Reconstructing adhesives : an experimental approach to organic palaeolithic technology

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6. Conclusion

The aim of this dissertation has been to use experimental archaeology to answer several main questions about the properties, production, efficacy, re-use, and finally decay of adhesives used by Neandertals and early modern humans during the Middle to Late Pleistocene. Below I will outline how my results answer the questions proposed in the introduction, and provide new insights into a significant technological development made by Pleistocene humans.

The story so far

Twenty years ago, little was known about adhesive technology in the Middle Palaeolithic and Middle Stone Age. With the exception of a small number of bitumen traces on stone tools from the Levant, there was no clear evidence showing what materials were being used. The last two decades have seen studies on ancient adhesives develop considerably. Through collaborations with chemists and other specialists archaeologists have been able to identify many more adhesive residues. We now know that both Neandertals and Middle Stone Age humans were using a range of natural adhesive materials, including different resins, compound adhesives, bitumen, and birch bark tar. Adhesive use dates back into the Middle Pleistocene, and the mental capacity to use adhesives for hafting may even have stemmed from the common ancestors of Neandertals and anatomically modern humans (Niekus *et al.* 2019). We also know that during the Middle and Late Pleistocene, humans were using adhesives for a number of different hafting-related tasks. These include not only the stereotypical spear or projectile point, but also scrapers, knives, and even seemingly random flakes (Degano *et al.* 2019; Niekus *et al.* 2019; Mazza *et al.* 2006).

What we did not know before the experiments conducted for this thesis, was the conditions required to invent and develop birch bark tar technology among Neandertals. Nor did we know why this material appears to have been favoured throughout much of prehistory, despite the presumed complexity of its production. It was also unclear how much of an effect ingredient ratios had on the performance of compound adhesives, making it difficult to gauge the level of knowledge or skill required for Middle Stone Age humans to successfully make and use this material. And finally, the potential for preservation biases hampered our ability to give an accurate representation of the range of adhesive technology in the past.

It is now possible to answer these questions, and fit them into a coherent story about Pleistocene adhesive technology. Adhesive technology likely began with single component materials such as bitumen or resin. These are adhesives that naturally occur with a sticky consistency, and require little further manipulation to use. However, birch bark tar and compound adhesives preserve better than others and archaeologists are more likely to find these types of materials from old dates. The earliest adhesives may have been used to provide a backing on simple stone flakes (cf. Niekus *et al.* 2019). Alternatively, they could have been added to an already existing composite tool haft to help strengthen the joint, or protect plant or animal bindings that are sensitive to moisture (Kozowyk *et al.* 2017a; Rots 2008).

With a combination of pyrotechnology, birch bark, and knowledge of some form of simple adhesive use, it is possible that Neandertals could have discovered (and re-discovered) tar accidentally and recognized its potential. Birch is well suited for the accidental discovery of tar, as it has many uses and was relatively abundant during much of the Late Pleistocene (Helmens 2014). Birch bark is waterproof, an excellent fire-starter, and has a high extractive content (Šiman *et al.* 2016; Harkin and Rowe 1971; Bacon 2007; Hordyjewska *et al.* 2019; Miranda *et al.* 2013), giving a relatively high yield of tar, more than twice that of pine wood, from a lightweight raw material.

Although three methods of producing tar from birch bark were tested in Chapter 2, it was hypothesized that other alternatives may have existed, thus providing even more basic starting points for the discovery of birch bark tar. Recently, experiments showing a method of tar production through condensation proved a simpler technique was possible (Schmidt *et al.* 2019). The condensation technique fits well within the developmental model of tar production, outlined in Chapter 2, being simpler than the ash mound method, but also producing significantly less tar.

In order to produce enough tar to use, a level of intentionality would likely have been required. Whether this was using the simplest method and gathering large amounts of raw materials, continually repeating the process, possibly among different individuals, and then combining all of the tar collected, or using a more complex method with multiple working parts. To make tar on demand, Neandertals needed to understand that with the right fuel (birch bark) and fire, tar can be formed. Then, given the right circumstances, it can be collected, and with the right application, it can be a beneficial addition to a tool. While condensed birch tar can be gathered after a small fire, the circumstances under which this is a regular occurrence need to be tested more thoroughly. Tar adhesives become brittle when heated at excessively high temperatures (Kozowyk *et al.* 2017a). A fire burning a combination of fuels other than birch bark (cf. Allué *et al.* 2017; Pop *et al.* 2016), may therefore burn away any tar condensing on nearby rocks before it could be collected.

It has been stated that the process of producing birch tar through the simplest method of condensation may be within cognitive grasp of nonhuman great apes (Schmidt *et al.* 2019). However, there is more to producing tar, even with the condensation method than simply "bringing 2 objects in close proximity and [the] gathering of a resource" (Schmidt *et al.* 2019, 4); one of those two objects needs to be on fire and a third object is needed to scrape or collect the tar. Further, there is more to adhesive use than only producing the material. Once collected, the tar is moulded to suit a particular task, and possibly joined with a fourth object and a fifth if a composite haft is used.

It is the combination of producing a new material with entirely new physical properties, and then shaping it and joining it with yet more objects which is of the greatest significance. This creation and combination would have influenced the way humans saw and interacted with the environment, in a manner akin to the technological paradigm shift most often ascribed to metallurgy (Wragg Sykes 2015; Golden 2010). Finally, manipulating and handling such a plastic material, would likely have helped mould our plastic minds (cf. Overmann and Wynn 2019).

After birch bark tar was first discovered, the technology was either maintained for hundreds of thousands of years, or rediscovered often enough to have been found in a number of different environments and times throughout the Palaeolithic. The loss and rediscovery of birch bark tar technology might explain the significant temporal gap between the Campitello tar and the Zandmotor and Königsaue tars. However, this may also be the result of the sparse archaeological record. If birch tar did not have any more beneficial properties than simpler adhesives, the technology might not have perpetrated through time. Instead, birch tar proved to be tougher, easier to work with, and better suited to re-use. The last point here is of particular significance for harsh environments where resources are scarce. Although initially requiring a higher investment, Neandertals could have produced birch bark tar and then curated and re-used it, carrying enough with them for whatever task arose. For example, large birch trees were relatively scarce in the environment at the time the Zandmotor tar was made and used around 50,000 years ago (Niekus *et al.* 2019). The ability to produce tar efficiently is therefore important, but perhaps more so is the ability to re-use the material.

The properties of birch bark might make it unique among plant resources in its ability to form significant quantities of tar from aceramic production processes. For example, birch bark tends to curl into a roll, more so when heated, thus limiting oxygen in the center of the roll and facilitating pyrolysis. Alternatively, it may burn with a smoke denser in tar particulates which can condense on nearby rocks than other barks or wood. To explore this further, more experiments testing the suitability of other plant materials for creating tar through aceramic methods are necessary.

Birch tar is the oldest known adhesive, but it was not the only natural material used in the past. In environments entirely devoid of birch, Middle Stone Age humans in southern Africa found other solutions for creating strong and re-usable adhesives. The addition of plasticizers and fillers, such as beeswax and ochre to resin creates a compound adhesive that approaches birch tar in terms of workability, performance and reusability.

The first compound adhesives could have occurred through contamination with the surroundings (soil, sand, ochre, charcoal) and a recombination of other materials and technologies used by Middle Stone Age humans. Through repeated use it would have become apparent that adhesives with the right amount of contamination are either easier to manipulate, or better suited to particular applications or use on stone tools made of specific raw materials. Old and brittle resin adhesives become softer when mixed with a plasticizer such as beeswax or fat, for example. However, it is not as simple as improving the properties by only adding a new ingredient. The results from Chapter 3 show that in order to make optimal compound adhesives, Middle Stone Age humans would have needed to carefully balance the ingredients and their ratios, as well as consider raw materials, surface roughness, and the particle size of fillers (Zipkin *et al.* 2014; Wadley 2010). Early compound adhesive users likely had a clear understanding of the effects of mixing different materials, and were able to successfully modify the properties of natural adhesives by combining disparate ingredients in specific ratios. Compound adhesive technology therefore helps show that Middle Stone Age humans had an increased capacity for creative thinking, knowledge, and skill, supporting the hypothesis that compound adhesives can be used as a suitable proxy for complex cognition (Wadley 2010).

Such evidence for the use of highly suitable materials, whether birch tar or compound resin based mixtures, suggests that Pleistocene humans, both Neandertals and anatomically modern humans, were aware of how to create some of the best adhesives from the materials available in their environments. The recent discovery of resin and potential beeswax adhesives made and used by Neandertals at the sites of Fossellone and Sant'Agostino caves (Degano *et al.* 2019) further highlights the similar capacities of Neandertals and anatomically modern humans for adhesive technology.

Beyond birch tar and compound adhesives, materials more prone to excessive degradation can survive in the archaeological record under exceptional circumstances. These include gum adhesives and animal glues (Sano *et al.* 2019; Bleicher *et al.* 2015). It is therefore possible that adhesive technology during the Pleistocene was more diverse than we currently have evidence for, leaving an abundance of further research opportunities.

Future directions

Through the experimental study of material properties and methods of production this thesis provides the foundation from which to study ancient adhesives. Research is ongoing that will help further improve our knowledge of adhesive materials and technology. However, there are a number of important questions and areas of study that remain relatively unexplored, and should not be overlooked.

It is clear that environmental constraints played an important role in the selection of adhesive materials. In order to better gauge material choices made by past populations, it is essential that we understand the environmental context of the finds. Questions associated with this topic are: How common were the trees associated with adhesives, both in the immediate locale, as well as the greater area, and how available were fillers and plasticizers, such as ochre and beeswax, in the environment? Access to certain additives may also influence the primary ingredient choice. Likewise, there are known differences in quality and quantity of plant exudates of different species, plant ages, and geographic locations. It will be necessary to expand our experimental datasets to include other prominent materials; *Prunus* gum, spruce resin, and bitumen have all been used as natural adhesives and sealants in the past, yet little systematic experimental work has tested the properties of these materials.

The recent debate about the complexity of tar production by Neandertals clearly highlights the need for more research on this topic (Schmidt *et al.* 2019; Niekus *et al.* 2019; Kozowyk *et al.* 2020; Schmidt *et al.* 2020). Similar to the work used for comparing production techniques and levels of re-use on Neolithic tars (Rageot *et al.* 2018), experiments exploring adhesives from different birch types, different regions/climates, and subjected to different regimes of re-use and degradation experiments will provide additional valuable information, necessary for future Palaeolithic research. For example, current studies on residue preservation and diagenesis are relatively limited and have often been conducted under field conditions (Cnuts *et al.* 2017; Monnier and May 2019). To reach a better understanding of how specific burial conditions effect different adhesive types, it is necessary to conduct laboratory-based experiments focusing on isolated variables, such as pH level, UV exposure or freeze-thaw cycles, (e.g., Braadbaart *et al.* 2009). This would allow archaeologists to understand which specific conditions are most significant with regards to certain adhesive materials and environments. Further, chemical analysis of such experimental samples would provide more insight into how archaeological adhesives change through time, thus facilitating more accurate identification of degraded material.

There are a number of ephemeral qualities of natural adhesive that are difficult to empirically test for, but may still have had a significant implications for the selection and use of such materials in the past. Aspects such as the colour of birch bark, or the smell of fresh pine resin may have been important criteria to early adhesive makers. A detailed ethnographic review would help to illuminate any potential non-technological reasons for the selection of certain materials. However, ethnographic results would still need to be tested against experimental and archaeological data before making conclusions about the deep past. If there can be no practical or economic benefit to using certain materials, then we may more reliably be able to attribute it to cosmological ideas.

Finally, it is necessary to expand the archaeological dataset. For experimental work to be of value, it must be comparable with archaeological material. Uniform methods of analysis will provide more accurate and comparable data from site to site. Common methods of analysis, such as gas chromatography mass spectrometry are not always possible due to sample size or material curation requirements. Better analytical techniques are continually being developed that require smaller samples, or that are non-destructive, circumventing sampling issues and further helping to elucidate preservation and research biases. New non-destructive methods that can be done *in-situ* also allow general characterization of residues that was previously not possible. As awareness is increasing regarding the importance of adhesives and residues from the Palaeolithic, more archaeological material will no doubt come to light, illuminating the significant gaps that currently exist between known Middle Palaeolithic adhesive finds. Increasing knowledge of how to handle and store residues, and where and what to look for is therefore of paramount importance. This will better equip archaeologists for finding and analyzing future residues, while ensuring research biases about the types of adhesive or tools used with adhesives are kept to a minimum.

Final remarks

The experiments conducted for this thesis have provided an explanation for how the earliest known adhesive technology developed, and why ancient humans chose to continue transforming birch bark into tar, making the first 'synthetic' material in the process. I have shown how precise Middle Stone Age humans needed to be with their ingredients to create strong compound adhesives, supporting hypotheses about what this means for their cognitive capacities. And finally, differential preservation creates a biased view, yet suggests that the past was far more diverse than we currently have evidence for. The recent increase in publications containing new Palaeolithic and Stone Age adhesive residues attests to this. Although we will never recreate the exact adhesives of the past, by using controlled and well formulated experiments to understand the relevant material properties, archaeologists can fill in the gaps and paint a clearer picture of what life was like for our distant ancestors.