disciplines, such as sociology, economics, and ethnography, approach methods, theory, and topics differently, which affects their research outcomes. ABM can help overcome these challenges by providing a framework for testing theories against empirical data, even when the data are limited or indirect. Using the example of Mesoudi and O'Brian (2008a; 2008b) on cultural transmission, Chattoe-Brown demonstrates the potential of combining ABM, archaeology, and modern experiments for empirical validation. ABM should be seen as a progressive research method, where each iteration of the model is improved based on empirical testing and validation. The paper argues for the significant potential of ABM to enhance interdisciplinary research in archaeology and other social sciences. And it calls for more widespread use of ABM, better integration of interdisciplinary methods, and continued development of empirical validation techniques to advance the field. The paper does not shy away from discussing the challenges of interdisciplinary research, such as different methodologies and theoretical approaches across disciplines. By acknowledging these challenges and offering solutions, Chattoe-Brown provides a balanced and realistic view of the potential and limitations of ABM.

Maja Gori and Frederik Schaff present a paper with an ABM that aims to explain human movement in the Adriatic-Ionic area of the Cetina culture between 2500 and 2000 BC. The paper challenges traditional large-scale approaches and emphasizes the complexity and multifaceted nature of mobility patterns. While traditional archaeological models focus on the spread of material culture and endpoints, and propose a single, uniform spread of Cetina characteristics due to maritime groups moving from the Balkans, Gori and Schaff suggest that the expansion of the Cetina was part of a complex network involving different groups and interactions over a longer period of time. The model explores the subtle socio-cultural differences between eastern and western Adriatic communities, focusing on the priority given to prestige versus social centrality. Eastern Adriatic communities prioritize prestige and exploration, leading to faster and more extensive migration patterns. Western communities prioritize social centrality, leading to less exploration. The subtle difference in prioritizing prestige over social centrality results in different migration patterns observed in the archaeological record. The study suggests that subtle behavioural differences can have significant and lasting effects on migration and settlement patterns. The paper effectively integrates insights from archaeology, anthropology, and computational science, demonstrating the strength of interdisciplinary research. This holistic approach provides a more comprehensive understanding of the Cetina phenomenon and its underlying causes. By using ABM, the authors successfully address the complexity and multifaceted nature of human mobility.

Martin Neumann's paper uses a simulation model to experimentally explore and theorize about the emergence of the state. The model analysed in this study was originally developed in the late 1980s and represents an embodiment of macrosociological theory, consistent with the early use of simulation in the social sciences. The goal of this replication is to perform a sensitivity analysis to explore the causal influence of social mechanisms. Archaeological theories often rely on parameters that cannot be precisely measured, leading to considerable uncertainty. Simulation models can help assess this uncertainty through sensitivity analysis, which allows for the investigation of the causal power of social mechanisms. The paper emphasizes that the study of social mechanisms is crucial in sociology and archaeology. Mechanisms are often based on plausibility and common sense but require formal means for critical examination and discussion. Various theories explain the emergence of the state, including social contract theories, economic factors (such as agriculture), warfare, and environmental conditions. The model used in this study does not favour any particular theory but focuses on the impact of self-organization on the formation of centralized institutions. The model conceptualizes social differentiation through decision centers that transform social problems into solutions. These centres are supported by surplus production and are responsible for the redistribution of resources.

The model uses the concept of decision centres (PTs) and their rulers (PTRs) to explain social differentiation. These centers deal with problem-solving strategies and redistribute surplus production. The simulations show a nonlinear dynamic in the emergence of PTR positions, interpreted as the formation of the state. This process is influenced by the strategies of redistribution and the power relations between social classes. The analysis shows that the bargaining power of the working class and wage stickiness significantly influence state formation. Power relations between economic and political elites also play a crucial role. The use of sensitivity analysis to assess the causal power of different parameters is particularly noteworthy. This methodological rigor ensures that the findings are not only insightful, but also robust and replicable, setting a high standard for future research in this area. From a complexity perspective, this paper is very interesting because it relies on the important complexity concept of self-organization and investigates the necessary conditions for self-organization to occur.

The papers on complex systems in archaeology collected in this volume demonstrate that complex systems science offers both useful concepts and tools for addressing a variety of high-level questions related to archaeological resources. All authors make a strong case for further research along these lines, while also demonstrating an awareness of the limitations and challenges of computational methods. It is certainly true that quantitative methods are reductionist and have a bias toward ideas that can be easily formalized. Nevertheless, they have the strength of expressing ideas in a precise and rigorous way and allow for virtual experiments that can show how robust hypothesized mechanisms are. There is great potential in this approach if the models are closely linked to empirical evidence and developed collaboratively by researchers from different disciplinary, methodological, and epistemic backgrounds. After all, they are one of many tools of scientific inquiry, and they yield their best results when they spark constructive discussions among heterogeneous researchers. While such interdisciplinary discourse is challenging, the papers presented here demonstrate that it is possible.

References

Barton, M., 2013. Stories of the past or science of the future? Archaeology and computational social science. In: A. Bevan and M. Lake, eds., *Computational Approaches to Archaeological Spaces*. Walnut Creek: Left Coast Press.

Cegielski, W.H. and Rogers, J.D., 2016. Rethinking the role of agent-based modeling in archaeology. *Journal of Anthropological Archaeology*, 41, pp.283-298.

Daems, D., 2021. *Social Complexity and Complex Systems*. London and New York: Routledge.

Hodder, I., 1978. *Simulation Studies in Archaeology*. Cambridge: Cambridge University Press.

Kohler, T.A. and Gumerman, G.J., eds., 2000. *Dynamics in Human and Primate Societies: Agent-Based Modeling of Social and Spatial Processes*. Oxford: Oxford University Press.

Lake, M.W., 2014. Trends in archaeological simulation. *Journal of Archaeological Method and Theory*, 21, pp.258-287.

Mesoudi, A. and O’Brien, M.J., 2008a. The cultural transmission of Great Basin projectile-point technology: an experimental simulation. *American Antiquity*, 73(1), pp.3-28.

Mesoudi, A. and O'Brien, M.J., 2008b. The cultural transmission of Great Basin projectile-point technology II: an agent-based computer simulation. *American Antiquity*, 73(4), pp.627-644.

Renfrew, C. and Cooke, K.I., eds., 1979. *Transformations: Mathematical Approaches to Culture Change*. New York: Academic Press.

Sabloff, J.A., ed., 1981. *Simulations in Archaeology*. Albuquerque: University of New Mexico Press.

Wurzer, G., Kowarik, K. and Reschreiter, H., eds., 2015. *Agent-Based Modeling and Simulation in Archaeology*. Cham: Springer.

Developing Agent-Based Modelling as a Tool for Interdisciplinarity with Particular Reference to Archaeology

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Although Agent-Based Modelling technology is increasingly used in archaeology, this article argues that its distinctive methodology and implications are less acknowledged. This is a general social science problem with existing Agent-Based Modelling tending to reinforce silos of disciplinary presumptions. Using a stylised Agent-Based Model (also illustrating the technique) I show how its conceptualisation can be developed to weaken such silos. Then, using a case study of real research, I show how it can also deliver archaeological value by suggesting substantive theoretical and empirical improvements involving interdisciplinarity.

Great Basin, Projectile Points, Computational Social Science, Calibration, Validation

Introduction

In this article, I shall make two related arguments linking interdisciplinarity, Agent-Based Modelling and archaeology. The first is that, correctly understood, Agent-Based Modelling should not be a mere technology inadvertently recapitulating disciplinary silos but, by contrast, an innovative methodology allowing *better* interdisciplinarity. The second is that this conceptual development delivers clear benefits to real archaeological research. These arguments are illustrated using two case studies of Agent-Based Models, one stylised but nonetheless suitable for illustrating core issues clearly (and introducing non-experts to the approach) and the other concerning a research programme on cultural transmission. In this section, however, I illustrate why effective interdisciplinarity is potentially so challenging (so it is clearer what Agent-Based Modelling contributes.)

One major challenge of interdisciplinarity (Choi and Pak, 2006) is that disciplines conceive the world very differently in several distinct senses. Firstly, their *methods* separate them. With few exceptions (Starr, 2014), economists eschew qualitative methods. By contrast,

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quantitative approaches are rare in anthropology. Unsurprisingly, this produces very different views about the relative importance of aggregate patterns and small scale detail. Secondly they differ in approaches to theory. Economics is unified by Rational Choice Theory which is sufficiently rigorous for testing (Güth, Schmittberger and Schwarze, 1982) while sociology is regularly reviled for vacuous theorising (Davis, 1994). By contrast, some disciplines (for example history) seem temperamentally uncomfortable with theory. Thirdly, they obviously differ in subject matter but the wider implications of this are less evident. Sociology, by studying *contemporary* societies using both quantitative and qualitative data is well placed to characterise aggregates *and* their underpinning agency. By contrast, economics (rejecting qualitative evidence) merely *attributes* individual reasoning. This may lead to explanatory failure. (Psychology further complicates matters with important evidence problematising relationships between subjective accounts and reality – Hastorf and Cantril, 1954.) The final difference, which is hardest to observe (because academic careers typically involve single disciplines), is what fields find thinkable and unthinkable. Economists largely find it unthinkable that economies should be fundamentally out of equilibrium. Ethnographers find it unthinkable that the detail they discover might be epiphenomenal to social dynamics. Statisticians find it thinkable that in all the buzzing blooming social confusion they might find meaningful patterns in a few key variables. The point here is not to say that any of these views are wrong, merely to show their great diversity and its potential for mutual incomprehension.

One possible solution to this problem is sharing research methods across disciplines. For example, although someone using regression in sociology (Pyke and Sheridan, 1993) might choose different variables from someone in archaeology (Wachtel, et al., 2018), both would broadly agree that the method generated legitimate knowledge of a certain kind and about what constituted good practice in use (the kind of data needed, how much, how to interpret results, what hazards exist and so on.)

However, this is only a partial solution because each research method gives a limited view of society. As already suggested, regression depends on the belief that there are robust and meaningful patterns in data to discover. What we need, ideally, is a research method that is less limited and less bound to any specific discipline. In the rest of this article I shall argue that Agent-Based Modelling (Gilbert, 2020) is such a method. However, it is very important not to give the wrong impression. Agent-Based Modelling is not a panacea. It will not supersede other research methods – actually they are essential to it for reasons I will explain – and it faces many challenges of its own. In fact, one of the major challenges is one I will analyse through my case studies, namely that the approach is relatively new and therefore a consensus has not yet emerged about how Agent-Based Modelling should be conducted (its methodology). This being so, there is currently a danger that, rather than promoting interdisciplinarity as a general framework, Agent-Based Models will just tend to reproduce the existing presumptions of disciplines. It is by presenting arguments about how and why Agent-Based Modelling should be done in a certain way (and what doing that delivers) that I hope to move away from the latter situation (which is less productive in my opinion) and towards the former.

A Framework for Understanding Agent-Based Modelling

The first challenge in making the most effective use of Agent-Based Modelling is the risk of conflating arguments at different conceptual levels (which is actually a general hazard in the social sciences). Before people can agree on how to do Agent-Based Modelling usefully, there has to be at least some agreement about the aims of scientific activity generally. For example, Agent-Based Modelling can be used for empirical research and this use has an associated methodology (procedures for establishing non subjectively whether something is true: For example, is this difference in variable means real or could it arise by chance?) However, it can be used in other ways (Edmonds, et al., 2019) but it is not clear if these also have associated methodologies There is thus, at one level, an argument about whether academics need to be scientific at all (in the sense of having a methodology), a subordinate argument about what should count as methodology for a particular Agent-Based Modelling use (establishing shared practice) and a third, subordinate again, about whether methodology is properly applied (doing good research). In statistics, broadly, the first two levels are agreed with debate mostly at the third. Thus I focus on empirical Agent-Based Models (hereafter ABMs) not because I think that is their only legitimate use but because I know they have a justifiable methodology which I can build on. I thus acknowledge, but sidestep, the contentious and sometimes confused debates about whether other uses of Agent-Based Modelling require methodologies (which personally I believe they do) and, if so, what those should be.

ABMs are distinctive in two main ways. Firstly, they are computer simulations. This means they describe social systems not through mathematics (for example regression) or narratives (ethnographic description) but through computer programmes. This already makes them unusual. However, the second difference marks them out still further and makes them even less familiar to social scientists (increasing possible misunderstandings). This is that, rather than simply using computers to process existing theories or constructs (like variables), they attempt to represent social processes directly: How individuals see the environment (including other individuals), make decisions and act and how their environment evolves (potentially independently).

A simple but practically sufficient illustration is endogenous path evolution (Grider and Wilensky, 2015). This has the advantage that readers can investigate it for themselves without having to know any programming by downloading a free software package called NetLogo (Wilensky, 1999). In this ABM, individuals make journeys between randomly selected locations. If there is a path available to them (given their limited vision), they will follow it because it is easier. However, in use, they also reinforce this path (for example wear down vegetation). This means it takes longer to fade (vegetation growing back) so that others continue to see and use it. Over time, these travel, reinforcement and fading processes (a mixture of human and environmental elements) stabilise a pattern of simulated paths (corresponding to something we *might* observe in reality.)

Of course, this particular outcome results from *all* the ABM assumptions and, for an example designed mainly for explication, some are plainly unrealistic. For example, how would path structure change if agents lived in groups/settlements? Would this pattern be more like that found in real locations? (One advantage of Agent-Based Modelling is precisely to enable such *what if* experiments!)

But this ABM, however stylised, allows two key methodological points to be made clearly. Firstly, it is evident in what sense representation of a social process is direct (which is obviously different from *correct*). The ABM is about agents at definite locations, behaving specifically. There are no theoretical constructs (like rationality) or technical abstractions (like perfect information). Agents act as specified based on what they see wherever they are. The paths arise just from this and not from any hypothesised law of development

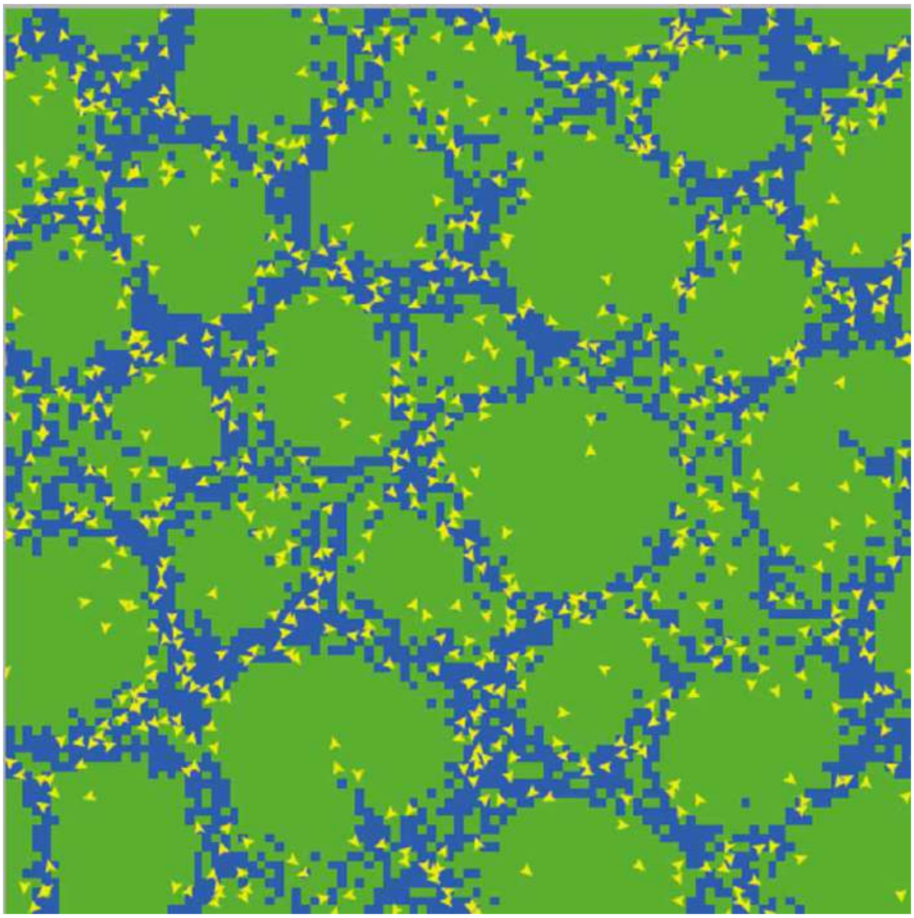

Figure 1: illustrates such a pattern with a cellular form (with cells varying somewhat in size/shape). The arrows are agents, the lighter spaces are ordinary terrain and the darker spaces are paths. Snapshot of one stabilised outcome of the paths ABM (author).

which may have no real-world referent.) Secondly, however wrong the ABM assumptions may turn out, they are subject to direct and independent testing according to empirical Agent-Based Modelling methodology (as stated in Gilbert and Troitzsch, 2005, pp.15-8 for example). Based on these assumptions does the system display behaviour (cellular paths) corresponding to reality? If not, the ABM is incorrect. This can be contrasted with traditional approaches where models are *fitted* to data i. e. the match between model and reality is deliberately contrived (through changes to parameters or model assumptions) rather than providing an independent *test*. I shall return to problems with this approach shortly. (More detail about aspects of Agent-Based Modelling methodology only sketched here is provided in Chattoe-Brown, 2019.)

Of course, that outline of empirical Agent-Based Modelling methodology glosses over many major challenges (forming part of subsequent discussion). How do we access or develop measures showing how similar real and simulated path patterns are? What happens if several ABMs generate equally similar path patterns? Practically, what does the Agent-Based Modeller do next if the ABM fails? But I shall try to suggest that these are *technical* issues in the sense that they involve existing solutions (or modifying these for new contexts). By contrast, direct representation and independent testing are potentially paradigm changing for social science and it is very important that we fully understand their implications and don't reinterpret them back into something we already know. For example, regression also involves fitting to data but using a *very* simple model – a line – and *lots* of data relative to model simplicity. In these circumstances, good fit is a legitimate result not plausibly occurring by chance or manipulation. Fitting models is not problematic *per se* but needs to be evaluated in a wider methodological context involving systematic characterisation of parsimony and adequate data given the ABM.[1] But if your data is limited (and noisy) – like a path structure – and you build an ABM with many assumptions – fitting *is* harmful as *some* parameter combination would probably reproduce any arbitrary data without really capturing underlying truth about the target social system.

But now I will address the next level of detail and justify some terminology. Assessing the match between real and simulated data is generally called *validation*. (But muddled terminology is another challenge in less institutionalised research methods.) However, it is useful to make a relatively uncommon (and inconsistently named) distinction in understanding how ABMs are constructed for testing. This is between *specification* (basic elements comprising the ABM: For example, do agents have *memory* or discover routes anew on each occasion?) and *calibration*. (Once we have decided the ABM elements, how do we assign empirical values: For example, for how many months can agents remember routes?)

Furthermore, it is useful to recognise *verification* (minimising the possibility that the computer programme doesn't do what the modeller thinks it does) and what one might christen *situation* (the empirical evidence supplied for ABM elements not mediated by agents i. e. how soon paths become indistinguishable if untraveled). This Agent-Based Modelling aspect is rather relevant to archaeology as I shall show. Further, at present, it isn't clearly conceptualised and named as a separate aspect of building empirical ABMs as far as I am aware. Finally, it is important that ABMs have well-defined *target systems* so it is clear what they should (and shouldn't) explain. The paths ABM would not apply either to societies where there was deliberate path creation/maintenance or with more complicated geography (i. e. avoiding swamps or mountains.) This in turn defines a legitimate explanation as something represented within the ABM which can be investigated. Trivially, if something is not part of the ABM, it cannot be part of the *test* for the ABM.

The ideal (which we should understand even if we are far from realising it for several legitimate reasons) is that any element of an ABM to be tested should have some empirical justification. (Furthermore, there should be a design principle that we avoid totally non empirical elements in empirical models. These really contribute nothing except being potential fudge factors in fitting.) For calibration, this may be relatively straightforward: At what distance can travellers perceive paths? For specification it may be significantly harder. This is somewhere where different disciplines may start from different presumptions and/or confuse shared socialisation with evidence. (For example, economists don't directly demonstrate that people are rational because their acceptable methods do not access

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1 This is an area where, to illustrate the point about technical challenges, Agent-Based Modelling needs to learn from existing statistical practice. Statistics already understands concepts like overfitting (Hawkins, 2004) and out-of-sample testing (Tashman, 2000) but these approaches have to be transferred effectively to ABMs and made to work in a different context where analytical results probably won't be available.

reasoning directly. Instead they devise *implications* for that assumption and, if these don't fit the data, they devise different implications – Brandstätter and Güth, 1994. The possibility that the initial assumption is wrong, rather than merely generating mistaken implications, is unthinkable.) How do we justify the claim, for example, that paths evolve mechanically and without cultural dimensions (never cross a burial ground?) One answer is pragmatic (following Occam's Razor). If we can explain patterns mechanically, perhaps we don't need to postulate additional mechanisms. But if we cannot, or there is other evidence for cultural aspects then we must represent it in the ABM as best we can. This process is scientific and serves to review existing knowledge. From all the research produced, what do we really *know* (rather than assume or hypothesise) about how paths form? The answer may turn out to be (by these criteria) not much. Then we may have to acknowledge this limitation and explore the implications of a *theory* in the absence of anything better: Supposing that people forage rationally do we see patterns in the ABM comparable to reality? Patterns of what? (I shall return to this point which is particularly relevant to archaeology.)

Of course, it is now obvious why some Agent-Based Modelling limitations may not be its own fault. Particular research methods create a focus on particular data types. Statisticians seek things that can be variables. Ethnographers investigate system detail. But Agent-Based Modelling will need data on decision making (including counterfactuals) and other *processes* for which existing research methods are typically less well suited. So ABMs also have value in drawing attention to kinds of data (and corresponding analysis modes) which existing methods don't consider.

Further, as a relatively new and un-institutionalised method, Agent-Based Modelling is still trying to develop a clear sense of research as a *progressive* activity. This issue is again well illustrated by comparison with statistics. As statistical analysis has progressed, it has built (and inculcated) stronger arguments for good practice, developed tools for dealing with more data, agreed standards by which one model can be said to improve on another and so on. As this is done, new research can then build on old in measuring new variables, improving fit (but without outstripping the data's capacity to challenge models) and identifying new theories and possible relationships. All of these processes are in the earliest stages for Agent-Based Modelling. In fact, this is one reason I argue so strongly for empirical ABMs because it is only the methodology that seems to give clear guidance about when one ABM is better than another. Without this, we may mistake mere proliferation of somewhat plausible ABMs for progress.

It is not my business to delve deeply into Agent-Based Modelling methodology (because it does not serve my wider synthetic argument) but a brief sketch of one possible approach can be given, using the paths model as an example. One ABM of paths may be (non-subjectively) better than another if it is:

- Accurate: Reproduces the path pattern better for a given metric.
- Parsimonious: Only reproduces the pattern equally well but has fewer parameters.
- Empirical: Only reproduces the pattern equally well but more parameters have empirically grounded values (or smaller uncertainty).
- Substantive: Only reproduces the pattern equally well but has better specification (i. e. replaces theory with an empirically grounded process description).

Of course, the technical details of implementing this methodology (how we trade off pattern reproduction against parameter uncertainty for example) remain to be established. However, this is unsurprising since Agent-Based Modelling has not yet agreed that we should all follow this approach! (This means that only a few scholars are developing this aspect of methodology.) I have now provided all the raw material needed to analyse interdisciplinarity using an Agent-Based Modelling framework (and demonstrate the value of this to archaeology).

Interdisciplinarity: Slight Return

One reason for doing conceptual development work in social science is to try and convert intuitions into claims that might be evidenced. I began this article by making assertions about different ways that disciplines could regard methods, data and theory. Now, still using the paths model as an example, it is possible to see more clearly how those differences play in ABMs (and what the consequences are).

In principle, sociology is well placed to follow the Agent-Based Modelling methodology outlined. It would observe present day paths. It could ask travellers directly about travelling (both functional and perhaps cultural/symbolic) and has statistical skills to characterise the resulting aggregate patterns. It could use observation to understand environmental aspects inaccessible from individuals or aggregates (what I earlier christened *situation*). By contrast, economists would be highly skilled in characterising path patterns but would *assume* rationality (perhaps creating parameters which couldn't be assigned empirical values).[2] Fitting these parameters might produce models performing badly on new data (a notorious problem with economics – Meese and Rogoff, 1983) and the exclusion of qualitative data would undermine reality checking of the specification. (Perhaps people's behaviour is actually socialised or they adapt over time?) Disciplines are more or less comfortable using theory to proxy phenomena (like decision making) which are not yet fully understood. They might also disagree about the *nature* of theory (and thus how likely it is to be congruent with data and stand a chance of effective explanation).

We thus see how Agent-Based Modelling (through the example of the paths ABM) offers a conceptual framework for understanding the dimensions (empirical, theoretical and substantive) in which disciplines can differ and how these differences may create challenges to progressive empirical research.

How Does All This Help Archaeology?

Writing on unfamiliar methods and also trying to be interdisciplinary, I feel that I should offer readers an ongoing apology. Unlike existing methods (saving lots of explanation by shared perception) it is important to be sure that the reader has the background understanding to any argument proposed. It is thus necessary to take several steps backward to make one step forward and that not only requires more reader patience but may initially look like irrelevance. Now (finally, the reader may say) I need to justify that all this discussion really does archaeology good.

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2 This is a general hazard of armchair theorising and another way of understanding the distinction between specification and calibration. If your specification is not empirically grounded, how do you know the parameters can be calibrated? Perhaps there simply isn't such a thing as discount rate to measure.

It should now be somewhat clear why archaeology faces particular challenges regardless of whether it adopts Agent-Based Modelling. Firstly, it studies the past and (like history) is limited to what survives. It does not (like sociology) have the option to create new data but at best can recover (or make better use of) what there is. (Further, multiple uncertainties create challenges of interpretation. For example, to pre-empt the case study in the next section, does this arrowhead have the wrong shape because it is misdated or because it is actually a dart tip?) Secondly, it may not be able to address social phenomena that interest it directly but may have to operate at one or more removes. To use the paths example again, a particular people made paths in a particular region at a particular time via certain behaviours. But not only can we not talk to those people now (or observe them doing it) but it is possible we do not even know the path pattern (but just the pattern of corn husks they spat out while travelling!)

However, as I shall now argue, Agent-Based Modelling offers both general and specific advantages in meeting this challenge. The specific advantage is, as already suggested, to take what we know (represented in an ABM) and test it against empirical patterns. This methodology is viable (though it may not be successful) no matter how partial the patterns are as long as research is a progressive and iterative process. The first ABM may not be much good at all (but then the first regression model probably wasn't very good either), but will at least put the knowledge and concepts in order while showing *some* evidential congruence (enough at least to encourage succeeding research). This allows the second model to be better, in defining terms, in collecting new data (or processing existing data more relevantly), in synthesising the issue and in clarifying what constitutes non subjective progress. In my view, this should become the normal science of Agent-Based Modelling in archaeology.

But, at the same time, this approach of gathering data, building an ABM and testing it helps us think differently about the wider research process. We cannot now talk to the people who made those ancient paths (but there is no point in developing theories pretending that they did not exist and act in certain ways). Is it better to theorise about how they did it in an armchair or investigate how similar *contemporary* societies do it? Might it even be useful to take *modern* individuals, have them role play a situation and observe/ask them what they did? (Under what *circumstances* could that be useful?) Such reflections, within the Agent-Based Modelling framework, have value in themselves. What is the closest knowledge we can get to what we need and what do we mean by close? (This illustrates what I meant by establishing shared practice.) For example, the original society may have had its path making mediated by cultural beliefs which left no unambiguous traces in the paths themselves. This might make comparison with modern behaviour unhelpful but could allow comparisons with contemporary traditional societies (which *might* have analogous cultural practices). On the other hand, if it turns out that path making mainly depends on perception and economy of effort then modern actors could still provide useful input since this basic psychology may be unchanged. But in each case, these conjectures are not merely matters of opinion but subject to test within Agent-Based Modelling methodology. Does the same ABM implemented using behaviour from modern individuals fit the data better than one implemented using the dominant archaeological theory?

The same argument applies to data at a remove. If we don't now know where the paths were, we can't correlate corn spitting with them without adding speculative assumptions. But could corn spitting on modern paths serve as an effective first approximation? It is having the debate about why (or why not) that sharpens perception about elements an ABM needs, the data available to test it and the ability to ground the assumptions in between empirically as far as possible[3] (this better than nothing approach to progressive research needs to be more deeply embedded in Agent-Based Modelling practice). I now turn to a concrete illustration of this approach using a real application of Agent-Based Modelling in archaeology based, in turn, on actual field data.

A Case Study of Methodological Thinking

Interdisciplinary research (and advocacy of methodology in new fields) creates two very real problems. One is to avoid mere generalities (which are safer in fields you don't profess to know). The other is maintaining that you have a contribution to make even though (or perhaps even because) you are not an archaeologist. I have tried to be very careful not to imply that I think the paths model is what archaeologists do (let alone what they ought to be doing) only that it is a useful basic way of explaining how Agent-Based Modelling conceptualises the relationship between human behaviours and physical traces they leave behind.

One practical way to deal with both problems is to show what this approach can contribute to critical reading of existing research and its potential improvement. If the arguments I have made prove to apply in detail to research done by proper archaeologists then this strengthens my case. To this end, using Google Scholar on 05.06.21 with the search terms <agent-based archaeological>, I selected a case study which was clearly archaeology (by the journal and author affiliation) in a publication good enough to be in JSTOR (and a prominent hit for Google Scholar itself.)

The resulting example (Mesoudi and O'Brien, 2008a; 2008b) is interesting because it independently supports my suggestion about not assuming that archaeological insight is limited to archaeological data. Nonetheless, despite the quality of their work, there is quite a lot more to be added to their approach from the arguments and conceptual development presented here.

In this pair of articles, Mesoudi and O'Brien use Agent-Based Modelling and experiments to examine an argument from Bettinger and Eerkens (1999). The topic of these related articles is the attributes of hard stone points used to tip atlatl darts and (later) arrows in the Western Basin (USA). These artefacts have the empirical advantages of being numerous, widely distributed, durable and (often) existing in stratigraphic context. Bettinger and Eerkens argue that correlations between point attributes (like length and weight) differ between Eastern California and Central Nevada because those regions differed in the cultural transmission mechanisms operating (something archaeologists cannot now observe directly). Where attribute correlations are low, changes to point design are

3 This raises an interesting problem for using data at a remove for which there may nonetheless be practical solutions. A sociologist could study paths directly, while an archaeologist might have to use corn husks. But it is possible that this may allow additional evidence into the chain of reasoning. For example, even if we just found just one place where a path was preserved (for example under a landslide), we could use the correlation of corn husks around that known path as an empirically sensible approximation in the ABM as a whole (which would mean that having to model husks rather than paths wasn't adding intolerable uncertainty to the ABM.) This aspect of situation (the empirical value of rare or even unique situations) is completely unconsidered by Agent-Based Modelling (I suspect because it isn't yet clearly aware of the *concept* of situation). A specific example is offered by Bettinger and Eerkens (1999, p.234), who argue that claims about the properties of dart and arrow points can be independently confirmed for the relatively small number of cases where the point is discovered still attached to the rest of the artefact.

hypothesised to occur through individual learning (so the point population is diverse). By contrast, high correlations occur under cultural transmission (where successful designs propagate relatively unchanged).

Mesoudi and O'Brien make two distinct contributions to this field connected by a very useful argument (nicely illustrating my claims about ABMs). They point out (as I have reiterated here) that ABMs are very valuable for understanding the relationship between individual processes (in this case actual point production and mechanisms of cultural transmission) and aggregate phenomena (like correlations between point attributes in samples.) However, they also make the important remark that ABMs are only as good as their assumptions and therefore build theirs using a study in which modern day student groups design points in different role play environments that provide feedback in terms of calories secured by hunting. In one condition, for example, students may have to improve points (through changing their attributes) based only on individual feedback while in another, they may get data on attributes and hunting success of points used by others.

In crucial respects, this research design (a topic often rather neglected in Agent-Based Modelling) for the article combination is very compelling. Do we find, studying real (albeit modern) people directly, that different mechanisms of cultural transmission really lead to the attribute correlations hypothesised by Bettinger and Eerkens? Given that we do, how can we then use an ABM based on these proven individual learning and cultural transmission mechanisms to investigate the overall system behaviour in ways that are either not viable experimentally (larger groups over longer time periods) or could be more directly related to empirical data about point distributions? (For example, generating simulated data on a scale sufficient for direct comparison to real attribute correlations.)

In a way, therefore, it is good that at least some archaeological research follows the approach I advocate (because it suggests that I am not mischaracterising what archaeologists do and how they might choose to do it). However, I shall now go on to show how Agent-Based Modelling, its methodology and their resulting implications for data use can improve this research programme still further. (I shall try, as far as possible, to link these arguments back to the conceptual developments presented earlier to demonstrate the value of the perspective proposed.)

Firstly, while Mesoudi and O'Brien acknowledge (at least generally) that modern students are not the same as the original hunters, they don't seem to reflect more generally on the issue of closeness to desired data that I raised previously. There is no discussion of ethnographic data about contemporary traditional societies and the value of being able to question people directly about how they learn to make artefacts and improve them (for example, Wiessner, 1983; González-Ruibal, Hernando and Politis, 2011). This is an interdisciplinary interface between archaeology and anthropology.

Further, the experiments encapsulate a specific (behavioural quantitative) view of research which is not necessary and may contradict the logic of the data sought. The experiment involves arbitrary attributes (not those used by archaeologists to characterise points or those relating to actual effectiveness in hunting). Further the optimal point (producing the largest calorific reward) is also arbitrary. As such, the experiments characterise "raw" participant adaptation mechanisms. They could just as easily be learning the recipe for (virtual) gazpacho. While such learning mechanisms may well be constant (being basically content free), it isn't clear if this is what we actually need to know. By the argument presented, point design is literally a matter of life and death via hunting success and, as such, expertise and real point effectiveness are both crucial.[4] For this reason, the thinking of actual point makers (even in relatively few contemporary traditional societies) may provide significant insight to ground the ABM specification.

Even if this argument is not accepted, however, there is no requirement that the experiments be strictly behavioural (which, ironically, still requires the researcher to interpret via theory when a major advantage of contemporary subjects is that they can talk). If the claim is that we want to know how people learn (and how they use cultural transmission information) then the experiment should provide that information directly. A common solution is to pair participants which potentially makes their discussions qualitative data (Dowsett and Burton, 2014). This not only accesses reasoning directly but allows researchers to check whether respondents understand the task as it was intended.[5]

This point returns us to the earlier argument about the best possible ABM specification data. We now turn to *situation* data.

Here the approach of Mesoudi and O'Brien (and how they build on Bettinger and Eerkens) is odd on two counts. Firstly, scattered through all three accounts are concepts presented as relevant but not integrated into the ABM. For example, one challenge of characterising points is that they may be resharpened (so the final recovered point shape is not the initial one). But there is no discussion about how resharpening fits the wider account linking behaviour and artefact distributions. Is it always done or only sometimes? If the latter, under what circumstances? Can it only be done with some point designs? (Might this capacity *affect* point design?[6]) Can archaeologists tell whether it has been done on specific points? Another such argument (with related implications) proposes resource scarcity to explain different artefact patterns in different regions (Bettinger and Eerkens 1999, p.231). This is, of course, perfectly plausible (so, for example, there may be more resharpening where suitable point making material is scarce) but the problems are, firstly, by what mechanism(s) does scarcity impact on artefact distribution and, secondly, what independent evidence is there for scarcity so this becomes part of the ABM and not just an *ad hoc* "fix" relating theory and data. This problem is most noticeable in the fact that, although Mesoudi and O'Brien are evidently part of the archaeological school favouring evolutionary accounts, it is really hard to establish what they claim about evolution and how it integrates with their account. For example, they may mean that cultural transmission is *analogous* to evolution (in that successful point designs propagate and poor ones don't) or that cultural transmission of point designs is itself subject to Darwinian selection (so the combination of point design improvements and effective ways to transmit these directly affects reproduction via hunting success). Again, given that this is such an important aspect

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4 This raises an additional research design issue. Although Mesoudi and O'Brien justify paying subjects for *participation* (rather than performance) they don't acknowledge possible effects of this relevant to their argument. For example, are some respondents just marking time for their $8 while others are highly self-motivated to improve performance (a motivation which the real environment might have *imposed* on original point users?) This motivation might be ensured by a contest design where only better performers were given further opportunities to earn money.

5 Another possibility is using more open ended experiments. Rather than forcing subjects to learn in certain ways, create environments generating some selective pressure (for example via hunting success) and then see how disposed people are to adapt or participate in cultural transmission. One potentially surprising result, which Mesoudi and O'Brien mention (but don't remark on), is that (when given a choice) subjects often *don't* engage in social learning.

6 Again, direct "modern" accounts might be useful here as a starting point for effective theorising.

of their narrative, it is surprising that it is not part of the empirical argument (or ABM). This example also illustrates the concern that ABMs should directly represent phenomena being explained (rather than only doing so via mediating narratives or theoretical categories.)

The important issue here is to consider, through the lens of empirical methodology, what the ABM needs to include and what data supports those decisions (specification and situation). One cannot convincingly argue from resource scarcity (a situational element) unless there are empirical grounds for its existence in the relevant areas and for a mechanism by which it can generate the patterns it is supposed to explain. Similarly, it has to be shown that the evolutionary account (whatever it is) is still compatible with the observed artefact distribution. Conversely, if one cannot provide enough empirical evidence to incorporate these mechanisms in the ABM then it is hardly convincing to use them as narrative explanations (since they have no stronger evidence in that role).

This brings us back to another major challenge faced by archaeology. Despite the very clear and relevant research design proposed by Mesoudi and O'Brien, we have to think very carefully about a theory that allows people to learn individually in one place and, in another, accepts (or even requires) cultural transmission. This suggests, for example, that these behaviours are not hard wired psychology (contrary to the logic of the Mesoudi and O'Brien role play which strips out content and context) and/or that Darwinian constraints only weakly determine how surviving societies can be organised. (This is not a problem empirically. The world is as it is. But it does create problems for arguments that something has happened on evolutionary grounds.)

In a sense, we are returning to the methodology proposed earlier. To be part of a testable explanation, social processes must be integrated into the ABM. They can't simply be raised *ad hoc*. At the same time, however, how complicated the ABM can be is significantly constrained by available data (both in the artefact distribution and in justifying specification, calibration and situation). Thus one cannot just keep adding processes without further data. (Mesoudi and O'Brien illustrate this challenge nicely by showing that while their ABM can fairly convincingly distinguish individual learning and general cultural transmission, it cannot separate more specific accounts of the latter – exactly what kind of artefact is copied by who).

This brings us to a third important dimension where the work of Mesoudi and O'Brien could be developed, that of validation and its implications. This issue also demonstrates connections between several points already raised.

Bettinger and Eerkens (1999, p.237) show that the pattern of correlations (higher and lower in the two study regions) matches their hypothesis more times than chance would indicate. Mesoudi and O'Brien show (with simplified learning of arbitrary attributes) that their correlations are broadly compatible. But from a design perspective, it is necessary to consider the information content of this result. Mesoudi and O'Brien are not predicting the pattern of correlations for specific attributes let alone the actual correlations. As such (as they show with differing cultural evolution mechanisms) the data may be too weak to make further distinctions. Is it then possible to extend the research to make the relationship between ABM and data more exacting? By the system logic, this can be done in two ways, either by designing and analysing the ABM differently or by using the real data differently. An example of the first approach would be to run the experiments (and then ABM) using not arbitrary attributes but, as far as possible, those used by Bettinger and Eerkens.[7] Further, and Mesoudi and O'Brien mention this but do not pursue it, the research process could use (or perhaps even generate) more data on the real effectiveness of point designs (see, for example, Cheshier and Kelly, 2006).[8] Following this approach we introduce more kinds of data to ground the ABM by not assuming that point design is arbitrary. An example of trying to raise the validation game from the data end is to think more carefully about the properties of artefacts to see whether they could generate any additional data beyond attribute correlations. For example, if we can find a way to identify resharpened points, does this behaviour correlate with other data about (for example) resource scarcity? Should we think about sampling broken points as well as whole ones? (Because broken points may be worse designs or used more.) Should we try to assess point bluntness to establish whether they were discarded because they were beyond use or not?[9] (This is not the only possible approach. It may also be, for example, that different mechanisms of cultural transmission have different *spatial* implications. This could be explored in the ABM and then investigated in reality. But such new data discipline will not be found unless it is sought.)

Thus it can be seen that the four core categories of specification, calibration, validation and situation along with the methodological principles of direct representation and testing allow us to organise effective improvements to existing studies and thus enable progressive research. The conceptualisation of Agent-Based Modelling and its methodology I propose in the paths example actually does work in improving programmatic and empirical archaeological research.

Conclusions

In this article, I have presented a complicated argument. After illustrating the Agent-Based Modelling approach and its distinctive methodology in general terms, I laid out several distinct conceptual categories (specification, calibration, validation and situation) and a number of design principles (direct representation, maximal empirical support and independent testing). This argument was supported by a discussion of the way that different disciplines take distinct positions on methods, theory and subject matter. (For example, archaeology faces particular challenges by dealing with subject matter in the far past for which only data at a remove may be available.)

In a manner of speaking these categories and principles were then tested by using them to clarify (and improve on) a randomly selected strand of real archaeological research (including Agent-Based Modelling) concerning learning, cultural transmission

7 This argument needs further clarification in Mesoudi and O'Brien. They use arbitrary attributes like "Shape 1" because they argue that respondents will not recognise the actual point type terminology (like corner notched). But these attributes are actually no less arbitrary in the experimental set up because in learning terms there is still nothing to recognise. All that is left to the respondent is trial and error because there is nothing in the attributes to suggest why some points might function better than others.

8 This kind of analysis may also contribute empirically regarding whether the space of point designs is multimodal or not.

9 Behind these questions are cultural details absent in the Mesoudi and O'Brien account. Could there be physical transfer of points from one individual to another? What evidence is there for or against specialisation in point production (which would also lead to attribute correlation?) Can we learn anything from the proportion of points that are unused or still usable? Some of these questions connect with arguments made by Mesoudi and O'Brien about issues like resource scarcity and resharpening.

and the distribution of points with different attribute correlations. I hope the argument was well made that value was added to progressive research by this process.

However, this analysis also suggested a number of significant research programmes, both for Agent-Based Modelling in general and archaeology in particular.

The first of these (despite the fact it may prove to be mainly technical) is to draw together and make relevant the tools needed to justify various claims about the relationship between Agent-Based Modelling and data. What does it mean, for example, for an overly complicated ABM to be able to fit *any* data? How do we operationalise the claim that one ABM has less parameter uncertainty than another? But before we can attack these tasks, we need to have our conceptual framework coherent and clear enough to specify them effectively and we need substantive research (like that of Mesoudi and O'Brien) against which we can assess them (rather than arguing in the abstract without any possibility for refutation).

The second is to hone these ideas by much more extensive use. Obviously using a real archaeological example is better than not doing so but I am still not an archaeologist and the acid test is whether these concepts and principles can add value to *many* studies (and whether programmes of progressive Agent-Based Modelling research can become more widespread as a result). My main hope is that I have stated the issues clearly and persuasively enough that this can now be attempted by more archaeologically qualified researchers (and that they will therefore want to do so.)

The third is the importance of self-conscious interdisciplinarity in meeting these challenges. Mesoudi and O'Brien have already shown (with some caveats) the potential value of combining ABMs, archaeology and modern-day experiments. I have suggested the added value of combining Agent-Based Modelling and ethnographic studies of contemporary societies. More novel approaches may even be possible: What would contemporary traditional societies be able to tell us about the Western Basin points from their own perspective? Could the challenges of reproducing the point making process in the present day be informative? But underlying these ideas are contributions I have attempted in this article: To make clear the distinctive contribution of Agent-Based Modelling and its methodology and to follow the principle of making ABMs as empirical as possible (which in turn involves thinking about what it would mean for something to be the best available data.)

References

Bettinger, R.L. and Eerkens, J., 1999. Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric Great Basin. *American Antiquity*, 64(2), pp.231-242.

Brandstätter, H. and Güth, W., eds., 1994. *Essays on Economic Psychology*. Heidelberg: Springer.

Chattoe-Brown, E., 2019. Agent based models. In: P. Atkinson, S. Delamont, A. Cernat, J.W. Sakshaug and R.A. Williams, eds., *SAGE Research Methods Foundations*. Available at: https://methods.sagepub.com/foundations/agent-based-models [Accessed 26 July 2021].

Cheshier, J. and Kelly, R.L., 2006. Projectile point shape and durability: the effect of thickness: length. *American Antiquity*, 71(2), pp.353-363.

Choi, B.C.K. and Pak, A.W.P., 2006. Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine*, 29(6), pp.351-364.

Davis, J.A., 1994. What's wrong with sociology? *Sociological Forum*, 9(2), pp.179-197.

Dowsett, A.J. and Burton, A.M., 2015. Unfamiliar face matching: pairs out-perform individuals and provide a route to training. *British Journal of Psychology*, 106(3), pp.433-445.

Edmonds, B., le Page, C., Bithell, M., Chattoe-Brown, E., Grimm, V., Meyer, R., Montañola-Sales, C., Ormerod, P., Root, H. and Squazzoni, F., 2019. Different modelling purposes. *Journal of Artificial Societies and Social Simulation*, 22(3).

Gilbert, N., 2020. *Agent-Based Models*. 2nd ed. Thousand Oaks, CA: Sage.

Gilbert, N. and Troitzsch, K.G., 2005. *Simulation for the Social Scientist*. 2nd ed. Maidenhead: Open University Press.

González-Ruibal, A., Hernando, A. and Politis, G., 2011. Ontology of the self and material culture: arrow-making among the Awá hunter-gatherers (Brazil). *Journal of Anthropological Archaeology*, 30(1), pp.1-16.

Grider, R. and Wilensky, U., 2015. NetLogo paths model. [computer program] Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. Available at: http://ccl.northwestern.edu/netlogo/models/Paths [Accessed 26 July 2021].

Güth, W., Schmittberger, R. and Schwarze, B., 1982. An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior and Organization*, 3(4), pp.367-388.

Hastorf, A.H. and Cantril, H., 1954. They saw a game: a case study. *The Journal of Abnormal and Social Psychology*, 49(1), pp.129-134.

Hawkins, D.M., 2004. The problem of overfitting. *Journal of Chemical Information and Computer Sciences*, 44(1), pp.1-12.

Meese, R.A. and Rogoff, K., 1983. Empirical exchange rate models of the seventies: do they fit out of sample? *Journal of International Economics*, 14(1-2), pp.3-24.

Mesoudi, A. and O'Brien, M.J., 2008a. The cultural transmission of Great Basin projectile-point technology I: an experimental simulation. *American Antiquity*, 73(1), pp.3-28.

Mesoudi, A. and O'Brien, M.J., 2008b. The cultural transmission of Great Basin projectile-point technology II: an agent-based computer simulation. *American Antiquity*, 73(4), pp.627-644.

Pyke, S.W. and Sheridan, P.M., 1993. Logistic regression analysis of graduate student retention. *The Canadian Journal of Higher Education*, 23(2), pp.44-64.

Starr, M.A., 2014. Qualitative and mixed-methods research in economics: surprising growth, promising future. *Journal of Economic Surveys*, 28(2), pp.238-264.

Tashman, L.J., 2000. Out-of-sample tests of forecasting accuracy: an analysis and review. *International Journal of Forecasting*, 16(4), pp.437-450.

Wachtel, I., Zidon, R., Garti, S. and Shelach-Lavi, G., 2018. Predictive modeling for archaeological site locations: comparing logistic regression and maximal entropy in North Israel and North-East China. *Journal of Archaeological Science*, 92, pp.28-36.

Wiessner, P., 1983. Style and social information in Kalahari San projectile points. *American Antiquity*, 48(2), pp.253-276.

Wilensky, U., 1999. NetLogo. [computer program] Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. Available at: http://ccl.northwestern.edu/netlogo/ [Accessed 26 July 2021].

Simulating resource exploitation strategies in Iron Age to Hellenistic communities in southwest Anatolia

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The sustainability of resource exploitation in any inhabited landscape depends on the strategies employed. Often, only the cumulative effects of successive periods of human presence are evident in archaeological and paleo-environmental datasets. In this paper, we therefore present an agent-based modelling framework to gauge the year-to-year effects of possible resource exploitation strategies in the area of Sagalassos, southwest Anatolia. The model simulates agriculture, wood gathering and clay exploitation in a semi-realistic GIS environment, using known site locations from Iron Age to early Hellenistic settlements. Long-term simulations predict the unsustainability of land use in each settlement's catchment area. Future avenues of research based on this framework are discussed.

Social-environmental systems, NetLogo, resource simulation, resource accessibility, energy returns

Introduction

People have always been in constant interaction with their environment, collecting foodstuffs, hunting animals, working the land, and exploiting resources. All human societies need energy and resources to sustain themselves. As a result, humans have a profound impact on the environment. All the aims and practices of a society to target and collect resources can be subsumed under the moniker of resource exploitation strategies. In order for societies to be resilient over longer time scales, these strategies need to be sustainable. That is, a balanced interaction between society and nature is needed in which the consumption of resources does not exceed their availability and/or regeneration rate.

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 247-262.

Yet, societal resilience is not a mere matter of rational decision making through the imposition of top-down strategies of resource exploitation. On the contrary, the overall system state of a society and its natural environment can be considered an emergent outcome from multitudes of individual and collective strategies that need not be aligned or coordinated. The effects of human-environment interactions as part of coupled social-ecological systems are therefore characterised by inherent unpredictability and uncertainty (Berkes, Colding and Folke, 2003, p.5). Due to system thresholds, feedback loops, and time lags, nonlinear outcomes of past human-environment interactions have pronounced legacy effects on present conditions and future possibilities (Liu, et al., 2007). To better understand these outcomes on long-term time scales, it is of primordial importance to explore the underlying practices and strategies of decision-making that shape overall trajectories of human-environment interactions and potential societal resilience and sustainability.

While archaeology, historical sources and paleo-environmental studies provide windows onto past social and ecological dynamics (see for example Izdebski, et al., 2016; McCormick, et al., 2012), their primary focus lies in tracing the cumulative effects of human-environment interactions, for example through aggregated patterns of soil erosion and sedimentation (e.g. Van Loo, et al., 2017). To explore the generative effects of resource exploitation that drive these patterns, we must turn to other methods that can help disentangle multiple strategies on the level of individual and collective decision-making. A suitable approach that offers such a bottom-up perspective to study emergent system properties can be found in the field of complex systems theory, more specifically in one of its methodological staples: agent-based modelling (ABM) (Schulze, et al., 2017). In recent years, ABM has been applied in archaeological research on human-environment interactions and resource exploitation strategies to study topics such as decision-making in subsistence strategies (Gunaratne and Garibay, 2020), risk-decreasing strategies driving social organization (Shultz and Costopoulos, 2019), and resource distribution and exploitation strategies (Janssen and Hill, 2016). Even though simulations have been applied in archaeology for several decades, many research avenues remain unexplored. Deepening the consilience between the historical and natural sciences through such simulation efforts will continue to yield promising results in understanding environmental change and its effects on human societies in the past, as well as in the present (Haldon, et al., 2018).

In this paper, we explore a new computational framework to study human-environment interactions in the area of Sagalassos (southwest Turkey) from Iron Age to early Hellenistic times (1000-200 BCE). Archaeological and paleo-environmental studies in the Gravgaz valley (Fig. 1) have suggested a significant human impact on the environment – expressed through changes in vegetation cover and soil thickness – from the 9th century BCE onwards (Daems, et al., 2021; Van Loo, et al., 2017). This primary phase of human impact can be associated with the onset of the so-called Beyşehir Occupation Phase (BOP), characterised by warmer and more humid circumstances that favoured agricultural and arboricultural production at higher altitudes, resulting in the increased appearance of cultivated tree species in the pollen record (Bottema and Woldring, 1984; Kaniewski, et al., 2007). While the BOP is generally considered a phase of environmental change caused by human impact, we still lack detailed knowledge regarding the drivers of change and decision-making processes underlying human-environment interactions and human impact on local and regional levels.

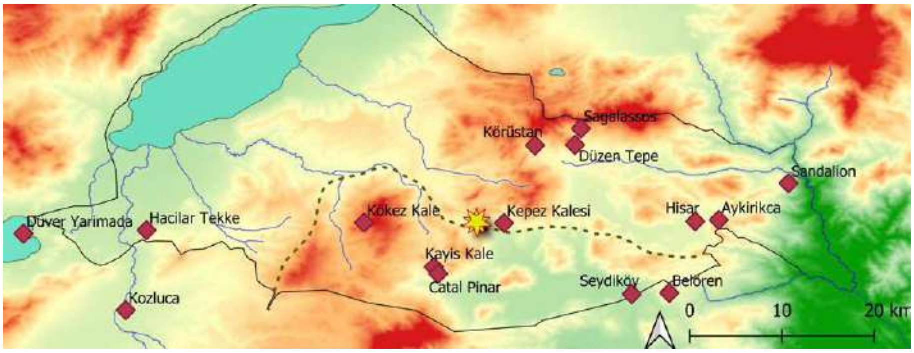

Figure 1: Study area of the Sagalassos Project (full line) with indication of sites discussed in the text (diamond) and the Gravgaz valley (star), the southern extent of the territory of Sagalassos in Hellenistic times is indicated with a dashed line (authors with QGIS).

We aim to address some of these gaps by developing an agent-based model of resource exploitation and subsistence strategies.[1] This model will be used to further explore research questions and hypotheses from the archaeological and ecological partners studying human-environment interactions within the Sagalassos Archaeological Research Project. The main aim of this paper is to present the outlines of the base model in our modelling framework that is currently under development, as well as some of the planned extensions of the model in future iterations. In the base model, we simulate 15 settlements based on archaeological data of Iron Age to Hellenistic settlement patterns in a semi-realistic GIS environment to shed additional light onto the underlying mechanisms and strategies of resource exploitation in Iron Age to Hellenistic hilltop sites in the area of Sagalassos. The primary hypothesis we wish to address is whether the hilltop sites in this area can be considered the major drivers of environmental change during the Iron Age to Hellenistic period.

Archaeological background

The data used for constructing the computational framework is derived from excavations, intensive and extensive archaeological surveys, geophysical studies, pollen cores, chemical analysis and geomorphological models. For this first ABM-approach to studying human-environment interactions in the 1,200 km^2 study area of the Sagalassos Project, we explicitly limit the temporal scope of the model starting with the first attestation of archaeological sites in the Early Iron Age around 1000 BCE until the early Hellenistic period in 200 BCE. The emergence of urban communities from the second century BCE onwards falls beyond the scope of this paper but has been explored elsewhere (Daems and Poblome, 2016; Daems and Talloen, 2022).

Material studies conducted on pottery material collected during intensive and extensive archaeological surveys, have indicated the presence of ten sites during the Early Iron Age (1200-850 BCE), 32 during the Middle Iron Age (850-700 BCE), 39 during the Late Iron Age and Achaemenid periods (700-333 BCE) and 68 during the Hellenistic period (333-25 BCE). From these sites, we selected 15 main settlements, which constituted the largest sites attested in the area for the time period under consideration here, to be included in the

1 See https://github.com/driesdaems10/Resoc for data, source code and documentation of the model.

model. This selection consists of the main sites that already existed from the Early Iron Age onwards (Kayiş Kale, Kökez Kale, Kepez Kalesi, Seydıköy, Hacılar Teke, Düver Ada, Aykırıkça, Körüstan, and Kozluca) as well as some of the other main sites that emerged during the later phases of the chronological window considered here (Sagalassos, Düzen Tepe, Çatal Pınar, Belören, Sandalion and Hısar). Many of these sites were fortified hilltop sites on strategic locations, having good visibility over the surrounding valleys and access to a considerable amount of arable land in their direct vicinity. It has been suggested that each of these sites exercised a certain degree of control over the valley(s) in their immediate surroundings (Vanhaverbeke, et al., 2011).

We mainly focus on the role of the hilltop sites as these constituted the apex of the local settlement pattern in most of the area, serving as foci of population congregation. Of all the sites in our selection, only Düzen Tepe and Sagalassos have been extensively studied through a combination of archaeological excavations, geophysical surveys and material studies. While most information from Sagalassos pertains to the later Hellenistic, Roman Imperial and Byzantine periods, Düzen Tepe offers a unique window into community and settlement formation during the later Iron Age. Due to a lack of detailed information from other sites, we take the data from Düzen Tepe as archetypical for settlement patterns in the area at this time. Studies at Düzen Tepe have suggested that these were agricultural communities characterised by an economic system geared towards the usage of the immediate landscape surrounding the site for their main subsistence and resource procurement (Cleymans, Daems and Broothaerts, In Preparation; Daems and Poblome, 2016; Vanhaverbeke, et al., 2010). Düzen Tepe was a sizable settlement, with a settlement nucleus of about 15 ha and architectural remains spread across the entire 60 ha plateau overlooking the Ağlasun valley. Recent calculations based on house counts and the area of habitation have estimated a population size of about 1,000 people for Düzen Tepe (Cleymans, Daems and Broothaerts, In Preparation).[2] Archaeobotanical data indicates a variety of crops were produced, including wheat and barley, as well as various pulses. Faunal data of Düzen Tepe suggests that goat and sheep herding constituted an important economic activity for daily subsistence (De Cupere, et al., 2017b). Analysis of stable nitrogen and carbon isotope signatures (δ13C and δ15N) also indicated that animals were likely herded together or kept in enclosures in the vicinity of the site and fed a nearly identical diet (Fuller, et al., 2012).

The intensity of exploitation in their immediate surroundings meant that hilltop sites such as Düzen Tepe were likely major drivers of environmental change in the local landscape (Daems, et al., 2021). Pollen data from the study area of Sagalassos indeed show a significant human impact associated with the emergence of hilltop sites in the region (De Cupere, et al., 2017a). However, despite past efforts, our knowledge of how these communities operated, the nature of their resource exploitation strategies, and subsequently, their impact on the environment, remains limited as it is based only on this one proxy. The more intricate coupling of social and ecological spheres on the micro level elsewhere in the study area of the Sagalassos Project remains understudied. Unfortunately, most of these sites are located on private lands, which, under the current regulations, significantly hinders future excavations and sampling. So far, it has proven impossible to conduct more traditional archaeological research on these sites.

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2 The Gaussian distribution of all applied estimation methods resulted in a 1 sigma range (68.2%) of 958 ± 504 inhabitants.

Simulating resource exploitation in the past

From the previous part, it is clear that a lot of the detailed history of human-environment interactions in the area of Sagalassos is still left to be explored. However, due to the limitations of the available data, the Sagalassos Project is increasingly turning towards the potential of simulation models to fill in the gaps. For this paper, we wish to present the first outlines of the computational environment under development to test our hypothesis that the Iron Age hill-top sites in the area of Sagalassos can be considered the main drivers of environmental change, as observed particularly in the paleo-ecological data from the Gravgaz valley. To do so, we are building an agent-based model to explore subsistence and resource exploitation strategies for these small-scale agricultural communities.[3]

Model environment

In our model, we plot the aforementioned 15 site locations in a semi-realistic GIS landscape with properties relating to resource availability and accessibility (Fig. 2). For each settlement, households alternate between farming and resource exploitation (either wood or clay) to meet basic needs in subsistence, fuel, and (artisanal) production. The model registers collective accumulation of foodstuffs, wood and clay on the level of the settlement, in order to assess the viability of each community within its immediate environment. Second, the model also traces patterns of land use and human impact on the environment by registering the degree of deforestation in function of subsistence and resource exploitation activities. Combining these outputs, we will then be able to compare simulated results with the archaeological and environmental datasets from the Sagalassos Archaeological Research Project, including historical settlement patterns, geomorphological data and patterns of erosion and sedimentation to explore the underlying decision-making strategies of past communities.

Archaeobotanical and archaeozoological studies at sites such as Düzen Tepe have shown that people in the past exploited a wide variety of resources for various purposes such as subsistence, (artisanal) production and fuel (Cleymans, et al., In preparation; De Cupere, et al., 2017a). To simplify matters, we simulate in this model three resources, one for each of these general categories, spread across the landscape: agricultural products (subsistence: renewable), wood (fuel for subsistence and production: renewable) and clay (production: non-renewable). The (re)generation and exploitation of these resources is explicitly spatially informed. A GIS environment was prepared in QGIS v. 3.0.3 – Girona. Altitude data was taken from ASTER GDEM V1, resampled to a raster pixel size of one ha. All subsequent GIS layers, relating to soil fertility (1 raster layer expressing the initial value), forest standing stock (3 raster layers expressing maximum standing stock, growth rate and the initial standing stock) and accessibility (1 raster layer expressing slope), were based on this altitude layer.

Soil fertility is measured in terms of potential wheat harvest per ha and per year, as defined in the fertility map by Maarten Van Loo (2018). The map coverage was extended by running an OLS regression (R^2 = 0.46) with altitude as the single explanatory variable for fertility. The results of this analysis were then applied to the entire area. Actual soil fertility, taking into account loss through harvesting, was subsequently modelled using the Verhulst equation (see Appendix 1). Fertility takes an amount of time to fully regenerate, the extent

3 Coded with the NetLogo software (Wilensky, 1999).

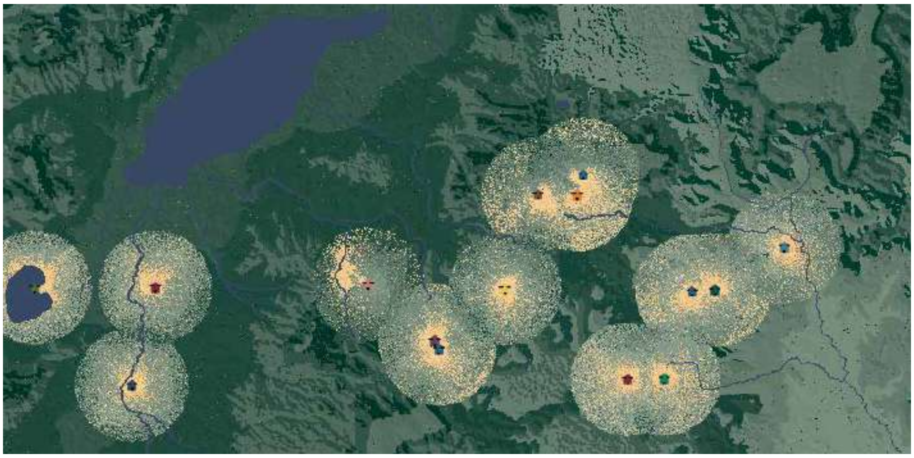

Figure 2: View of model interface in NetLogo after full simulation run of 2,000 time steps. Shades of green indicate the relative tree cover of forest patches while shades of brown illustrate the actual fertility of plots used for agriculture (authors).

of which is determined by a slide variable with values between one and three years. When an agent harvests a patch (see below), the harvest will be equal to the actual fertility value.

Forest growth was simulated using spatially matched data from the GREFOS gap succession model, which is calibrated specifically for the Sagalassos area (Kint, et al., 2014). In the original publication, the model was validated by running it for 330 inventarised vegetation plots, covering the variability of the territory in terms of climate, altitude and exposition. As the GREFOS model is computationally intensive, a simplified growth model, calibrated with this validation data, was used instead (see Appendix 2).

When an agent chooses to gather the wood from a patch, it is cleared in its entirety and the standing stock resets to an initial value in the subsequent time step. Finally, soil fertility and maximum forest standing stock were permanently set to zero on patches crossed by rivers or situated inside a lake. Clay sources are simulated by turning a random selection of 1% of the total amount of land patches within the environment into potential clay sources. Each is given a value between 1-100 for two main variables: clay quality and quantity.

Besides resource abundance, agent behaviour is also determined by resource accessibility. The ASTER altitude raster was first converted to slope data and subsequently to a walking time raster through use of Tobler's (1993) hiking function (see Appendix 3).

Through use of the walking time raster, the least-cost distance (LCD) from every settlement to every patch within a certain radius, as defined by a numerical slider (see below), was then calculated. A five km radius is selected by default, which is roughly equivalent to one hour of walking on flat terrain, the theoretical maximum distance of exploitation for traditional agricultural societies (Bintliff, 1999).

Model initialization

Before initiating the model, one can choose to work with real settlement data (as described above) or simulate a number of communities (defined by a slider on the interface) on random locations across the landscape. The latter option is included in function of future explorations of model dynamics, where the random mode can act as a null model to compare against the data-driven simulations. For the remainder of this paper, we will discuss simulations based on the actual settlement data. At the start of each simulation, a range of variables are defined to structure the initialization of communities and resources in the landscape, along with the subsequent dynamics of resource exploitation and regeneration.

Settlements are simulated at known site locations and given a main catchment area for subsistence production and resource exploitation, with a radius defined by a slider set on the interface to the default value of 50 (corresponding to a territory with a five km radius or one hour of walking distance, see above). For every community, population size is sampled from a normal distribution determined by two numerical sliders, indicating household size and number. The households constitute the main agents within the model that will exploit the landscape. Soil fertility is initialized at maximum (K in Appendix 1). Forest standing stock is initialized by setting the age of the stand (t in Appendix 2) to a random number between 200 and 400, resulting in more or less mature forests across the area. An overview of all parameter settings can be found in Appendix 4.

Simulations

The duration of each simulation can be defined by a slider on the interface but is set at 2,000 timesteps or ticks, corresponding to a period of 1,000 years (matching the chronological window of 1200-200 BCE). Each tick consists of two main procedures: resource exploitation and regeneration. During the first procedure, each individual agent moves in turn to the most attractive patch within its reach, harvests the available resource and returns to its home community where all gathered resources are pooled. The desirability of a patch is determined by the ratio of resource availability to accessibility. The regeneration procedure then restores soil fertility or forest standing stock in all patches (governing equations in Appendix). In the case of clay, quality is also taken into account by the households for selecting the most suitable targets. Clay resources do not regenerate and are removed from the resource pool upon depletion. Agriculture and forest patches are harvested in their entirety; only a slider-defined percentage of a visited clay resource is gathered (default: 10%).

Within the simulations, two ticks correspond to a single calendar year. During even ticks, only food is harvested (and subsequently regenerated according to the regeneration procedure), while for uneven ticks, agents either exploit forested plots for wood or gather clay, based on a random choice. The only exception to this dual strategy is when an agent initially selects a patch for agriculture that had not been cultivated before and was therefore still covered by forest. In this case, the wood is also taken back to the community along with the first harvest. Once a patch has been used for agriculture, forest no longer regenerates there. Similarly, once a patch has been exploited for clay, agriculture and forestry are rendered impossible. On the model interface, we visualize the degree of exploitation for each of the resources for visual inspection during the simulation.

To illustrate the dynamics of the base model, we include simulations that show the impact of wood exploitation practices on long-term timescales (Fig. 3), as well as a basic series of simulations where we tweak the value of the regeneration time of agricultural resources to explore the viability of our local communities (Fig. 4).[4]

4 Data and source code available at: https://github.com/Stef-Boogers/SagaScape.

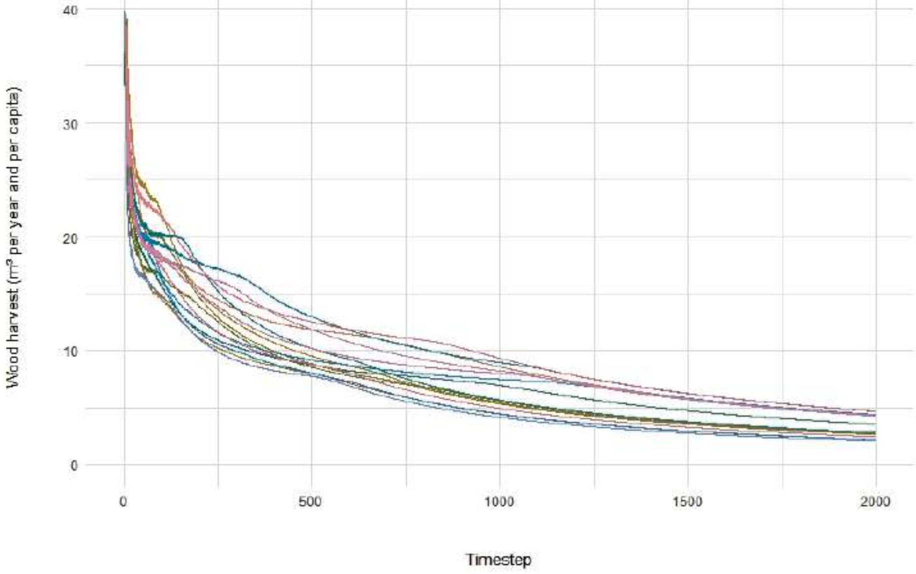

Figure 3: Wood exploitation rates for each of the 15 communities (in m³ per year and per capita). Each color represents a different community (authors).

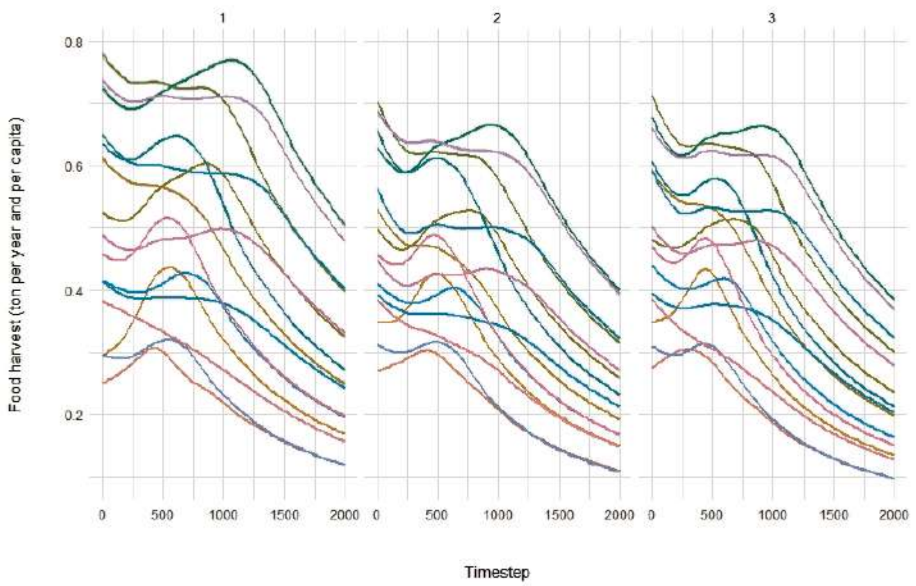

Figure 4: Crop harvest rates (in tons per year and per capita) for 30 simulation runs, tweaking the value for regeneration time between 1 to 3. Each line represents the results for a particular community after smoothing (using GAM) over 10 repeats, with 95% confidence intervals surrounding the lines in grey. The three columns correspond to the three settings for regeneration time (authors).

In this figure, we see a clear initial spike in wood harvests for the first timesteps, which can be related to the accumulation of wood through clearance of land plots that are prepared in function of agricultural production. The strong inequality in the initial abundance of wood resources quickly disappears in light of the initialisation of wood exploitation as the landscape starts to settle into a new equilibrium. However, these equilibria clearly attain a downward trend as the simulation unfurls. This suggests that continued wood exploitation within the immediate catchment areas of each of the communities, without additional measures for conservation and preservation of resources, will eventually result in the depletion of available resources, regardless of the initial state of the woodland and divergent abundances of trees.

To assess the viability of agricultural production within the catchments, we simulated the base settings of the model (see model documentation) while tweaking the value of the regeneration time between one and three years. We ran a total of 30 simulations, with ten runs for each value. It seems that simulations with little regeneration time between harvests result in higher variability in crop yields, depending largely on the natural fertility of the catchment. On the other hand, regeneration times of two and three years, corresponding to an extensive fallow system, result in more narrow ranges of crop yields. This narrow range likely follows from the reduced productivity of the more fertile soils, as well as the increased reliance on less fertile soils. Overall, crop productivity appears to remain stable well beyond the first half of the simulation time. However, regardless of the regeneration time, it is clear that crop productivity eventually starts to decline. This suggests that intensive exploitation of the immediate catchment area of each community would eventually result in a depletion of the available agricultural production.

With our model, we aim to assess the hypothesis that hilltop sites in the area of Sagalassos in southwest Anatolia can be considered the major drivers of environmental change during the Iron Age to Hellenistic period. These nucleated settlements with relatively high population densities were characterised by locally oriented strategies of subsistence and resource exploitation which likely required extensive energy and resources from the immediate environment. Our simulations appear to provide some preliminary corroboration for this hypothesis, showing gradually declining yields in crop and wood harvests, especially towards the second half of the simulation. This suggests that communities which might have remained viable during the Iron Age, would have started to feel the effects of declining returns from the Achaemenid period onwards. This observation is in agreement with simulations of historical erosion patterns and sedimentation rates in the Gravgaz valley, which indicated that reduced soil depths started to occur on the slopes of the valley from the Iron Age onwards, resulting in the decrease of agricultural potential in the higher slope areas (Van Loo, et al., 2017). While these initial results are promising, further work is needed to explore the underlying mechanisms and effects of these human-environment dynamics in more detail. The current model and simulation outcomes should be seen as a first step towards this new research avenue.

Future developments

To this end, a series of model extensions are still envisioned in which we gradually expand functionality to explore new aspects of the case study, while at the same time avoiding the addition of unnecessary details. A first aim will be to refine parameters such as the productivity estimates of clay and wood to better match the spatial extent of the study area by running the model for more classes of geographic variables.

Second, the inclusion of more diverse food procurement strategies, most notably animal husbandry, will be an essential addition to the model to produce a more realistic system of subsistence as animal products (e.g. meat, milk, cheese) would have constituted an important part of consumption in this period of time. The concordant changes in land use through herding would likely also influence the assessments of landscape changes through land use.

Finally, we will implement a trade module to allow communities to exchange resources. This will provide an additional layer of interaction between communities to enable them to deal with shortages in one resource through potential surpluses in another. Additionally, communities can also utilize their surpluses to generate additional capital and obtain prominence within the local settlement hierarchy.

Through these extensions we aim to construct an integrated modelling environment to explore a variety of research questions and hypotheses in future studies of human-environment interactions, resource exploitation and subsistence production within the area of Sagalassos in southwest Anatolia. While the primary research interests of the authors specifically involve the Iron Age to Hellenistic periods, the model environment will also be used to explore long-term human-environment interactions over a period of 5,000 years, ranging from the Early Bronze Age to Late Ottoman times (3100 BCE – 1900 CE).

References

Berkes, F., Colding, J. and Folke, C., 2003. *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge: Cambridge University Press.

Bintliff, J., 1999. Settlement and territory. In: G. Barker, ed., *Companion encyclopedia of archaeology (Vol. 1-2)*. London: Routledge, pp.505-545.

Bottema, S. and Woldring, H., 1984. Late Quaternary vegetation and climate of southwestern Turkey. *Palaeohistoria*, 26, pp.123-149.

Cleymans, S., Daems, D. and Broothaerts, N., in preparation. *Sustaining people: reassessing carrying capacity through the socio-ecological metabolism of the ancient community at Düzen Tepe, SW Turkey*.

Daems, D. and Poblome, J., 2016. Adaptive cycles in communities and landscapes: the case of Sagalassos and Düzen Tepe during the Classical/Hellenistic period. *Archaeological Review from Cambridge*, 31(2), pp.91-107.

Daems, D. and Talloen, P., 2022. Moving in together? Synoikismos and polis formation at Sagalassos and in southwest Anatolia. *Bulletin of the American Society of Overseas Research*, 387, pp.181-205. DOI: 10.1086/719184

Daems, D., Vandam, R., Cleymans, S., Broothaerts, N., Boogers, S., Matsuo, H. and Mirhanoğlu, A., 2021. The social metabolism of past societies: a new approach to environmental changes and societal responses in the territory of Sagalassos (SW Turkey). In: P. Erdkamp, J.G. Manning and K. Verboven, eds., *Climate change and ancient societies in Europe and the Near East: diversity in collapse and resilience*. Palgrave Studies in Ancient Economies. Cham: Springer International Publishing, pp.587-614. DOI: 10.1007/978-3-030-81103-7_20

De Cupere, B., Frémondeau, D., Kaptijn, E., Marinova, E., Poblome, J., Vandam, R. and Van Neer, W., 2017a. Subsistence economy and land use strategies in the Burdur province (SW Anatolia) from prehistory to the Byzantine period. *Quaternary International*, 436, pp.4-17.

De Cupere, B., Van Neer, W., Vyncke, K. and Vanhaverbeke, H., 2017b. Animal exploitation during the Classical/Hellenistic period at Tepe Düzen (SW Turkey): preliminary results. In: M. Mashkour and M. Beech, eds., *Archaeozoology of the Near East 9*. Oxford: Oxbow Books, pp.404-410.

Fuller, B., De Cupere, B., Marinova, E., Van Neer, W., Waelkens, M. and Richards, M., 2012. Isotopic reconstruction of human diet and animal husbandry practices during the Classical-Hellenistic, Imperial and Byzantine periods at Sagalassos, Turkey. *American Journal of Physical Anthropology*, 149, pp.157-171.

Fyllas, N. and Troumbis, A., 2019. Simulating vegetation shifts in north-eastern Mediterranean mountain forests under climatic change scenarios. *Global Ecology and Biogeography*, 18(1), pp.64-77.

Gunaratne, C. and Garibay, I., 2020. Evolutionary model discovery of causal factors behind the socio-agricultural behavior of the Ancestral Pueblo. *PLOS ONE*, 15, e0239922. DOI: 10.1371/journal.pone.0239922

Haldon, J., Mordechai, L., Newfield, T.P., Chase, A.F., Izdebski, A., Guzowski, P., Labuhn, I. and Roberts, N., 2018. History meets palaeoscience: consilience and collaboration in studying past societal responses to environmental change. *Proceedings of the National Academy of Sciences of the United States of America*, 115(13), pp.3210-3218.

Izdebski, A., Pickett, J., Roberts, N. and Waliszewski, T., 2016. The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the eastern Mediterranean in Late Antiquity. *Quaternary Science Reviews*, 136, pp.189-208. DOI: 10.1016/j.quascirev.2015.07.022

Janssen, M.A. and Hill, K., 2016. An agent-based model of resource distribution on hunter-gatherer foraging strategies: clumped habitats favor lower mobility, but result in higher foraging returns. In: J.A. Barceló and F. Del Castillo, eds., *Simulating prehistoric and ancient worlds*. Cham: Springer International Publishing, pp.159-174.

Kaniewski, D., Paulissen, E., De Laet, V., Dossche, K. and Waelkens, M., 2007. A high-resolution Late Holocene landscape ecological history inferred from an intramontane basin in the Western Taurus Mountains, Turkey. *Quaternary Science Reviews*, 26(17-18), pp.2201-2218.

Kint, V., Aertsen, W., Fyllas, N.M., Trabucco, A., Janssen, E., Özkan, K. and Muys, B., 2014. Ecological traits of Mediterranean tree species as a basis for modelling forest dynamics in the Taurus Mountains, Turkey. *Ecological Modelling*, 286, pp.53-65.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H. and Taylor, W.W., 2007. Complexity of coupled human and natural systems. *Science*, 317, pp.1513-1516.

McCormick, M., Büntgen, U., Cane, M.A., Cook, E.R., Harper, K., Huybers, P., Litt, T., Manning, S.W., Mayewski, P.A., More, A.F.M., Nicolussi, K. and Tegel, W., 2012. Climate change during and after the Roman Empire: reconstructing the past from scientific and historical evidence. *The Journal of Interdisciplinary History*, 43(2), pp.169-220. DOI: 10.1162/JINH_a_00379

Özkan, K., Mert, A., Aertsen, W. and Muys, B., 2013. Hierarchical land classification and mapping of Aglasun forest ecosystems in the Mediterranean region, Turkey. *Journal of Environmental Biology*, 34(3), pp.623-633.

Schulze, J., Müller, B., Groeneveld, J. and Grimm, V., 2017. Agent-based modelling of social-ecological systems: achievements, challenges, and a way forward. *Journal of Artificial Societies and Social Simulation*, 20(2), 8. DOI: 10.18564/jasss.3423

Shultz, D.R. and Costopoulos, A., 2019. Modeling environmental variability and network formation among pastoral nomadic households: implications for the rise of the Mongol Empire. *PLOS ONE*, 14, e0223677. DOI: 10.1371/journal.pone.0223677

Tobler, W., 1993. Three presentations on geographical analysis and modeling: non-isotropic geographic modeling; speculations on the geometry of geography; and global spatial analysis. *NCGIA Technical Reports*, 93(1).

Van Loo, M., 2018. *Human – environment interactions in the past: modeling ancient crop yields in a Mediterranean environment*. PhD thesis. Leuven: KU Leuven.

Van Loo, M., Dusar, B., Verstraeten, G., Renssen, H., Notebaert, B., D'Haen, K. and Bakker, J., 2017. Human induced soil erosion and the implications on crop yield in a small mountainous Mediterranean catchment (SW Turkey). *CATENA*, 149(Part 1), pp.491-504.

Vanhaverbeke, H., Degryse, P., De Cupere, B., Van Neer, W., Waelkens, M. and Muchez, P., 2011. Urban – rural integration at ancient Sagalassos (SW Turkey). Archaeological, archaeozoological and geochemical evidence. *Archaeofauna*, 20, pp.73-83.

Vanhaverbeke, H., Waelkens, M., Vyncke, K., De Laet, V., Aydal, S., Mušič, B., De Cupere, B., Poblome, J., Braekmans, D., Degryse, P., Marinova, E., Verstraeten, G., Van Neer, W., Šlapšak, B., Medarič, I., Ekinci, H.A. and Erbay, M.O., 2010. 'Pisidian' culture? The Classical – Hellenistic site at Düzen Tepe near Sagalassos (southwest Turkey). *Anatolian Studies*, 60, pp.105-128.

West, P., 2015. Stem volume and taper functions. In: *Tree and forest management*. 3rd ed. Cham: Springer International Publishing, pp.37-51.

Wilensky, U., 1999. *NetLogo*. Available at: http://ccl.northwestern.edu/netlogo/ [Accessed 18 December 2024].

Appendices

Soil fertility

$$\frac{d\,F(t)}{dt} = r \times F(t) \times \left(1 - \frac{F(t)}{K}\right) \quad (1)$$

With:

- F(t) the soil fertility at time t [tons of wheat/year and ha]
- r the growth rate [$year^{-1}$]
- K the potential soil fertility [tons of wheat/year and ha]

The r parameter in Equation 1 was derived from the solution of the Verhulst equation and the regeneration time parameter. Equation 1 can be solved as follows:

$$F(t) = \frac{F(0) \times e^{r \times t}}{1 + F(0) \times \frac{e^{r \times t} - 1}{K}}$$

With:

- F(t) the F(t) the soil fertility at time t [tons of wheat/year and ha]
- F(0) the initial value of F(t) [tons of wheat/year and ha]
- r the growth rate [year^{-1}]
- K the potential soil fertility [tons of wheat/year and ha]

F(0) needs to be non-zero in order to ensure growth. An initial value F(0) of 0.1 was therefore used. Patches with a K-value lower than 0.1 were deemed permanently barren and received a static F-value of zero. Afterwards, the value of r could be calculated from the regeneration time parameter by assuming that when t is equal to the regeneration time, F(t) is equal to K:

$$F(RT) = \frac{F(0) \times e^{r \times RT}}{1 + F(0) \times \frac{e^{r \times RT} - 1}{K}} = K$$

With:

- RT the regeneration time [years]
- Other symbols as above

Solving this equation however leads to the conclusion that K = F(0), or that the only way to achieve K is to start there. In order to circumvent this asymptotic behavior inherent to Verhulst growth models, it was instead assumed that F(RT) = 0.99 x K:

$$\frac{F(0) \times e^{r \times RT}}{1 + F(0) \times \frac{e^{r \times RT} - 1}{K}} = 0.99 \times K$$

$$F(0) \times e^{r \times RT} = 0.99 \times K \times (1 + F(0) \times \frac{e^{r \times RT} - 1}{K})$$

$$e^{r \times RT} = 99 \times \frac{K}{F(0)} - 99$$

$$r = \frac{1}{RT} \times (ln\ (99) + ln\ (\frac{K}{F(0)} - 1))$$

With:

- Symbols as above

Forest growth

The modeled growth output available from GREFOS was first converted from basal area per stand and per species to total standing volume per ha using the formulae and species-specific parameters presupposed by the model (see Fyllas and Troumbis, 2009 for details) and a taper number of 0.3 (West, 2015). The model simulates both generative and destructive processes (e.g. single tree death from old age, forest fires) over the course of 2,000 years. Accordingly, most model runs fail to reach a steady state. For each validation plot, the median “peak” value, i.e. the highest value before a large (> 75% of standing stock) decline, was therefore calculated. This value was then used as P in Equation 2, after the grouping procedure described below. At each of these peaks, a year counter was also reset. Afterwards, Equation 2 was fitted to this partitioned time series using OLS regression after log transform.

$$\frac{d\,S(t)}{dt} = S(0) \times g \times e^{gt} \quad \text{when } S(t) < P$$
$$\frac{d\,S(t)}{dt} = 0 \quad \text{when } S(t) = P \qquad (2)$$

With:

- S(t) the forest standing stock at time t [m^3 of wood/ha]
- S(0) the initial S(t) [m^3 of wood/ha]
- g the growth rate [$year^{-1}$]
- P the maximal standing stock [m^3 of wood/ha]

The 330 plots were then classified into 28 groups on the basis of climatic zone (three classes), altitude (seven classes) and exposition (two classes). These groups are intended to show differing behaviour in terms of forest growth (Kint et al., 2014). Within the 28 groups, the coefficients fitted using Equation 2 were then averaged. Every pixel in the final dataset was then matched to one of these 28 groups and received the corresponding parameter values. If no exact match in terms of climatic zone, altitude and exposition was found, the parameter values from the neighboring left pixel were taken instead.

This matching step required the subdivision of the entire area into three climatic zones, in accordance with the requirements of GREFOS: Mediterranean, semi-Mediterranean and semi-continental. The exact boundaries of this zonation are documented for only a part of the area in Özkan et al. (2013). The climatic zones were therefore extrapolated by following terrain contour lines.

Tobler hiking speed

The time required to cross a patch with side 100 m can be estimated as follows (Equation 3).

$$t = \frac{100}{6000} \times e^{3.5 \times |S + 0.05|} \qquad (3)$$

With:

- t the walking time or time it takes to cross the patch [hour]
- S the slope of the terrain [radian]

As agents will move to a candidate patch and then return to their starting position following the same path, slope directionality (the sign of S in Equation 3) was ignored

Model Settings

Global parameters		
Name	**Explanation**	**Value range**
time-limit	Maximum number of timesteps within a simulation run, with two steps constituting one year	2000 timesteps
territory	Maximum radius of area wherein households will commit to resource gathering	50 patches
number-households	Number of households per settlement	100
household-size	Size of one household	6 people
regeneration-time	Duration of fallowing required to fully restore soil fertility from zero to its initial value; RT in section 6.1	1/2/3 years
clay-exploitation-rate	Annual rate at which a clay resource is exploited	10%
Patch variables		
Name	**Explanation**	**Value range**
elevation	Mean elevation of patch from ASTER data	249 – 2621 masl
walking-time	Time required to cross a patch; t in section 6.3	0.02 – 0.7 hrs
wood-age	Amount of time a patch has been under forest cover; t in 6.2	0 – Inf years
wood-power	g in section 6.2	0.003 – 0.02 $year^{-1}$
wood-rico	S(0) in section 6.2	13.3 – 242.1 m^3/ha
wood-maxStandingStock	P in section 6.2	70.5 – 289.5m^3/ha
wood-standingStock	S(t) in section 6.2	0 – wood-maxstandingStock
original-food-value	K in section 6.1	0 – 7.5 ton/ha
food-fertility	F(t) in section 6.1	0 – original-food value
clay-quantity	Amount of clay present	0 – 100
clay-quality	Quality of clay present	0 – 100

Migration in the Cetina Phenomenon? An Agent-Based Modelling Approach to Reasons for Mobility in the Adriatic Area between 2400 and 2000 BCE

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The so-called Cetina culture is better understood as a broad pattern of connectivity, primarily traceable through the spread of a distinctive ceramic style from Dalmatia across the Adriatic – Ionian region between ca. 2400 and 2000 BCE. Previous studies of this phenomenon have typically employed large-scale perspectives: while these approaches acknowledge the necessity of crossing regional boundaries, they tend to obscure the complexity and multifaceted dynamics underlying mobility processes. This paper introduces a theory-driven, socio-geographic agent-based model that offers a new explanatory framework for human movement within the Adriatic during the later phases of the Early Bronze Age.

Cetina phenomenon, mobility, migration, agent-based modelling

Introduction

In the second half of the 3rd millennium BCE, a widespread connectivity pattern can be recognized in the Central Mediterranean. A new set of long-range contacts can be traced by the spread of peculiar ceramic style and features along the entire eastern Adriatic, and from central Dalmatia over the Adriatic-Ionian, area connecting the Balkans to the Italian Peninsula up to Sicily, the Maltese Islands and the Peloponnese (Gori, 2020; Cazzella, et al., 2020) (Fig. 1). This pattern is known in the literature as Cetina culture (Govedarica, 1989; Della Casa, 1995; Maran, 1998; 2007; Cazzella, 1999; Kaiser and Forenbaher, 1999; Rambach, 2004, 2007, Broodbank, 2013; Cazzella and Recchia, 2015; Arcuri, et al., 2016; Recchia

In: M. Gori, C. Von Rüden and T. Stöllner, eds. 2026, *Resources in Premodern Societies: New Approaches to Lifeworlds, Skills and Complexity*, Leiden: Sidestone Press, pp. 263-284.

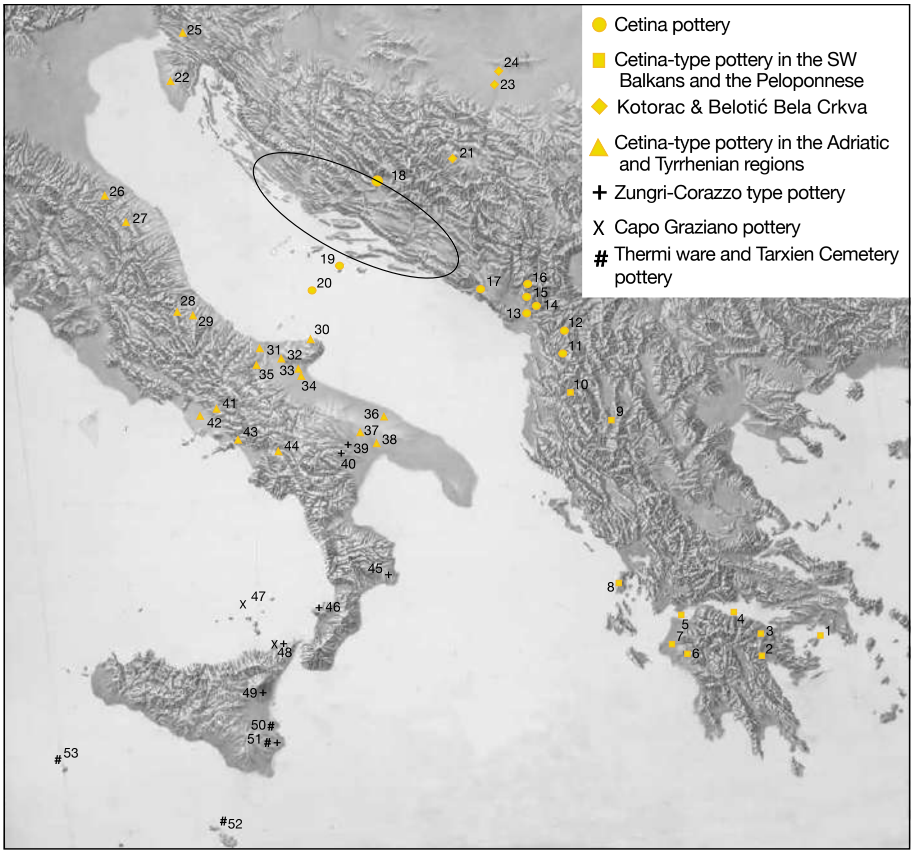
and Cazzella, 2017; Gori, et al., 2021). New research, however, has challenged the definition of Cetina as a unitary archaeological culture with clear physical borders. The term 'phenomenon' (Forenbaher, 2018a) is now commonly preferred, as it reflects the complexity of the Cetina archaeological record and acknowledges that the connectivity patterns are marked by the spread of a distinct ceramic style along the eastern Adriatic and overseas (Gori, et al., 2021). In Europe, the 3rd millennium BCE is characterised by the presence of large-scale networks typified by the establishment of large value-systems that spread over the continent and beyond, such as the Corded Ware Complex and the Bell Beaker Phenomenon (Czebreszuk, 2004; Vander Linden, 2007; Furholt, 2018; 2021). These cultural systems and networks are materially expressed through complex archaeological assemblages, in which various traits and practices are distributed across wide areas, facilitating the circulation of knowledge and people. Together with the introduction of new ideologies, these networks are identified as potential triggers of increased mobility, accompanied by fluctuations in population size (Müller, 2015).

The spread of Cetina features has been framed as periphery of the wider connectivity patterns materialised by the presence of Bell Beakers across Europe (Heyd, 2007; 2013; Turek, 2013; Gori, 2020). Indeed, in the Central Mediterranean, Cetina features spread alongside and, in some cases, in conjunction with Bell Beakers ones. Furthermore, genomic research on human ancient DNA undertaken in central and northern Europe (Brandt, et al., 2013; Haak, et al., 2015; Allentoft, et al., 2015; Olalde, et al., 2018) showed that changes in the European gene pool occurred in association with these extensive interactive networks, suggesting the presence of a recognisable gene influx from the steppe into Central Europe connected to wide mobility patterns.

A crucial aspect in understanding the 3rd millennium BCE is *migration*, an issue that has not been sufficiently problematised in archaeological research, beginning with the very definition(s) of migration itself (Gori and Abar, 2023). Migration is generally defined as the movement of groups and individuals from one place to another, involving a change of usual residence, and it is usually distinguished from mobility by arbitrary conventions of spatial and temporal scales. Recent approaches such as the New Mobilities Paradigm, on the contrary, emphasise the role of social relations into travel by connecting different forms of transport and movement with complex patterns of social experience conducted through communications at-a-distance (Sheller and Urry, 2006). Journeys and movements of people in the ancient Mediterranean can be thus approached from different points of motivation and understandings, overcoming the notion that long-distance travel is primarily connected with raw material procurement and/or trade. It has been suggested indeed that travelling had a strong social and symbolic meaning by itself (Cummings and Johnston, 2007). Overcoming the limitations of traditional archaeological models that focus on binary explanations of migration and cultural transmission in terms of foreign versus domestic material culture, this paper challenges the assumption that tracing and understanding mobility is achieved simply by examining the spread of a particular type of material culture and identifying its start and end points.

Archaeological Models for the Cetina phenomenon

A widely accepted model for the Cetina expansion connects this phenomenon to the circulation of Alpine and Balkan metal and is suggestive of maritime groups on the



Peloponnese
1 - Kolonna
2 - Lerna
3 - Tzoungiza
4 - Keryneia
5 - Teichos Dymaion
6 - Olympia
7 - Andravida-Lechaina

Ionian Island
8 - Lefkada

Albania
9 - Sovjan
10 - Pazhok
11 - Blazi cave
12 - Nezir
13 - Shkoder
14 - Gajtan
15 - Shtoj
16 - Shkrel

Montenegro
17 - Mala Gruda & Velika Gruda

Croatia & Bosnia Herzegovina
18 - Cetina culture
19 - Sušac
20 - Palagruža
21 - Kotorac
22 - Monkodonja

Serbia
23 - Bela Crkva
24 - Belotić Šumar

Northern & central Adriatic Italy
25 - Ciclami cave
26 - Monte Ceti
27 - Sassoferrato
28 - Navelli
29 - Popoli

Southern Adriatic Italy
30 - Rodi Garganico
31 - Chiantinelle - Serracapriola
32 - Pedegarganica km.12
33 - Coppa Nevigata
34 - Fontanarosa
35 - Carlantino
36 - Rutigliano
37 - Altamura (Pulo, Pisciulo)
38 - Laterza
39 - Trasano
40- Murgecchia

Ionian and southern Tyrrhenian Italy
41 - Gaudello
42 - Gricignano
43 - Oliva Torricella
44 - Atena Lucana
45 - Corazzo
46 - Zungri
47 - Aeolian Islands
48 - Milazzo
49 - Novalucello cave
50 - Ognina
51 - Castelluccio
52 - Maltese Islands
53 - Pantelleria

Figure 1: Distribution of Cetina features in the Adriatic and Ionian area between 2500 and 2000 BC (after: Gori 2020).

move from the Balkans (Maran, 2007) bringing the Adriatic into wider Mediterranean prominence. The two main hypotheses regarding the nature of Cetina maritime networks focus primarily on the time scale of their expansion and on the complexity of the networks reflected in the spread of material culture, and can be summarised as follows:

1. the spread of Cetina features is a single and fairly uniform pattern of connectivity that took place during the last centuries of the 3rd millennium BCE, in which a pivotal role was played by small groups of Adriatic seafarers. According to Maran (1998; 2007) followed by Broodbank (2013), Cetina is the common denominator behind the migration of small groups on the move from Dalmatia that are connected to the circulation of metals.
2. the Cetina phenomenon began earlier, around 2500 BCE and has two main phases. According to Recchia and Cazzella (2017), Balkan seafarers were not the only key players in spreading Cetina features in the central Mediterranean, since western Greek groups played a significant role in conveying Cetina-type features across the central Mediterranean as well. Adriatic seafarers would have represented only one face of a more nuanced and complex network (Cazzella, et al., 2020).

Both models present certain problems. The first conflicts with the available data, as the archaeological record offers little evidence for metal procurement as a pull factor; metal objects are scarce in Cetina contexts. Instead, further research has suggested Gargano flint procurement as a more plausible driver of Adriatic overseas mobility (Forenbaher, Perhoč, 2017; 2015; Forenbaher, 2008). For lithics as well, the available data remain limited. The second model, on the other hand, acknowledges the complexity of the Cetina expansion by pointing out that its chronological framework was longer-lasting, and not just restricted to the last centuries of the 3rd millennium BCE (Forenbaher, 2018b; Gori, et al., 2018; Cazzella, et al., 2007; 2020), and that it emerged from the interaction of different networks. Both models address mobility aspects emerging from the archaeological record – raw material procurement and network complexity – and acknowledge that mobility existed; however, they do not provide a formal explanation for the reasons behind mobility. The co-presence of different smaller networks within the larger Cetina phenomenon has been investigated by one of the authors (Gori, et al., 2021). Modularity analysis was applied to the network to understand its structure and to detect relevant hubs in the creation of these networks, while mobility was approached through the lens of the New Mobilities Paradigm. The paper acknowledges the presence of different, intertwined networks and assumes that rituality played a key role in their creation and maintenance, highlighting the socialising role of the maritime Adriatic-Ionian space.

Building on Gori, 2020 and Gori, et al., 2021, this paper makes a further step toward the explanation of Cetina mobility by presenting a causal ABM as a tool to test theory-driven hypotheses against available archaeological data, thus attempting a possible explanation for Cetina mobility patterns in the second half of the 3rd millennium BCE.

In this study, we propose a potentially additive theory suggesting that the formation of diverse socio-geographic population networks, correlated with the emergence of different models of social hierarchy and status, can be the product of diminutive differences in cultural aspects. The archaeological record available for c. ca. 2400 and 2000 BCE in the Adriatic-Ionian area suggests that the patterns traced through the spread of Cetina material culture reflect a stronger drive toward mobility among eastern Adriatic communities compared to their western counterparts.

In the context of ceramics, which serve as a key proxy for reconstructing Cetina interaction networks, ongoing petrographic analyses conducted by one of the authors (M. Gori) in collaboration with S. Amicone and G. Recchia indicate that Cetina ceramics recovered from the Peloponnese – and possibly those from the Italian Peninsula – are not imports from the eastern Adriatic. Instead, these ceramics appear to have been locally manufactured, yet they incorporate technological traditions and production techniques characteristic of the eastern Adriatic region. Analyses of Cetina ceramics on the Italian peninsula have not yet been carried out, but a preliminary examination of some fragments suggests local production. The distribution of these ceramics across the Adriatic and Tyrrhenian zones of Italy indicates not only mobility but also prolonged stays at destination sites, exceeding what short-term commercial exchanges would account for. Conversely, no ceramic evidence reflecting western traditions has been identified on the eastern Adriatic coast. The presence in some eastern Adriatic Cetina contexts of prestige items – such as wrist-guards of Italian Bell Beaker origin and raw materials like flint from the Gargano – seems to have acted as a pull factor for the mobility of eastern Adriatic communities toward the west. In addition to the possession of objects and raw materials considered prestigious, the ability to move across landscapes and seascapes, combined with geographic knowledge, may also have been perceived by eastern Adriatic communities as a marker of prestige and social power (Gori, 2020). Based on current archaeological evidence, mobility – both maritime and terrestrial – should be understood as a multifaceted phenomenon, functioning simultaneously as a social and economic strategy. Moreover, it likely played a crucial role in shaping social dynamics of eastern Adriatic communities.

Setting the Scene: Subtle Differences with Strong Effects

In this paper, we examine whether variations in social strategies alone are sufficient to account for significantly different migration patterns. For the purposes of this study, migration is defined as a mobility behavior in which individuals or groups cross a cultural boundary and relocate for a sustained period of time. Available archaeological indicators (Forenbaher, 2019; Cazzella, et al., 2020; Gori, 2020; Recchia, 2021) suggest that communities living on both sides of the Adriatic between c. ca. 2400 and 2000 BCE were socially, culturally, and technologically similar. We hypothesise thus that socio-cultural differences in both regions – so subtle that they cannot be embodied in the archaeological record but can only be understood in behavioural patterns – were the trigger for mobility.

Taking inspiration from Bourdieu's social theory (1986) we propose that a single pervasive mechanism based on cultural and social capital defines the rank of an individual in its social network. In our theory, cultural capital is represented by *prestige* and social capital by *social centrality*.[1] *Prestige* is here intended as material or immaterial resources – socially produced constructions expressing what people perceive as relevant for their social needs (e.g. particular raw materials/objects and/or the meaning attributed to them) – which are perceived as valuable within a community, while with *social centrality* we intend the ranking of a person/family/group within its community.

1 In the source code used to produce the results, we call this property *social recognition*. But we feel the term *social position* fits better to the concept.

Treatment	SWITCH_KnowledgeModel	StrategyPriorityDistribution
Zero Intelligence	0 (Random Walk)	-/- (0, but not effective)
Local Prestige	1 (“Local Search”)	0 (“Priority Prestige”)
Local Social	1 (“Local Search”)	1 (“Priority Social”)
Local Fifty-Fifty	1 (“Local Search”)	2 (“Priority Fifty-Fifty”)
Prestige	2 (“Full Search”)	0 (“Priority Prestige”)
Social	2 (“Full Search”)	1 (“Priority Social”)
Fifty-Fifty	2 (“Full Search”)	2 (“Priority Fifty-Fifty”)

Table 1. Treatment Groups (n=1,000 for each).

We model the concept of *prestige* with the attribution of geographically scattered, scarce resources. The perceived and thus relevant scarcity of any resource depends on the apparent scarcity in the local social network. The concept of *social centrality* is implemented as directed interactions and again a localised phenomenon: The individual which gets more “positive attention” has higher *social centrality* in the perception of its peers. This universal social calculus which determines cultural capital (i.e. *prestige*) and social capital (i.e. *social centrality*) of any person/family/group is an omnipresent cultural aspect shared among all individuals irrespective of their geographical location.

We propose the following scenario for our model: eastern Adriatic communities believed that one should first aspire to adequate *prestige* and only then focus on *social centrality*. By contrast, communities on the western Adriatic considered their position within their social network (*social centrality*) more relevant than the acquisition of *prestige*, which was instead regarded as secondary for determining the rank of a person, family, or group within the community. To be even more precise, we assume that this subtle difference in evaluating the relevance of *prestige* and *social centrality* is not reflected in a different calculus of social status (i.e. the outcome) between the two types of communities. Instead, this difference determines which kind of capital in Bourdieu’s terminology should be increased first, i.e. a subtle difference in social strategies. This subtle difference is decisive for the individual only when it has not yet met its ambitions for both *prestige* and *social centrality*. Only in such a situation the individual needs to favour one target over the other. In our theory, the individual in the eastern Adriatic will choose an activity that targets increased *prestige*, whereas the individual in western Adriatic shore will instead choose an activity connected to an increase of *social centrality*. Starting from the same background the difference in the perceived relevance of behaviours will result, over time, in different materialisations of this behaviour as visible patterns. It should be stressed that for the implementation of our model it is not relevant what are the reasons behind this preference: it is sufficient to assume that such a subtle difference in behaviour exists.

Simulating Mobility Patterns

Here we provide a high-level description of the model and the results. The code and the instructions to reproduce the results, all the raw results and analysis, as well as a detailed technical appendix describing the model and the experimental setup has been published in the CoMSES repository.[2] The model has been implemented with an extended version of Laboratory for Simulation Development, which is published at GitHub and Zenodo (Pereira et al., 2021).

High-level perspective

Our model represents individual agents in a simplified abstract geography made of quadratic patches. The geography is a rectangle with a width of 50 patches and a height of 250 patches. There is no *wrapping*, meaning the borders cannot be passed. We choose to use the so-called Chebychev[3] distance metric, which is also known as von Neumann neighbourhood: each patch has eight neighbours and movement from one patch to any neighbour has the same normalised cost of one *action*. We assume that any agent can travel from one patch to a neighbour once per turn. Initially, agents are located in the lower area of the abstract geography, a rectangle area of 50 times 25 patches. Our main aim is to understand which conditions affect the speed of migration to the upper area of the abstract geography and if these differences can provide a possible explanation for the Cetina phenomenon.

Within the artificial world, two aspects of artificial locations (patches) are of particular value for the agents in the artificial society:

- Is there some kind of rare resource available, whose possession increases the social status, i.e. *prestige*, of an agent?
- Is the location regularly visited by many other agents, such that the agents' own presence will increase its social status, i.e. *centrality*, due to the increased interaction with other agents?

Artificial agents do not know where they would find scarce resources, nor are they able to predict where the best meeting place will be. Instead, akin to real humans, the agents experience their local environment only when they are present there, constructing individualized models of their environments. These individual mental models – simulacra of (artificial) reality – fuel a heuristic decision mechanism based on their aspirations and levels of satisfactions for the conflicting goals:

- To locate scarce resources inaccessible to its peers, an agent must independently explore uncharted territory.
- To achieve centrality within the social network, an agent must maintain a continuous presence within its community.

Readers familiar with the topic might anticipate that societies with relatively high (or low) aspiration levels for *prestige* tend to explore their artificial reality more (or less) than those with comparatively high (or low) aspiration levels for *social centrality*. We have, however, deliberately avoided selecting this parameter as explanatory. Such a configuration, and its implicit assumptions, would portray eastern and western Adriatic communities as

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2 Data and source code available at: Gori and Schaff 2025 https://www.comses.net/codebases/b218bde7-a323-48c3-ab3c-f6934959cc68/releases/1.0.0/.

3 Sometimes also written Chebyshev or Tschebyschew.

Parameter	min	max	incr	Type	Comment
xn	50			Fixed	The size of the geography in x direction
yn	250			Fixed	The size of the geography in y direction
wrap	0	15	1	Fixed	Special bit code, defines world wrapping. Default 0 (off).
JumpParameter	5			Fixed	Defines the max distance for a new random target in case the strategies do not provide a valid target.
SWITCH_ KnowledgeModel	1	2	1	Fact-orial	Knowledge Model used for Pathfinding. 0: Random Walk – no strategy, 1: Constrained Random Walk. 2: Pseudo-Rational.
StrategyPriorityDistribution	0	2	1	Fact-orial	Defines the priority distribution. 0: All Prestige. 1: All Social. 2: Fifty-Fifty
n_resources	-0.4	-0.01	0.01	LHD	Positive: Absolute number of resources. Negative Fractional: Relative density of resources.
nAgents	100	1000	10	LHD	Number of Agents
Evaluation UpdatingSpeed	0.1	0.9	0.01	LHD	Weight parameter. Defines the relative importance of the newest evaluation of a meeting place.
InertiaChance	0.01	0.8	0.01	LHD	The chance that a person that is confident stays at the current place.
VisionRadius	1	20	1	LHD	Defines how far away a person can observe other persons when looking for a place to meet.
MeetingPlaces Remembered	2	20	1	LHD	The number of meeting places that a person can remember.
seed				RND	The random seed, saved to allow repro-duction of any single experiment.

Table 2. Design Point Matrix.

fundamentally divergent – an interpretation that contradicts our reading of the archaeological record. Moreover, the agents are not modelled as striving for fixed levels of prestige or social centrality; rather, they seek to optimize their relative position within the social network, in line with the notion of myopic knowledge described by Schaff (2016).

A key finding of this model is that even subtle intersocietal differences can give rise to markedly distinct migration patterns. Although aspiration levels vary among individuals, producing a distribution within each societal system, the crucial assumption is that this distribution remains identical for both eastern and western Adriatic societies during the test period. The difference lies in how the two communities approach their social goals. We assume that the factors giving rise to different mobility patterns cannot be identified within the value system of each society as evident in its archaeological material outcomes. Rather, they can be discerned in patterns of behavior – that is, in the norms governing everyday life rather than in ideals of what life ought to be, which are not distinguishable in the archaeological record of societies on either Adriatic shore. In our model members of eastern Adriatic communities prioritize strategies aimed at gaining prestige when their personal aspiration levels for both prestige and social centrality are not met. Western Adriatic communities, by contrast, seek to establish social recognition primarily through social activities, attempting to remain within peer hubs until they feel secure in their position. Technically, within the model, the difference lies in the hierarchy of goals rather than in the levels of the goals.

Strategy Distribution / Search Algorithm	All "Priority Prestige"	½ "Priority Prestige" ½ "Priority Social"	All "Priority Social"
Neighbour Search	Eastern Adriatic communities	Mixed (control)	Western Adriatic communities
Full Search	Eastern Adriatic communities	Mixed (control)	Western Adriatic communities

Table 3. Six different experiment scenarios.

When considering the average individual agent within an *in silico* society, the effects of this subtle but important difference have a relatively small effect. But if one looks at the margins of the model – specifically among those agents who define the boundaries of migration – the effect becomes both evident and robust. In the very long run, the distinction may not alter the ultimate outcome, as both types of society eventually migrate. Yet, over several simulation steps, the model demonstrates that differences in the hierarchy of goals, and thus in the sequence of strategy selection, give rise to markedly distinct mobility patterns. These patterns are also recognizable in the westward distribution of the Cetina ceramic style.

For the experiment, we define six scenarios plus a "random walk" scenario as control, in which agents follow no strategy but instead move in entirely random directions. The six scenarios vary according to search strategy (local vs. global search) and the primary goal pursued (*prestige* or *social centrality*) In addition, to assess whether a minority of prestige-oriented individuals would be sufficient to influence outcomes, a seventh scenario is included in which half of the population prioritizes *prestige* over social recognition (*social centrality*).

An Example: Experiment 105

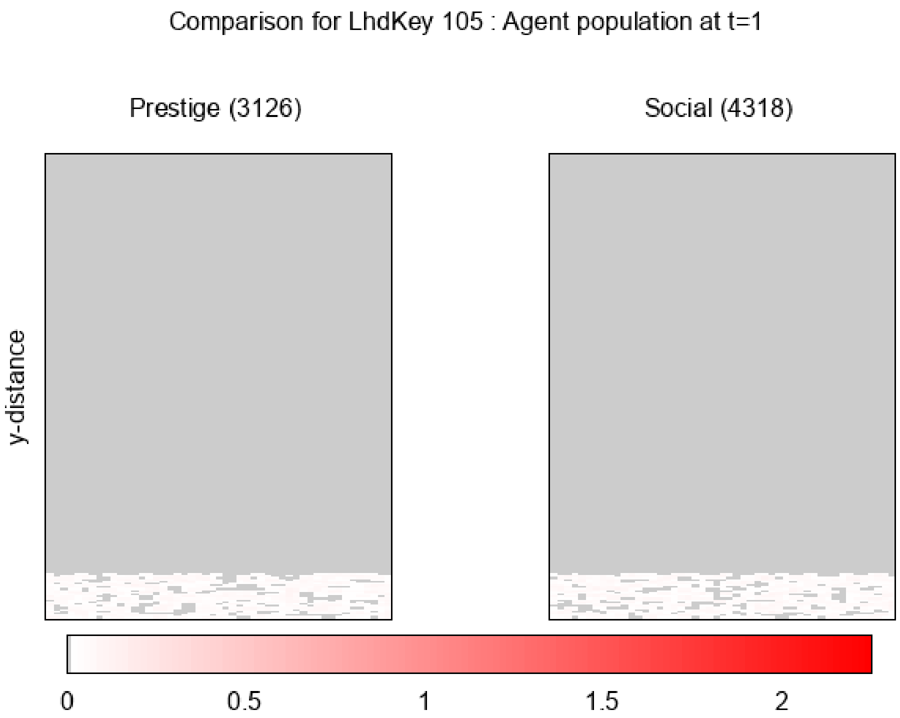
Experiment 105 (Fig. 2) illustrates the variation in migration patterns over time for two agent populations: one prioritizing *prestige* and the other prioritizing social recognition (*social centrality*). Apart from this single parameter difference, all other configuration settings remain identical. The results show that societies in which agents focus on their (relative) *prestige* within their social networks migrate more quickly and over greater distances. As indicated by the red coloration, which represents the number of agents in proximity, the difference is largely driven by a small subset of individuals. Over time, a form of equilibrium emerges, as exploration of the environment gradually diminishes. This outcome can be attributed to the fact that, in our artificial society, agents cannot die, allowing the system to adjust to varying aspiration levels. Once an agent has met its aspirations for *prestige* and *social centrality*, it no longer seeks to further increase its position and therefore reduces its activity, effectively remaining in place.

Experimental Setup and Analysis

A complete experimental setup and analysis is available in the CoMSES repository.[4] Although slightly oversimplifying, we can state that we conducted an analysis in which all relevant parameters have been varied in extremes, controlling a few central switches carefully:

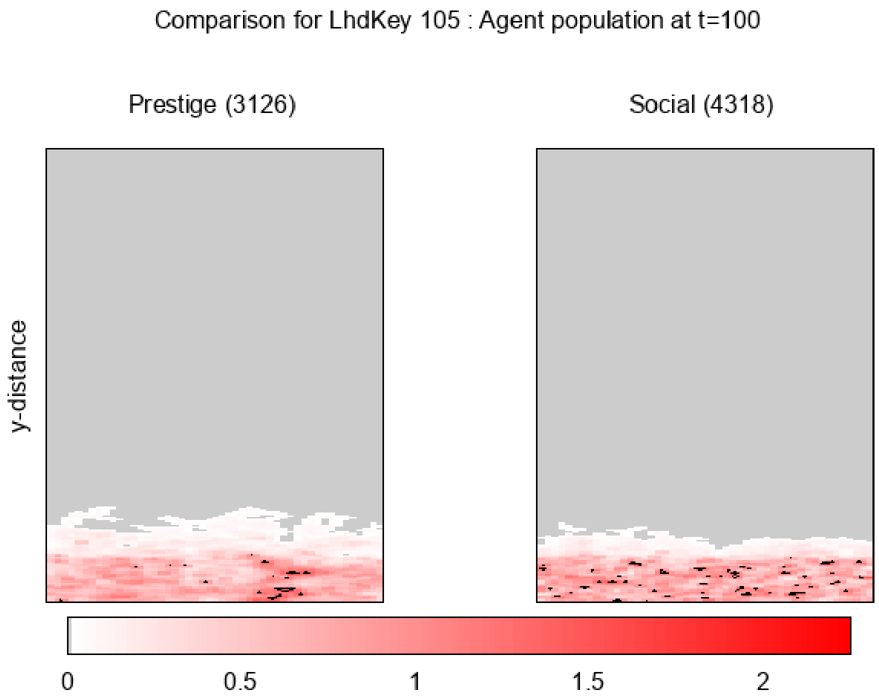
The "*intelligence*" of the agents: following the paradigm of setting a benchmark with random behaviour as *neutral* model (see e.g. Brantingham, 2003), we then implemented

4 Data and source code available at: Gori and Schaff 2025 https://www.comses.net/codebases/b218bde7-a323-48c3-ab3c-f6934959cc68/releases/1.0.0/



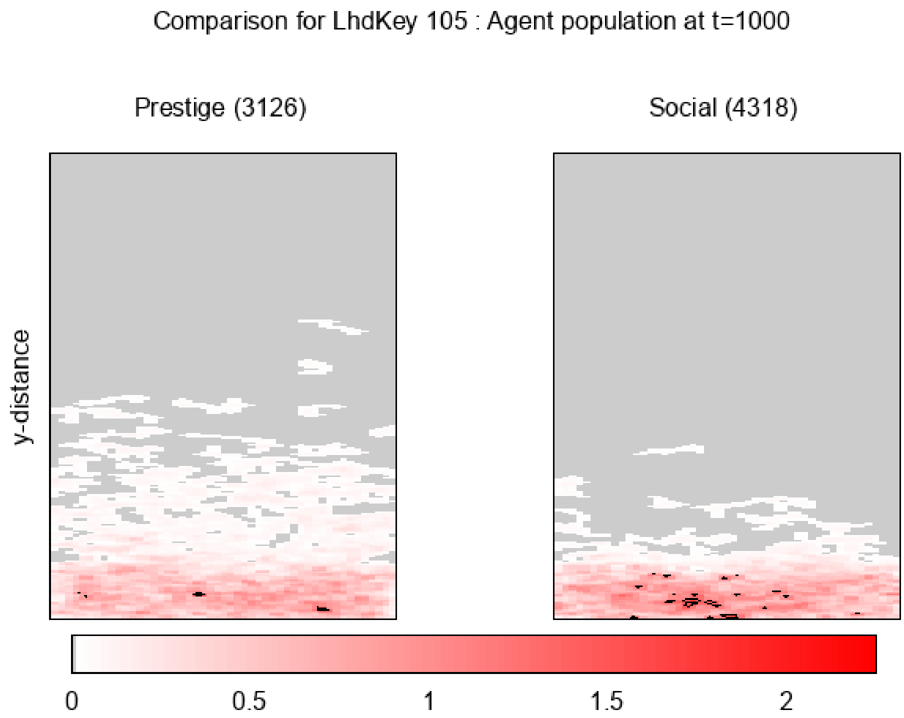
Comparison for LhdKey 105 : Agent population at t=1
Prestige (3126)
Social (4318)
y-distance
0
0.5
1
1.5
2

a

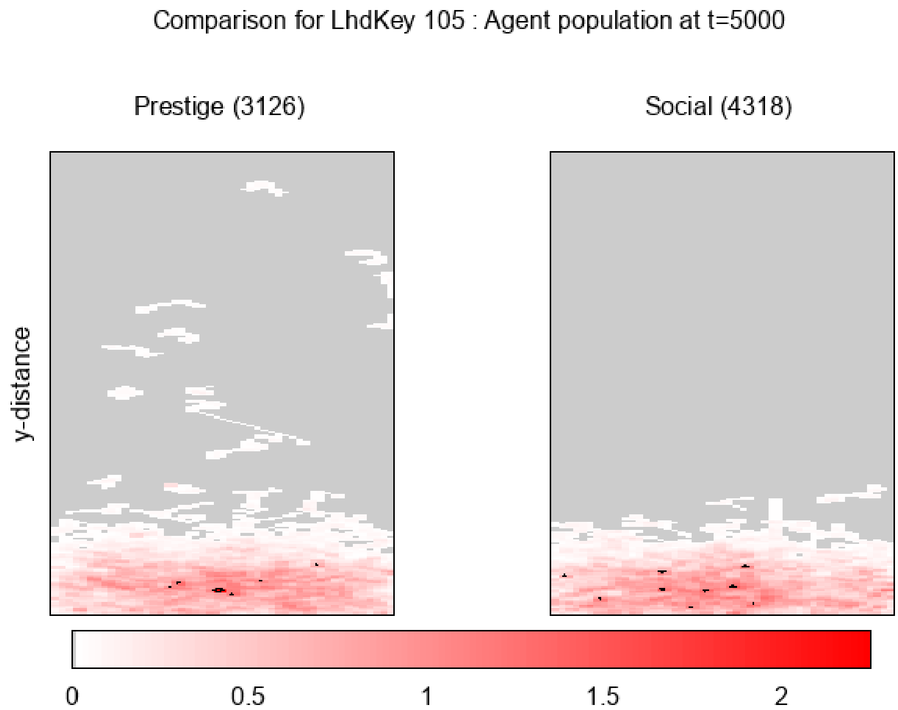


Comparison for LhdKey 105 : Agent population at t=100
Prestige (3126)
Social (4318)
y-distance
0
0.5
1
1.5
2

b



c



d

Figure 2: a) Mobility Pattern I: maximum mobility of the 5% individuals that travel least; b) Mobility Pattern II: maximum mobility of the 5% individuals that travel most; c) Mobility Pattern III: mobility of the single individual that travels most; d) Mobility Pattern IV: average maximum distance travelled (differences) (authors).

two more sophisticated approaches to explore the environment. In “*local search*” an agent takes only the close proximity into consideration, whereas in “*full search*” the agent makes use of the complete model it has of its environment (through past exploration), allowing it to strategically move through less favourable terrain in order to find new opportunities.

The descriptive factor of our model: the share of people within the society which prioritises attaining *prestige* over *social centrality*.

Our experiment reports the number of unique patches identified – i.e. the proxy for migration activity – for the 95 percent of the population performing worst in this category (i.e. excluding the top explorers). Each dot in the plot represents a single configuration, and all configurations are identical except for the two factors defined above. The results clearly indicate that the “random walk” model constrains migration compared to the “intelligent” implementations. Only a single plot is provided for the random walk model, since goal-attainment strategies, by assumption, do not affect behavior in this scenario. In the other setups, the homogeneous population of *prestige*-oriented agents explores the environment substantially more than the mixed population (half prioritizing prestige, half social centrality), which in turn outperforms the homogeneous populations oriented solely toward *social centrality*.

Conclusions

In our agent-based model, becomes evident that the seemingly subtle difference of whether a society prioritizes *prestige* or *social position* can produce profound, structural, and lasting effects on mobility patterns. This holds true even though both types of society ultimately pursue the same goals with the same strategies, share identical distributions of aspiration levels, and operate within the same geography. Within the boundaries of the model’s assumptions, a society that first privilege *prestige* over *social centrality*, explore the geography faster and more comprehensively. This outcome persists even under mixed conditions, where only a portion of the population prioritizes *prestige* over *social centrality*, compared to the case where the population is entirely oriented toward *social centrality*.

Agents act as individuals rather than as groups, which generates a strong tendency to return to the areas where meeting places were first experienced and remembered as means of maintaining social position (*social centrality*). Distinct patterns are recognizable even over very long time-scales. It is also noteworthy that only a small subset of agents actually engage in geography exploration – a behavior consistent with patterns observed in human societies. Incorporating more realistic features, such as intergenerational learning in which older agents transmit knowledge and social positions to younger ones, can be expected to amplify these differences rather than diminish them.

Future extensions of the model could be enhanced by including learning capabilities related to environmental exploration, like adding the feature of a *Sea* to the abstract geography, and mechanisms of trial and error enabling the acquisition of seafaring skills, together with processes for transmitting this knowledge within the community. Similarly, the model focusing on *social status* could be strengthened with more complex learning modes for identifying meeting places, allowing temporal patterns of meeting and exploration to evolve. In addition, mechanisms for transmitting both knowledge and social status across generations are likely to further shape the results.

Future research will also examine the period between 2000 and 1500 BCE, when significant shifts in settlement patterns occurred in the Adriatic, marked by the foundation of numerous hillforts, particularly along the eastern shore. These fortified settlements, often located in elevated and strategic positions that controlled surrounding territories and communication routes, point to a transformed relationship between Adriatic communities and mobility during the early 2nd millennium BCE compared to the preceding 3rd millennium BCE.

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References

Allentoft, M.E., Sikora, M., Sjögren, K.-G., Rasmussen, S., Rasmussen, M., Stenderup, J., Damgaard, P.B., Schroeder, H., Ahlström, T., Vinner, L., Malaspinas, A.-S., Margaryan, A., Higham, T., Chivall, D., Lynnerup, N., Harvig, L., Baron, J., Della Casa, P., Dąbrowski, P., Duffy, P.R., Ebel, A.V., Epimakhov, A., Frei, K., Furmanek, M., Gralak, T., Gromov, A., Gronkiewicz, S., Grupe, G., Hajdu, T., Jarysz, R., Khartanovich, V., Khokhlov, A., Kiss, V., Kolář, J., Kriiska, A., Lasak, I., Longhi, C., McGlynn, G., Merkevicius, A., Merkyte, I., Metspalu, M., Mkrtchyan, R., Moiseyev, V., Paja, L., Pálfi, G., Pokutta, D., Pospieszny, Ł., Price, T.D., Saag, L., Sablin, M., Shishlina, N., Smrčka, V., Soenov, V.I., Szeverényi, V., Tóth, G., Trifanova, S.V., Varul, L., Vicze, M., Yepiskoposyan, L., Zhitenev, V., Orlando, L., Sicheritz-Pontén, T., Brunak, S., Nielsen, R., Kristiansen, K. and Willerslev, E., 2015. Population genomics of Bronze Age Eurasia. *Nature*, 522(7555), pp.167-172.

Anthony, D.W., 1990. Migration in archaeology: The baby and the bathwater. *American Anthropologist*, 92(4), pp.895-914.

Arcuri, F., Albore Livadie, C., Di Maio, G., Esposito, E., Napoli, G. and Soriano, E., 2016. Influssi balcanici e genesi del Bronzo antico in Italia meridionale: la koinè Cetina e la facies di Palma Campania. *Rivista di Scienze Preistoriche*, LXVI, pp.77-95.

Bourdieu, P., 1986. The forms of capital. In: J.G. Richardson, ed., *Handbook of Theory and Research for the Sociology of Education*. New York: Greenwood, pp.241-258.

Bouwman, A.S., Brown, K.A., Brown, T.A., Chilvers, E.R., Arnott, R. and Prag, A.J.N.W., 2000. Kinship in Aegean prehistory? Ancient DNA in human bones from mainland Greece and Crete. *Annual of the British School at Athens*, 95, pp.115-119.

Brandt, G., Haak, W., Adler, C.J., Roth, C., Szécsényi-Nagy, A., Karimnia, S., Möller-Rieker, S., Meller, H., Ganslmeier, R., Friederich, S., Dresely, V., Nicklisch, N., Pickrell, J.K., Sirocko, F., Reich, D., Cooper, A., Alt, K.V. and The Genographic Consortium, 2013.

Ancient DNA reveals key stages in the formation of Central European mitochondrial genetic diversity. *Science*, 342(6155), pp.257-261.

Brantingham, P.J.A., 2003. A neutral model of stone raw material procurement. *American Antiquity*, 68(3), pp.487-509.

Broodbank, C., 2013. *The Making of the Middle Sea: A History of the Mediterranean from the Beginning to the Emergence of the Classical World*. London: Thames and Hudson.

Burmeister, S., 2000. Archaeology and migration: Approaches to an archaeological proof of migration. *Current Anthropology*, 41(4), pp.539-567.

Cabana, G.S. and Clark, J.J., 2011. *Rethinking Anthropological Perspectives on Migration*. Gainesville: University Press of Florida.

Carlà, F. and Gori, M., 2014. Introduction. In: F. Carlà and M. Gori, eds., *Gift Giving and the "Embedded" Economy in the Ancient World*. Heidelberg: Universitätsverlag Winter, pp.7-47.

Cazzella, A., 1999. L'Egeo e il Mediterraneo centrale fra III e II millennio: una riconsiderazione. In: V. La Rosa, D. Palermo and L. Vagnetti, eds., *Epi Ponton Plazomenoi. Simposio italiano di studi egei dedicato a Luigi Bernabò Brea e Giovanni Pugliese Carratelli, Roma, 18-20 febbraio 1998*. Rome and Athens: Scuola Archeologica Italiana di Atene, pp.397-404.

Cazzella, A., Pace, A. and Recchia, G., 2007. Cultural contacts and mobility between the south central Mediterranean and the Aegean during the second half of the 3rd millennium BC. In: S. Antoniadou and A. Pace, eds., *Mediterranean Crossroads*. Athens: Pierides Foundation, pp.243-260.

Cazzella, A. and Recchia, G., 2015. The Early Bronze Age in the Maltese islands. In: D. Tanasi and N.C. Vella, eds., *The Late Prehistory of Malta: Essays on Borġ in-Nadur and Other Sites*. Oxford: Archaeopress, pp.139-159.

Cazzella, A., Gori, M., Pacciarelli, M. and Recchia, G., 2020. 2500-2000 BC: Connectivity phenomena between the Balkans, Greece, Southern Italy, Eastern Sicily, the Aeolian Islands and Malta. *Rivista di Scienze Preistoriche*, Special Issue *Italia tra Mediterraneo ed Europa: Mobilità, Interazioni e Scambi*, pp.175-192.

Chilvers, E.R., Bouwman, A.S., Brown, K.A., Arnott, R.G., Prag, A.J.N.W. and Brown, T.A., 2008. Ancient DNA in human bones from Neolithic and Bronze Age sites in Greece and Crete. *Journal of Archaeological Science*, 35(10), pp.2707-2714.

Cummings, V. and Johnston, R., eds., 2007. *Prehistoric Journeys*. Oxford: Oxbow Books.

Czebreszuk, J., ed., 2004. *Similar but Different: Bell Beakers in Europe*. Poznań: Adam Mickiewicz University.

Davis, R., Shrobe, H. and Szolovits, P., 1993. What is a knowledge representation? *AI Magazine*, 14(1), pp.17-33.

De León, J., 2013. Undocumented migration, use wear, and the materiality of habitual suffering in the Sonoran Desert. *Journal of Material Culture*, 18(4), pp.321-345.

Della Casa, P., 1995. The Cetina group and the transition from Copper to Bronze Age in Dalmatia. *Antiquity*, 69(264), pp.565-576.

Driessen, J., ed., 2018. *An Archaeology of Forced Migration: Crisis-Induced Mobility and the Collapse of the 13th c. BCE Eastern Mediterranean*. Louvain: Presses Universitaires de Louvain (AEGIS Arch.).

Edmonds, B. and Moss, S., 2005. From KISS to KIDS – An "anti-simplistic" modelling approach. In: P. Davidsson, B. Logan and K. Takadama, eds., *Multi-Agent and Multi-*

Agent-Based Simulation. MABS 2004. Lecture Notes in Computer Science, vol. 3415. Berlin: Springer, pp.1-18.

Edmonds, B., Le Page, C., Bithell, M., Chattoe-Brown, E., Grimm, V., Meyer, R., Montañola-Sales, C., Ormerod, P., Root, H. and Squazzoni, F., 2019. Different modelling purposes. *Journal of Artificial Societies and Social Simulation*, 22(3).

Eisenmann, S., Bánffy, E., van Dommelen, P., Hofmann, K.P., Maran, J., Lazaridis, I., Mittnik, A., McCormick, M., Krause, J., Reich, D. and Stockhammer, P.W., 2018. Reconciling material cultures in archaeology with genetic data: The nomenclature of clusters emerging from archaeogenomic analysis. *Scientific Reports*, 8, pp.1-12.

Fatès, N. and Chevrier, V., 2010. How important are updating schemes in multi-agent systems? An illustration on a multi-turmite model. In: *Proceedings of the Ninth International Conference on Autonomous Agents and Multiagent Systems (AAMAS'10)*, vol. 1. Toronto: ACM, pp.533-540.

Fernandes, D.M., Mittnik, A., Olalde, I., Lazaridis, I., Cheronet, O., Rohland, N., Mallick, S., Bernardos, R., Broomandkhoshbacht, N., Carlsson, J., Culleton, B.J., Ferry, M., Gamarra, B., Lari, M., Mah, M., Michel, M., Modi, A., Novak, M., Oppenheimer, J., Sirak, K.A., Stewardson, K., Mandl, K., Schattke, C., Özdoğan, K.T., Lucci, M., Gasperetti, G., Candilio, F., Salis, G., Vai, S., Camarós, E., Calò, C., Catalano, G., Cueto, M., Forgia, V., Lozano, M., Marini, E., Micheletti, M., Miccichè, R.M., Palombo, M.R., Ramis, D., Schimmenti, V., Sureda, P., Teira, L., Teschler-Nicola, M., Kennett, D.J., Lalueza-Fox, C., Patterson, N., Sineo, L., Coppa, A., Caramelli, D., Pinhasi, R. and Reich, D., 2020. The spread of steppe and Iranian-related ancestry in the islands of the western Mediterranean. *Nature Ecology & Evolution*. Available at: DOI:10.1038/s41559-020-1102-0 [Accessed 18 December 2024].

Fitting, M., 2014. Intensional logic. In: E.N. Zalta, ed., *The Stanford Encyclopedia of Philosophy*. Stanford, CA: Stanford University.

Forenbaher, S., 2008. Archaeological record of the Adriatic offshore islands as an indicator of long-distance interaction in prehistory. *European Journal of Archaeology*, 11(2-3), pp.223-244.

Forenbaher, S., 2018a. Ljubljana and Cetina: Pottery styles of the third millennium BC in the eastern Adriatic. *Prilozi Instituta za Arheologiju u Zagrebu*, 35, pp.113-158.

Forenbaher, S., 2018b. *Special Place, Interesting Times: The Island of Palagruža and Transitional Periods in Adriatic Prehistory*. Oxford: Archaeopress Archaeology.

Forenbaher, S. and Perhoč, Z., 2015. Lithic artifacts from Nakovana (Pelješac): Continuity and change from early Neolithic until the end of prehistory. *Prilozi Instituta za Arheologiju u Zagrebu*, 32, pp.5-74.

Forenbaher, S. and Perhoč, Z., 2017. Lithic assemblages from Nakovana (Croatia): Raw material procurement and reduction technology from the Early Neolithic until the end of prehistory. *Journal of Mediterranean Archaeology*, 30(2), pp.189-211.

Furholt, M., 2018. Massive migrations? The impact of recent aDNA studies on our view of third millennium Europe. *European Journal of Archaeology*, 21(2), pp.159-191.

Haak, W., Lazaridis, I., Patterson, N., Rohland, N., Mallick, S., Llamas, B., Brandt, G., Nordenfelt, S., Harney, E., Stewardson, K., Fu, Q., Mittnik, A., Bánffy, E., Economou, C., Francken, M., Friederich, S., Garrido Pena, R., Hallgren, F., Khartanovich, V., Khokhlov, A., Kunst, M., Kuznetsov, P., Meller, H., Mochalov, O., Moiseyev, V., Nicklisch, N., Pichler, S.L., Risch, R., Rojo Guerra, M.A., Roth, C., Szécsényi-Nagy, A., Wahl, J., Meyer, M., Krause, J., Brown, D., Anthony, D., Cooper, A., Alt, K.W. and Reich, D., 2015. Massive migration from the steppe was a source for Indo-European languages in Europe. *Nature*, 522(7555), pp.207-211.

Hamilakis, Y., 2016. Archaeologies of forced and undocumented migration. *Journal of Contemporary Archaeology*, 3(2), pp.121-139.

Heyd, V., 2007. When the West meets the East: The eastern periphery of the Bell Beaker phenomenon and its relation with the Aegean Early Bronze Age. In: I. Galanaki, H. Tomas, Y. Galanakis and R. Laffineur, eds., *Between the Aegean and Baltic Seas: Prehistory Across Borders. Proceedings of the International Conference "Bronze and Early Iron Age Interconnections and Contemporary Developments between the Aegean and the Regions of the Balkan Peninsula, Central and Northern Europe"*, University of Zagreb, 11-14 April 2005. Aegaeum 27. Liège and Austin: Université de Liège/University of Texas at Austin, pp.91-104.

Heyd, V., 2013. Europe 2500 to 2200 BC: Between expiring ideologies and emerging complexity. In: H. Harding and A. Fokkens, eds., *The Oxford Handbook of the European Bronze Age*. Oxford: Oxford University Press, pp.47-67.

Heyd, V., 2017. Kossinna's smile. *Antiquity*, 91(356), pp.348-359.

Hosking, J.R.M., 1990. L-moments: Analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society: Series B (Methodological)*, 52(1), pp.105-124.

Hosking, J.R.M., 1992. Moments or L-moments? An example comparing two measures of distributional shape. *The American Statistician*, 46(3), pp.186-189.

Johannsen, N.N., Larson, G., Meltzer, D.J. and Vander Linden, M., 2017. A composite window into human history. *Science*, 356(6343), pp.1118-1120.

Jung, R. and Weninger, B., 2015. Archaeological and environmental impact of the 4.2 cal BP event in the central and eastern Mediterranean. In: H. Meller, H.W. Arz, R. Jung and R. Risch, eds., *2200 BC – Ein Klimasturz als Ursache für den Zerfall der Alten Welt? / 2200 BC – A Climatic Breakdown as a Cause for the Collapse of the Old World?* 7. Mitteldeutscher Archäologentag, Halle (Saale), 23-26 October 2014. Tagungen des Landesmuseums für Vorgeschichte Halle 12(1). Halle (Saale): Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, pp.205-234.

Kaiser, T. and Forenbaher, S., 1999. Adriatic sailors and stone knappers: Palagruža in the third millennium BC. *Antiquity*, 73(280), pp.313-324.

Kintigh, K.W., Altschul, J.H., Beaudry, M.C., Drennan, R.D., Kinzig, A.P., Kohler, T.A., Limp, W.F., Maschner, H.D.G., Michener, W.K., Pauketat, T.R., Peregrine, P., Sabloff, J.A., Wilkinson, T.J., Wright, H.T. and Zeder, M.A., 2014. Grand challenges for archaeology. *American Antiquity*, 79(1), pp.5-24.

Lake, M.W., 2014. Trends in archaeological simulation. *Journal of Archaeological Method and Theory*, 21(2), pp.258-287.

Lightfoot, E. and O'Connell, T.C., 2016. On the use of biomineral oxygen isotope data to identify human migrants in the archaeological record: Intra-sample variation, statistical methods and geographical considerations. *PLoS ONE*, 11(4), p.e0153850.

Maran, J., 1998. *Kulturwandel auf dem griechischen Festland und den Kykladen im späten 3. Jahrtausend v. Chr.: Studien zu den kulturellen Verhältnissen in Südosteuropa und dem zentralen sowie östlichen Mittelmeerraum in der späten Kupfer- und* *frühen Bronzezeit*. Universitätsforschungen zur prähistorischen Archäologie 53. Bonn: Habelt.

Maran, J., 2007. Seaborne contacts between the Aegean, the Balkans and the central Mediterranean in the 3rd millennium BC – The unfolding of the Mediterranean world. In: I. Galanaki, H. Tomas, Y. Galanakis and R. Laffineur, eds., *Between the Aegean and Baltic Seas: Prehistory Across Borders*. Aegaeum 27. Liège and Austin: Université de Liège/University of Texas at Austin, pp.2-26.

Marović, I., 1991. Istraživanja kamenih gomila cetinske kulture u srednjoj Dalmaciji. *Vjesnik za Arheologiju i Historiju Dalmatinsku*, 84, pp.15-214.

McKay, M.D., Beckman, R.J. and Conover, W.J., 1979. A comparison of three methods for selecting values of input variables in the analysis of output from a computer code. *Technometrics*, 21(2), pp.239-245.

Moscati, I., 2012. Intension, extension, and the model of belief and knowledge in economics. *Erasmus Journal for Philosophy and Economics*, 5(2), pp.1-26.

Müller, J., 2015. Eight million Neolithic Europeans: Social demography and social archaeology on the scope of change – From the Near East to Scandinavia. In: K. Kristiansen, L. Smedja and J. Turek, eds., *Paradigm Found: Archaeological Theory – Present, Past and Future. Essays in Honour of Evžen Neustupný*. Oxford: Oxbow Books, pp.200-214.

Olalde, I., Brace, S., Allentoft, M.E., Armit, I., Kristiansen, K., Booth, T., Rohland, N., Mallick, S., Szécsényi-Nagy, A., Mittnik, A., Altena, E., Lipson, M., Lazaridis, I., Harper, T.K., Patterson, N., Broomandkhoshbacht, N., Diekmann, Y., Faltyskova, Z., Fernandes, D., Ferry, M., Harney, E., de Knijff, P., Michel, M., Oppenheimer, J., Stewardson, K., Barclay, A., Alt, K.W., Liesau, C., Ríos, P., Blasco, C., Vega Miguel, J., Menduiña García, R., Avilés Fernández, A., Bánffy, E., Bernabò-Brea, M., Billoin, D., Bonsall, C., Bonsall, L., Allen, T., Büster, L., Carver, S., Castells Navarro, L., Craig, O.E., Cook, G.T., Cunliffe, B., Denaire, A., Egging Dinwiddy, K., Dodwell, N., Ernée, M., Evans, C., Kuchařík, M., Farré, J.F., Fowler, C., Gazenbeek, M., Garrido Pena, R., Haber-Uriarte, M., Haduch, E., Hey, G., Jowett, N., Knowles, T., Massy, K., Pfrengle, S., Lefranc, P., Lemercier, O., Lefebvre, A., Heras Martínez, C., Galera Olmo, V., Bastida Ramírez, A., Lomba Maurandi, J., Majó, T., McKinley, J.I., McSweeney, K., Mende, B.G., Modi, A., Kulcsár, G., Kiss, V., Czene, A., Patay, R., Endrődi, A., Köhler, K., Hajdu, T., Szeniczey, T., Dani, J., Bernert, Z., Hoole, M., Cheronet, O., Keating, D., Velemínský, P., Dobeš, M., Candilio, F., Brown, F., Flores Fernández, R., Herrero-Corral, A.-M., Tusa, S., Carnieri, E., Lentini, L., Valenti, A., Zanini, A., Waddington, C., Delibes, G., Guerra-Doce, E., Neil, B., Brittain, M., Luke, M., Mortimer, R., Desideri, J., Besse, M., Brücken, G., Furmanek, M., Hałuszko, A., Mackiewicz, M., Rapiński, A., Leach, S., Soriano, I., Lillios, K.T., Cardoso, J.L., Parker Pearson, M., Włodarczak, P., Price, T.D., Prieto, P., Rey, P.-J., Risch, R., Rojo Guerra, M.A., Schmitt, A., Serralongue, J., Silva, A.M., Smrčka, V., Vergnaud, L., Zilhão, J., Caramelli, D., Higham, T., Thomas, M.G., Kennett, D.J., Fokkens, H., Heyd, V., Sheridan, A., Sjögren, K.-G., Stockhammer, P.W., Krause, J., Pinhasi, R., Haak, W., Barnes, I., Lalueza-Fox, C. and Reich, D., 2018. The Beaker phenomenon and the genomic transformation of northwest Europe. *Nature*, 555(7695), pp.190-196.

Primas, M., 1996. *Velika Gruda. 1. Hügelgräber des frühen 3. Jahrtausends v. Chr. im Adriagebiet*. Bonn: Habelt.

Rahmstorf, L., 2008. The Bell Beaker phenomenon and the interaction spheres of the Early Bronze Age East Mediterranean: Similarities and differences. In: A. Lehoerff, ed., *Construire le temps: Histoire et méthodes des chronologies et calendriers des derniers millénaires avant notre ère en Europe occidentale. Actes du XXXe colloque international de Halma-Ipel, UMR 8164 (CNRS, Lille 3, MCC), 7-9 décembre 2006*. Bibracte: Glux-en-Glenne, pp.149-170.

Rambach, J., 2004. Olympia im ausgehenden 3. Jahrtausend v. Chr.: Bindeglied zwischen zentralem und östlichem Mittelmeerraum. In: E. Alram-Stern, F. Felten and N. Efstratiou, eds., *Die Ägäische Frühzeit 2. Serie. Forschungsbericht 1975-2002. 2. Band, Teil 1 und 2: Die Frühbronzezeit in Griechenland, mit Ausnahme von Kreta*. Wien: Österreichische Akademie der Wissenschaften, pp.1199-1254.

Rambach, J., 2007. Olympia and Andravida-Lechaina: Two Bronze Age sites in the northwest Peloponnese with far-reaching overseas cultural connections. In: I. Galanaki, H. Tomas, Y. Galanakis and R. Laffineur, eds., *Between the Aegean and Baltic Seas: Prehistory Across Borders. Proceedings of the International Conference "Bronze and Early Iron Age Interconnections and Contemporary Developments between the Aegean and the Regions of the Balkan Peninsula, Central and Northern Europe"*, University of Zagreb, 11-14 April 2005. Aegaeum 27. Liège and Austin: Université de Liège/University of Texas at Austin, pp.279-289.

Recchia, G. and Cazzella, A., 2017. Permeable boundaries in the late 3rd millennium BC Central Mediterranean: Contacts and mobility between the Balkans, Greece, Southern Italy and Malta. In: M. Fotiadis, R. Laffineur, Y. Lolos and A. Vlachopoulos, eds., *Ἕσπερος / Hesperos: The Aegean Seen from the West. Proceedings of the 16th International Aegean Conference, University of Ioannina, 18-21 May 2016*. Leuven and Liège: Peeters, pp.93-104.

Riede, F., Hoggard, C. and Shennan, S., 2019. Reconciling material cultures in archaeology with genetic data requires robust cultural evolutionary taxonomies. *Palgrave Communications*, 5, p.55.

Romanowska, I., Crabtree, S., Harris, K. and Davies, B., 2019. Agent-based modeling for archaeologists: Part 1 of 3. *Advances in Archaeological Practice*, 7(2), pp.178-184.

Saqalli, M. and Vander Linden, M., 2019. *Integrating Qualitative and Social Science Factors in Archaeological Modelling*. Berlin: Springer.

Schaff, F., 2016. *Pure Agent-based Computational Economics of Time, Knowledge and Procedural Rationality with an Application to Environmental Economics*. Dissertation. FernUniversität in Hagen, Fakultät für Wirtschaftswissenschaft. Online available at http://nbn-resolving.org/urn:nbn:de:hbz:708-dh196 [Accessed 20 September 2016].

Schaff, F., 2017. Archaeology as complexity science: An agent-based perspective. Poster presented at "Tag der Forschung" at the DBM. Online available at https://www.bergbaumuseum.de/en/research/research-projects/archaeology-as-complexity-science-an-agent-based-perspective [Accessed 19 December 2024].

Schaff, F., 2020. Conceptualising Artificial Anasazi with an explicit knowledge representation and population model. In: H. Verhagen, M. Borit, G. Bravo and N.

Wijermans, eds., *Advances in Social Simulation*. Cham: Springer International Publishing (Springer Proceedings in Complexity), pp.399-403.
Simon, H.A., 1978. Rationality as process and as product of thought. *The American Economic Review*, 68(2), pp.1-16.
Spyrou, M., Spyrou, A., Tukhbatova, R.I., Wang, C.-C., Andrades Valtueña, A., Lankapalli, A.K., Kondrashin, V.V., Tsybin, V.A., Khokhlov, A., Kühnert, D., Herbig, A., Bos, K.I. and Krause, J., 2018. Analysis of 3800-year-old *Yersinia pestis* genomes suggests Bronze Age origin for bubonic plague. *Nature Communications*, 9, 2234. DOI: 10.1038/s41467-018-04550-9.
Sutcliffe, A., Wang, D. and Dunbar, R., 2012. Social relationships and the emergence of social networks. *Journal of Artificial Societies and Social Simulation*, 15(4), 3. Online available at https://www.jasss.org/15/4/3.html [Accessed 19 December 2024].
Turek, J., 2013. Echoes and traditions of the Bell Beaker phenomenon. In: M. Bartelheim, J. Peška and J. Turek, eds., *From Copper to Bronze: Cultural and Social Transformations at the Turn of the 3rd/2nd Millennia B.C. in Central Europe. Dedicated to PhDr. Václav Moucha, CSc. on his 80th Birthday*. Beiträge zur Ur- und Frühgeschichte Mitteleuropas 74. Langenweissbach: Beier & Beran, pp.9-23.
van Dommelen, P., 2014. Moving on: Archaeological perspectives on mobility and migration. *World Archaeology*, 46(4), pp.477-483.
van Dommelen, P. and Knapp, A.B., 2010. *Material Connections in the Ancient Mediterranean: Mobility, Materiality and Identity*. London and New York: Routledge.
Vanberg, V.J., 2002. Rational choice vs. program-based behavior. *Rationality and Society*, 14(1), pp.7-54. Online available at http://rss.sagepub.com/content/14/1/7.abstract [Accessed 19 December 2024].
Vander Linden, M., 2007. What linked the Bell Beakers in third millennium BC Europe? *Antiquity*, 81(312), pp.343-352.
Vander Linden, M., 2016. Population history in third-millennium-BC Europe: Assessing the contribution of genetics. *World Archaeology*, 48(5), pp.714-728.
Vander Linden, M., 2019. Toward a clearer view into human prehistory. *Science*, 363(6432), pp.1153-1154.
Wilensky, U. and Rand, W., 2015. *An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with NetLogo*. Cambridge, MA: MIT Press.

APPENDIX. Steps performed to tidy the data.

Merge individual simulation results

- collect all the individual results into a single big one, using the merge script 01_merge_origini.R
- output: sa_origini_rev2.tsv
- Info: this includes the full sample (AbmatConfigID 1 to 7000)

Tidy the information on the resources

- Use the script 02_tidy_origini.R to prepare the data for the analysis.

Number of resources

- background: The number of resources is provided in the Design Input Matrix (DPI) as negative fractionals, which are then adjusted in the setup process to absolute values that fit within the geometric distribution $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}$,... for the shares of all resources. The corrected fraction is saved back as parameter.
  For the analysis, as the size of the geography is kept fixed, we want to have absolute numbers instead.
- from any batch simulation logfile, gather information on the absolute number of resources gained from the relative number and create a mapping of raw input from the design point matrix DPM_origini_rev1.tsv (respective the single files) to raw data in sa_origini_rev2.tsv and the corresponding absolute resources from the .log file.

raw data	absolute resources	raw input DPM bounds	sample size (incl. random walk)
-0.00504	63	[-0.01]	78 (91)
-0.01016	127	[-0.02]	150 (176)
-0.0204	255	[-0.03,-0.04]	312 (363)
-0.04088	511	[-0.05,-0.08]	612 (714)
-0.08184	1023	[-0.09,-0.16]	1230 (1435)
-0.16376	2047	[-0.17,-0.32]	2466 (2877)
-0.3276	4095	[-0.33,-0.4]	1152 (1344)

- exchange raw data with absolute data according to this table
- *note* that the sample is, accordingly, not equal distributed on the number of resources. This is considered unproblematic as the study is exploratory and there is no information on what a plausible value / distribution would be.

Objective Prestige

- background: the *ObjectivePrestige* depends on the number of distinct resource categories available. The id of a prestige item represents its relative scarcity – the item which is available in 50% of the potential resource locations has id 2. The next item is available in 25% of the locations and has id 4, etc. In other words, the id reflects the denominator of the geometric sequence that defines the distribution of the prestige items. The objective prestige of any person is the sum of unique item's ids it posseses. – In order to allow a comparison, we need to adjust them as follows (total range [0,1]):

absolute resources	correction factor
63	1 / (2+4+8+16+32+64) = 1/126
127	1 / (2+4+8+16+32+64+128) = 1/254
255	1 / (2+4+8+16+32+64+128+256) = 1/510
511	1 / (2+4+8+16+32+64+128+256+512) = 1/1022

absolute resources	correction factor
1023	1 / (1022 + 1024) = 1 / 2046
2047	1 / (2046 + 2048) = 1 / 4094
4095	1 / (4094 + 4096) = 1 / 8190

Degree

- background: The *Degree* is the absolute number of people known and thus a function of the possible number.
- In order to allow comparison, we divide it by the number of nAgents.

Define a unique LHD key and calculate differences between priority treatments

- background: Our main interest is on the effect of the priority on the attainment of two goals, prestige and social position. Accordingly, the DOE has been specified as mixed Factorial (knowledge model and priority) and LHD design. In order to allow an explicit analysis of this effect, we need to identify the individual LHD combinations.
- We calculate individual LHD keys that also take into account the factorial variable SWITCH_KnowledgeModel which results in 2,000 LHD keys for each treatment. The control treatment were agents simply perform a random walk is not considered for this analysis.
- Based on this key, we can calculate the differences per experiment and comparing the alternative treatments (priority on social position/recognition) directly with the base treatment (priority on prestige) – this calculation is performed as part of the graphical analysis.

Save Tidy Data

Finally, we save the tidied-up data as sa_origini_rev2_tidy.tsv
Graphical analysis
The script used for these operations is 03_analysis_origini.R

- plot the distribution of the output measures as a function of the two factors, **SWITCH_KnowledgeModel** and **StrategyPriorityDistribution** (facet plots).
- plot the individual effects for each combination of these two major factors and each parameter that has been varied in the DOE.
- Calculate the differences between the base treatment (priority on prestige) and the other treatments (priority on social recognition/position and mixed priorities), but only for the knowledge models neighbour search and full search.

Micro Level Statistics

Note that the statistics that have been taken at the end of the simulation (after 1000 steps). For each simulation and for each output measure, the following statistics have been taken:

suffix	statistic
n	number of elements
min	minimum
p05	0.05 percentile (round down to next rank)

suffix	statistic
p25	0.25 percentile (round down to next rank)
p50	0.5 percentile (interpolate if necessary)
p75	0.75 percentile (round up to next rank)
p95	0.95 percentile (round up to next rank)
max	maximum
avg	arithmetical average
sd	standard deviation (uncorrected)
mae	mean absolute error
Lcv	L-cv (L-Moment)
Lsk	L-Skewness (L-Moment)
Lku	L-Kurtosis (L-Moment)

The output measures considered are:

Variable (Agent level)	Description
MaxDistance	The maximum distance in vertical direction traveled by the agent (theoretical max 249)
SocialRecognition (alias SocialPosition)	The relative rank position of the person in its egocentric social network (0,1]
ObjectivePrestige	The relative "objective" prestige in [0,1] – a value of 1.0 indicates that an agent in this set was able to find all different resource items. The weights of each unique resource are proportional to their scarcity.
Agent_UniquePatchesFound	The absolute number of unique patches found
Degree	The relative degree (fraction of total agents to which the agent is connected) in [0,1]
Prestige	The relative rank prestige in its egocentric social network.
ItemCount	The number of prestige items held.
AspirationLevel_Prestige	The aspiration level for prestige.
AspirationLevel_SocialRecognition	The aspiration level for social recognition/position.

In addition, comparative statistics for the combination of aspiration level and satisfaction level have been taken for both, prestige and social recognition/position, considering always the complete population at the end of the simulation:

suffix	statistic
n	number of elements
L1	L1 distance (mean absolute distance)
L2	L2 distance (standard deviation)
gam	gamma correlation
ta	correlation
tb	correlation
xcr	cross-correlation (Pearson)

A model of the emergence of the state

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This chapter presents a replication of a system dynamics model of the emergence of the state. The model is a very abstract one. It is not a model of an empirical phenomenon, but rather an instantiation of a theory of social power dynamics, a theory of so-called power territories. The theory implemented in the model can be regarded as a Weberian ideal type, abstracting from blurred empirical data for providing a standard of comparison. The model describes social differentiation as a power dynamics between three "social classes": working class, economic and political elites. Model assumptions represent the social mechanisms of this theory. In the simulation, the emergence of the state is a result of the non-linear self-organization of social positions. A sensitivity analysis of the model parameter enables an investigation of the causal power of the social mechanisms of the theory, that is: experimenting with theories. This experimental approach to theory fosters a rational discussion of social theory that opens a potential pathway for closer integration of theoretical and empirical social research. This is briefly outlined by discussing a central result of the sensitivity analysis, namely that the theoretical assumption with the strongest causal power found in the analysis is a so-called "bargaining power of the working class", which again has to be understood as a Weberian ideal type. This enables identifying a social mechanism behind environmental contextual factors such as in Carneiro's comparison of the circumscribed territory in which the Inca empire grew and the Amazon region which did not face an emergence of the state. Namely, the environment in the Amazon region provides conditions for a "high bargaining power" against attempts at subjugating the local population.

Emergence of the State, Power Territories, System Dynamics Model, Sensitivity Analysis, Causal Analysis, Theory Experimentation

Introduction

This paper will attempt to use a simulation model for experimental research into theory building. For this purpose, a model of the emergence of the state has been replicated. The combination of agent-based models with GIS-based computation now allows archaeological

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modelling to examine very detailed empirical research questions, such as those about land use patterns in a narrowly defined territory (e.g. Knitter et al., 2019). There has been an expansion in the use of simulation models since the turn of the millennium. In a survey article Lake (2014) counted some 70 simulation projects undertaken in the period since the millennium in various archaeological domains, such as reaction-diffusion models, models of long-term societal change, human-environment interaction, and those involving aspects of human evolution. One early example is the well-known model of the decline of the Anasazi culture (Dean et al., 1999). The model examined in this study was originally developed in the late 1980s, however, and is an instantiation of a macro-sociological theory following the spirit of early applications of simulations in the social sciences. The objective of the replication is to undertake a sensitivity analysis for investigating the causal power of social mechanisms. It is hoped that this might recall the potential of this methodology for an experimental approach to theory building.

Simulation models have been used for different purposes, and they are classified in different ways (Aldenderfer, 1981; Mithen, 1994; Lake, 2010; Lake, 2014). The way the model is used here roughly follows Mithen's (1994) distinction between hypothesis testing models, and exploratory, theory building modelling. Mithen (1994) argues that archaeologists are firstly concerned with the reconstruction of what happened in the past, and secondly, with explaining why things have happened, in order to contribute to questions of human and cultural evolution (Mithen, 1994). Simulation models have the potential for answering these archaeological research questions because empirical data is relatively rare. Simulation models allow us to study the implications of assumptions. They provide a way to think through complicated issues (Mithen, 1994), and to deal with the complexity that is required for an explanation. Instead of studying a target directly, which is obviously impossible in the case of archaeology, simulation models allow the behaviour of the model to be studied: by running a computer simulation one is able to study the properties of model assumptions and then compare the model behaviour with the data about the target (Doran & Palmer, 1995). This firstly allows us to investigate whether the model assumption can generate the patterns found in the historical record, and secondly to connect data that is largely scattered in space and time. Mithen argues that simulation models contribute to archaeological hypothesis testing and theory building (Mithen, 1994). Here, the model, and in particular the exploration of the model, contributes to theory testing by examining the uncertainty of explanatory mechanisms. According to William Wimsatt (1994), a model exploration provides a means to navigate through the causal thicket.

The example that will be investigated here in detail is a model that was originally written in the late 1980s. It is thus concerned with themes that were heatedly debated at this time, such as nonlinear dynamics, self-organization, and phase transitions (Lake, 2014). It is a system-dynamics (that is and equation-based) model with no spatial resolution. It is an instantiation of a general sociological theory. The attempt is thus what Aldenderfer (1998) denoted as 'whole society modelling'. The method of simulation has been used for theory building: the theory has been formulated as nine abstract simulation models which cover different aspects of a general theory of power and governance. The objective of the models is to adapt this theory for different cases. The emergence of the state is just one phenomenon that the theory is intended to cover, but the model is not intended to simulate a specific historical phenomenon such as the emergence of a specific state, such as Mesopotamia or Egypt. The objective of this article is to use this example to examine whether and how modelling can be used for experimenting with theories (Dowling, 1999) by experimenting with the model. Specifically, the way how sensitivity analysis can be used for investigating the uncertainty of explanatory mechanisms in social theory will be demonstrated. The modelling purpose (Edmonds et al., 2019) can be described as theoretical exposition, however, this can only be a first step. Hopefully, this might stimulate a dialogue between different disciplines, for instance by posing questions about empirical data, even though these questions cannot be answered in detail within the scope of this article.

The article is organised as follows. After a brief exposition of uncertainty of explanatory mechanisms, and theories of the origin of the state, the theoretical framework of the model and the model of the emergence of the state will be outlined in more detail. The simulation results are then documented. Subsequently the experimentation with the theoretical assumptions that are implemented in the model are presented. This is followed by a discussion of how these results can potentially be linked to empirical research. The article ends with a brief conclusion and suggestions for future work.

Uncertainty of explanatory mechanisms

Archaeological explanations often involve a hierarchy of interpretations, due to considerable amounts of uncertainty. Archaeological theories also have to rely on parameters which cannot be measured exactly. Instead, their values can only be determined by gross estimates and considerations based on plausibility (Mithen, 1994). A line of plausible generative mechanisms, which have these uncertainties, however, might ultimately be very misleading. This uncertainty is hard to control without formal means. Simulation models, however, allow for sensitivity analyses to evaluate this uncertainty. This article reports on this kind of theory testing.

It has to be emphasised, however, that these problems with uncertainty are not specific to archaeological models. Seen from a sociological perspective, this is a problem with the investigation of social mechanisms in general. This problem is urgent in the case of archaeology, due to the scarcity of observational data. The investigation of social mechanisms, however, is a general research programme in sociological theory (Elster, 1989, Hedström & Swedberg, 1998, Bunge, 2004, Mayntz, 2004). However, what actually is a social mechanism? Mechanisms can be analysed by laboratory experiments within the natural sciences, but this is not possible in the social sciences. Lipset gives an example from political science that “democracy is a social mechanism for resolving the problem of societal decision-making among conflicting interest groups with minimal force and maximum consensus” (1959, cited in Bunge, 2004: 185). This seems to be plausible. This claim, however, cannot be tested or even numerically determined, for example, by laboratory experiments, but has to rely on its intuitive plausibility. A realist comprehension of social mechanisms therefore has to begin with common sense descriptions of social phenomena (Outhwaite, 1998). There can, however, be controversial intuitions. For example, Schelling (1971) provides a mechanism for the explanation of ethnic segregation as an unintended effect of individual decisions, even when the individuals do not vote intentionally for ethnic segregation. Bunge (2004) criticises Schelling’s explanation as ideological, since it omits the fact that Afro-Americans are actively discriminated against. According to Bunge, a model representing the real structure of US American society should include the causal connection between discrimination and segregation.

It follows that insights into mechanisms are ultimately bounded to the epistemological interests of the observer (Balci, 1994). The postulation of mechanisms has to rely on plausibility considerations, but the objective of an evaluation of mechanisms is not to find a single number, determining its correctness (Oreskes et al., 1994; Barlas, 1996) but to enhance a rational discussion. It can already be regarded as progress in the social sciences if assumptions about the nature of the social world not just contradict each other but rather a rational discussion can be stimulated. Theoretical explanations can be seen as more reliable if they are open for critique and rational discussion. This is expressed in the formulation 'keep them talking' (Outhwaite, 1998).

Within this context of investigating explanatory mechanisms, simulation models provide a means to improve the rationality of the discussion: they provide a way to estimate the uncertainty inherent in the assumed mechanisms. Since the degree of their influence cannot be determined by measurement, a sensitivity analysis can help with the estimation inasmuch their causal power is dependent on arbitrarily chosen values. This cannot overcome the model uncertainty inherent in the choice of the assumptions implemented in a model (Hare & Pahl-Wostl, 2001). What a sensitivity analysis can provide is a means of evaluating the uncertainty parameter inherent in the investigation of social mechanisms based on plausibility considerations. This exploration could thus be called a weak exploration (Richardson, 2003). It will be seen, however, that even this limited analysis will open directions for theoretical questions. A detailed examination of archaeological models can therefore be seen as a contribution to sociological research on social mechanisms. Following Richardson et al. (2000), this can be regarded as a pathway from the weak exploration of the parameter space of a model to a strong evaluation of qualitatively different theoretical assumptions.

Theories of the emergence of the state

A model of the emergence of the state (Müller, 1991) will be used in this study for illustrating the pathway from weak to strong evaluation. The emergence of the state was a highly successful innovation of organising social units, which spread almost all over the world (Carneiro, 1970; Mann, 1990). It is not exactly clear when the state emerged, nor is it clear whether this took place independently within different settlements, or whether this innovation in the organisation of society diffused from one centre to what is now most of the whole world. It is also not clear why the state emerged. There are several theories, however, stressing different aspects which potentially contributed to the emergence of the state.

A review of theories of the emergence of the state is out of the scope of this article. Theories in the tradition of a social contract theory emphasise social evolution (Skyrms, 1996, 2004). Other theories stress economic factors: according to these theories the invention of agriculture was a necessary precondition for the establishment of the state. This goes back to the British archaeologist G. Childe (1936). A more elaborate theory of this kind was developed by Karl Wittvogel (1957), wherein early states were established along river valleys and accompanied a new type of agricultural production, alluvial agrarian production, generating a remarkable surplus unknown in former organisations for securing the subsistence of the society. Another class of theories stress the evidence for warfare in the early stages of state formation. This has led to a view that force and violence was the mechanism leading to the evolution of the state (Oppenheimer, 1926; Spencer, 1967). Carneiro (1970), on the other hand, stresses environmental conditions. In his opinion the early states were established as a circumscribed territory limited by mountains, seas, or deserts. People could not therefore move away to maintain their political autonomy.

After the agricultural revolution around 10,000 BC (Barker, 2007), at least some early states emerged independently in some regions (Mann, 1990). In Egypt the emergence of the state dates back to around 3000 BC, in Mesopotamia to around 3500 BC, the Indus Valley to around 2500 BC, and in China around 1800 – 1500 BC. This went along with a territorial expansion (Spencer, 2010) and urbanisation (Dietz, 2009). It thus took roughly 7000 years from the time humankind began to settle down until social organisation achieved a new level of complexity (Watkins, 2009). The recent archaeological and anthropological literature emphasises the complexity of contextual conditions, such as the role of material culture in the emergence of hierarchies and property rights (Earle, 2004), including prestige items (Bayman, 2002). Campagno (2004) discusses different motivations for war as the driving factor in the emergence of the Egyptian state. Using the example of Egypt, Koehler (2010) discusses various aspects involved in the formation of early states, such as economic factors and trade, bureaucracy, social complexity, centralisation and urbanism, and kinship and ideology, and their varying effects in different eras.

There are numerous theories of the origin of the state, but they have one premise in common: namely that centralised institutions were developed along with the establishment of the state, and a social differentiation took place, releasing a social class from direct agricultural production (Lenski, 1973). In contrast to chiefdoms, states partially delegate authority to subordinates (Wright, 1998; Spencer, 2010).

Framework for modelling the emergence of the state

The point of social differentiation is at the centre of the model of the emergence of the state that will be considered here. The model does not decide between the competing theories, but only investigates the impact of self-organisation on the establishment of centralized institutions, which is not denied in any theory. Following Mueller (1985), these institutions are characterised as decision centres that transform the input of certain social problems into the output of a problem-solving strategy. Members of decision centres are perceived as being released from direct productive activities. Social differentiation is thus conceptualised by the notion of decision centres. Societies are always confronted with specific problems that need to be solved. Formally, the relationship can be described as an operation that transforms an input (a social problem) to a system into an output (a problem-solving strategy) of the system. A decision has to be made for this purpose. For instance, societies produce waste such as food leftovers that need to be disposed of. This involves the transformation of an input, the food, into an output, the waste. Individuals or small groups might simply eat things and throw their rubbish away. This is a decision made by the individual who eats the food. In large social units, however, many transformational mechanisms are no longer in the decision-making power of individuals. Cities, for instance, would collapse if everybody simply threw their rubbish away wherever they wanted. Instead, landfill sites are created. During the cholera epidemic, for example, sewer systems were built. This had to be decided by, for example, a mayor or a city council. This is an example of a decision made by decision centres. Decision centres are people or groups of people with certain influence. This influence might be informal, such as when 60% of the taxes of a town are paid by only one or two individuals, or a decision might also be formally delegated to a decision centre such as a city council. This is an example of an organisation

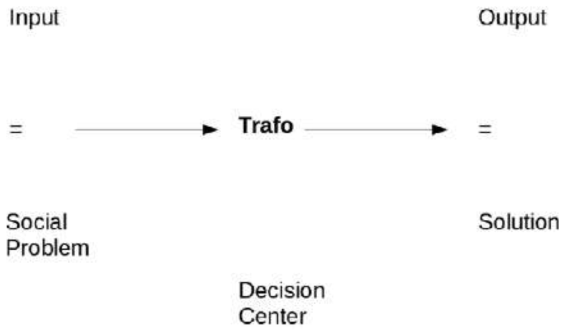

Figure 1: Schematised theory of decision centres as transformational (Trafo) mechanism (author).

with formally defined positions. A mayor, for instance, can be replaced by another person who becomes the new mayor. Figure 1 shows the schematised idea of decision centres.

In order to calculate the number of people that can be released from direct agricultural production, production is expressed in terms of subsistence minima, called C, within this theoretical framework. A production volume of C = 1 means that the production of one member of the society is sufficient to feed one member of the society. It follows that, given a social unit of N members, the necessary minimal production volume has to be:

1) $X = NC$

The production of one member of the social unit shall be denoted by P_i. Then the following condition has to be fulfilled for successful social reproduction:

2) $\Sigma P_i \geq X = NC$.

This terminology leads straightforwardly to a calculation of the number of people who can be released from direct agricultural production. Given the number N of members of the social unit and their production volume P_i, this number can be derived as:

3) $\Sigma P_i - N = V$ (virtual heads).

The value of V denotes the surplus produced, which is open for redistribution. Note, that value V is expressed in subsistence minima. The term V therefore equals the number of people that can be supported by the surplus. However, it has to be noted that every society includes people who are either not able or less able to work or might support elderly people who can no longer work. For this reason, the number of productive people is typically less than the number of people in a social unit. So $M \leq N$ might denote the productive members of a social unit. Moreover, it might be fair to presume that certain risks also have to be taken into account: there might be a drought, or big-game hunting might be unsuccessful, for instance. Social units that produce at least a small surplus are thus more resilient. Social units that are not able to realise at least a small surplus are likely to become extinct. This might be denoted by a risk parameter α with standard deviation σ. It follows that the following condition should be realised:

4) $M(Pi - \alpha\sigma) \geq X$

The calculation of the production volume of a social unit is the condition for deriving the surplus generated by a social unit.

5) $M(Pi - \alpha\sigma) - N = V$, with V again denoting virtual heads.

Within this framework the theory formulates a mechanism for social operations governing the process of redistribution. A fundamental assumption of the theory is that the redistribution is not performed by the working class itself but by specialised institutions, which have to be supported by the surplus. These institutions are denoted by the term 'power territory' (PT), governed by a so-called 'power territory ruler' (PTR). V is the subsistence base of a power territory PT (Mueller, 1989). The maximum size of the social élite is thus V. However, since in this case no surplus could be redistributed, this is an extreme case of total exploitation. Typically, the PT system is legitimised by a specific competence from which it gains the privilege to distribute the surplus produced. This competence means they are legitimised to shape the social world in the domain of their specific competence. They are therefore qualified as the main social decision centre (Dye, 1976; Müller, 1979). Social operations are performed by persons holding positions in the decision centre (Müller, 1985). This is identified by the PT system. Social influence is thus specified in this theoretical framework according to formal positions. Certainly, this is an abstraction from other more informal forms of influence. However, it is a characteristic of organised human societies that such formal positions exist, as illustrated, for example, by the saying "the king is dead, long live the king" with which the death of a king and the name of his successor is announced in France. This can be seen as an ideal type in the sense of Max Weber (1968), by providing a precise terminology as a standard of comparison for real world data.

The related theory of the PTs is concerned with their structural features. It aims to formulate idealised structural conditions for its behaviour: three existence conditions and one operation condition (Mueller, 1989, p. 30 ff.):

- Existence Condition 1 (competence): At least one competence field has to be defined for each PT.
- Existence Condition 2 (scope and effect): Let individuals or social units in the competence field of a PT be called clients of the PT; the relationship between the number of clients and the number of PT members may not fall below a certain minimum. It is clear that this minimum number is greater than or equal to 1, i.e. that there has to be at least one client allocated to each PT member.
- Existence Condition 3 (budget): The PT has to dispose of sufficient financial assets.
- Operation Condition: If a PT exists, a central condition for its undisturbed operation is that PT strategies are effective.

The specific competence field in which the PT operates is not specified, however, and thus, no decision is made between the diverging theories of the origins of the state: for example, the competence of a PT could be a military competence in emerging states (Mann, 1990). A surplus does not have to be redistributed among the producing members of the social unit, but can be spent, for example, on defence expenditure. In this case, the effectiveness of the PT strategy is proven by warfare. If a war is lost, the assumption of the effectiveness

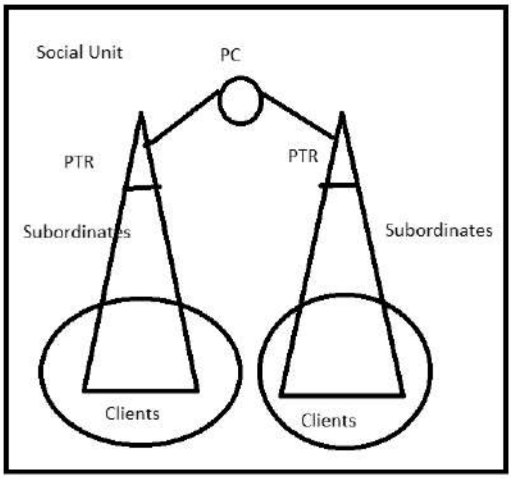

Figure 2: Structure of a PT system (author).

of the PT strategy is falsified and consequently the PT loses its territory; it is gained by the conqueror. Such a competence field would be in line with theories that emphasise force and violence as the mechanism leading to the evolution of the state. The institutions could also be concerned, for example, with the management of irrigation channels. Such a competence field would be in line with economic theories. This difference in the competence field, however, would not affect the structural aspect of their operational conditions.

The organisational structure of PTs, regardless of their specific task, is modelled as a strict hierarchy with a PTR at the top, a number of sub-oligarchs and an even greater number of subordinates. Figure 2 shows the schematised structure.

Figure 2 again represents an ideal type, in this case a hierarchy in the sense outlined by Max Weber (1968). It can be regarded as a stylised fact, using some simple assumptions to stress those aspects of social reality which are under consideration. The square illustrates the specific social unit in which PTs operate, characterised by a competence field in which they serve clients, for example, with medical or military services. At the top of a PT is the PT ruler (PTR). The overall social unit is also conceived as characterised by a centralised power, or power centre (PC).

These very general considerations are used to formulate the minimal conditions for organised societies. For instance, the formulation of "virtual heads" and the calculation of their maximum number is a clear abstraction from the division of labour in the empirical world, however, following Max Weber's notion of ideal types it provides a theoretical standard for evaluating the empirical world: there cannot be more persons released from food production than the number V of individuals who can be provided with food at the level of the subsistence minimum. The objective of the simulation models is to explore the implications of these theoretical abstractions, which allows an evaluation of what, and to what degree, empirical phenomena can be replicated by such minimal assumptions.

A model of the emergence of the state

This section provides a short description of the model. It was originally written in DYNAMO (Mueller, 1991) and replicated in a PowerSim program code. As the original source code was available, the original model was first replicated by translating the source code

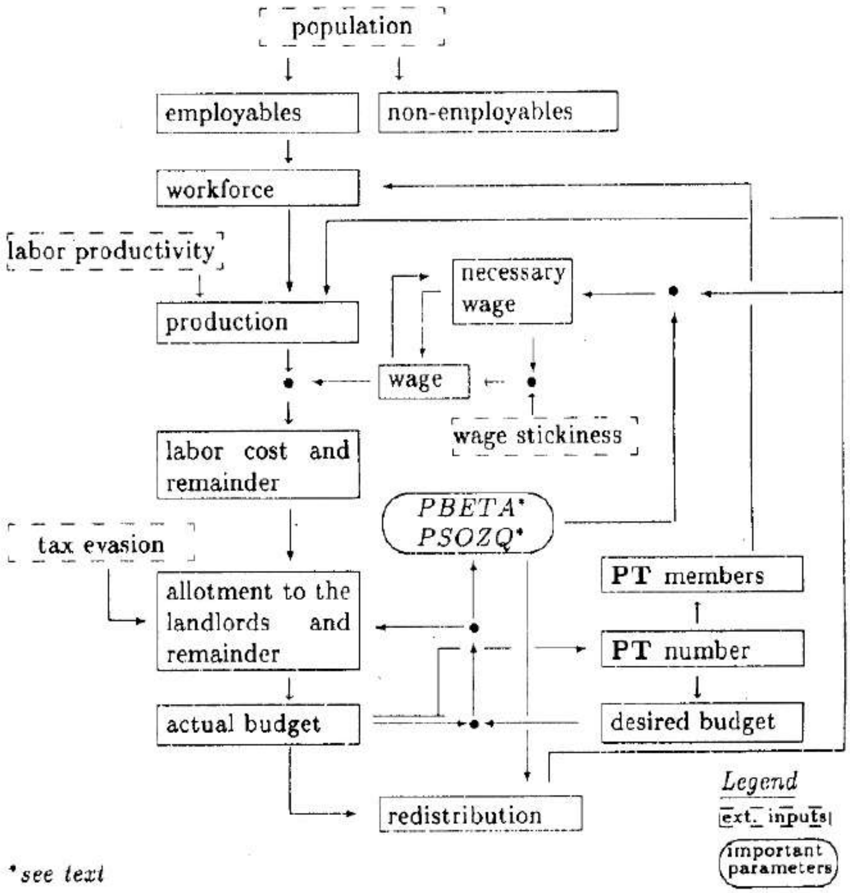

Figure 3: Causal structure of the model (author).

in the different programme languages. This turned out to be less simple than expected, because in DYNAMO the equations have to be typed in line by line, whereas PowerSim applies a graphical user interface. The one-to-one replication was then transformed into a core model. The original model consisted of more than 200 variables, however, a closer inspection revealed that it included, for instance, a number of constant variables that did not affect the dynamics of the model. The core model was reduced to 40 variables und it was then experimentally verified that the core model exhibited the same dynamics as the original model (Yilmaz, 2006).

The model of the emergence of the state is a model of the emergence of PT positions. Following the logic of not deciding between competing theories on the emergence of the state, it is solely a model of the distribution and redistribution of surplus stemming from production, regardless of how the surplus is utilised. For example, it might be used for agricultural investments as well as for warfare. The population is differentiated into three classes, the working class, landlords, and PT members. The model thus extrapolates a social differentiation which can be observed in contemporary societies or prehistoric ones for tracing the origins of social differentiation, and specifically the differentiation between the rulers and the ruled.[1] Figure 3 provides an overview of the causal structure of the model.

The model does not take demographic mechanisms into account. Population is modelled as slowly growing, without taking migration into account. The production volume is thus dependent only on the labour productivity, which is specified by a table function that mimics a constant growth of productivity from 1.77 to 3.08, measured in subsistence minima. While no substantial mechanisms for productivity growth are specified, the value of 1.77 roughly corresponds to the subsistence minimum M(Pi – ασ). Production volume is thus calculated by multiplying the workforce by the labour productivity. In consequence, besides slowly, but constantly growing productivity, the production volume depends on the labour market. In the 'labour market' section of the model, the number of people who are capable of working is regarded as a fraction of the total population, that is, it is taken into account that children or elderly people, for example, might not be productive. The fraction is simply a constant. The number of unemployed, and PT members are subtracted from this fraction, whereas landlords are seen as productive. Unemployment results when a certain part of the workforce potential is sufficient to achieve the desired level of production at a given level of labour productivity. Again, the notion of unemployment is an abstraction: it could also imply that individuals spend less time on production.

The desired production is calculated in the 'production' section of the model. It is calculated as the sum of the payments to the three social classes of the working class, the landlords, and the PT system. It is assumed that the aspirations for the payment of each class will grow by a certain factor at each time step: aspiration level(t+1) = x·payment(t), with x denoting the growth of aspirations, which is dependent on factors that are calculated in different sections of the model. The model thus contains a high number of indirect causal chains, based on plausibility assumptions, which generates what Wimsatt (1994) described as a causal thicket.

The largest sector of the model is concerned with calculating the distribution of the production. Note that debts are not modelled. Access priorities to the produced values are formulated for three classes of the social unit in this sector: the working class have first access, the landlords, as the economic elite have, second access priority, and the PT system has the third access priority. The PT system thus receives what is left after the production is distributed to the other classes. As the model implements a general theory of society, the supply of food is denoted as wages. Notably the notion of wages is derived from modern societies. For prehistoric societies this is an abstraction. In this general theory, however, the concept of wages is a placeholder for the minimal condition under which the members of a society need to be supplied with food. The wage of the working class is calculated as being dependent on the wage one time step before plus a change function: wage(t+1) = wage(1) + change. The change function again contains several factors such as a minimal wage set at the subsistence minimum, wage stickiness, and the bargaining power of the working class. After paying the working class the amount that the landlords receive from the remaining production volume (or more specifically: the amount of the change of their alimentation) is

1 While Egypt and Mesopotamia had strong emperors, it is unclear however, whether the Indus culture had such a system of rulers and the ruled (Wright, 2010). The concept of a class structure is a placeholder for social differentiation which could also imply for instance slavery and owners of individual property regarding the differentiation between working class and landlords.

calculated by taking into account three factors: tax evasion, a distribution struggle between the landlords and the PT system, and a distribution struggle between the landlords and the working class. The remainder of the production volume is distributed to the PT system. It is assumed that it goes to the treasury, however, the amount of the remainder depends on the distribution struggle between the PT system and the landlords. Here the desired budget of the PT system comes into play. Again, this depends on the amount that the PT system gained one time step before. From the perspective of the PT system, the desired demand is affected by the redistribution tasks and the demand for the PT system itself. The former is specified in the section 'redistribution' of the model, the latter is composed of the average demand per PTR, including payment to the staff at the different hierarchy levels. The relationship between the size of the different hierarchy levels is calibrated as 1: 10: one PTR has 10 subordinates and so on, an assumption roughly oriented around the hierarchies of the roman legions in which a group of 10 soldiers was commanded by a decurion. Again, this is a stylised abstraction for numerically representing the idea of a hierarchy cone. The demand of the PT system is moderated by the relationship between the desired maximum number of PTRs and the minimum number of PTRs. The maximum value is dependent on the number of PTRs and a demand for more personnel. The minimum number is calibrated by

6) $n = h \cdot N$, with $h = 10^{-4}$

Thus, there is at least one PTR for 10,000 people. This is a stylised assumption in order to represent hierarchisation as a response to growing system complexity (Magnusson, 2020). The central task of the PT system is the redistribution of the production volume. Again, access priorities are formulated, however, in contrast to the distribution of the production volume, the PT system has the first access priority in redistribution, in order to realise the demand specified above. The landlords have second access to the remainder of the surplus, calibrated by a constant quota. Next, the remaining surplus is transferred to the unemployed. Specialised institutions need to exist to realise this task. This is calculated using a clip function which switches between two different redistribution strategies. These are implemented as table functions with opposing directions in reaction to a comparison of the actual and the desired budget. One strategy, denoted as PBETA, is to increase revenues by expanding the territory of the PT under consideration if the desired demand exceeds the resources. The idea is to increase the number of clients for extracting additional surplus. One might think of big men societies (Sahlins, 1963). The other, denoted as PSOZQ, is to save expenditure if the desired demand exceeds the resources. Austerity politics would be a contemporary example of this. Finally, transfer to non-employable people is financed from the remainder. Any surplus that remains after all transfers have been completed accumulates in treasuries (for a comprehensive description see Mueller, 1991).

Simulation results

Following Damerow, et al. (1988), the simulation run starts roughly at the historical time when archaeological artefacts indicate first settlements, that is small agrarian communities. This is calibrated at 6000 BC. One time step of the model is calibrated as representing 20 years. At this time, the number of PTR positions remains a sleeping variable, however, at 1500 BC the model shows a rapid growth in the number of PTR positions, as shown in Figure 4. The model thus

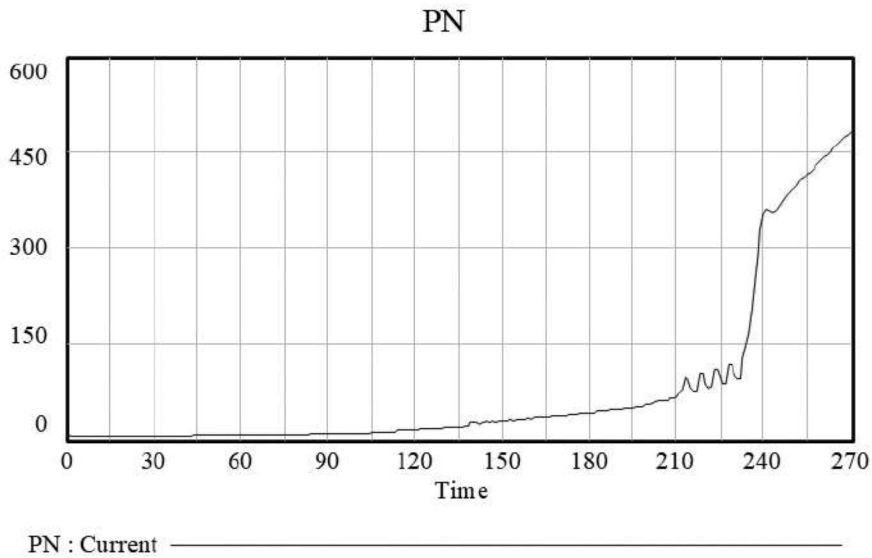

Figure 4: Emergence of the state (author).

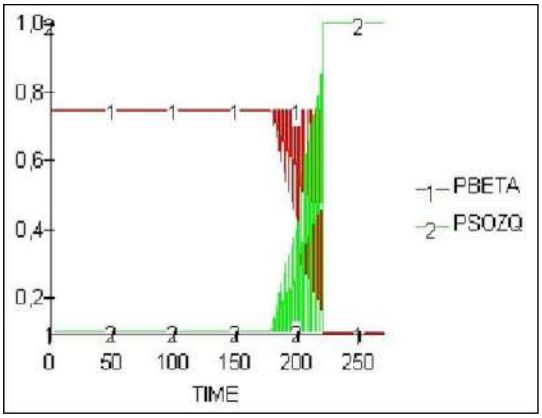

Figure 5: Development of redistribution strategies (author).

exhibits a nonlinear dynamic. This nonlinear dynamic is interpreted as the emergence of the state, containing centralised institutions with a bureaucratic structure. Thus, the model covers a timespan of around 4500 years. While the exact timing remains uncertain and not all states emerged at the same time (e.g., much later on the American continent), it seems that the emergence of the state as a process is faster in the model than in reality. Presumably this is due to the fact that the model provides only a baseline of minimal conditions which are superimposed by numerous contextual factors in the empirical reality.

The rapid growth of PTR positions is accompanied by a switching of the variables PBETA and PSOZQ. This is displayed in Figure 5, which shows that these strategies change just before the rapid growth. The strategy to enlarge the competence field remains the dominant strategy until the emergence of the PBETA state. This changes with the emergence of the state, when saving becomes prevalent. This is interpreted in the idea that weak institutions tend to react to budget scarcity with a drive to enlarge their competence field. According to

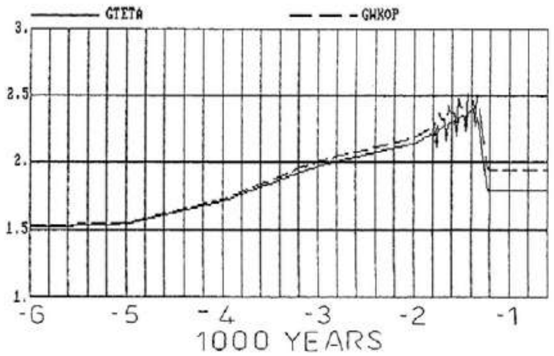

Figure 6: Wages and total income including transfers (author).

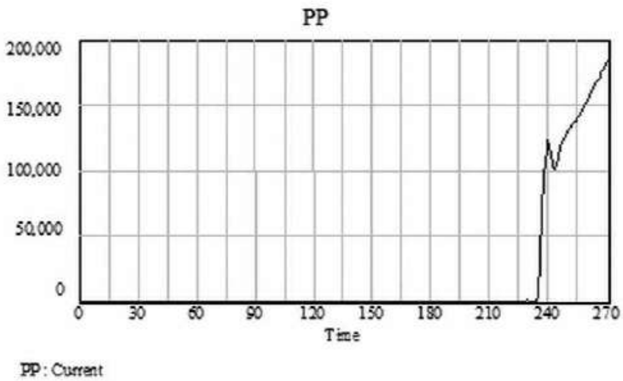

Figure 7: Accumulation of treasuries (author).

the author of the model the rationale for this is that weak institutions would be in danger of vanishing entirely if they pursue a strategy of saving. Only strong institutions have the power to establish a strategy of saving expenditure. The sensitivity analysis undertaken later, however, casts doubt on this explanation.

Implications of state formation

An empirical validation of the model involves showing that the model behaviour is trustworthy. If the model behaviour also shows similarities to archaeological data in other aspects, this would thus improve its validity. There are several aspects of the model which are consequences of the state formation. It can be seen in the further model analysis undertaken below that these consequences are also important for the analytic evaluation of the model.

Two consequences for living conditions for the working class can be observed in the model as soon as these centralised transfer institutions are established. After a long period of slowly but constantly growing wages, a sharp decline in wages can be observed at the moment the state is established. This is partly compensated, however, by a sudden increase in the transfers which the working-class gains from the PT system. Hence, this model behaviour is open to empirical testing. It is shown in Figure 6, where the black line represents the wages, while the dotted line represents the income including transfers.

A remarkable accumulation of treasuries can also be seen in the model, as displayed in Figure 7. In fact, this also seemed to be the case in the early history of the state (Lenski, 1973; Schaps, 2004). The model behaviour thus shows features that can also be observed in historical records.

Experimenting with theories

As noted above, the possibility of a critical examination and discussion of the mechanisms implemented in the model would improve its theoretical credibility. Theories which are open for rational discussion improve the chances of theoretical progress. Methodologically, this is a fundamental advantage of theory formulation with simulation models which have the potential for an experimental investigation of the theory (Dowling, 1999). They provide a framework for rational discussion. Following Outhwaite (1998) the objective of the experimentation is to 'keep on talking': the model runs using a causal chain of social mechanisms governing the process of distribution and redistribution. These mechanisms are not empirically validated but are taken from scale order considerations about plausible causal relationships. They rely on common sense knowledge. A sensitivity analysis will thus be undertaken for estimating the causal power of the mechanisms that are implemented in the model. This can be described as experimenting with the theory.

As indicated by the causal diagram above (Fig. 3), the model is primarily concerned with the process of distribution and redistribution of surplus. A close examination of these processes will therefore be undertaken with regard to the question of how the emergence of the state is affected by them. The objective of this model is investigating the dynamics of the variable PN, denoting the number of PTR positions created by the model. This is thus the dependent variable. The model starts with 2.5 positions (not persons) at the beginning. In the standard scenario 480 positions are created at the end. The mechanisms which generate these positions have to be investigated to understand the dynamics. In the first step this is done by varying the central parameters governing the processes of distribution and redistribution. The parameter values cannot be determined by empirical measurement. All that is possible is thus the postulation of plausible assumptions and gross estimates. This leads to the question mentioned at the beginning of this article: Is their causal power due to the specific values chosen for the parameters?

The investigation of the causal power is done by experimenting with a) the redistribution strategies, b) the distribution struggle between the landlords and the working class, c) the distribution struggle between economic and political elites, and d) the distribution to the working class. The causal power of the distribution struggle between the state and the landlords is investigated in two ways: first, the degree to which the state has access to the landlord's revenues is investigated, and second, the role of tax evasion is examined. Wage stickiness and the bargaining power of the working class is examined to determine the causal power of the amount of distribution to the working class as regards state formation. Certainly, further exploration is possible, for instance by taking interaction effects into account. Within the scope of this article, it might be sufficient to demonstrate that the single parameter variation already raises theoretical questions.

Experimenting with redistribution strategies

First, the process of redistribution will be investigated. For this purpose, the causal power of the strategies for redistribution, that is, the variables BPETA/PSOZQ, will be examined. The hypothesis that the model behaviour is determined by their nonlinear dialectic will be specifically tested. The question remains, however, about what would happen if they worked in the same direction. This is tested in two ways: firstly, the direction of PBETA

PBETA	0.13/0.44/1	1/0.44/0.13
PN	480	252

Table 1: Experimenting with redistribution strategy to enlarge the competence field.

PSOZQ	1/0.5/0.1	0.1/0.5/1
PN	480	258

Table 2: Experimenting with the redistribution strategy of saving revenue.

GORGQ	1.0	0.75	0.666	0.5	0.333	0
PN	520	505	498	480	480	480

Table 3: Experimenting with the distribution struggle between landlords and working class.

is changed, and secondly the direction of PSOZQ is changed the other way round. The results at the end of the run time of the model will be presented in the following, but not the dynamics. Only the final number of PNs are displayed.

In fact, the model behaviour is dependent on the opposing directions of these variables. It doesn't matter which variable is changed, but the dynamics are considerably slower if the variables are not opposing. This result casts doubt on the content-related assumption that only institutions have the power to enforce savings.

Distribution struggle between landlords and working class

It is assumed that there is a distribution struggle between landlords and the working class. The proportion of the produced value that the landlords receive is dependent on the degree of the working class's powerlessness, denoted by GWPOW. This term is calculated by comparing the number of unemployed and the size of the workforce potential, representing the idea that their power is stronger if there is a shortage of workforce potential. This is smoothed, however, by the degree of organisational intensity in the workforce, denoted as GORGQ. Although the term 'organisational intensity' is reminiscent of labour unions, which only emerged in the 19th century, this term is also an ideal type of possible social action, which could also imply, for instance, slave revolts. Since nothing is known about the organisational intensity of the workforce at the time of the emergence of the state, it is chosen by scale order as 0.5. The rationality behind this parameter value is that no reasons are known either in favour or against the assumption of an organisational alliance of the workforce, however, the causal power of the degree of the organisational intensity on the model results can be analysed using a sensitivity analysis.

Again, the term can vary between 0 and 1. Qualitatively, however, its effect on the value of PN can be ignored. This is because it affects the distribution struggle between the working class and the landlords, and not between the working class and the state. Common sense descriptions of modern societies support this assumption.

PNMXQ	1	0.9	0.8	0.75	0.5	0.25	0.1	0
PN	145	180	223	478	479	480	479	480

Table 4: Experimenting with the distribution struggle between the economic and political elite.

GTAXYQ	1	0.75	0.5	0.25	0
PN	480	480	480	480	480

Table 5: Experimenting with tax evasion.

Distribution struggle between the economic and political elite. It is highly plausible, and supported by historical evidence, that there was a distribution struggle between the economic and political elite. This is modelled as a conflict between the landlords and the state. The conflict is described as the degree to which the state has access to the budget of the landlords. This is dependent on a variable denoted as GPOLWW. This variable is calculated endogenously, dependent on the desired budget of the state. Its demand is then calculated by the demand for the alimentation of its subordinates. The variable PNMXQ, however, is a crucial term that can be varied. It denotes the propensity to realise the budgetary maximum number of PTRs together with their personnel. In the standard scenario its value is chosen as 0.25.

The sensitivity analysis shows that the self-organising capacity of state formation is highly dependent on the power relationship between the economic and political elite. Its dynamics, however, is surprising: PNMXQ is a constant in a linear combination for calculating the desired number of PTRs with the maximum (PNMAX) and the actual PTR number (PN) as arguments:

7) PNMX = PNMXQ*PNMAX + (1 – PNMXQ)*PN

Thus, in the case of PNMXQ = 1 this is reduced to PNMX = PNMXQ*PNMAX. In the case of PNMXQ = 0 a value of PNMX = PN remains. Surprisingly, the dynamics of state formation are much stronger in the latter case. If its demand is oriented to the maximum possible amount, the state remains at a weak level. The model is also highly sensitive with regard to the chosen parameter value: there is a threshold between 0.8 and 0.75. Between these values the state formation process is switched on and does not change any more with the further variation of PNMXQ. According to common sense knowledge, there is no doubt that power relations between political and economic elite are very important. Globalisation is just an actual example. Nevertheless, it is an interesting result, that the state has more power if it orients itself to facts and not to fictions: when PNMX depends on PN. Perhaps this can be interpreted as meaning that state operations are more effective in this case. This result, however, is hard to evaluate with common sense knowledge alone, and requires more detailed empirical study.

Tax evasion. It is assumed that landlords attempt to undertake tax evasion. This, however, is subject to a distribution struggle. This is denoted as GTAXYQ: if the tax collector demands GPOLWW at the landlords' site, a quota of GTAXYQ·GPOLWW is concealed. In

GWSPR	50%	10%	7%	5%	3%	2.5%	2%	1.75%	1.5%	0%
PN	480	480	480	480	480	480	483	148	145	147

Table 6: Experimenting with wage stickiness.

the standard scenario, the degree of GTAXYQ is chosen as 0.5. Again, the rationale for this choice of numerical value is the absence of any knowledge. This can thus be varied to investigate its causal power.

Surprisingly, the sensitivity analysis shows that tax evasion has no causal power in the process of state formation in the model. At first sight, this result is counterintuitive. Common sense knowledge would indicate that the state is financed by taxes. Tax evasion should thus be highly relevant. However, the factual result is due to the modelling approach: GTAXYQ is merely the effect of the PT's request on the landlords' access to the produced value, and not the mechanism of distributing values to the PT system. The PT system gains what is left after the distribution to the working class and the landlords. Only in addition, the PT receives the quota of the taxes that are handed out from the landlords to the PT system.

Distribution to the working class

The working class has the first access priority to the produced value. The amount distributed to the working class depends on the average wage level. The wage level at time t is calculated as the wage level at (t-1) + the change from (t-1) to t. History is also taken into account. Note that the change can also be a negative term. It cannot fall, however, below the threshold of the necessary standard of living. The change in wages, denoted as GTETAV, is calculated by assumptions based on plausibility and scale order considerations. The driving factors for this change will be analysed. They depend in particular on the bargaining power of the working class and wage stickiness.

Wage stickiness. It is a plausible hypothesis that wages cannot be lowered within one time step below a certain threshold. In the standard scenario of the model, it is assumed that in case of a negative wage change GTETAV, wage lowering cannot exceed 5%. This is denoted as GWSPR. It seems to be plausible that wages cannot be lowered to extremes within a time step of one year. Common sense knowledge indicates that a dramatic lowering would lead to massive protest. The time steps in the model, however, are not one but 20 years, to indicate one generation. Nevertheless, it seems reasonable to investigate the causal power of this assumption using a sensitivity analysis.

The experiment reveals that this variable has a remarkable effect: there is a threshold between 2% and 1.75%. Except for the minimal change between 2.5% and 2% wage lowering, which is due to chaotic fluctuations, a further reduction (more than 2%) has no effect. The ability to reduce wages at all, however, has a dramatic influence. Bearing in mind that one time step consists of 20 years, it seems to be highly plausible that lowering wages by 2% is the least possible option. It can be questioned, however, whether such a threshold is likely in social reality. As we have seen in the standard scenario, in fact, wages are lowered at the advent (it's beginning) of the state. Now we see that, according to the model, this is not arbitrary, but a necessary condition for state formation.

GWPOWC	1.00	0.9	0.857	0.7	0.5	0.3	0
PN	2.75	65	480	481	562	703	703

Table 7: Experimenting with the bargaining power of the working class

Bargaining power of the working class.

It is also a plausible assumption that the amount the working class receives is dependent on their bargaining power.[2] In the model this is specified as a constant added to the term by which GTETAV is calculated. Its value is GWPOWC = 0.857. Obviously, this is not an empirical value, and to investigate the causal power of the variable, it has to be investigated inasmuch as the model results depend on the arbitrariness of this assumption. GWPOWC is a factor regulating what is really handed out to the working class from the maximum possible amount. Its value can thus vary between 1 and 0.

The model results show a high sensitivity with regard to the variable 'bargaining power of the working class'. In fact, no other variable is able to vary the results as much as this variable does. Since the working class has the first access priority to the produced values, however, this seems to be quite plausible: a value of GWPOWC = 1 means that the working class receive the maximum possible amount of goods, while a value of GWPOWC = 0 means that wages cannot rise above the threshold of the subsistence minimum. The model shows that in the former case (GWPOWC = 1) the number of PTR positions remains at its starting value. If all goods are consumed by the working class, nothing is left to allot to the PT system. In the latter case (GWPOWC = 0), the maximum possible number of positions can be created under the conditions of the given level of productivity.

There seems to be a threshold between the values 0.9 and 0.857 and between the values 0.5 and 0.3: between 0.5 and 0.3 the subsistence minimum is reached, so a further reduction of the bargaining power has no effect anymore. More interesting is the threshold between 0.9 and 0.857: this can be interpreted that the process of self-organising can enfold its autocatalytic power only if a certain level of already created positions is reached. Presumably, in this case the dynamics of the interaction between the variables governing the redistribution process are getting important. This can only affect the model behaviour if redistribution is actually taking place, and this can only be the case if a certain level of positions is created to perform this redistribution.

Discussion: from weak to strong evaluation

The theory can be defined as a structuralist theory: no assumptions are made about the specific competence fields of the PTs. Only the conditions for the operations of a PT are under consideration. This implies that contextual factors, for instance, geographical factors such as river valleys, remain out of the scope of the model. The model favours none of the competing theories of the emergence of the state but merely investigates the self-organisation processes of emerging positions which are modelled by stylised hierarchies. The model can be seen as a baseline of minimal conditions. For instance, the distinction between productive and non-productive members of the society might not be that clear-cut

2 In contrast to the distribution struggle between the landlords and working class, this value involves the total amount of produced goods.

in reality. The model is an ideal type of a precise (and even deterministic) terminology. Certainly, in empirical reality the mechanisms implemented in the model are superimposed with numerous other factors, however, the model provides a standard of comparison in a Weberian sense.

The model assumptions can be seen as mechanisms in the sense outlined, for example, by Bunge (2004). They are simple assumptions with a seemingly high degree of plausibility according to common sense knowledge. The strength of their effect, however, can be estimated only roughly. This is quite a typical situation in archaeological modelling. In this case a sensitivity analysis provides the means for an investigation of the causal power of these assumed mechanisms. Opening the way for a critical examination of the model assumptions means that a sensitivity analysis could contribute to the investigation of social mechanisms in general. Even though the research does not lead to a single number, expressing the model validity, it might work as guidelines for theoretical discussions. According to Richardson (2003), a sensitivity analysis of the parameter values of the model opens a way from weak to strong evaluation. The following remarks will thus suggest some possible directions for further discussions arising from this model analysis.

The central results can be summarised in the following way. The emergence of the state is highly dependent on their bargaining power and wage stickiness of the working class. It also depends on the power relations between the political and economic elite. Furthermore, they depend on the strategies of how redistribution is performed. The question, called a test of sufficiency for social mechanisms, was whether the qualitative model behaviour is robust within a degree of tolerance prescribed by common-sense knowledge.

1) The high sensitivity of the bargaining power of the working class seems to be plausible: it is known that there are societies where no state emerges even though the level of productivity would allow for it (Mann, 1990). The emergence of the state is not a necessary consequence of rising productivity. This, however, has to rely on material assumptions about the social reality. This is the most important finding of the sensitivity analysis. The importance of wage stickiness requires empirical evidence: if it can be empirically demonstrated that there is a correlation between the emergence of the state and lowering of wages, then this theory offers an explanation for it. This calls for future empirical examinations which could link theoretical and empirical work.

2) According to common sense knowledge, there is no doubt that power relations between political and economic elite are very important. Nevertheless, it is an interesting result, that the state has more power if it orients itself on facts and not on fictions: when PNMX depends on PN, and not on PNMAX. This result is hard to evaluate simply with common sense knowledge but requires more detailed empirical studies.

3) Finally, the strategies of redistribution proved to be effective. Even though the model is more sensitive to the variation of other variables, the opposing direction of the redistribution strategies is important for the model result. A sociologically surprising effect of the experiment was that it doesn't matter which variable is changed: the simulation results are more or less identical if both variables PBETA and PSOZQ act to increase the competence field, or if they both react with saving strategies in the case of budget shortening. One could guess that the dynamics of state formation would even be stronger if a drive to enlarge the competence field is implemented in both variables. This is not the case. Nevertheless, the computational effects of their nonlinear interaction are important for the model behaviour. This is again a theoretical finding which calls for future empirical work.

It will be demonstrated in one brief example below that the model shows how contextual factors, including geographical ones, transform into social forces. The strong causal power of the working class on state formation suggests a comparison with empirical findings. Archaeological theory cannot provide an unambiguous answer about why states emerged. But nevertheless, a causal analysis is the main task of archaeological explanations. It has already been emphasised that there are several theories, stressing different aspects. For instance, the theory outlined by Carneiro (1970) was inspired by a comparison between the Amazon region and the Andes mountains. In the Andes mountains the Inca empire grew, and in the Amazon no state emerged. However, Carneiro emphasised that sufficient surplus had been produced in both regions for the emergence of positions that could be released from food production. This happened in the Andes, but not in the Amazon. Carneiro's explanation was that the Andes were a strictly circumscribed territory: on the one side were the mountains and on the other side the Pacific Ocean. Only a small region suitable for agricultural food production remained. This territory could easily be conquered, and people had no chance to move elsewhere where it still was possible to produce food. In the Amazon in contrast, extensive amounts of food could be found nearly everywhere. The dense jungle provided conditions in which it was easy to flee. Small distances are sufficient to disappear untraceably. Carneiro's theory was controversially debated as emphasising geographical factors and the role of violence. In the light of this simulation model however, the Andes mountains and the Amazon can be regarded as contrasting examples of the bargaining power of the working class. In the Andes they only had low bargaining power, in the Amazon their bargaining power was high. As revealed by the sensitivity analysis of this model parameter, a state emerged in one region, but not in the other. The model's theoretical framework thus discovered a social mechanism behind contextual factors.

Conclusions and future work

To summarize, we have hopefully demonstrated that a sensitivity analysis allows an analysis of the causal power of social mechanisms. While the importance of contextual factors in empirical realisations of processes of state formation shall by no means be denied, the model provides a baseline of minimal conditions for investigating only the effects of processes of self-organisation which are more blurred in the empirical mix of different factors. This opens a way to connect theoretical and empirical investigations in future work. The results of the sensitivity analysis provide data that can be compared with empirical data and therefore function as advice for comparative empirical studies. Causal analysis therefore enables theory building to be connected to empirical research and enlighten a rational discussion of controversial intuitions behind grand social theories.

Only one cursory example could be provided in this article to correlate the theoretical assumptions with empirical findings. The results presented here are only a first step: future work needs to include interdisciplinary research to examine in more detail whether and how these assumptions are substantiated or questioned by empirical data and vice versa, and how empirical findings about contextual factors can be interpreted as social mechanisms within the framework of these assumptions.

References

Aldenderfer, M.S., 1981. Computer simulation for archaeology: An introductory essay. In: J.A. Sabloff, ed., *Simulations in Archaeology*. Albuquerque, NM: University of New Mexico Press, pp.67-118.

Aldenderfer, M.S., 1998. Quantitative methods in archaeology: A review of recent trends and developments. *Journal of Archaeological Research*, 6, pp.91-120.

Balci, O., 1994. Verification, validation, and testing techniques throughout the life cycle of a simulation study. *Annals of Operations Research*, 53, pp.121-173.

Barker, G., 2007. *The Agricultural Revolution in Prehistory: Why Did Foragers Become Farmers?* Oxford: Oxford University Press.

Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, 12(3), pp.183-210.

Bayman, J., 2002. Hohokam craft economies and the materialisation of power. *Journal of Archaeological Method and Theory*, 9(1), pp.69-95.

Bunge, M., 2004. How does it work? The search for explanatory mechanisms. *Philosophy of the Social Sciences*, 34(2), pp.182-210.

Campagno, M., 2004. In the beginning was the war: Conflict and the emergence of the Egyptian state. In: S. Hendrickx, R.F. Friedman, K.M. Ciałowicz and M. Chłodnicki, eds., *Egypt at Its Origins: Studies in Memory of Barbara Adams*. Leuven: Peeters, pp.689-703.

Carneiro, R., 1970. A theory of the origin of the state. *Science*, 169, pp.733-738.

Childe, V.G., 1936. *Man Makes Himself*. London: Watts.

Damerow, P., Englund, R.K. and Nissen, H.J., 1988. Die Entstehung der Schrift. *Spektrum der Wissenschaft*, 2, pp.74-85.

Dean, J., Gumerman, G., Epstein, J., Axtell, R., Swedlund, A., Parker, M. and McCarroll, S., 2000. Understanding Anasazi cultural change through agent-based modelling. In: T.A. Kohler and G.J. Gumerman, eds., *Dynamics in Human and Primate Societies*. Oxford: Oxford University Press, pp.90-116.

Dietz, E., 2009. *Geschichte Mesopotamiens: Von den Sumerern bis Alexander dem Großen*. München: Beck.

Doran, J. and Palmer, M., 1995. The EOS project: Integrating two models of Palaeolithic social change. In: N. Gilbert and R. Conte, eds., *Artificial Societies: The Computer Simulation of Social Life*. London: UCL Press, pp.103-125.

Dowling, D., 1999. Experimenting on theories. *Science in Context*, 12(2), pp.261-273.

Dye, R., 1976. *Who's Running America? Institutional Leadership in the USA*. Englewood Cliffs, NJ: Prentice Hall.

Earle, T., 2004. Culture matters in the Neolithic transition and emergence of hierarchy in Thy, Denmark: Distinguished lecture. *American Anthropologist*, 106(1), pp.111-125.

Edmonds, B., Le Page, C., Bithell, M., Chattoe-Brown, E., Grimm, V., Meyer, R., Montañola-Sales, C., Ormerod, P., Root, H. and Squazzoni, F., 2019. Different modelling purposes. *Journal of Artificial Societies and Social Simulation*, 22(3), p.6. Available at: https://www.jasss.org/22/3/6.html [Accessed 19 December 2024].

Elster, J., 1989. *Nuts and Bolts for the Social Sciences*. New York: Cambridge University Press.

Hare, M. and Pahl-Wostl, C., 2001. Model uncertainty derived from choice of agent rationality. In: N. Giambiasi and C. Frydman, eds., *Simulation in Industry – Proceedings of the ESS 2001 Simulation Symposium*. Marseille: SCS.

Hedström, P. and Swedberg, R., eds., 1998. *Social Mechanisms: An Analytical Approach to Social Theory*. Cambridge: Cambridge University Press.

Knitter, D., Günther, G., Hamer, W., Keßler, T., Seguin, J., Unkel, I., Weiberg, E., Duttmann, R. and Nakoinz, O., 2019. Land use patterns and climate change: A modelled scenario of the Late Bronze Age in southern Greece. *Environmental Research Letters*, 14(12), p.125003.

Koehler, C., 2010. Theories of state formation. In: W. Wendrich, ed., *Egyptian Archaeology*. Chichester: Wiley, pp.36-54.

Lake, M., 2010. The uncertain future of simulating the past. In: A. Costopoulos and M. Lake, eds., *Simulating Change: Archaeology into the Twenty-First Century*. Salt Lake City, UT: University of Utah Press, pp.12-20.

Lake, M., 2014. Trends in archaeological simulation. *Journal of Archaeological Method and Theory*, 21(2), pp.258-287.

Lenski, G., 1973. *Macht und Privileg: Eine Theorie der sozialen Schichtung*. Frankfurt a.M.: Suhrkamp.

Lipset, S., 1959. Political sociology. In: R. Merton, L. Broom and L. Cottrell, eds., *Sociology Today: Problems and Prospects*. New York: Basic Books.

Magnusson, M., 2020. T-patterns, external memory and mass-societies in proteins and humans: An eye-blink the naked ape became a string-controlled citizen. *Physiology & Behavior*, 227, p.113146. Available at: DOI:10.1016/j.physbeh.2020.113146 [Accessed 19 December 2024].

Mann, M., 1990. *Geschichte der Macht. Bd. 1*. Frankfurt a.M.: Campus.

Mayntz, R., 2004. Mechanisms in the analysis of social macro-phenomena. *Philosophy of the Social Sciences*, 34(2), pp.237-259.

Mithen, S., 1994. Simulating prehistoric hunter-gatherer societies. In: N. Gilbert and J. Doran, eds., *Simulating Societies*. London: UCL Press, pp.165-194.

Mueller, N., 1979. *Empirische Herrschaftstheorie: Zur Beziehung zwischen Kontextdifferenzierung, politischer Herrschaft und politischer Sozialisation*. Köln: Westdeutscher Verlag.

Mueller, N., 1985. Real structure modelling: A methodology for the description of large-scale social units. *Social Science Information*, 24(3), pp.603-624.

Mueller, N., 1989. *Civilization Dynamics, Vol. 1: Fundamentals of a Model Oriented Description*. Aldershot: Avebury.

Mueller, N., 1991. *Civilization Dynamics, Vol. 2: Nine Simulation Models*. Aldershot: Avebury.

Oppenheimer, F., 1926. *The State*. New York: Vanguard.

Oreskes, N., Shrader-Frechette, K. and Belitz, K., 1994. Verification, validation, and confirmation of numerical models in the earth sciences. *Science*, 263, pp.641-646.

Outhwaite, W., 1998. Realism and social science. In: M. Archer, R. Bhaskar, A. Collier, T. Lawson and A. Norrie, eds., *Critical Realism: Essential Readings*. London: Routledge, pp.282-296.

Richardson, K., 2003. On the limits of bottom-up computer simulation: Towards a nonlinear modelling culture. *Proceedings of the 36th Hawaii International Conference on System Sciences*. Big Island, HI: IEEE Computer Society Press.

Richardson, K.A., Mathieson, G. and Cilliers, P., 2000. The theory and practice of complexity science: Epistemological considerations for military operational analysis. *SysteMexico*, 1, pp.25-66.

Sahlins, M., 1963. Poor man, rich man, big man, chief: Political types in Melanesia and Polynesia. *Comparative Studies in Society and History*, 5(3), pp.285-303.

Schaps, D., 2004. *The Invention of Coinage and the Monetarization of Ancient Greece*. Ann Arbor: University of Michigan Press.

Schelling, T., 1971. Dynamic models of segregation. *Journal of Mathematical Sociology*, 1, pp.143-186.

Skyrms, B., 1996. *Evolution of the Social Contract*. Cambridge: Cambridge University Press.

Skyrms, B., 2004. *The Stag Hunt and the Evolution of Social Structure*. Cambridge: Cambridge University Press.

Spencer, C., 2010. Territorial expansion and primary state formation. *Proceedings of the National Academy of Sciences*, 107(16), pp.7119-7126.

Spencer, H., 1967. *The Evolution of Society: Selections from Herbert Spencer's Principles of Sociology*. Chicago: University of Chicago Press.

Watkins, T., 2009. From foragers to complex societies in southwest Asia. In: C. Scarre, ed., *The Human Past: World Prehistory and the Development of Human Societies*. London: Thames & Hudson, pp.201-233.

Weber, M., 1968. Die Objektivität sozialwissenschaftlicher und sozialpolitischer Erkenntnis. In: J. Winckelmann, ed., *Max Weber – Gesammelte Aufsätze zur Wissenschaftslehre*. Tübingen: Mohr, pp.148-161.

Wimsatt, W., 1994. The ontology of complex systems: Levels of organisation, perspectives, and causal thickets. *Canadian Journal of Philosophy*, 24(suppl. Vol. 1), pp.207-274.

Wright, H.T., 1998. Uruk states in southwestern Iran. In: G.M. Feinman and J. Marcus, eds., *Archaic States*. Cambridge: Cambridge University Press, pp.173-197.

Wright, R., 2010. *The Ancient Indus: Urbanism, Economy and Society*. Cambridge: Cambridge University Press.

Yilmaz, M., 2006. *Diploma Thesis*. Osnabrück.

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