Invention as a Process: Pyrotechnologies in Early Societies

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The identification and analysis of invention is fundamental to understanding early societies. Yet invention tends to be only sporadically addressed by archaeologists, and then usually only within broader studies of innovation. Doubts concerning the ability of the archaeological record to yield data of sufficient quality to investigate invention, together with the perception that the concept leads inevitably to nineteenth-century societal narratives of technological progress, remain widespread. This paper reviews the theoretical approaches to invention in early societies with a particular focus on pyrotechnologies. It highlights the papers within this special section, which demonstrate the capacity of an integrated approach incorporating materials science, archaeology and archaeological theory to understand the processes of both invention and innovation underlying the appearance of pyrotechnologies and their relationships to early societies throughout Europe, Africa, Asia and South America. It is argued that the importance of historical and contemporary debates on inventions, innovations and societies across the world continues to increase—and will do so with or without the active contribution of archaeologists.

Introduction

This special section seeks to challenge the widespread negative perceptions surrounding invention in the archaeology of early societies. Invention is typically thought of as being too ephemeral to be recorded or analysed as well as being too closely bound up with deterministic ideas of social evolution through technological progress. One inescapable consequence of these nineteenth- and early twentieth-century technological schemes is the continued use of temporal labels and frameworks for early societies throughout Europe, Asia and Africa, founded upon the inventions and innovations of pyrotechnologies (see Díaz-Andreu 2007; Roberts *et al.* 2013; Rowley-Conwy 2007). Yet the durability of the inorganic products and residues from pyrotechnologies, together with their traditional importance within archaeological scholarship, means that they continue to be at the core of modern archaeological narratives of early societies across the world.

The spatial analysis of large-scale interaction in world archaeology—whether trade systems, archaeological cultures or migration—invariably draws upon the earliest presence of pyrotechnologies or their products (see Oka & Kusimba 2008; Roberts & Vander Linden 2011). The analysis of social identities and sociopolitical structures frequently concentrates upon the differences in the funerary or ritual use of ceramics and metals, or the proficiency of an individual or community in making, obtaining or trading them (e.g. Feinman & Price 2010; Flannery & Marcus 2012; Wailes 1996). Understanding the invention of pyrotechnologies within early societies evidently remains important. Yet there are lingering questions of whether pyrotechnological inventions can be identified in the archaeological record and also whether their analysis leads inevitably either to reconstructing flawed models and metaphors for technological advancement (see Gamble 2007) or to speculative ideas drawn from ancient mythology (e.g. Eliade 1962).

It is argued that both pyrotechnological invention and innovation can be identified and understood within early societies and that this is demonstrated by the papers within this special section. The range of the papers spans the creation of ceramics, copper, gold,

Cambridge Archaeological Journal 25:1, 299–306 © 2015 McDonald Institute for Archaeological Research
doi:10.1017/S0959774314001188

https://doi.org/10.1017/S0959774314001188 Published online by Cambridge University Press

tin-bronze, iron, glass and glaze throughout Europe, Africa, Asia and South America. They show that an integrated inter-disciplinary approach, incorporating materials science, archaeology and archaeological theory allows a deeper understanding of the processes in transformation of clays, ores and sands into ceramics, metals, glasses and glazes.

Understanding pyrotechnologies

Pyrotechnology is defined as the 'deliberate processes utilizing the control and manipulation of fire' (McDonnell 2001, 493) or more simply 'the use of fire as a tool' (Bentsen 2013). The term is frequently used in respect of high-temperature processes involved in the production of inorganic materials (e.g. McDonnell 2001), but can also be used in respect of earlier habitual and controlled uses of fire for cooking, heating, light and other activities (e.g. Bentsen 2013). The uses and impacts of fire upon human evolution are ongoing debates (e.g. Bentsen 2013; Brown *et al.* 2009; Wrangham 2009; Wrangham & Carmody 2010) and it is the interaction of high-temperature processes and inorganic materials that is addressed within this special section.

There has long been a traditional disciplinary emphasis on the where and when of the earliest high-temperature pyrotechnologies. These two questions have provided a major focus for fieldwork, laboratory analysis and occasionally experimental replication by several generations of material scientists, chemists and geologists (e.g. Craddock 1995; Gourdin & Kingery 1975; McDonnell 2001; Rehder 2006; Tylecote 1987; Wertime 1964; Wertime & Wertime 1982, to name just a few). The societal revolutions underpinned by the introduction of new pyrotechnologies as proposed by earlier, yet still highly influential, archaeologists such as V. Gordon Childe (1930; see Trigger 1986) have been exposed as largely speculative. However, the contribution of these pioneer archaeological scientists beyond this traditional emphasis to investigate how and why early pyrotechnologies were created was, with notable exceptions such as Cyril Stanley Smith and his students (e.g. Kingery *et al.* 1988; Lechtman 1980; Smith 1981; Thornton 2009), frequently limited to explanations grounded in technical constructions (e.g. kilns and furnaces); technical thresholds (e.g. temperature and atmosphere); resource exploitation (e.g. fuel and raw materials); and rational economic behaviour (e.g. least cost benefit and labour mobilization).

These traditional explanations were critiqued extensively by theoretically orientated archaeologists for treating the technologies and materials in isolation and are far too disengaged from the societal context in which they were produced, used and understood (Dobres 2000; Dobres & Hoffman 1994; 1999; Lemonnier 1993; Pfaffenberger 1992). Yet as more recent scholarship has demonstrated convincingly, pyrotechnologies can provide the detailed data required to evaluate how and why technological changes occurred within human history. The choices underlying the observed sequences of transformative actions on materials performed by individuals and communities can be reconstructed and subsequently compared across space and time as well as within their environmental, physical and social contexts (e.g. Miller 2007; Roux 2003; Shimada 2007).

However, the archaeometric data and discussions, relating in this particular case to early pyrotechnologies, are usually published primarily in journals such as *Journal of Archaeological Science* or *Archaeometry*. The technical presentation of archaeometric findings is either not understood or simply not engaging the majority of mainstream archaeologists. The consequence is that major advances in understanding pyrotechnological inventions and innovations in early societies have simply not reached a broader archaeological audience. Though the relationship between archaeology and archaeomaterials research remains the subject of intense debate, the aim to analyse materials and technologies and investigate how were they shaped by past societies is no longer in doubt (e.g. Jones 2004; Killick & Fenn 2012; Martinón-Torres & Rehren 2008; Pollard & Bray 2007; Shimada & Wagner 2007).

Defining invention and innovation

Invention is frequently defined as the discovery of a new idea, material or process, deliberately or by chance (cf. Renfrew 1978; see Killick this volume; Radivojević this volume). An invention may include a radically new product as much as a recombination of technological components in a novel manner (Basalla 1988; Nelson & Winter 1982; Weber *et al.* 1993). Alternatively, an invention may involve the application of an existing technology to a new purpose (Fleming & Sorenson 2004; Henrich 2010).

It has been frequently argued that when an invention affects the evolution of the system and is successfully transmitted within a population, and beyond, it is recognized as an innovation (e.g. Henrich 2001; O'Brien & Shennan 2010a; Ottaway 2001; Renfrew 1978; 1986; Torrence & van der Leeuw 1989). A technological innovation itself is not usually only a monolithic entity, but an 'amalgam of units', or a 'recipe' containing ingredients required to make an object (Lyman & O'Brien 2003; Mesoudi & O'Brien

https://doi.org/10.1017/S0959774314001188 Published online by Cambridge University Press

2008; Neff 1992; 1996; O'Brien & Shennan 2010b). In a technological context, this recipe is a list of what, how, and when to make something, and for how long (Krause 1985).

Michael Schiffer (2005; 2010; 2011) proposes a more nuanced definition of invention, arguing that invention is 'the creation of an idea or vision for a technology that has performance characteristics—often use-related ones—differing from those of other technologies' (Schiffer 2011, 36). The emphasis on invention as the idea, rather than the materialization of the idea, is more common within industry and commerce, where 'invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice' (Fagerberg 2004, 3; see Schumpeter 1939). However, there remain disagreements within these disciplines, as there are within archaeology, as to whether invention should also encompass the realization of the idea (e.g. Rogers 1962; 2003; *contra* Wiener 1993). Similar ambiguities and debates in the definition and evidencing of an invention also underlie the development of modern patent law (Pottage & Sherman 2010). Indeed, the intellectual history of the terms 'invention' and 'innovation' reveals ever-shifting definitions, meanings and applications relating to the societies in which they were used (Godin in press). It is worth remembering that the successful rehabilitation of innovation in archaeology by Robin Torrence and Sander van der Leeuw (1989) started with an admission of its being 'a topic that is certainly not new and which, from the perspective of modern social anthropology, thankfully died years ago' (van der Leeuw & Torrence 1989, 1).

Establishing the provenance of an idea is significant challenge, even in industrial societies where a detailed and diverse range of evidence is available for analysis (e.g. Moon 2014). The single moment of individual inspiration, later mythologized and elevated into the canon of hero-inventors, has long been deconstructed and discredited as a concept—even for Archimedes (see Dalley & Oleson 2003; Greene 2009)—as the social networks and dynamic processes underlying each invention have been revealed (e.g. Arthur 2009; Latour 2005; Lienhard 2006; Moon 2014; Schiffer 2010; 2011, 57–85).

The frequently poor data quality and dating resolution that characterize the archaeology of early societies—especially when compared to more recent industrial societies—would seem to present a significant obstacle to analysing inventions as defined solely as ideas. The archaeological record reveals the materialization of ideas, and therefore, from this perspective, the innovations, rather than the inventions (see Ingold 2007; Jones 2004; Lemonnier 2012; Malafouris 2013; Meskell 2005; Miller 2005; Renfrew *et al.* 2005). However, it is argued that the time-depth of the archaeological record can, with sufficient data resolution, provide the possibility of investigating the accumulation of knowledge or process components preceding and underlying the invention of a particular technique or material. These would be observable through experiments, re-combinations, or re-applications (to a new purpose) over a period of several decades, centuries or millennia (Basalla 1988; Henrich 2010; Lienhard 2006; Weber *et al.* 1993).

Taking invention as the appearance of a new idea, process or material, the differentiation between an invention and an innovation within pyrotechnologies is potentially far less ambiguous than in other aspects of past human activities in the archaeological record. As the papers within the special section demonstrate, targeted archaeological fieldwork and surveys enable the careful recovery and scientific dating of sequences of durable inorganic residues of pyrotechnologies—including those prior to the successful invention or innovation. These include slags and crucible fragments which have frequently been missed by archaeologists, due to their small size, anonymous and aesthetically unappealing appearance. The subsequent use of materials science can determine if a specific new material or technology has been created and can identify the raw materials and conditions involved in any pyrotechnological transformation, if one has indeed taken place. It is only through archaeometric analysis that this information can be achieved, as superficial assumptions have frequently been demonstrated to have been incorrect.

Rather than primarily seek to identify patterns, as is usual in archaeological approaches to material culture and technology (see Roberts & Vander Linden 2011), the approach taken in materials science seeks instead to identify and investigate anomalies, thus enabling the evidence of inventions to be evaluated more easily. These exceptional anomalies are not only preserved in the durable inorganic residues of pyrotechnologies; they are also identifiable. The conceptualization of invention as a process—rather than a singular event—as has been extensively explored in archaeology by Schiffer (2005; 2010; 2011, 57–85) upon mainly modern technologies, enables the anomalies to be placed within the choices and sequences of transformative actions underlying each pyrotechnology.

Pyrotechnological invention as a process

The transformation of matter—a fundamental prerequisite in the invention and innovation of a pyrotechnology—requires a shift in the community

https://doi.org/10.1017/S0959774314001188 Published online by Cambridge University Press

perception of the natural environment as specific rocky outcrops, riverbanks and coasts are newly understood and exploited for appropriate raw materials in the pyrotechnological processes (cf. Boivin & Owoc 2004). This is clearly demonstrated in the shift in the sourcing, collection and use of copper minerals for decoration and use of copper ores (minerals actually smelted) to produce metals by communities in the Balkans (Radivojević this volume). The selection of the raw materials for pyrotechnologies reveals societal choices being made from a range of technologically feasible possibilities. Whether this is the selection of the black and green, rather than green, copper ores in the Balkans (Radivojević this volume) or the use of calcite and basalt as temper in the earliest ceramics of the Near East (Gibbs this volume), it is evident that specific raw materials and their sources are being repeatedly chosen for properties deemed suitable to make desirable objects (cf. Knapp *et al.* 1998).

The importance of colour, both in this raw material selection process and the in shaping of the final pyrotechnological product, should not be underestimated (cf. Jones & MacGregor 2002; Smith 1981). In raw materials, this is seen in the Balkans where it led to the creation of a natural tin-bronze alloy nearly three millennia before the widespread adoption of tin-bronze in the region (Radivojević this volume; Radivojević *et al*. 2013). The desire for specific colours also seems to have underpinned the invention of metals such copper, gold and tin-bronze in the Balkans (see Leusch *et al.* this volume; Radivojević this volume) as well as gold in South America (Martinón-Torres & Villegas-Uribe this volume).

The invention and innovation of pyrotechnologies requires that ideas extend across available multiple technologies and materials. These cross-craft and cross-material relationships (cf. Card 2013; Frieman 2012; Lechtman 1996; Miller 2007; Rebay-Salisbury *et al.* in press; Shimada 2007)—in particular the underlying influence of different pre-existing materials, technologies and forms—are especially important. This can be seen in the basket, textile bag and groundstone and wooden bowl production prior to ceramics in the Near East (Gibbs this volume; Read & van der Leeuw 2008); metals and metallurgy prior to glass and glazes (Fenn this volume); copper metallurgy prior to metallurgy of gold (Leusch *et al.* this volume); or beeswax prior to lost-wax casting in gold in South America (Martinón-Torres & Villegas-Uribe this volume). However, these cross-craft and cross-material relationships are not always present or identifiable—as in the converse absence of any secure evidence for the firing of clay prior to ceramics in East Asia (Gibbs this volume) or the use of charcoal as a prerequisite for the earliest metallurgy (Roberts *et al.* 2009; Roberts & Thornton 2014).

The potential for pyrotechnological inventions and innovations to occur several times within a similar timeframe throughout the world is evident—proposed for both ceramics in the Near East and East Asia (see Gibbs this volume) and copper and tin-bronze in the Balkans (see Radivojević this volume). As Roux (2003; 2010) demonstrates clearly with wheel-thrown pottery in the East Mediterranean and Radivojević *et al.* (2013) show with tin-bronze in the Balkans, it is certainly possible for specific inventions and innovations apparently to fall out of use, and subsequently re-appear, after significant periods of time. The punctuated, rather than continuous, rate of change within pyrotechnologies is closely related to: the close interaction of the physical properties of materials; the constraints within the environment; the social practices surrounding their production process; and the broader societal dynamics (Martinón-Torres & Rehren 2009; Sillar & Tite 2000; Tite *et al.* 2001). For instance, Killick (this volume) argues persuasively that the multiple inventions of iron smelting in Africa, which emerged in very different environments, do not become successful innovations due to three key factors: population density (e.g. towns and cities), geographical routeways (e.g. rivers and navigable land routes) and literacy. Also, the invention of pottery does not have the same trajectory for hunter-gatherer communities as it does for sedentary farmers (see Gibbs this volume), and neither does it have the same rates and pathways of innovation adoption and transmission (Eerkens & Lipo 2014).

Inventing the past

It is argued that archaeologists in recent decades have been reluctant to engage with the concept of invention in early societies. This is not only due to the partial nature of the archaeological record, which frequently reveals earlier dates for defined phenomena as investigations intensify, but also to the intellectual baggage of technological determinism. The social evolutionary schemes of Lubbock (1872), Morgan (1985) and others, whereby 'inventions and discoveries stand in serial relations along the lines of human progress, and register its successive stages' (Morgan 1985, vi), casts a long shadow. The subsequent proposals of the hyper-diffusion of inventions across the globe from mother civilizations such as Egypt by G. Smith (1930) or a refined classification scheme of technological stages within social evolutionary schemes (cf. Childe 1944) have contributed to this intellectual unease.

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The more recent exploration of the socially constructed underpinnings to modern understandings of technology and a more in-depth recognition of technology as a socially embedded phenomenon (e.g. Dobres & Hoffman 1994; 1999; Lemonnier 1993; 2012; Schiffer 2001) has reinforced the suspicion that the concept of invention is an anachronism. This suspicion is reinforced by debates over inventions within archaeology that begin with scientific criticisms of the proposed earliest dates for a phenomenon, but can rapidly become mired in academic, nationalist and post-colonial politics (Han 2004; Killick this volume).

The danger of drifting into 'Originsland' as eloquently deconstructed by Gamble (2007, 61ff.) is ever present. Yet the importance of analysing and understanding the processes underlying inventions within societies and their relationship to world history is increasingly paramount. It features strongly in major ongoing debates such as: the ability of societies in Africa to invent new technologies (e.g. see Killick this volume); explanations surrounding the rapid conquest of the Americas by Europeans (Diamond 1997); the apparent cessation of inventions in China in the fifteenth century and the consequences for the rise of the West (e.g. Morris 2010; Needham 1969; Pomeranz 2000); and the decline of science and technology within the Islamic world (e.g. Saliba 2011).

There is also the widely held opinion expressed by scholars working in later, usually industrial, societies, but seemingly endorsed by archaeologists, that '[i]n studies of technology in the ancient through to the early-modern periods ... data on invention are scarce to say the least' (Edgerton 2010, 689). Recent surveys of inventions and innovations in early societies throughout the world (e.g. Fagan 2004; Troeng 1993) highlight the range of potential evidence and the current state of knowledge beyond pyrotechnologies. It is readily conceded that identifying and analysing the process of invention is not always possible within the archaeological record. This could be due to frequently poor preservation (e.g. see organic material: see Hurcombe 2014); uncertainties surrounding materialization (e.g. ritual and religious activity: see Renfrew & Morley 2009); or the definition of specific points within complex processes (e.g. urbanization: see Wilkinson *et al.* 2014, or domestication: see Larson *et al.* 2014, but not necessarily agriculture: see van der Veen 2010). However, as is demonstrated by the following papers on pyrotechnologies, it is possible not only to identify and analyse the processes underlying inventions, but also to enable a more in-depth understanding of early societies that frequently challenges, rather than reproduces, existing interpretations and explanations of the past.

Acknowledgements

The authors are indebted to Durham University, the UCL Institute of Archaeology and the AHRC-funded project 'Rise of Metallurgy in Eurasia' for supporting the organization of a conference session entitled 'Invention as a process: pyrotechnologies in pre-literate societies' at the SAA annual meeting in Honolulu, Hawaii (April 2013), which inspired the collection of papers presented in the special section in this journal. We are most grateful to Heather Miller and John Robb for their patience and guidance during the preparation process.

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https://doi.org/10.1017/S0959774314001188 Published online by Cambridge University Press