Reconstructing adhesives : an experimental approach to organic palaeolithic technology

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1. Introduction

The archaeological record of the Palaeolithic, as the name implies, is dominated by the presence of objects made from stone. Decay often limits the preservation of organic remains from the deep past, creating a biased view in the archaeological record. Yet under exceptional circumstances organic materials persist, providing a glimpse of the more unfamiliar materials and technologies of past populations (Hurcombe 2014). The scarcity of organic material, however, creates a problem in itself. Rare finds are often assigned great significance by archaeologists, while by the very nature of their rarity, little is known about the material itself.

As an example, it is widely accepted that the earliest adhesives and the role they played in hafting was an important advancement in the history of technology and in the evolution of the human mind (Ambrose 2001, 2010; Barham 2013; Haidle *et al.* 2015; Lombard 2007; McBrearty and Brooks 2000; Wadley 2010, 2013; Lombard and Wadley 2009; Coolidge and Wynn 2009). Adhesives, sometimes singular finds, have featured in many heated discussions about Neandertal and modern human cognitive and technological abilities (Coolidge and Wynn 2009; Marean 2015; Roebroeks and Soressi 2016; Wragg Sykes 2015; Wadley 2013; Lombard and Wadley 2009), yet our knowledge of the adhesive material itself is comparatively limited. The materials we engage with are an integral part of who we are (Malafouris 2013), and together with the fossil record are our only link to understanding where we came from. To comprehend the material world of the past, we must first therefore directly engage with the materials we want to understand (Ingold 2007). That is the principle aim of this thesis. Throughout the four research articles that follow, I will experimentally reconstruct and analyse aspects of adhesive manufacture, application, use, re-use and decay. By focusing on material properties, aspects fundamental to materiality and how we interact with and are shaped by our environment (Jones 2004), this thesis will answer several pressing questions about the technology and material choices made by Middle to Late Pleistocene humans.

Research context

Much of the research in Palaeolithic archaeology ultimately revolves around discovering what makes us human, and how we got here. Studying Neandertals provides a unique opportunity here. *Homo neanderthalensis* are our closest ancestral relatives, and are the most well researched of all extinct hominin species. They are distinctly human, yet still 'not us'. Although there was some interbreeding (Prüfer *et al.* 2014), we survived to colonize every continent on Earth, and Neandertals disappeared approximately 40,000 years ago (Higham *et al.* 2014). Palaeolithic research thus often focuses on the behavioural, cognitive, and technological abilities of Neandertals compared with modern humans (Villa and Roebroeks 2014; Villa and Soriano 2010; Wadley 2013; Nowell 2010). At the forefront of this research over the past decade are debates about early fire production and use (Sorensen 2017; Sorensen *et al.* 2018; Dibble *et al.* 2018; Heyes *et al.* 2016; Roebroeks and Villa 2011; Aranguren *et al.* 2018; Stahlschmidt *et al.* 2015; Gowlett 2016), bone tool manufacture (Soressi *et al.* 2013), exploitation of marine resources (Cortés-Sánchez *et al.* 2011; Hardy and Moncel 2011), the presence of ornaments, pigments and symbolic behaviour (Zilhão 2011; Zilhão *et al.* 2010; Jaubert *et al.* 2016; Hoffmann *et al.* 2018a; Hoffmann *et al.* 2018b; Aubert *et al.* 2018; Bonjean *et al.* 2015; Dayet *et al.* 2014; Dayet *et al.* 2019; Roebroeks *et al.* 2012; Finlayson *et al.* 2012; Mellars 2010; Peresani *et al.* 2011), and finally, adhesive production and hafting (Degano *et al.* 2019; Niekus *et al.* 2019; Schmidt *et al.* 2019; Zilhão 2019).

At first glance, adhesives may not seem as significant or relevant to what makes us human as controlling fire or symbolic behaviour. Yet today, adhesives are an integral part of every-day life. They help hold together everything from the shoes we walk on to the electronics we use to communicate. During the Middle and Late Pleistocene, adhesives were used for backing or hafting stone tools – creating a handle to improve prehension and efficiency (Fig. 1). A process which fundamentally altered the way humans made and used tools (Barham 2013). Beyond this, adhesives are a practical material for studying human behaviour for a number of reasons. They come from a range of environmental sources and have different functional roles, as well as unique appearances, colours, tactility, smells and tastes. Differences in adhesive technology are therefore likely to represent decisions made by ancient humans, providing a window onto their behaviour (cf. Sillar and Tite 2000). Adhesives often require the controlled use of fire to produce, undergoing chemical and physical transformations and can also be freely moulded, shaped, combined and re-used. This makes them the first transformative, additive and plastic technology.

It could be argued that other technologies included any one of these aspects. Fire, cooking, heat treating lithics, or altering pigment could be considered transformations. Hafting is an additive technology, and perhaps playing with wet clay could be considered plastic. Whether these all preceded the first use of adhesives is another question. Yet one thing remains certain; they do not individually meet all of the criteria. Transformative metallurgy, or the ability to transform copper ore into bronze by adding tin, is the first time another technology satisfies all three criteria. It is transformative (the molecular structure is altered, creating an entirely new material), additive (a mixture of tin and copper creates bronze, which can also be melted and combined into larger pieces), and plastic (the material can be freely moulded and shaped). Ceramic technology is similar, but is only plastic before it has been fired. Transformative metallurgy is seen as a technological paradigm shift, fundamentally altering the way humans understood and interacted with the materials of their environment (Golden 2010). Adhesives share many of these qualities, yet appear more than 150,000 years before the advent of ceramics and metallurgy.

Fig. 1. Two recreated examples of adhesive hafts. A backing made of pine resin, beeswax and red ochre (left) providing a safer grip for a flint knife. And birch bark tar used to glue a flint spear point to a wooden handle. Both allow the tools to be used more easily, safely, and with greater force.

In 1996, direct evidence of adhesives used by Pleistocene humans was published, (Boëda *et al.* 1996) and its implications and significance summarily discussed (Holdaway 1996). Five years later, a clear case was made for the importance of adhesives in the discussion about Neandertal cognition and technology. Two lumps of tar (also referred to as pitch) found in an open pit mine near Königsaue, Germany were chemically analysed and discovered to have originated from birch bark (Koller *et al.* 2001; Grünberg *et al.* 1999). The intentional production of birch bark tar by Neandertals was seen as a clear sign of their considerable technical abilities (Koller *et al.* 2001). The same year it was suggested that the production of composite tools (containing a handle, stone insert, and binding material) is analogous to grammatical language, in which hierarchical assemblies can be combined or recombined for different functions (Ambrose 2001). Explaining how to make a composite tool was also said to be the equivalent of sharing a recipe or telling a short story, suggesting Neandertals were likely able to speak (Ambrose 2001). Yet at the time this was written, very little was actually known about adhesives during the Palaeolithic. It was unclear how birch bark tar could have been produced, or even discovered, using Neandertal technology. It was also unknown what types of adhesives contemporaneous modern humans in Africa were using, or what these were like to make.

Experimental studies a few years later showed that red ochre, present on a number of Middle Stone Age backed artefacts from Rose Cottage and Sibudu Caves in South Africa, served a functional role by making adhesives stronger and easier to manipulate (Wadley 2005). The distribution patterns of ochre on Howiesons Poort segments also suggests that Middle Stone Age humans were using different adhesive recipes depending on the raw material of the tool (Lombard 2007), corroborating the functional use of ochre.

Further experimental work by Wadley (2010) and Wadley, Hodgskiss and Grant (2009) explored the role of ochre in compound adhesives in greater detail. The research by Wadley put forth the hypothesis that compound adhesive manufacture can be used as a proxy for modern cognition (Wadley 2010, 2013; Wynn 2009). On top of combining different parts of a composite tool, Wadley detailed that manipulating adhesives required mental processes such as forward planning, mental rotation and abstraction. The adhesives needed to be kept in attention and rotated near a fire while the artisan balanced the handle and position of the tool with the consistency of the adhesive and the heat of the fire (Wadley 2010). The addition of disparate materials without adhesive-like characteristics of their own, collected at different times and in different places, to improve and transform the material, balancing properties such as tack and viscosity, point to modern-like levels of cognitive ability (Wadley 2010; Wadley *et al.* 2009; Ambrose 2010).

The discovery of Neandertal associated adhesives from as old as 191,000 years ago (Mazza *et al.* 2006) pushed the discussion about adhesive technology back to the Middle Pleistocene. Further Middle Palaeolithic adhesive finds (Boëda *et al.* 2008b) helped open up comparisons between Neandertal and modern human adhesive and hafting technologies. Villa and Soriano (2010) suggest that the transport and use of sandy balls of a naturally occurring tar-like petroleum substance known as bitumen for hafting Levallois artefacts and the distillation of tar from birch bark are clearly analogous to early modern human technological capacities. Tar production by Neandertals has since been used as evidence of the controlled use of fire and a clear demonstration of their technological and cognitive abilities. Most frequently referenced is the complexity of producing tar without modern fire-resistant containers and the strict control of fire temperatures (Roebroeks and Soressi 2016), often stating that temperatures must be kept between 340 and 400 °C (Zilhão 2011; Roebroeks and Villa 2011; Wragg Sykes 2015). However, claims of the narrow range of temperatures were overzealous, as tar can actually be produced at temperatures above and below what was previously stated (Şensöz 2003; Puchinger *et al.* 2007).

Wragg Sykes (2015) gives the most in-depth look at Neandertal tar technology, providing a possible *chaîne opératoire* of a birch tar hafted tool, and describing the greater cognitive, social and behavioural implications. She concludes that Neandertal tar production is equivalent to early modern human compound adhesive use in southern Africa. Both required advanced cognitive capacities such as enhanced working memory and attendant executive processing (Wragg Sykes 2015). Perhaps even more intriguing, are the effects that the recognition of a fundamental and non-reversible transformation of matter might have had on the way humans understand and engage with the material world (Wragg Sykes 2015). Over evolutionary spans of time these interactions with materiality have the potential to yield new brain structures, influencing the development of the human capacity for conceptual thought (Overmann and Wynn 2019). However, unlike the lithic record, one of the examples used by Overmann and Wynn (2019) to postulate the effects of materiality on human cognition, evidence for early adhesive technology is not so abundant. Further, many of the discussions and arguments given above are based on how Middle Palaeolithic and Middle Stone Age adhesives were produced, and how they behave; empirical information for which is limited in the archaeological record, but can be expanded on thorough experimentation.

Archaeological context

It is important to describe the known archaeological material before proceeding with the methods and aims of this thesis. I have already stated that preservation of adhesives and other organic artefacts from the European Middle Palaeolithic and African Middle Stone Age is rare. Here I will present a brief overview of the relevant archaeological material to help clarify just how scarce securely dated and chemically identified adhesives are (Fig. 2).

Currently, the oldest known adhesives are two approximately 200,000 year old flint flakes containing lumps of birch tar from Italy (Mazza *et al.* 2006). Other securely dated and chemically identified birch bark finds come from Zandmotor, the Netherlands (Niekus *et al.* 2019) and Königsaue, Germany (Koller *et al.* 2001). Similar to the Campitello find, the Zandmotor piece is an unretouched flint flake with a significant portion still encased in birch bark tar. It has been directly dated to approximately 50,000 years ago (Niekus *et al.* 2019). At Königsaue, two lumps of tar were found, no longer adhering to any flint. However, one of these pieces does show impressions of what is thought to be a bifacial knife, a fingerprint, and some wood fibres, suggesting it may have been used as part of a haft. The two Königsaue pieces were also directly dated, providing minimum ages of 43,000 and 48,000 years ago (Koller *et al.* 2001).

Adhesives likely associated with Neandertals, have also been found at sites in Syria, Romania, and Italy. Umm el Tlel, Syria yielded bitumen residues on flint artefacts from approximately 71,000 years ago (Boëda *et al.* 2008b; Bonilauri *et al.* 2007). At the nearby site of Hummal, artefacts containing residues which were also identified as bitumen, dating between approximately 80,000 and 50,000 years ago were found (Hauck *et al.* 2013; Monnier *et al.* 2013). At Gura Cheii-Râşnov Cave, Romania, bitumen residues were identified with potential attribution to a very young Mousterian layer of approximately 30,000 years ago. At Fossellone Cave, Italy, flakes and scrapers with pine resin and possibly beeswax were found dating between 55,000 – 40,000 (Degano *et al.* 2019). At Sant'Agostino Cave, Italy, additional flakes and scrapers were found with pine resin residues dated to approximately 43,000 years ago (Degano *et al.* 2019). Roughly contemporaneous with these last two, but attributed to anatomically modern humans is evidence of a mixture of plant gum and ochre at the Uluzzian site of Grotta del Cavallo, Italy (Sano *et al.* 2019). Although while the materials mentioned above were all identified with gas chromatography mass spectrometry, at Grotta del Cavallo, only Fourier transform infrared spectroscopy was used, making the precise nature of the organic component more tenuous.

Apart from the securely dated and identified adhesives, several more sites contain possible evidence of adhesive use by Neandertals in Palaeolithic Europe. The following examples suggest that adhesive residues may be more widespread than previously indicated, although current thorough analysis of the adhesives themselves remains relatively limited. The site of Inden-Altdorf, Germany contains numerous micro-residues dating to between 128,000 and 114,000 years ago believed to be birch bark tar on the basis of SEM-EDX and optical microscopy (Pawlik and Thissen 2011). At El Sidrón, Spain, indirect evidence of bitumen use has been suggested by the presence of bitumen residues in the dental calculus of one Neandertal individual (Hardy *et al.* 2012). Residues associated with hafting, but not subjected to any chemical analysis have also been found at Starosele (80–40,000 BP), Ukraine (Hardy *et al.* 2001). Numerous other examples of hafting based on microwear, morphology, and impact fractures have been identified (Solecki 1992; Lenoir and Villa 2006; Rots 2009, 2015; Shea 1997; Shea *et al.* 2002), but without the presence of adhesives these will not be discussed further.

Contemporaneous with many of the finds from western Eurasia, are residues identified as belonging to the Middle Stone age at three different sites in South Africa. At Border Cave, artefacts were found to contain a possible tar produced from yellowwood (*Podocarpus*) bark between 43,000 and 40,000 years ago (Villa *et al.* 2012). Alternatively, this material may have been heated and partially pyrolysed yellowwood resin. Diepkloof Rock Shelter yielded one analysed Late Howiesons Poort (60,000–55,000 BP) quartz flake containing resin originating from the yellowwood tree (Charrié-Duhaut *et al.* 2013). At Sibudu, two Howiesons Poort segments contain similar yellowwood resin, dated to between 65,000 and 62,000 years old (Villa *et al.* 2015).

More evidence of potential adhesive use from the African Middle Stone Age has been identified based on the presence of microscopic residues, including ochre and possibly resin from Sibudu and Rose Cottage Cave, South Africa (Gibson *et al.* 2004; Lombard 2006b). Further, hafting inferred from microwear analysis and the presence of ochre has been identified at three sites in Northeast Africa spanning approximately 150,000 years of the Middle Stone Age (Rots *et al.* 2011).

This puts the number of Middle Palaeolithic sites containing securely dated and chemically identified adhesive residues at five from Europe (six if Gura Cheii-Râşnov Cave, Romania, and seven if Grotta del Cavallo, Italy are included). Two Middle Palaeolithic sites from the Levant, and three Middle Stone age sites in Africa meet the same criteria (Fig. 2).

Although preservation makes residues rare, hafting appears to be widespread throughout western Eurasia and Africa during the late-Middle and Late Pleistocene. Among both Neandertal and African human populations, different adhesives and adhesive mixtures were used. Further, tools hafted with adhesives were clearly employed for a wide variety of tasks, including cutting, scraping, piercing, and for projectiles or hunting implements (Hardy 2004; Hardy *et al.* 2001; Lombard 2006b; Rots 2009, 2013; Rots *et al.* 2015). Due to the available varieties, improving our understanding of ancient adhesive materials will greatly aid in our understanding of the technological choices of these past populations. How this is accomplished in this thesis will be the topic of the following section.

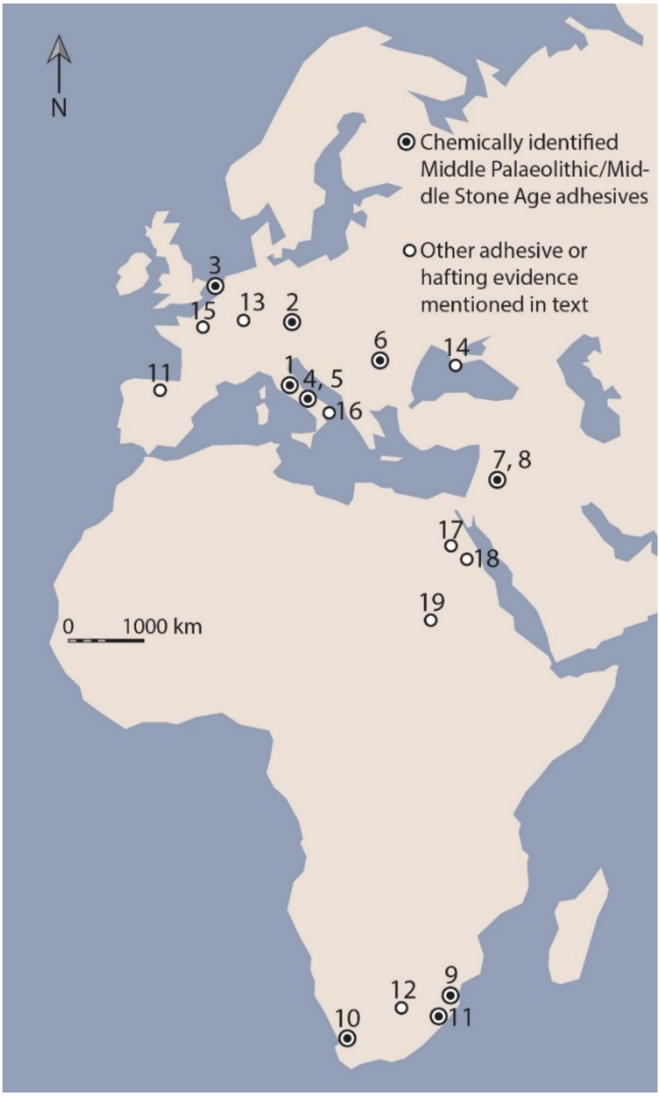

Fig. 2. Map of Africa and western Eurasia showing the location of all known sites containing Middle Palaeolithic or Middle Stone Age adhesives that have been securely chemically identified, and other sites referenced in the text. 1) Campitello Quarry, Italy: birch bark tar, >191 ka. 2) Königsaue, Germany: birch bark tar, ~45 ka. 3) Zandmotor, the Netherlands: birch bark tar, ~50 ka. 4) Fossellone Cave, Italy: pine resin, beeswax, 55–40 ka. 5) Sant'Agostino Cave, Italy: pine resin, ~43 ka. 6) Gura Cheii-Râşnov Cave, Romania: bitumen, ~30 ka. 7) Umm el Tlel, Syria: bitumen, ~71 ka. 8) Hummall, Syria: bitumen, 80–50 ka. 9) Border Cave, South Africa: yellowwood tar or resin, 43–40 ka. 10) Diepkloof Rock Shelter, South Africa: yellowwood resin, 60–55 ka. 11) Sibudu, South Africa: yellowwood resin, ochre, 65–62 ka. 12) Rose Cottage Cave, South Africa: ochre, possible resin, 68–60 ka. 13) Inden-Altdorf, Germany: possible birch bark tar, 128–114 ka. 14) Starosele, Ukraine: hafting residue, 80–40 ka. 15) Biache-St-Vaast: hafting wear traces, ~253 ka. 15) El Sidrón, Spain: bitumen in dental calculus, 51–47 ka. 16) Grotta del Cavallo, Italy: gum, ochre, 45–40 ka. 17) Taramsu, Egypt: hafting wear traces, Nubian. 18) Sodmein Cave, Egypt: hafting wear traces, Nubian. 19) Sai 8-B-11, Sudan: hafting wear traces, <60 ka.

Approach

There are two approaches to improve our understanding of ancient adhesive use. First, archaeologists can seek out new discoveries or explore ways to obtain more information from the archaeological material itself. This provides new data that is helpful in answering *what* materials were Neandertals using for adhesives? Or w*hat* types of tools did they haft with adhesives? The answers to these questions have been, in part, discussed in the previous section, although new finds will undoubtedly create a far more complete picture. When dealing with organic remains from a period as remote as the Middle Palaeolithic, however, there will always be missing and partial information. The second way we can improve our understanding of ancient adhesives is by comparison to ethnographic and experimental references. This approach helps answer questions as to *why* certain adhesives were used for particular tools or tasks.

Using ethnographic analogies has a long history in Palaeolithic Archaeology as a way of bridging the gap between the present and fragmentary archaeological record, and the behaviours of past populations. By combining resources from ethnography, primatology, experimentation and archaeology we are able to interpret the fragments of remaining material to the best of our ability (Atici 2006). Ethnographic analogy and experimental archaeology have long since been used in many prominent Palaeolithic discussions (Binford *et al.* 1988; Binford *et al.* 1985; Dibble and Whittaker 1981; Kuhn 1989). Ethnography has also played a direct part in discussions about ancient adhesives (Sahle 2019; Wadley *et al.* 2015; Binford 1984).

Experimenting with adhesives

Some of the earliest experiments in archaeology were concerned with distinguishing naturally and artificially flaked stones (Evans 1897; Lin *et al.* 2018). Knowledge of flintknapping, and of the processes and fracture mechanics involved, have allowed for a thorough understanding and recreation of the production processes and chaîne opératoires of stone tools (e.g. Rezek *et al.* 2011; Dibble and Rezek 2009; Dibble and Pelcin 1995; Dibble 1997; Soressi and Geneste 2011; Cotterell *et al.* 1985). This has culminated in a level of understanding whereby differences in production sequences can be used to explain the degree of social intimacy between Neandertals and early modern humans in Europe (Roussel *et al.* 2016). No such research history or body of knowledge exists for Palaeolithic adhesives.

That is not to say that there have been no experiments on ancient adhesives. Only that compared with lithics, adhesive experiments are in relative infancy. In the 1980s experimental work explored the role of ochre in Upper Palaeolithic adhesives (Allain and Rigaud 1986; Allain and Rigaurd 1989). Since then a number of studies have investigated other aspects of adhesive production and use. These include testing tar production methods (Piotrowski 1999; Pomstra and Meijer 2010; Osipowicz 2005; Rageot *et al.* 2018; Schenck and Groom 2016; Schmidt *et al.* 2019; Pfeifer and Claussen 2016), re-heating of Australian resins (Parr 1999), the benefits of adding ochre to resin and gum adhesives (Wadley 2005, 2010; Wadley *et al.* 2004), the influence of filler particle size and surface roughness on adhesive performance (Zipkin *et al.* 2014), and the role of fire in the life of an adhesive (Cnuts *et al.* 2017). Additionally, extensive experimental work has been conducted which, although aimed at lithic analysis, particularly impact fractures and wear, makes direct use of adhesives in the tests (Barton and Bergman 1982; Fauvelle *et al.* 2012; Hutchings 2011; Iovita *et al.* 2014; Pétillon *et al.* 2011; Pokines 1998; Schmitt *et al.* 2003; Shea *et al.* 2002; Sisk and Shea 2009; Waguespack *et al.* 2009; Moss and Newcomer 1982; Gaillard *et al.* 2015).

Despite the breadth of these experiments, there remains a number of areas where further research is still necessary. First, although there have been numerous studies into the Palaeolithic distillation of birch bark into tar, very few have been successful in producing useable quantities of tar. Second, the benefits of adding ochre have primarily been tested by actualistic studies, lacking a quantification of specific performance metrics. Third, the re-use of materials is an important aspect of Palaeolithic technologies (Venditti *et al.* 2019; Vaquero 2011) and has been understudied, particularly with regards to Palaeolithic adhesive materials. Fourth, many of the performance experiments that have been described above (with the noted exception of Zipkin *et al.* 2014) test adhesives as part of a complete hafted system. Evidence shows that adhesives were used for a number of different tool types and functional roles (Rots 2013). To test each of these functions and hafting forms poses significant logistical challenges. Experiments that test bulk properties, that is, material properties of the adhesives itself, independent from joint geometries, are therefore more practical for initially comparing materials for a wide range of applications (Petrie 2000). Finally, very little is known about the post depositional decay on different adhesive types, and how this affects what survives to the present. The experiments in this thesis address the issues outlined above and will be explained in greater detail below.

Research Assumptions

There are some limitations and assumptions to both ethnographic and experimental approaches to studying adhesives. Using analogies without considering these assumptions may therefore be misleading and over-stepping. First, as a significant limitation of a purely ethnographic approach, there is no contemporary population that produces birch bark tar using technology similar to that from the Palaeolithic. Specific questions regarding birch tar technology can therefore not be directly addressed. Second is a wider problem which also encompasses some experimental work. When parallel examples do exist between the ethnographic and Palaeolithic record, the cognitive processes of humans operating within a specific cultural context are used to explain past material in a modern-centric way (Garofoli 2016; Lin *et al.* 2018). The line is blurred even further when the population in question did not share the same brain shape or ontogeny as us, as was the case with Neandertals (Hublin *et al.* 2015; Gunz *et al.* 2010; but see also: Ponce de León *et al.* 2016). We are implicitly biased in trying to understand materials and devising experiments to look at aspects which we, today, find significant or important. This is no guarantee that ancient hominins thought about them in the same way as us, or even thought about them consciously at all (cf. Corbey *et al.* 2016).

Other assumptions that are commonly left implicit in experimental archaeology are uniformitarian in nature. Uniformitarian assumptions comprise a significant part of how we study the past and should be stated explicitly (Faith and Lyman 2019; Domínguez-Rodrigo 2008; Lin *et al.* 2018). It seems obvious that natural processes and physical properties, such as fracture mechanics, molecular adhesion, and thermodynamics, operate today as they did in the Palaeolithic (Eren *et al.* 2016; Lin *et al.* 2018). But what of the materials these processes were acting on? It is unlikely that flint is any different now than it was 100,000 or even 3 million years ago. What about the resin from a pine tree, or the tar from birch bark? Perhaps there were slight differences during the Palaeolithic, but these most likely fall well within the range of natural variation among trees today (cf. Holonec *et al.* 2012; O'Connell *et al.* 1988). Species such as pine and birch are still recognizable during the Pleistocene, (Bertran *et al.* 2008; Bigga *et al.* 2015) and the physical principles which govern natural adhesive functional requirements (adhesion, phase/state changes, pyrolysis) remain the same.

Another assumption relates to the material acquisition. Most of the adhesive materials used for the research in this thesis were either commercially purchased, or produced in a laboratory. In this case it was considered that the benefits from controlling variables and using highly replicable materials outweighed the improved likeness to Palaeolithic materials by using naturally sourced ingredients. A similar example would be using glass for lithic flaking experiments (Dibble and Rezek 2009). In attempting to determine fundamental principles of flake shape and size, using natural flint, or naturally sourced resins, introduces too many variables.

As long as archaeologists acknowledge these assumptions, and understand the limits, experimentation is a valuable aid in Palaeolithic archaeology. There are fundamental questions that can be answered and data that can be produced using experiments, which reinforce hypotheses and theories about technologies in ancient societies and peoples (Outram 2008). With a combination of actualistic and laboratory experiments, and careful consideration of the research questions and limitations, experiments can provide a solid framework for studying past behaviour.

Aims

For all of the discussion surrounding Middle Palaeolithic and Middle Stone age adhesives, remarkably little work has been done on the methods of production, and the properties and preservation of the materials themselves. Discussions are often centred on Neandertals or Middle Stone Age humans, and what they did with adhesives, or how adhesives reflect increasing cognitive capacity. Because there is no overview of the material itself, the discussion of the technology is incomplete, lacking a clear empirical base. How can we discuss Neandertal control of fire or technological complexity if we do not understand the temperatures needed to create tar and what techniques were at their disposal? How can we discuss the efficacy of compound adhesives production and its implications for the cognitive capacities of Pleistocene humans without understanding the extent to which different materials and their ratios affect the properties of compound adhesives? And finally, how can we assign significance to the presence of certain adhesive types without knowing how distorted what we find in the archaeological record is due to taphonomic processes?

I will therefore use the material as a starting point for this thesis, exploring the different stages in the lives of different natural adhesives from their first production through to their re-use and the effects of taphonomic decay after being discarded. I will show what influence the materials, their production and properties have on the technological developments of the Middle to Late Pleistocene. This type of empirical information on material properties, gained only through experimentation, is necessary if we wish to further the discussion in any meaningful way. No matter whether we want to test theories against data, or fit data into a coherent story (Hodder 2004, 28), we first need more data to begin with.

Research questions

To address the issues outlined above, this thesis is divided into four independent research papers. These papers will answer the following primary research questions:

1. How was birch tar first discovered and then produced using Palaeolithic technology?
2. How do ingredient ratios influence adhesive performance and the efficacy of compound adhesive production?
3. Why did Neandertals use birch bark tar despite the high investment in time, resources, and production complexity?
4. Is there a preservation bias favouring certain adhesive types in the archaeological record?

Answering the above questions will help resolve some of the broader issues associated with ancient adhesive studies. For example:

a) Different tar production strategies have implications for our understanding of the complexity of Neandertal technology and mastery of pyrotechnology. Knowledge of different potential tar production methods is therefore necessary to understand the range of technologies at their disposal, and also what we should look for in the archaeological record.
b) The suitability of compound adhesives as a proxy for studying complex cognition. Currently, there is little empirical data on the performance of compound adhesives, making comparisons with other materials and ingredients difficult, thus hampering discussions about behaviour and cognition.
c) The material choices made by Neandertals. Without a comparison of adhesives and their relevant material properties it is impossible to assess why certain materials were used and others were not.
d) Finally, how accurately does the archaeological record reflect what was being used in the past. Preservation of organic material is highly dependent on burial conditions. However, there also exists considerable variation among natural adhesive types and it is unknown what effect this has on their preservation.

Thesis outline

Chapter 1 – introduction. The current chapter includes background information on the current state of Palaeolithic adhesive research and archaeological adhesive findings, and states the research questions and assumptions.

Chapter 2 – birch tar production provides an explanation as to how the oldest, and potentially most complex and costly, known adhesive technology was discovered and developed. Without a solid framework for how birch tar can be produced using Palaeolithic technology furthering discussions about the cognitive and technological abilities of Neandertals based on this technology is not possible. By testing the efficiency of three distinct tar production techniques, we created a framework for how Neandertals may have initially recognised birch bark tar, and developed the process into more efficient methods of tar production necessary to produce the large volumes we find associated with individual Neandertal artefacts.

Chapter 3 – adhesive efficacy uses modern internationally recognized materials testing standards (ASTM) to further understand the functional role of ochre and beeswax in resin and gum adhesives. The hypothesis that adhesives can provide a proxy for studying the cognition of Pleistocene humans was first raised based on the identification of ochre hafting residues on Middle Stone Age artefacts from southern Africa (Wadley 2010). However, these tests were primarily field-based actualistic experiments. In order to further substantiate this hypothesis, I conducted a series of lap shear and impact tests following ASTM protocols. The aim of this research was twofold: 1) To test whether ingredient ratios play a significant role in the performance of a Stone Age adhesive, supporting the hypothesis that the Middle Stone Age people who made compound adhesives must have been skilled artisans. 2) To employ modern standardized testing to answer an archaeological question, creating a body of experimental material property data that can be used as a reference for future work. The increase in the use of experimental archaeology to answer questions about the deep past has been increasing, and the ability to conduct replicable and reliable tests is more important than ever before.

Chapter 4 – Use and re-use expands on chapter three by testing a greater number of material qualities that are important for stone tool hafting adhesives. While the lap shear tests in chapter 3 are useful in expediently comparing the static performance of an adhesive, real life applications call for a more dynamic method of testing. Rheology, hardness measurements after differential heating, and thermogravimetric analysis, provide a far more thorough account of Palaeolithic adhesive performance. This chapter also shifts the focus from the African Middle Stone Age, to the European Middle Palaeolithic, with an emphasis on studying birch bark tar – a material used by Neandertals since the Middle Pleistocene. There have been multiple discussions about Neandertal adhesive use, in direct comparison with that of anatomically modern humans in southern Africa, with very little experimental work or understanding of the adhesives themselves and how they compare (cf. Villa and Soriano 2010). This chapter contributes significantly to our understanding of the material properties of Palaeolithic adhesives, and the technological choices associated with making and using different natural adhesive types.

Chapter 5 – preservation represents one of the final stages in the life of an adhesive. Taphonomy plays an important role in all of archaeology, but becomes even more significant the farther back in time one goes, especially when dealing with organic materials. Understanding the role of taphonomy on the life of an adhesive from the Middle to Late Pleistocene is therefore of the utmost importance. This chapter explores the issue of adhesive preservation by leaving replica adhesives and flint flakes, some with wood handles and some without, to weather naturally at two different locations for six months, two years, and three years. The differential preservation of natural adhesives provides an explanation for why we find what we do in the archaeological record. It also greatly increases the scope for future research by suggesting the number of adhesive types used in the past may well have been far greater than what we find today.

Chapter 6 – conclusion. The final chapter synthesizes chapters two to five, summarizing answers to the research questions and describing how they fit into a narrative of early modern human and Neandertal technological choices and abilities, as well as providing scope for future research.