THE INVISIBLE FIRE STARTERS

A usewear-based approach to identifying evidence of fire production by Neandertals

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A usewear-based approach to identifying evidence of fire production by Neandertals

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1. INTRODUCTION

Outside the well known story in Greek mythology of Prometheus stealing fire from the gods and giving it to mankind, myths the world over almost exclusively state that man was given fire by some mythical or ancestral being after having been recovered or stolen from some other source; but few ever suggest that man was actually taught the art of independently creating fire. As unlikely as it is that Prometheus handed fire to early hominins, wished them luck, and then went on his way leaving our early ancestors only to discover how to make fire on their own, this scenario is essentially how the history of fire and mankind has played out.

Even prior to our ancestral lineage splitting off from chimpanzees around 6 million years (Ma) ago (Glazko and Nei 2003; Stauffer et al. 2001; Green et al. 2008), fire had at least been observed and experienced in nature, leading to a basic understanding that fire burns and is to be avoided; this ability to conceptualize the "behavior" of fire has been observed in modern wild chimpanzees (Pruetz and LaDuke 2010). However, to 'know' fire does not instantly translate to being able to utilize it, despite studies showing some chimpanzees in captivity, after having been taught how to smoke, were able to manipulate fire to light cigarettes in order to satisfy their nicotine cravings (Brink 1957).

Ultimately, the ability to effectively use and create of fire originated within the human lineage. Advocates for early use of fire (the 'long chronology') argue that the active exploitation of fire was more than a mere technological innovation, but a driving force in early hominin evolution (Gowlett 2010; Wrangham 2009, 2010). Wrangham, a primatologist and evolutionary biologist by trade, builds his hypothesis on non-archaeological grounds by citing biological (i.e. the nutritional aspects of raw verses cooked food) and morphological (i.e. the sudden, punctuated appearance of a large-brained, large-bodied mammal in *Homo erectus* ca. 1.9 Ma ago) aspects of human evolution to infer fire has been an integrated part of human evolution for a very long time. Gowlett, an evolutionary archaeologist, broadly agrees with Wrangham, and admits to archaeological evidences for anthropogenic fire in the early parts of the early Pleistocene to be ambiguous, but nonetheless represent hominin caused-fire rather than natural fire. He points to localized fire-affected or 'baked' patches of earth at Lower Palaeolithic East African sites like Koobi Fora and Chesowanja (Gowlett 1999; Gowlett et al. 1981; Harris and Issac 1997), often associated with animal bones, some of which exhibiting cutmarks from stone tools as seen at Swartkrans in South Africa (Brian and Sillen 1988), as reasonably good indications of anthropogenic fire in the early Pleistocene, ca. 1.0-1.5 Ma ago (for counterarguments to some of these claims, please refer to James 1989). More definitive evidence of 'phantom' hearths appears a bit later on in the Middle Pleistocene at sites like Gesher Benot Ya'aqov in Israel around 700 ka ago (Goren-Inbar et al. 2004), possibly due to these younger deposits having suffered less taphonomic attrition than older sites. This trend of increased visibility of anthropogenic fire continues into the Middle Palaeolithic (discussed further in Chapter 1.2).

Much like the myths surrounding the origin of fire, the first fires were not artificially 'created' by early humans, but in all likelihood 'captured' from natural sources like brush fires, lightning strikes, spontaneous combustion of matted organics, or, in some regions, volcanic sources, and then transported to another location to be rekindled (Bond and Keeley 2005; Gowlett 2010; Gowlett et al. 1981). This method of harnessing, transporting, and maintaining fire appears to have been the standard for the bulk of human history, having still been employed by recent hunter-gatherer groups like the Tasmanian aboriginals, who despite retaining the ability to make fire at will commonly carried slow-burning rolls of bark from campsite to campsite (Roth, Butler, and Walker 1899; Völger 1972). At some point in our past, however, a cognitive and technological leap was made to where humans could produce fire of their own volition (the different methods for doing this discussed in Chaper 1.1). More often than not, this leap has been attributed to anatomically modern humans in the Upper Palaeolithic, a contention seemingly supported by the archaeological record; no unequivocal evidence for fire production has been recovered or recognized from any archaeological sites not affiliated with modern human activity (Stapert and Johansen 1999). This view, however, is not without its critics.

A continually contentious issue within the field of Palaeolithic Archaeology is the possibility of fire production originating in the Middle Palaeolithic. Did Neandertals possess the cognitive capacity, the manual dexterity, the ecological necessity, and the technological ingenuity, combined with a healthy dose of evolutionary serendipity, to attain the ability to recognize, utilize, synthesize, and ultimately, create fire? The answer to this question comes down to two primary variables. The first is plausibility, and the second, visibility. The plausibility of Neandertal fire production is by far the easier of the two variables to make an argument for. Any researcher can provide a logical, well-thought out reason why they *think* Neandertals were able to make fire, usually basing their opinion on ancillary physical evidence and research data. Paleoanthropologists have cited advances in Neandertal cognition based on an increase in brain size and encephalization, as ascertained by studying Neandertal fossil crania (a.o. Ruff et al. 1997). Archaeologists have demonstrated that Neandertals possessed the technological know-how not only to control and use fire for simple tasks like cooking meat or vegetal matter for consumption (Henry et al. 2011), but also used fire as a tool to perform complex tasks like synthesizing birch bark pitch for hafting stone tools, like those found at Königshaue in Germany (Koller et al. 2001), and Campitello Quarry in Italy (Figure 1.1; Mazza et al. 2006). Others have pointed to a marked increase in the number of sites possessing evidence for the presence of fire near the onset of the Middle Palaeolithic (300–400 ka ago) onward as another possible indication of Neandertal fire production (Roebroeks and Villa 2011a; see Chapter 1.2). Getting more to the crux of this thesis, artifacts generally associated with fire production (see Chapter 1.1) – specifically sulphuric iron (commonly referred to as pyrite in the literature) nodules exhibiting unknown or ambiguous usewear traces, have been recovered sparingly in solid Middle Palaeolithic contexts, including a 'newly discovered' reference to one such nodule at La Cotte á la Chévre on the island of Jersey (Sinel 1912, 1914; see Chapter 4.2.2), hitherto excluded from recent discourse on this subject – again lend credence to the argument for Neandertal fire production. However, despite these arguments *suggesting* Neandertals were in all likelihood smart enough, skilled enough, and possessed the requisite tools to produce fire, in the end, the fact remains that all lines of evidence presented up to this point are either supplementary or proxy data supporting fire production, but not one presents proof-positive verification that it occurred. This then begs the question, what sort of data *can* provide the unequivocal (or as close to unequivocal as one can get in this field) evidence needed to prove Neandertals were indeed able to produce fire?

Ultimately, it comes back to the issue of visibility. As intuitive as it might seem, the mere evidence of fire on a site, whether it be an actual hearth feature, or by-products of burning or fire-affected artifacts acting as proxy data (i.e. heated flints, burned bone, charcoal, and ash) is not enough to conclude that the fire was artificially made on site, but perhaps brought in from elsewhere. In this case, the 'smoking gun' is not the fire itself, but the tools used to make the fire.

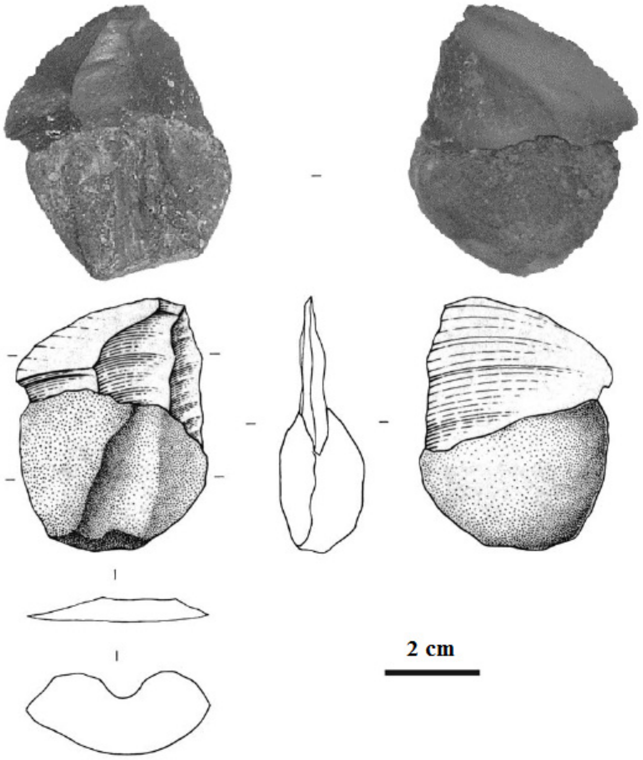

Figure 1.1. Flint flake with associated birch tar, Campitello Quarry, Italy (after Mazza et al. 2006).

1.1. Prehistoric fire production methods

According to most ethnographic accounts of fire-making by typical hunter-gather groups, there are two basic means by which fire is produced (outlined extensively in Hough 1926, 1928; Weiner 2003). The first system is characterized by wood on wood friction, and contains a variety of methods for producing friction, some by rotation and others by linear friction. Within the methods creating friction via rotation, the most basic and well-known method is the hand turned fire-drill, which based on ethnographic examples, is comprised of a straight stick usually with a tapered end (the 'drill') that is inserted into a shallow depression carved in the surface of another piece of wood (the 'hearth') and then rapidly turned between the hands until a small pile of super-heated smoldering wood powder accumulates around the point of contact of the drill and hearth, soon becoming an ember that can be used to light a fire. Other more complicated compound friction-by-rotation systems have been used in the more recent past like the bow-drill, the cord-drill, and the pump-drill. Linear friction methods include the fire-plough, the fire-saw with wood, the fire-saw with cord, and the fire-plane (for more information regarding the mechanics behind all of these methods, please consult Hough 1926 and 1928, as they will not be discussed here).

The second system by which fire is traditionally made is stone on stone percussion or friction, generally using a combination of flint (silicon oxide) and sulphuric iron (iron sulfide). For the sake of clarity, it should quickly be noted that for this thesis the nomenclature will follow Weiner (1997; 2003) by referring to what is traditionally called "pyrite" in the published literature as "sulphuric iron". There are two reasons for this. First, the sulphuric iron most commonly associated with prehistoric fire-making comes in a nodular form that is generally comprised of marcasite, a polymorph of pyrite, which typically exhibits a spherulitic crystalline growth pattern (i.e. a rounded aggregate of needle-like crystals radiating from a central nucleus). Being chemically identical, marcasite can be intergrown with or converted to pyrite and visa versa, so further analysis with X-ray diffraction or other laboratory methods is required to be certain which mineral is present. Secondly, the occasional exploitation in the past of the more massive cube-shaped forms of pyrite or other crystalline forms of sulphuric iron cannot be ruled out, even if generally less effective and more difficult to work with than their fine-grained counterpart.

According to numerous online posts and web pages by survivalists, 'earth-skills-movement' adherents, and prehistoric technology recreationists, it is possible to generate sparks using minerals other than sulphuric iron (e.g. pentlandite [iron nickel sulfide], hematite [iron (III) oxide], or magnetite [iron (II, III) oxide]), however, sulphuric iron has been found to be the most effective at producing relatively hot and long-lived sparks (Jürgen Weiner, personal communication 2011) when struck or forcibly scraped with a piece of flint (or other hard, usually silica-rich rocks like quartz, quartzite, chert, jasper, etc.), referred to hereafter as a 'strike-a-light'. The forcible contact made by a strike-a-light dislodges small fragments of the sulphuric iron that react with the oxygen in the air to produce a spark, an exothermic reaction generally hot enough to produce light and ignite a fire.

Both the wood-on-wood and stone-on-stone methods require a suitable tinder material to capture a spark and/or maintain an ember prior to being placed amongst dry grass or other easily ignited kindling material and fanned or blown into a flame. Ethnographic accounts list numerous suitable natural tinder materials that have been observed being used historically, and at least one example is known to have been utilized prehistorically. These include numerous dried fungus varieties, the most noteworthy being *Fomes fomentarius* (also known as 'tinder fungus', 'German tinder', or 'hoof fungus) and *Inonotus obliquus* (commonly known as Chaga mushroom), as well as punky wood, dried moss, *Typha* (commonly called 'cattial' or 'bulrush') down, downy bird feathers, or the silky down from *Silax* (willow tree) catkins (Hough 1926, 1928). According to Weiner (2003), *Fomes fomentarius* is arguably the most suitable tinder for readily capturing a spark using the stone-on-stone method. Furthermore, *Fomes fomentarius* is not only important due to its wide geographic distribution, occurring on four continents including Europe (Schwarze 2000), Africa, Asia, and North America (Schmidt 2006). Its importance lies also in having been recovered from archaeological sites as old as 11,555 ± 100 BP, most famously amongst the personal belongings of Ötzi, a well-preserved ca. 5,300 year old Copper Age mummy found in the Italian Alps (Peintner et al. 1998). The fungus was found tucked inside a leather girdle pouch with a larger and smaller flint blade and found to exhibit traces of sulphuric iron (Sauter and Stachelberg 1992).

The advent of artificial fire production, both the means and timing, has always been a contentious issue. Hypotheses on how both the stone-on-stone and wood-on-wood methods came to be discovered range from the practical to the fanciful, at times, and almost always include an accidental element. Also, to assume a single great mind started the 'fire revolution' is a bit naïve, as both methods were certainly independently invented and reinvented many times over before the technology became more or less 'fixed' within the human techno-culture. The discovery of the flint-on-sulphuric iron percussion method is generally attributed to a practical and accidental genesis during stone tool making, where perhaps a rounded sulphuric iron nodule, while being used as a hammerstone, unexpectedly drove a spark. Whether it was the recognition of the utility or merely the novelty of the spark that prompted the would-be inventor to try to recreate the phenomenon will never be known; and whether these subsequent sparks were consciously directed at an ignition material to make fire (surely the inventor in the very least had a solid grasp on combustion and fire building), or the sparks just happened to land on dry organic tinder material littering the inventor's workspace (perhaps even on the inventor's animal fur clothing) creating the tiny puff of smoke that helped connect the dots between sparks and fire.

The origins of the fire-drill seem to some to be less readily intuitive than the stone-on-stone method, but one hypothesis suggests an accidental discovery stemming from drilling activities with the aim of perforating a piece of wood (Hough 1926, 1928; Kidder 1994). Weiner (2003) doubts the likelihood of this scenario, specifically within a Palaeolithic context, citing primarily kinematic reasons (i.e. drills were almost exclusively hand-held tools; and the rapidity of the rotation needed to generate fire is impractical for the needs of Palaeolithic people based on their technology), as well as the fact that drills, as a rule, were made from inorganic materials like flint, other stone, or sometimes shell, all of which are incongruent with the modus operandi of the wood-on-wood friction method. Of the more entertaining hypotheses was one proposed by a German linguist named A. Kuhn, who suggested the friction method was born when prehistoric man observed two branches burst into flames after vigorously rubbing against one another during a storm (Kuhn 1959 in Weiner 2003; Saint John 1832 in Hough 1926). Surely, numerous bits of knowledge gleaned from other aspects of daily life had to be acquired for both methods before the final piece of the puzzle fell into place resulting in the 'Eureka!' moment of invention; but ultimately, the sequence of events leading up to these moments will probably never truly be known, destined to remain in the realm of speculation.

There is still some debate over which of these fire-making technologies pre-dates the other. Walter Hough, one of the foremost scholars on this subject, within a two-year span changed his mind from initially believing the stone-on-stone technology was older, to asserting the fire-drill was probably invented first (Hough 1926, 1928). Those advocating the latter generally cite the overall simplicity of the hand fire-drill and its widespread distribution amongst many different modern hunter-gatherer groups worldwide, having been observed or documented historically on every continent save for Antarctica, as testament to an earlier origin. Despite this contention of some, no unequivocal examples of a fire drill have been recovered that predate the end of the last glacial period (Collina-Gerard 1998). Therefore, most researchers tend to agree that the stone-on-stone method was invented first, but based on the archaeological evidence available – or more appropriately, the lack there of – we cannot necessarily exclude the possibility that the opposite is true.

It is here, however, that the issue of visibility returns once again to the forefront. This thesis is focused on the stone-on-stone percussion and friction methods, due not only to the contention that this technology is the most ancient, but also for the simple fact that stone stands a much better chance of being preserved in the archaeological record compared to the organic components of the wood-on-wood system. For the sake of argument, suppose both of these methods were being employed by Neandertals during the Middle Palaeolithic; ultimately, the relative durability of the stone-on-stone tool kit provides a much more promising, albeit still challenging, avenue of research. Determining what these tools might look like coming from a Middle Palaeolithic context forms the heart of this thesis.

1.2. Neandertals and fire: takers or makers?

Evidence has suggested the controlled habitual use of fire increased around ~400 to 300 ka, just prior to or at the onset of the Middle Palaeolithic (Roebroeks and Villa 2011a), with sites like Beeches Pit in England (Preece et al. 2006), and Schöningen in Germany (Thieme 1996, 1999, 2005), marking the beginning of this trend. While this does not provide any direct evidence that Neandertals were producing fire at will, it does lend support to the idea. This view has been contested by some who argue Neandertals remained obligate fire users until near the end of the Late Pleistocene (Sandgathe et al. 2011a, 2011b). Sandgathe et al. make the argument against habitual fire use (and by default, fire production) by Neandertals primarily on the basis of their findings at two Middle Palaeolithic sites in the Dordogne (France), citing the lack of continuous presence of hearth features in multiple occupation levels, especially those associated with colder climate regimes. They go on to suggest that "if Neandertals had the ability to make fire at will, then evidence for it should occur with much greater frequency in Middle Palaeolithic sites and occupations and especially, those sites associated with such cold stages".

There are a number of factors that should be considered which could account for the absence or perceived absence of fire in different occupation layers. When formal hearth structures are not present, fire proxies can provide reasonable evidence for the presence of fire. However, taphonomic processes such as the dissolution or washing away of lighter, less durable material like charcoal, ash, or burned bone fragments must be considered. However, one could reasonably expect to find heated flint artifacts still in place acting as a proxy for former hearth locations, if they had indeed been present (Stapert 1992). The spatial usage of rock shelter sites is variable (even more so for open-air sites), meaning the hearth will not always appear in a test pit; so unless a site is excavated in its entirety, sampling strategies could also be a factor. Possibly even more vexing to this issue is the harsh reality that even though Neandertals by and large may have been capable of habitually controlling and even creating fire, some groups may have lost the ability to do. There are multiple ethnographic examples of modern hunter-gather groups having lost the ability to make fire, including the Northern Ache hunter-gatherers of Paraguay (Hill et al. 2011). Furthermore, seasonality in relation to the duration of occupation for different find levels is another option to consider: not all seasons in glacial climates are bitterly cold, and not every month of the year in interglacial climates are scorching hot. Given the broad timescales generally utilized to define different occupation layers, timing could be the primary factor dictating whether or not fire was implemented.

Moreover, Roebroeks and Villa (2011b) counter the argument made by Sandgathe et al. (2011a, 2011b) by pointing out that in the Upper Palaeolithic record, analogous to their Middle Palaeolithic counterparts, 1) relatively few sites and occupation layers contain preserved hearth features, 2) many more sites and occupation layers have one or more fire proxies present in the depositional matrix indicating fire was used, and 3) even sites with well-stratified sequences (Roebroeks and Villa cite Abri Pataud in the Dordogne as an example) do not always exhibit evidence for fire in all occupation layers. These data, coupled with the fact that only a handful of convincing fire-making tools have been recovered from Upper Palaeolithic contexts (Stapert and Johansen 1999), are not enough to dissuade most researchers from arguing that these people were habitual fire users. Why then is there this double standard with regard to Middle Palaeolithic hunter-gatherers?

Perhaps finding a Middle Palaeolithic burial like that unearthed at the Middle Neolithic site of Schipluiden (Lower Rhine basin, Netherlands) of a man clutching in his hand several flint strike-a-lights and a sulphuric iron fragment (Figure 1.2; Smits and Louwe Kooijmans 2006; Van Gijn et al. 2006) would be the definitive find settling this debate. Since is it highly unlikely that archaeologists will recover a Neandertal skeleton clutching in his hand a similar fire-making set anytime soon, alternative lines of firm evidence must be sought within the archaeological record to corroborate the assertions of some that Neandertals were indeed able to produce fire of their own volition. This MA-thesis hopes to shed some light on this contentious issue.

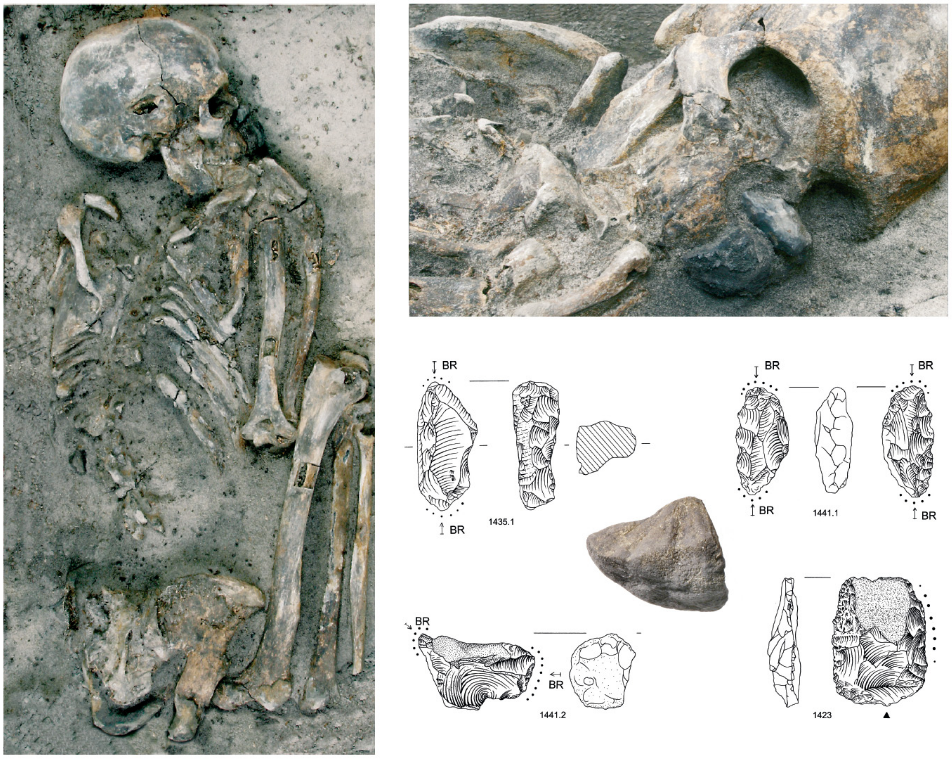

Figure 1.2. Neolithic grave (Grave 2) and offerings from Schipluiden, Netherlands, including three strike-a-lights, one sulphuric iron fragment, and one retouched flake (after Smits and Louwe Kooijmans 2006, 96–97; photos not to scale).

1.3. Research Questions

This study was designed and conducted with the intention that the information gained be used as a ‘guide book’ detailing what the discerning archaeologist should be mindful of when examining a lithic assemblage from a Middle Palaeolithic site with evidence of fire in order to identify tools exhibiting usewear traces indicative of their possible usage as fire-making implements. It should be noted that some of the results derived from this study could easily be applied to any archaeological site where stone-on-stone fire production technology may have been utilized, regardless of age or location. Arguments and evidence are presented that discuss the likelihood of Neandertals being able to produce fire themselves as opposed to merely collecting it from natural sources or stealing it from adjacent groups. Macroscopic and microscopic traces observed during the usewear analysis of experimental flint and sulphuric iron pieces are outlined, as are the results of the application of the data gained from experimentation and gleaned from extant literature to actual Middle Palaeolithic artifact assemblages in search of strike-a-lights, a process tantamount to finding a needle in a haystack; except, in this case, there is no guarantee that the 'needle' is present at all.

The experiments in this study were approached with a 'Neandertal mindset,' focusing on the assertions of some researchers that Neandertals generally practiced an *ad hoc*, minimal investment technological strategy (Dibble 1984, 1987; Roebroeks et al. 1997). In other words, an emphasis was placed on replicating 'expedient' strike-a-light specimens that exhibit only very short term usage prior to being discarded, some for only a single fire-making 'episode' (see Chapter 2.3.3), as opposed to more heavily used specimens that seem to be more prevalent in existing comparative studies. These 'curated' strike-a-lights tend to more closely resemble archaeological examples recovered from more recent (possibly some Upper Palaeolithic, but mainly Mesolithic and Neolithic) settings (Stapert and Johansen 1999; Van Gijn 2010; Van Gijn et al. 2006), and to this point have not been observed conclusively in the Middle Palaeolithic record. The hypothesized Neandertal 'use-and-lose' mentality towards strike-a-lights, and the possible subsequent failure of researchers to recognize them as such due to less evident usewear traces, could account for the invisibility of these tools in the Middle Palaeolithic archaeological record. Therefore, the research questions for this research thesis are as follows:

1. What lines of evidence, both present in the literature and based on new usewear experimentation, should researchers be aware of in order to recognize possible tools associated with producing fire within a Middle Palaeolithic artifact assemblage, specifically focusing on flint implements exhibiting usewear suggestive of use as strike-a-lights, and sulphuric iron pieces exhibiting usewear indicative of human alteration and use as a contact material with a strike-a-light?

2. How do the different methods of applying the strike-a-lights to the sulphuric iron compare in terms of effectiveness (i.e. spark generation success), and what variables might factor into the possible differences in rates of success?

3. With regards to the 'expedient strike-a-light' hypothesis, how readily does usewear appear after only very short term usage, and do these usewear traces manifest themselves differently than those generated by longer-term usage?

4. What artifacts discussed in extant literature add credibility to the hypothesis that Neandertals were capable fire-makers? Special attention is given to La Cotte à la Chèvre, a Middle Palaeolithic cave site on the island of Jersey, where a sulphuric iron nodule that has not been a part of the modern discourse on this subject was recovered from an archaeological find layer in 1881 (Sinel 1912).

5. Are any artifacts present within an actual archaeological assemblage that exhibit traces consistent with being used as a possible strike-a-light, specifically herein the Last Interglacial site of Neumark-Nord 2/2 in Germany? If so, are these lines of evidence only easy to identify during trait-specific analysis of an artifact collection, or could cursory analysis (e.g. during cataloguing or lithic analysis) be sufficient to single out possible strike-a-light specimens for further study?

6. How could the findings from this study be applied to other related areas of research?

2. FUNCTIONAL ANALYSIS – EXPERIMENTAL METHODS AND TECHNIQUES

The following section provides a detailed account of the methodologies employed to create and analyze a set of flint 'strike-a-light' comparative specimens that, through different variable-length application procedures, have come into repeated contact with sulphuric iron for the express purpose of generating sparks for the production of fire. Damage incurred by both the flint strike-a-lights and the sulphuric iron fragments is identified and described through various analytical methods at the macroscopic and microscopic level, the latter employing both low and high magnification.

2.1. Introduction to usewear analysis

Typo-morphological studies alone have been shown to be inadequate for determining the function of an artifact or specific artifact types (a.o. Jeffreys 1955; Van Gijn 1999). Functional analysis (or: usewear analysis) provides a more objective means by which the specific task performed by a tool (or a specific tool form) can be identified, as task and tool form are not always mutually inclusive. This is accomplished through the observation and recognition of microscopic wear or damage to the surface of a tool that can be ascribed to a specific task, either by comparison with ethnographic examples where tool form and function are known, or, more commonly, by replicating usewear patterns through the creation and utilization of experimental facsimiles. This methodology was developed during the 1960s after Semenov's groundbreaking publication laying out the procedures for identifying usewear traces on flint, stone and bone was translated from Russian to English (Semenov 1964). When conducting usewear analysis, both low and high magnification methods have been employed. Semenov (1964) used lower magnifications for his study (up to 100 times), while Keeley (1974, 1980) introduced the use of higher magnifications (up to 400 times). For this study, both low and high power methods were used.

According to van Gijn (1989), the four primary types of damage inflicted on tools are edge-removals (which includes use-retouch and stacked edge-removals, commonly referred to as crushing), edge-rounding, polish, and striations. Within these phenomena, other attributes like polish texture, topography, brightness, striation density, and edge-removal distribution can be further defined. No one attribute is by itself indicative of how a tool was used in the past, and usually a combination of characteristics is needed to create an identifiable pattern. Given that this study deals exclusively with damage caused by repeated flint-on-sulphuric iron contact, only the attributes considered most diagnostic of this activity will be discussed in any detail here. Based on strike-a-light experiments conducted by a number of researchers (i.e. Stapert and Johansen (1999); Van Gijn et al. 2006; Van Gijn 2010), and usewear traces observed on experimental strike-a-light comparative specimens residing within the Leiden Laboratory for Artefact Studies experimental collection, the most common suite of traces exhibited on the worked flint surfaces included substantial edge-rounding, densely packed subparallel striations within distinct zones of polish (or: gloss), and stacked edge-removals (see Chapter 3.1).

Edge-rounding is easily the most common use-damage present on tools since contact with any material is bound to round a tool edge to some extent (Van Gijn 1989). Nevertheless, the degree of rounding can in some cases can be indicative of what material the tool came in contact with, or at least the relative hardness of the contact material and possibly to what extent the tool was used.

The formation of polish on flint is to this day not fully understood, with some asserting that it is formed as a result of chemical (Anderson-Gerfaud 1990) or a mechanical reaction (Yamada 1992), though most researchers today believe that it is most likely a mechanical phenomenon that is sometimes influenced by certain materials (e.g. plant juices) that may cause chemical reactions (Van Gijn, personal communication, 2011). Whatever the formative process, the end result is an increased reflectivity of the tool surface, and it is the degree of reflectivity (or: brightness) or the texture of the polish that helps infer the contact material.

Crushing – as indicated by sets of stacked edge-removals usually terminating in step fractures – on the salient points of a stone tool is generally indicative of battering (i.e. impact) or the application of high pressure between the tool and another relatively hard contact material. Crushing tends to be more prevalent when employing percussive activities due to Hertzian fracture propagation initiated by the force of the strikes. Crushed portions of a flint artifact generally stand out macroscopically from uncrushed areas as white or lighter colored features when compared to the surrounding matrix due to small fractures in the flint that create internal reflective surfaces. This can be even more prevalent under magnification, where transmitted light is reflected off these internal fracture planes (Figure 3.4: D). To what degree an edge or surface exhibits crushing could also provide insight into the extent of usage, the hardness of the contact material, or the amount of force applied during usage, though how one could really know the difference could be difficult.

Edge-removals, both macroscopic and microscopic, can often be associated with crushing, especially when the flint is applied to harder contact materials like sulphuric iron. The general rule is the harder the contact material, the larger the removals, with medium-hard materials typically producing flake scars exhibiting hinged terminations, and hard materials typified by stepped terminations (Odell and Odell-Vereecken 1980). As a rule, edge-removals can be size graded as follows: very small = 0–0.5 mm; small = 0.6–1 mm; medium = 1.1–2 mm; large = 2.1–5 mm; and very large = >5 mm (Van den Dreis 1998).

The final usewear feature to be discussed is striations. Striations appear to be associated with polish insofar as formative processes are concerned, i.e. the mechanical and/or chemical reactions taking place on the surface of the flint during usage. Striations also only seem to appear within zones of polish (Van Gijn 1989; Mansur 1982, 1983; Mansur-Franchomme 1983). As far as what causes the striations themselves, it is generally believed that they are formed by the presence of abrasive particles (e.g. edge-removals, pieces of the contact material, or gritty additives) between the tool-surface and the contact material (Van Gijn 1989; Keeley 1974; Semenov 1964). Striations are arguably one of the most important attributes to consider in usewear studies, especially when identifying strike-a-lights, as in this study. Not only are they fairly easy to recognize, but depending on what contact material a tool is used on, striations of different shapes and characteristics can be very distinctive and often diagnostic (Plisson 1985). Furthermore, by observing the directionality of the striations present on the tool, one can often infer the motion involved in its usage (Vaughan 1985; Semenov 1964).

A plethora of post-depositional (or even post-excavation) processes are notorious for altering the surfaces of artifacts, either destroying usewear traces or creating confusing faux-use-damage. These consist of a wide range of chemical and mechanical alterations, including varicolored patinas, glosses, and large or small scale surface damage or breakage (Van Gijn 1989). A few of the processes more pertinent to this study include polish or rounding created by the deposition of an artifact in sandy matrix (i.e. ‘soil-sheen’), or by water transport; and rounding and crushing that could be caused by any number of natural mechanisms: tumbling caused by water transport or rock fall, deposition in gravelly soil, or even extreme pressure and/or movement caused by glacial action.

2.2. Experimental procedures

2.2.1. Kinematics

The methods for applying a flint strike-a-light to an iron sulfide fragment almost certainly varied not only by culture through time, but from person to person based on preference. The most marked difference in techniques would have to be percussing versus scraping (i.e. the friction method) the iron sulfide with the flint. Both techniques are effective at producing sparks, each possessing possible advantages and disadvantages (which, again, may be so considered purely on personal preference). It could be argued that the percussion method allows for a more rapid succession of blows, possibly increasing the number of spark-generating strikes within a given timeframe compared to the friction method. However, the friction method may afford more control and an accompanied higher rate of success of spark production per attempt, as well as a higher degree of directionality of the sparks, thereby increasing the likelihood of tinder ignition. Also, one could argue that the friction method would preserve more fragile pieces of iron sulfide for longer given less stress is being applied compared to striking, hence reducing the chances of fracturing and crumbling. The same argument may not necessarily be the case for the flint implements used. When applied to the iron sulfide in both techniques – until a stable edge has developed – all tools experience some degree of edge damage under the percussing force when struck, or the pressure applied when scraped. Which method was employed at any given moment in the past could have been dependent on the raw materials present (size of raw pieces, quality, internal flaws, etc.), with specific regard to the size of the flint implements that can be made, not to mention simply due to technological choices made by individuals.

Based on the author's personal experiences, the percussion method is more easily facilitated by larger pieces of flint that allow for more distance between the striking surface of the iron sulfide and the operator's knuckles, whereas the friction method can be performed with both larger fragments as well as smaller pieces, especially when the smaller pieces are hafted providing a surer grip and more leverage. Factors such as these and other morphological attributes (e.g. a sturdy working edge) dictated that the pieces used for experimentation were not selected at random, and for the most part, this can be assumed to be the case for archaeological specimens, as well. Expedient tools (specifically flake tools) were almost certainly preferentially selected by morphological attributes for a specific task from a larger but limited assemblage of debitage, though some could have been created with the desired form predetermined. For this study, flakes were preferentially selected to incorporate a number of different edge types to assess their effectiveness, and how a particular piece was applied was guided primarily by ‘how it felt’ in the hand, as well as by the abovementioned morphological factors. Taking all of this into account, it was decided the prudent approach to this study would be to do parallel experiments using multiple techniques (see Chapter 2.3.4).

2.2.2. Proficiency, materials, and duration of use

Proficiency at producing fire using the percussion or friction method obviously varies from person to person, as well as between different raw material and tinder types, so determining what exactly the proper number of strokes the average Middle Palaeolithic fire-starter would need to propagate a fire is unknown. It could be assumed, however, that these people would be fairly proficient in these methods (if indeed utilized at all), as they probably depended on them for daily survival. They may not have needed to employ such technology on a daily basis, per se, but a working knowledge of how to kindle a new fire from scratch would have been crucial in instances where fire is lost. That being said, one wonders: should focus be placed on the total number of strikes, or the number of strikes that generate sparks, as the baseline for how many strikes should constitute a single fire-making episode? How many spark-generating strikes would be needed, on average, before one is captured in the tinder? Based on personal communication with Jürgen Weiner (2011), as well as commentary and videos posted by numerous survivalists and prehistoric technologies enthusiasts on the internet, a spark can be captured by tinder in fewer than ten strokes, but can often take possibly hundreds of strokes depending on proficiency, tinder quality, and any number of other factors (flint quality, sulphuric iron type and quality, humidity, etc.). As discussed above, certainly the method used (percussion verses friction), kinematic variation, tool size, form, and edge selection all will influence the effectiveness of the strike-a-light, as well. Therefore, for the sake of consistency, the total number of strokes per fire-making event (or: series) has been arbitrarily set at 25 strokes to provide the best control, while the number of spark-generating strokes within each series will be noted potentially providing interesting data on tool effectiveness per methodological variation applied.

A few possible sources of variation in the effectiveness of the sulphuric iron contact material being used were encountered through the course of experimentation. The experiments were performed on similarly flat interior fracture faces, yet over time the contact surfaces became more worn and smooth due to crushing. The different faces had comparable surface areas despite the variation in the actual size and weight of sulphuric iron fragments themselves due to the failure of the nodule during the course of the experiments, as described above. One strike-a-light (Experiment 2013 in the Leiden Laboratory for Artefact Studies experimental comparative collection) was unique in that it involved the application of a concave working edge to the convex surface of a nodular fragment different from the other two primary surfaces employed. It is unknown if these sources of variation had any significant effect on the experiments, as no additional experiments were performed to test for them.

2.3. Flint strike-a-light experiments

2.3.1. Selecting materials

When selecting the materials to be used in the experiments described below, a number of factors came into play. First and foremost was the desire for control and consistency between the experiments described below. With this in mind, only one type of flint from a singular nodule was used for the experimental strike-a-lights, and sulphuric iron from a singular nodule was used as the contact material.

The flint nodule used was collected from a beach roughly 200-m south of the Lower Palaeolithic Happisburgh 1 site near Happisburgh, Norfolk County, England, during excavations there in July 2011. Prior to collection, the nodule was tested and found to be of good quality, moderately translucent flint with few internal flaws or fractures. The nodule had a very thin, dull dark gray (10YR 4/1) cortex, overlying a very dark brown (7.5YR 2/3, thicker fragments) to dark brown (7.5YR 3/4, thinner fragments) band approximately 5-mm thick (possibly different from interior due to weathering), followed by gray (7.5YR 5/1) band approximately 2-mm thick, with the interior exhibiting a very dark gray (7.5YR 3/1 to 10YR 3/1) color overall, with common to many (15–25%) medium to coarse, irregular rounded to oblong, light gray (2.5Y 7/1 to 10YR 7/1) mottles having a slightly coarser texture than the surrounding matrix. This type of flint does not have a formal name, but occurs in secondary lag deposits derived from Cretaceous age chalks (Parfitt et al. 2010) The nodule was flattish and oblong in shape, weighed approximately 1.6 kg, and, though not formally measured, approximately 25-cm long by 10-cm thick in maximal dimensions.

2.3.2. Creating experimental pieces

Statistically speaking, the vast majority of artifacts produced during stone tool manufacture are flakes. Whether they are intentionally produced for use as a tool or are by-products of tool manufacture (i.e. waste flakes or debitage), flakes are the most readily abundant artifact type available for use as expedient tools. Therefore, all but one experimental specimens used in this study are small to large sized flakes (minimally 2.3-cm, and maximally 6.6-cm in length, measured perpendicular to the striking platform), the other (Experiment 2006) being an elongated salient portion of the nodule with a naturally rounded and battered surface (6.8-cm in length)

The somewhat flattish nature of the flint nodule lent well to knapping with a generic radial (or: centripetal) reduction strategy with the intention to create the greatest number of useable flakes with sturdy proximal edges as was possible. These flakes are probably similar to what one could expect to find when similar generic radial, Levallois, or disc core reduction strategies have been employed. Knapping was performed via hard-hammer percussion with a flattish, oblong, water-rounded hammerstone composed of basalt porphyry with plagioclase phenocrysts, also recovered from the beach near Happisburgh 1. This hammerstone was also used to perform light to moderate platform preparation prior to flake removal. Grinding was executed transversely across the top of the platform surface in an attempt to mirror similar probable platform preparation observed on a number of flakes from the Middle Palaeolithic site of Neumark-Nord 2/2 (see Chapter 5.2).

2.3.3. Documentation

The number of strokes decided on to represent one fire-making episode (or: series) has been set at 25, which seemed to be a reasonable average for the minimum number of strokes needed on average for a proficient fire-maker to kindle a fire (Jürgen Weiner, personal communication, 2011). Each experimental strike-a-light was used for sets of one, two, three, or four series, with the maximum number of strokes applied to any one piece being 100. For specimens progressing beyond a single series, an incremental approach was taken to show the evolution of the working edge over multiple episodes of use. The number of series conducted per specimen was assigned more or less arbitrarily. Careful description and documentation of each experimental piece was conducted prior to and after each series. The methods for conducting a single series are as follows.

Prior to experimentation, each strike-a-light specimen was assigned an experiment number, drawn, and described on an experiment form, including a description of the tool itself, how it was employed, notes on tool effectiveness, and so on (Appendix I).

Each specimen was weighed prior to experimentation, and photos were taken to document the 'baseline' of the experiment. Macroscopic photos of both the dorsal face and the working edge of each piece were taken with an Olympus Camedia C-5000 Zoom digital camera (Appendix II). Low power microscopic photos were taken of two or three strategic edge locations using a Nikon DS-Fi1Digital Sight camera mounted on a Wild M3Z binocular microscope. These locations are clearly delineated on the artifact drawings on the experiment forms. Higher magnification photos were taken of various samples through the course of experimentation and analysis using a Nikon Optiphot-1 metallographic microscope at 100 or 200 times magnification, with limited photos taken using a Nikon Optiphot-2 metallographic microscope at 500 times magnification. Photos at higher magnifications were taken incrementally at different levels of focus for each location. The different layers were combined and rendered using Helicon Focus 4.80 Lite, which adjusted for the variability in the depth of field for individual photos, thereby producing more focused compound images. Not all samples were photographed at higher magnification due to the redundancy of the information contained in the images. Video documentation of the working edge as a whole was also conducted using a Hitachi KP-050 color digital video camera mounted on the Wild M3Z binocular microscope scope, recorded onto VHS tape, and then converted to digital format (Appendix VI).

When choosing a location to perform the experiments, it was decided that a constant environment should be maintained to reduce inter-experiment variability, however minor. Therefore, the experiments were conducted indoors in a closed room with a relatively constant temperature and humidity. The indoor setting also provided a dependable light source that facilitated consistent lighting for capturing the procedure on video. Each series was digitally recorded using a Samsung H300 OIS Duo HD camcorder so the kinematics of each experiment type can be observed and described, or possibly even reproduced.

During the execution of each series, the number of strokes administered and the number of strokes generating *visible* sparks were counted simultaneously. Not all sparks are necessarily visible to the naked eye in a lit environment, so it is possible the number of strokes generating sparks could potentially be higher than observed. The number of spark-generating strokes was noted on the artifact forms and entered into a Microsoft Excel 2003 table for initial statistical analysis. More detailed statistical analysis on other metric factors like tool lengths and edge straightness performed using SPSS (Statistical Programming for Social Sciences) v.19 to see if any significant trends could be seen in the data regarding how these factors influence the effectiveness of each method over time and compared with one another (see Chapter 3.3).

Also for each series, a clean plastic sheet was placed on the floor in an attempt to capture any debris (e.g. edge-removals, small flakes, broken fragments, etc.) that might be detached during experimentation. If produced, all of the debris present was collected, though it is possible that in some instances an errant fragment traveled beyond the plastic. Exactly what information can be gleaned from this debris is uncertain at the moment and beyond the scope of this study, but would be available for future research.

2.3.4. Application methods, techniques and kinematics

As discussed above, two different methods of applying the flint strike-a-light to the sulphuric iron contact material were employed in this study: the percussion method and the friction method. The utilized edge on every experimental piece was the dorsal edge of the striking platform, save for one where a naturally rounded edge was worked. The reasoning behind selecting the proximal dorsal edge of the striking platform as the primary working edge for the experiments lies primarily in the fact that this edge on average tends to be thicker than the lateral and ventral flake edges and has a higher relative platform-to-dorsal surface angle, which creates a sturdier working edge more resistant to edge failure, an important feature when being applied to a hard contact material like sulphuric iron with the amount of force necessary to create sparks.

To account for variations in usewear traces caused by gesture differences, some experimental pieces were held so the working edge was brought across the contact-surface transversely to the edge, while others were applied longitudinal to the edge. This creates four groups of experiments based on the method applied and the positioning of the tool edge: friction/longitudinal, friction/transverse, percussion/longitudinal, and percussion/transverse. Experiment 2006 was placed into a fifth category – the percussion/natural group – due to the very different character of the naturally rounded surface employed by that strike-a-light.

Prior to experimentation, ‘practice runs’ were conducted using the abovementioned methods to determine what hand grip and body position was the most comfortable and effective in generating sparks, while still being easily visible during video recording. Every attempt was made to be as consistent as possible within and between each experiment group, though given that not all the strike-a-lights were of the same size or shape, some minor differences were inevitable. All experiments were conducted while kneeling on the right knee, left elbow resting on the left knee, the strike-a-light held in the right hand and actively applied to the sulphuric iron nodule held passively in the left hand.

For the friction/longitudinal method, the sulphuric iron nodule was firmly gripped in the left hand with the contact-surface positioned slightly tilted off-vertical (ca. 10-20 degrees) away from the body (see Appendix VII for video of the various techniques applied for each experiment). The strike-a-light was gripped firmly between the thumb and forefinger with the working edge of the tool in a vertical position. For a single stroke, the working edge was placed near the top of the contact-surface applying moderately firm pressure. Using a linear vertical wrist and forearm movement, the tool was brought sharply downward for the length of the contact surface, with the stroke generally progressing to around 10-cm beyond the edge of the contact surface.

For the friction/transverse method, the sulphuric iron nodule was firmly gripped in the left hand with the contact-surface positioned slightly tilted off-vertical (ca. 10-20 degrees) away from the body. The strike-a-light was gripped firmly between the thumb and forefinger with the thumb on top, the tool itself held at an approximately 45 degree angle to the length of the forearm with the working edge in a horizontal position. For a single stroke, the working edge was placed near the top of the contact-surface applying moderately firm pressure directed into the surface. Using a slight twisting wrist-action and straight vertical forearm movement, the tool was brought sharply downward for the length of the contact surface, directing the stroke across the top of the surface of the striking platform, with the stroke generally progressing to around 10-cm beyond the edge of the contact surface.

For the percussion/longitudinal method, the sulphuric iron nodule was firmly gripped in the left hand with the contact-surface positioned slightly tilted off-vertical (ca. 10-20 degrees) away from the body. The strike-a-light was gripped firmly between the thumb and forefinger with the working edge of the tool in a vertical position. For a single stroke, the working edge was positioned approximately 10-cm above and away from the contact surface. Using a linear vertical wrist-action and forearm movement, the tool was brought sharply downward striking near the center of the contact surface, with the stroke generally progressing to around 10-cm beyond the edge of the contact surface.

For the percussion/transverse method, the sulphuric iron nodule was firmly gripped in the left hand with the contact-surface positioned slightly tilted off-vertical (ca. 10-20 degrees) away from the body. The strike-a-light was gripped firmly between the thumb and forefinger with the thumb on top, the tool itself held perpendicular to the length of the forearm at an approximately 45 degree down-angle from horizontal. The tool was brought sharply downward with the forearm and slight wrist-action at an approximately 45 degree angle directing the blow more ‘into’ the center of the contact-surface (verses more across the surface as in the other experiments), with the stroke generally progressing down and away from the contact-surface after the impact and terminating around 10–20-cm beyond the edge of the contact surface. This grip and positioning direct the blow across the dorsal surface of the strike-a-light as opposed to across the top of the striking platform. The reason for this was that during the ‘practice experiments’, it was determined that striking across the top of the platform resulted in a higher incidence of fragments being detached from the strike-a-light (i.e. edge-removals and edge-failure) and projected towards the operator’s face, making the method appear too unsafe to be a practical.

The percussion/natural group (Experiment 2006) - a tool type unique to the data set - required a striking technique that employed a grip similar to that used for the percussion/longitudinal group, but the blow trajectory corresponded more closely to that of the percussion/transverse group.

2.3.5. Casting procedure

After each series, the specimen was cleaned by hand using soap and running water to remove excess sulphuric iron adhering to the working edge. Once dry, the worked edge was documented photographically just as it had been prior to being utilized. If any notable damage occurred to the working edge, it was described and drawn on the experiment form.

If an experimental piece was selected to undergo another series of use, molds and casts were made of the worked edge using fast-setting Provil® novo silicone impression material (vinyl polysiloxane). Care was taken not to touch the edge of the tool with the metal spatula used to apply the molding gel to avoid leaving behind traces of metal. The compound begins to set within a minute or two, and is usually completely set within 3–4 minutes. The mold was then carefully peeled off the sample. It should be quickly noted that the sulphuric iron must be thoroughly cleaned from the working edge prior to this process, as it was found that excess sulphuric iron appears to impede the setting process of the molding gel, thus ruining the mold.

The mold was then used to create a cast of the worked edge using the same materials and very similar methods to those discussed above, with only a few differences. Prior to creating the cast, the inner part of the mold was sprayed with a couple coats of Dolcis Trend Spray, a fabric waterproofing spray, and allowed to dry. The mold was then filled with the mixed molding compound and allowed to set. Very soon after the compound has set, the small metal spatula was used to carefully separate the mold from the cast. It was found that without the waterproofing spray, the compound binds to itself making it impossible to separate the cast from the mold, ruining both. While the practice of producing negative casts of tool edges is common in usewear experimentation, the process outlined here for creating positive casts from the negative molds is not standard operating procedure, and was developed by the author through trial and error. The only other minor problem encountered was that sometimes small air bubbles become trapped in the molding compound during the mixing process, and if they come to rest on the working edge, that small section is missing. Overall, however, this process is certainly adequate for the preservation of detail at the macroscopic and lower magnification levels, while finer usewear details (e.g. striations) are often preserved by this process, as well (FIGURE 2.1).

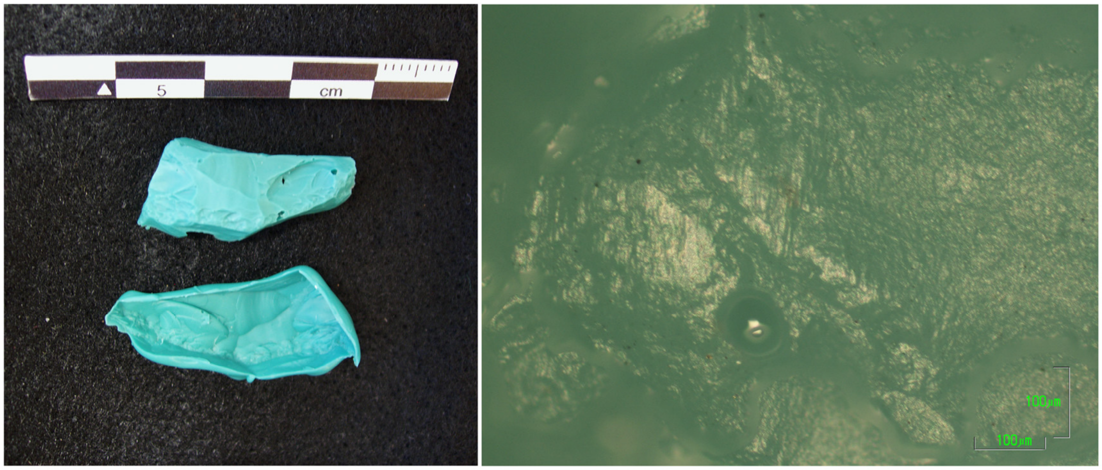

Figure 2.1. Photographs of strike-a-light cast (Experiment 2002-2). Left, positive and negative casts. Right, preserved usewear and air bubble on positive cast (100x).

2.3.6. Summary

In total, 14 strike-a-light experiments were conducted for this study, with 13 conducted using flakes, and one using a detached elongated salient portion of the nodule with a naturally rounded and battered edge (Table 3.1). Seven of the experiments employed the friction method, with six scraping transversely to the proximal dorsal edge of the flake across the top of the striking platform, and one scraping longitudinal to the dorsal edge of the striking platform. Six of the experiments employed the percussion method, with two striking transversely to the proximal dorsal edge of the flake across the dorsal surface of the flake, four striking longitudinally to the dorsal edge of the striking platform, and one striking a naturally rounded edge. Two experiments consisted of only one series (25 strokes total); three for two series (50 strokes total); three for three series (75 strokes total); and six for the full set of four series (100 strokes total).

A sample is labeled and identified in the text, figure captions, and forms as "2003-2" or "2011-0a", where the first number is the experiment number (2000–2013), the second the series number (0–4), followed by, in some instances, a lowercase letter (a-c) identifying a photo location on that piece. For the series number, zero represents the sample prior to experimentation, one for the first series of 25 strokes, and so on.

2.4. Sulphuric iron contact material

A true strike-a-light cannot exist without a suitable contact material for making sparks, the most efficient in prehistoric times being various forms of sulphuric iron. Therefore, it would be imprudent not to devote sufficient attention to this integral component of the stone-on-stone fire production tool kit. Despite the relatively low preservation potential for sulphuric iron when compared to flint – especially in open air environments where water in the soil can quickly degrade this type of mineral – nodules and fragments have been preserved in the archaeological record in more protected depositional environments like caves (see Chaper 4.2).

It should be noted that the conclusions drawn from the analysis the sulphuric iron nodule used as the contact material for the strike-a-light experiments were not based on formal experimentation of the nodule itself per se. They were instead observations made while preparing and using the nodule during the experimental process, and post-experimental analyses of the affected and unaffected portions of the nodule. The research questions concerning the sulphuric iron nodule – much in keeping with the theme of ‘expedience’ presented in this thesis – manifested themselves in an *ad hoc* fashion through the course of the study, and will be presented here in a similar fashion.

2.4.1. Description of material and methods

The sulphuric iron nodule used as the contact material was obtained from a beach near Cap Gris-Nez, northern France. These sort of sulphuric iron nodules are actively eroding out of Cretaceous age chalk cliffs and collected from secondary lag deposits on the beach below. The nodule, though composed almost exclusively of iron disulfide (FeS_2), possesses a 3–5-mm thick cortex that appears to be hematite replacing marcasite. The nodule was irregularly spherical in shape, and measured 7.5-x-7.5-x-6.5-cm in maximal dimensions. The pre-use weight of the nodule was not ascertained (estimated at 715 g), but its post-experiment weight is 700 g.

Prior to experimentation, the outer surface of the nodule was tested with flint and found to be mostly ineffectual at producing sparks, so the nodule was forcibly opened using a hammerstone to expose the fresh interior for use as the contact-surface for the strike-a-light experiments. After three firm blows with the hammerstone, the nodule broke into two fragments along a natural fissure that upon fracturing exhibited a thin surface coating of an unknown reddish mineral, probably iron oxide, as well as occasional very small crystalline growths, possibly calcite (Figure 3.10: A and B). This appears to be a common feature, having been observed in other nodules collected from the same locale, though some nodules are more fragile than others and may exhibit a white crusty power (iron sulfate, $FeSO_4$) along these fractures, a by-product of oxidization known as ‘pyrite decay’.

The smaller wedge-shaped nodule fragment was extensively used as a practice piece prior to experimentation. A relatively flat interior surface of the larger fragment was used for 15 out of the 40 series executed during experimentation prior to the nodule fracturing into three fragments along a series of internal fractures during Series 2006-2. After this point, a smaller wedge-shaped fragment of the same nodule with a similarly flat surface was employed for the remaining series, ultimately receiving approximately 650 strokes, both friction and percussion. Between each series, a dry paper towel was used to wipe away excess dust produced during experimentation from the contact-surface just in case a buildup between crystal structures influences the effectiveness of subsequent strokes.

Photo documentation of the nodule (reconstructed), its constituent pieces including all of the different surface 'types' (i.e. utilized, unutilized, weathered, and unweathered fracture faces) discussed here were analyzed and photographed at macroscopic and microscopic levels using the same equipment and procedures described in Chapter 2.3.3. The photos of unworked surfaces do not necessarily correspond directly to the same surface or surface location of photos depicting a utilized surface. In other words, photos of unworked surfaces are there to give an *impression* of what the worked surface on another fragment probably looked like prior to use. A photo was also taken of the reconstructed nodule as a whole (Figures 3.6 and 3.7). All worked surfaces were rinsed under running water to remove excess oxidized powder prior to photographing and analysis.

2.4.2. '*Ad hoc*' experiments

A number of research questions arose about various aspects of the sulphuric iron nodule during the course of the experiments:

1. How does a well-used surface compare with a very lightly used one as far as usewear is concerned, both macroscopically and microscopically?
2. How do a freshly broken surface and a slightly weathered fracture surface differ macroscopically and microscopically?
3. What do impact features on the surface of a nodule look like, and could they be used to indicate forcible opening by humans when other usewear traces are absent?

The most well-used experimental contact surface (subjected to ca. 650 strokes) was selected to address the first research question. A smaller nodule fragment with a flat fracture surface was subjected to 25 strokes using the friction/transverse method. These were compared and photographed.

To address the second question, a freshly broken surface was needed since all breaks in the nodule to this point had occurred along fracture planes. A fragment of the nodule was broken open using a hammerstone after repeated blows, many more than the three blows required to initially open the nodule. The freshly exposed surface was compared to an unworked fracture surface on another nodule fragment.

Addressing the final question merely required reconstructing the nodule and relocating the probable impact points of the hammerstone.

3. RESULTS

The following section discusses general trends and specific instances of phenomena observed during and after experimentation with regards to macroscopic and microscopic usewear traces and tool effectiveness. A basic rundown for each of the fourteen strike-a-light experiments conducted in this study is provided by Table 3.1, including the application method, location of worked edge, duration of use, and metric attributes (tool length and weights). For more detailed information regarding the individual experiments, please consult the individual experiment forms provided in Appendix I.

Experiment #	# of series	Total# of strokes	Method employed	Motion Used	Morphology	Surface worked	Max length (cm)	Edge Straightness Factor	Beginning weight (g)	Ending weight (g)	Weight lost (g)
2000	3	75	Friction	Transverse	Flake	Butt/Dorsal edge	5.8	1.1	32.03	31.79	0.24
2001	3	75	Percussion	Longitudinal	Flake	Butt/Dorsal edge	6.1	-	35.88	35.21	0.67
2002	3	75	Friction	Transverse	Flake	Butt/Dorsal edge	2.6	1.3	5.79	5.78	0.01
2003	3	75	Percussion	Transverse	Flake	Butt/Dorsal edge	4.8	-	28.81	27.56	1.25
2004	1	25	Percussion	Longitudinal	Flake	Butt/Dorsal edge	2.5	-	3.78	3.77	0.01
2005	2	50	Friction	Transverse	Flake	Butt/Dorsal edge	2.5	1.16	2.88	2.86	0.02
2006	4	100	Percussion	Misc.	Broken	Natural	6.8	-	93.46	93.21	0.25
2007	2	50	Percussion	Longitudinal	Flake	Butt/Dorsal edge	4.2	-	13.69	13.66	0.03
2008	1	25	Friction	Transverse	Flake	Butt/Dorsal edge	2.3	1.04	3.74	3.73	0.01
2009	4	100	Friction	Longitudinal	Flake	Butt/Dorsal edge	6.1	-	24.31	24.19	0.12
2010	4	100	Friction	Transverse	Flake	Butt/Dorsal edge	3.7	1.07	14.58	14.21	0.37
2011	4	100	Percussion	Longitudinal	Flake	Butt/Dorsal edge	5.8	-	26.62	25.96	0.66
2012	4	100	Percussion	Transverse	Flake	Butt/Dorsal edge	5.0	-	16.80	15.83	0.97
2013	2	50	Friction	Transverse	Flake	Butt/Dorsal edge	6.6	1.12	72.09	71.89	0.20

Table 3.1. List of strike-a-light experiments, methods, and metric data.

3.1. Usewear analysis of strike-a-light experiments

All usewear traces discussed in Chapter 2.1 were detected on each experimental sample to varying degrees, *even after a single series* (Figure 3.1: A), including striations, crushing (stacked edge-removals), edge-rounding, and polish. Sulphuric iron residue was observed adhering to the working surfaces of all the experimental pieces. The distribution of the residue was patchy and without any real discernable patterning, though it may be noted that it appeared to be slightly more prevalent on salient points than in recessed areas. However, despite sulphuric iron residue having been previously recovered from Neolithic strike-a-lights (Annelou van Gijn, personal communication, 2011), the probability of it being preserved on archaeological pieces recovered from Palaeolithic deposits is slim due to the susceptibility of the mineral to chemical erosion by air and water. Nevertheless, such a discovery is always a possibility as demonstrated by very minor amounts of probable sulphuric iron having been discovered embedded in recessed locations on a rounded burin from Oldeholtwolde, a late Upper Palaeolithic site in the Netherlands (Stapert and Johansen 1999). When compared to possible early Upper or Middle Palaeolithic examples, however, this specimen could be considered quite young still. The potential for preservation drops as the age of an artifact increases. Even if a minor amount of residue were still present on a worked edge, it would not be readily noticeable without the aid of high-tech analytical methods able to identify the chemical composition of a mineral residue like scanning electron microscopy in conjunction with energy-dispersive X-ray spectroscopy (SEM-EDAX), or X-ray diffraction (XRD). Identification of iron sulfide residue on a possible strike-a-light specimen would certainly add credence to its probable use as such, but should not be considered a viable avenue by which one would initially identify a possible strike-a-light. More readily identifiable and diagnostic traces can be found on the surface of the flint itself.

The most striking and diagnostic trace left by sulphuric iron on the experimental pieces are striations. Striations almost invariably appear as densely packed clusters of parallel to subparallel linear traces within discrete zones of polish. On average, the distribution rate of striations produced by sulphuric iron is 5-8 per 20 microns (Figure 3.1: B). The depth at which these striations tend to incise into the surface of the polish tends to be greater than striations observed within polish produced by softer materials like wood, hide, siliceous plants, or even softer stone (Van Gijn 1989). Polish on any given experimental piece is present over the length of the working edge, with interruptions usually only occurring at topographic depressions in the surface of the flint, or areas removed or destroyed during use. As a rule, these striations are quite long, often completely spanning the distance between these interruptions.

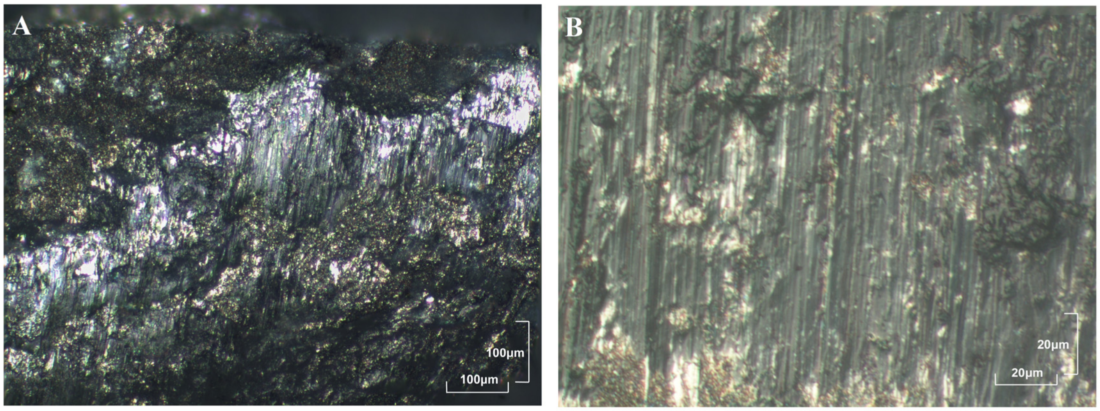

Figure 3.1. Photographs of striations on flint resulting from forcible contact with sulphuric iron, A) Experiment 2008-1A (100x), B) Experiment 2010-4A (500x).

Polish and striations appear to be more prevalent and continuous on pieces subjected to the friction method when compared to the percussion method, and can probably be attributed primarily to greater surface loss from crushing and edge-removals generated by partial Hertzian fracture propagation initiated by the force of the strikes employed by the percussion method. The blunt, naturally rounded surface employed by Experiment 2006 exhibits heavy crushing with minimally preserved polish or striations in the core of worked area (Figure 3.2).However, even with excessive crushing, so long as the working surface is not removed in its entirety (i.e. catastrophic edge failure), polish and striations are generally preserved on some salient points or along the peripheries of the worked edge or surface (Figure 3.3). For experiments having employed the percussion method, there is generally less crushing and fewer large edge-removals, and more polish and striations preserved on those striking longitudinally to the working edge rather than transversely. For all experiments, the orientation of the striations in relation to the working edge reflected the known kinematics of each experiment. In other words, when a strike-a-light was applied to the sulphuric iron nodule transversely to the working edge, the resulting striations appeared perpendicular to the edge, and when applied longitudinally, striations appeared running parallel to the edge.

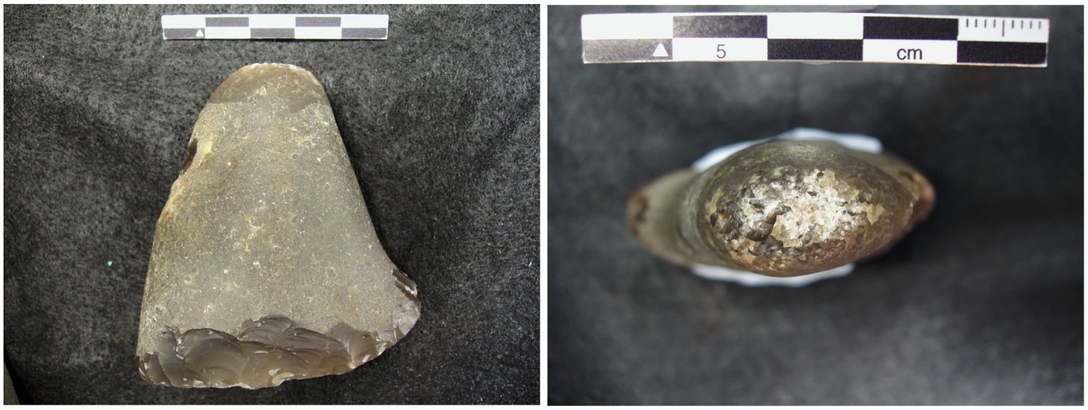

Figure 3.2. Photographs of Experiment 2006-3 showing extreme crushing on a naturally rounded flint surface as a result of forcibly striking sulphuric iron.

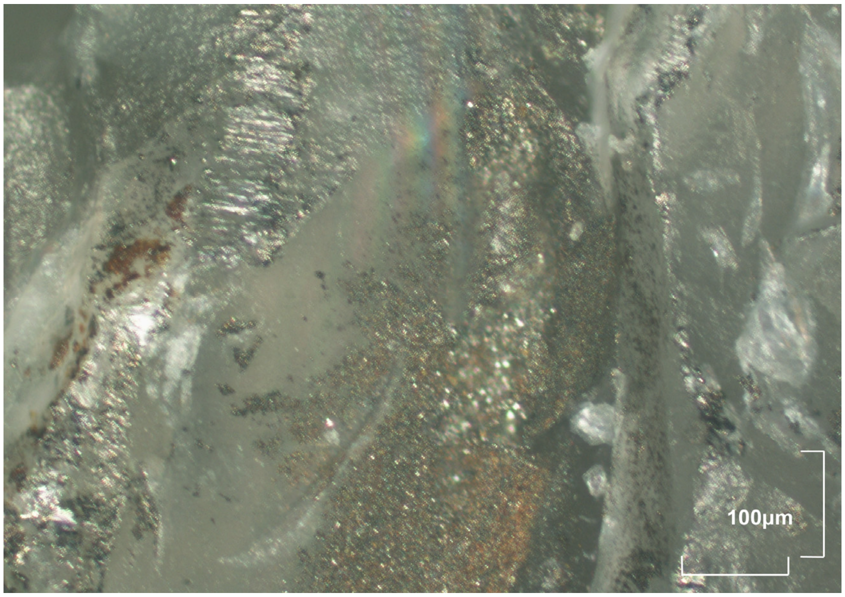

Figure 3.3. Photograph of remnant or incipient striations within crushed zone on flint as a result of forcibly striking sulphuric iron. Experiment 2011-4A (100x).

The presence of rounding corresponds very closely to the presence of polish and striations, in that 1) polish and striations are usually most prevalent on surfaces exhibiting rounding, 2) it is more prevalent on pieces employing the friction method due to less crushing and edge-removals, and 3) for the percussion method, rounding tends to preserve better on edges struck longitudinally to the working edge rather than transversely. Overall, the rounding observed on the experimental pieces, though quite obvious and pronounced under low magnification, is macroscopically fairly subtle, at least when compared to the extensively used pieces discussed in Stapert and Johansen 1999 (Figure 3.4). This is especially true after only one or two series had been performed. As one would expect, the rounding became more pronounced over the use-life of the experiments, especially on high spots and salient ridges along the effective working edge. Rarely, if ever, should one expect to see rounding on concave or recessed surfaces without the corresponding high points also exhibiting wear.

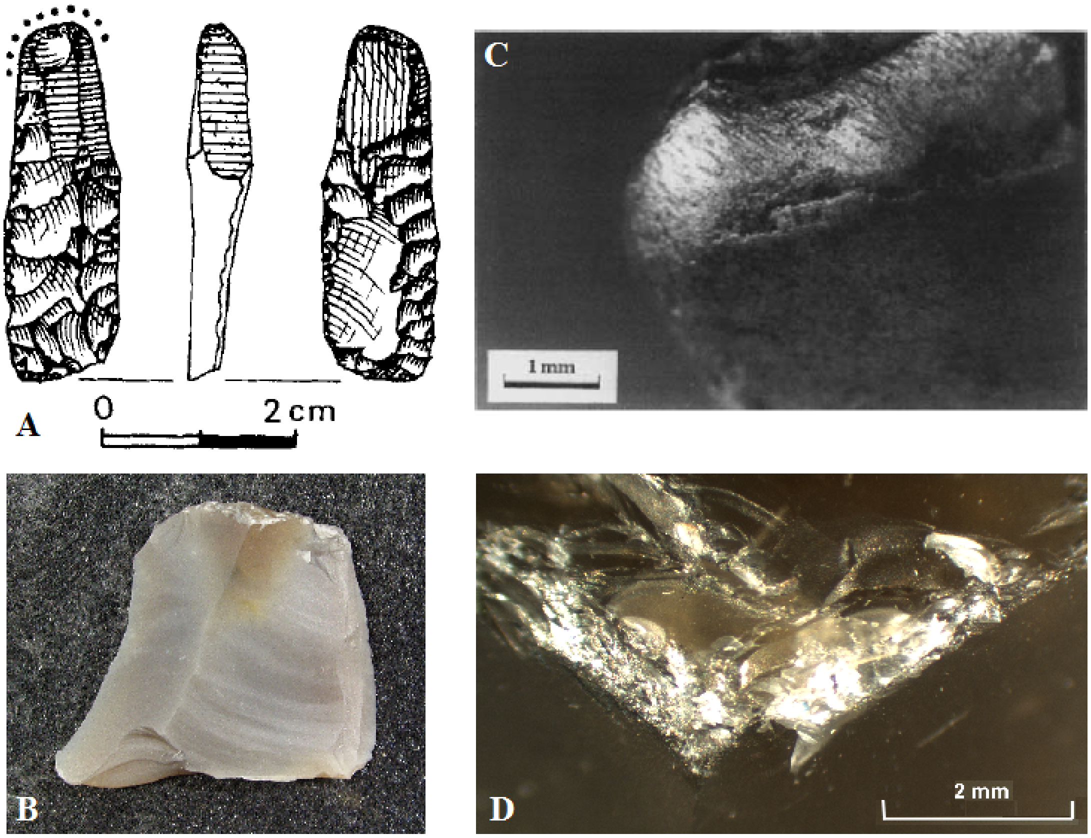

Figure 3.4. Photos comparing the form and worked edge of a heavily used strike-a-light from the Palaeo-Eskimo Dorset culture site of Ikkarlusuup (2-3 ka ago) in Greenland (A, C), with minimally used Experiment 2002-3A (B, D). The scale is the same for the macroscopic images (A, B); also between the low-magnification images (C, D). Images A and C are after Stapert and Johnasen 1999, Figure 6: 7 (774), and Figure 7 (775), respectively.

Larger edge-removals seem to correspond closely to areas of crushing as to where and how they tend to occur. Small, stacked edge-removals are ubiquitous throughout the experimental pieces, and depending on the degree of use are generally present for the length of the effective working edge. Medium edge-removals were noted in Experiments 2000-1, 2009-1, and 2013-1, while large and/or very large edge-removals occurred in Experiments 2001-2 & 3, 2010-1, 2011-1, 2, & 4. Experiment 2003 incurred heavy edge damage during series 1 and partial edge-failure during series 2, while Experiment 2012 suffered a catastrophic edge failure in series 4. The high number of edge-removals occurring during series 1 seems to correspond to a possible 'edge stabilization' phase. The total weight lost during some experiments tends to correspond closely to edge failure and edge-removals, with Experiments 2003 and 2012 having lost the most weight of all the experiments (Table 3.1). This in turn appears to correspond not only with the application method employed (i.e. more damage is incurred striking transversely to the working edge as was the case for 2003 and 2012), but also how far along the experiment has progressed. In other words – as on would expect – an increase in use often results in an increase in edge damage and loss. The crushing incurred by Experiment 2006 yielded small, angular removals that were different than the more flake-like removals on the other experimental pieces, making it difficult to compare with the group. The weight lost over the course of the experiment is most comparable to those having incurred medium edge-removals.

It was interesting to discover that even after only one series (25 strokes), the usewear traces left on the flint were significant, in both abundance and character. For the sake of curiosity, an *ad hoc* experiment was performed on a smaller flake, where the dorsal edge of the striking platform was applied to a fragment of sulphuric iron using the friction/transverse method for a single stroke. The flake was cleaned under running water, and then examined. Macroscopically, it was next to impossible to discern any difference from its pre-utilized state. With the aid of a stereomicroscope, a slight reflectivity was observed along the worked edge, as well as barely visible incipient edge-rounding. Under higher magnification, obvious traces of use were visible on discrete salient points along the working edge, including weak yet obvious edge-rounding and already well-developed polish and striations, though the striations did not appear as deeply incised as they did on more well-used edges. This suggests that even the strike-a-light of the most proficient fire-starter in prehistory could potentially be identified, even after only one stroke!

To ensure some of these sulphuric iron usewear traces were not relicts of platform edge preparation, unused flakes from the original Happisburgh flint nodule exhibiting platform preparation were analyzed for usewear traces. It should be remembered that the hammerstone used to reduce and grind the flint nodule for these experiments was a smooth, water-rounded piece of basalt porphyry with plagioclase phenocrysts. Focus was placed on the possible presence of polish and striations, since crushing and edge-removals are by themselves not diagnostic, especially when stone on stone contact is known or expected. Upon analysis, the few unique usewear traces observed were restricted only to isolated patches of polish on salient surfaces, with limited clusters of thin, shallow striations present in some of the larger patches of polish (Figure 3.5). The differences between the traces from the basalt hammerstone and that of sulphuric iron lie primarily in abundance and striation morphology. Patches of polish were much more prevalent and apparent on the pieces applied to sulphuric iron, with striations essentially ubiquitous within zones of polish. Furthermore, striations, while similar in terms of size, were noticeably more deeply incised into the surface of the flint, and more closely bunched together on the strike-a-light edges. The fine-grained nature of both the basalt and the sulphuric iron probably accounts for the comparable size of individual striations, while the greater depth and abundance of sulphuric iron-caused striations could be due to the greater hardness of sulphuric iron (6–6.5) as opposed to basalt (4–6, depending on the mineral composition ratio) on the Mohs scale of mineral hardness.

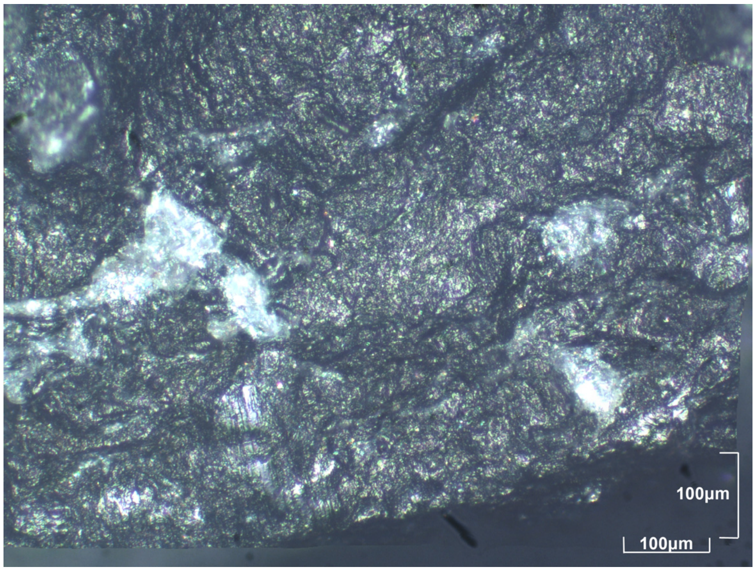

Figure 3.5. Photo of usewear traces (weak polish and striations) on flint edge from forcible contact with basalt during dorsal face platform preparation (100x).

When grinding an edge prior to a flake removal, the hammerstone was rarely applied more than ten times. So few applications notwithstanding, one will recall more use traces were present on a flint sample after coming into contact with sulphuric iron only once than observed on a number of unused flakes exhibiting platform preparation, where polish is largely absent. Therefore, the degree of use for a piece is not believed to be a significant contributing factor to the abovementioned differences. It is also believed that these differences are sufficient to ensure that previous usewear descriptions and interpretations concerning sulphuric iron traces were not confused with those imparted though platform preparation.

3.2. Usewear analysis of sulphuric iron contact material

The analysis of the sulphuric iron nodule used during the course of these strike-a-light experiments has yielded a number of interesting and readily identifiable usewear traces. The pieces of the nodule were refitted back together and the exterior examined for evidence of the three blows used to forcibly open the nodule. Three probable primary impact scars were identified along one of the fractures present in the nodule (Figure 3.6). The fact that these blows all lie along an extant fracture in the nodule suggests that they were intentionally directed towards this crack to take advantage of this weak entry point, and along which the nodule did ultimately break open. These impact scars were arranged in a roughly linear pattern spanning approximately 4.0-cm, each about 2-cm apart. The impact scars were not very large, making them (at least initially) not readily apparent, with one of the scars having been partially obliterated from use. The impact structures were quite comparable to one another, appearing as approximately 5–7-mm long, 3-mm wide lenticular-shaped depressions bisected by the fracture along which they occur. One impact scar exhibited a possible secondary point of contact on the periphery of the primary point of contact with a very small crush zone and associated fracture propagation, the half-lenticular spall still attached (Figure 3.6: A). One of the other scars has an associated surface spall removal. All three primary impact structures had in close proximity a few small, 'fresh and shiny', discrete 'scuff marks', generally exhibiting striations. These were most likely indirect secondary points of impact from the hammerstone.

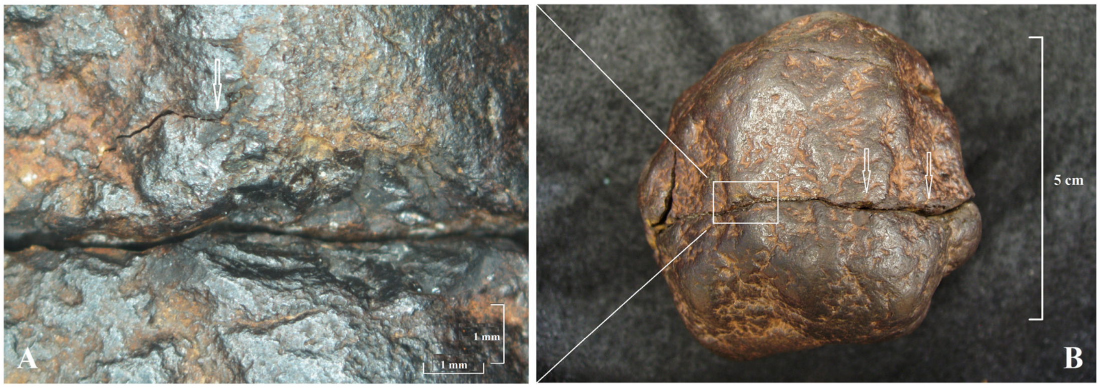

Figure 3.6. Photographs of refitted sulphuric iron nodule used for experiments. A) Magnified image of a primary impact feature with white arrow indicating possible secondary crush zone. B) Full nodule showing distribution of three (3) primary impact features indicated by white arrows.

On the opposite side of the nodule were observed two secondary impact features and one zone of scuffing that correlated exactly to the three primary impact features, both in orientation and spacing (Figure 3.7). The relationship between the primary and secondary impact features stems from the bipolar percussion method employed in opening the nodule (in this case, the anvil being a concrete sidewalk).The two secondary impact scars also exhibited the same lenticular shape and sizes (6–7-x-2-mm), similar associated ‘scuff marks’, and were located across another less weathered frost fracture, upon which the nodule eventually failed during the experimentation process. Opposite the third primary impact feature was a shallow concavity roughly 2–3-cm across, the rim of which exhibited a higher degree of scuffing when compared to surrounding surface areas, as well as a very small probable secondary impact feature just 2-mm wide.

Figure 3.7. Photographs of sulphuric iron nodule with A) primary impact features, and B) secondary impact features from 'anvil' resulting from bipolar percussion. White lines of equal length indicate near-identical distribution of impact features on opposing sides of nodule.

Upon completion of the strike-a-light experiments, including a couple supplementary experiments using the friction/transverse method to generate some short-term (25 strokes) usewear traces on one of the unused sulphuric iron fragments, usewear analysis was performed on a number of the variably used (and unused) interior surfaces of the nodule, from which a number of general observations were made.

At the macroscopic level, the most blatant evidence of use observed, especially on the well-used surfaces, consisted of zones of crushing and flattened ridges associated with the radiating linear crystal pattern typical of sulphuric iron nodules, in some areas having progressed to the point of the contact surface being completely smoothed over and flat, or even bordering on concave. In a few locations, this heavy wear extended to the edge of the nodule fragment, rounding it noticeably when compared to unworked edges, with another section of the same edge appearing to have incurred a higher degree of edge-removals. This phenomenon was made more apparent when observed under a binocular microscope (Figure 3.8).

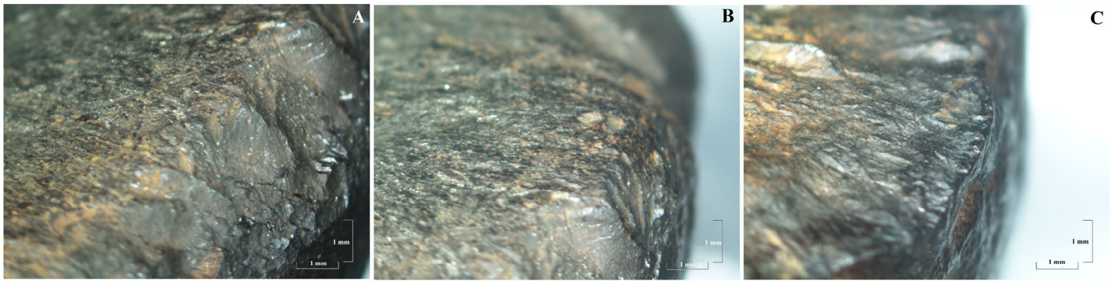

Figure 3.8. Photographs of use damage incurred at sulphuric iron nodule margins, including edge-removals (A) and rounding (B), compared to an unworked edge (C).

Regardless of how extensively a surface was worked – whether having received only 25, or over 600 strokes – sets of oriented, subparallel grooves (or: scratches) of varying length and size were observed both macroscopically and microscopically, sometimes exhibiting cross-hatching when the surface had been used extensively employing different methods or motions (Figure 3.10). These scratches were more easily observed using oblique, (or: indirect) lighting verses direct lighting. Scratches were generally seen cross-cutting the radiating linear crystal pattern, with some appearing deeper and more obvious than others. Under higher magnification, the more deeply incised scratches were quite obvious and easy to locate, while some of the more superficial examples appeared more as streaks or smears, often exhibiting striations very similar to those observed on the flint experimental pieces, though not nearly as prevalent.

Scratches with accompanying striations appeared to be more obvious and more well-preserved along the edges of the nodular fragments within the hematite outer cortex. This could be attributed to the hematite, unlike the sulphuric iron, not being as readily susceptible to chemical weathering (i.e. pyrite decay resulting from oxidization). Even on these ‘fresh’ experimental fragments, when left exposed to the air for a period of time, the surfaces became ‘dull’ looking, more so on utilized portions where 1) crushing of the crystalline structure appears to have made the surface more susceptible to weathering, and 2) easily-oxidized sulphuric iron dust had accumulated during experimentation. This oxidized coating often times obscured finer usewear traces, if not destroy them (it is currently unknown what effect this oxidation process can have on these traces in the long-term), though larger scratches were generally still visible. It is also inconclusive to what the effects of washing the sulphuric iron has on these minor traces, though light washing does not appear to have much adverse affect on visible scratches. Ultimately, these minor features (i.e. very fine scratches, smears, and striations) are unlikely to be visible if larger scratches are not preserved, reducing their overall importance.

An incidental experiment was performed on a sulphuric iron fragment using the friction/transverse method, where the tool was applied 25 times to an interior fracture surface exhibiting a thin reddish-orange mineral coating (Figure 3.10). The experiment resulted in the appearance of discrete scratches, zones of minor crushing, and minor truncation of crystal ridges, as discussed above. The most telling aspect of this experiment, however, was the striking visual contrast between the original dull, reddish-orange weathered surface and the metallic, freshly abraded areas. Another fragment of the experimental sulphuric iron nodule seemingly devoid of such fractures was smashed open to expose a fresh, unweathered surface for comparison with the weathered surfaces (Figure 3.9). This fragment required much more effort and many more blows before breaking than the nodule did originally. The much smaller size of this fragment almost certainly played a part in this difficulty, but ultimately, the point to be made remains that it is more difficult to break apart an unweathered sulphuric iron fragment than one containing weak points of entry. This is significant, considering the likelihood that nodules in the past contained similarly weak, weathered fracture planes that were the surfaces most likely to have been exposed upon forcible opening by prehistoric people.

Figure 3.9. Photograph of sulphuric iron nodule fragments exhibiting unweathered (left) and weathered (right) fracture surfaces.

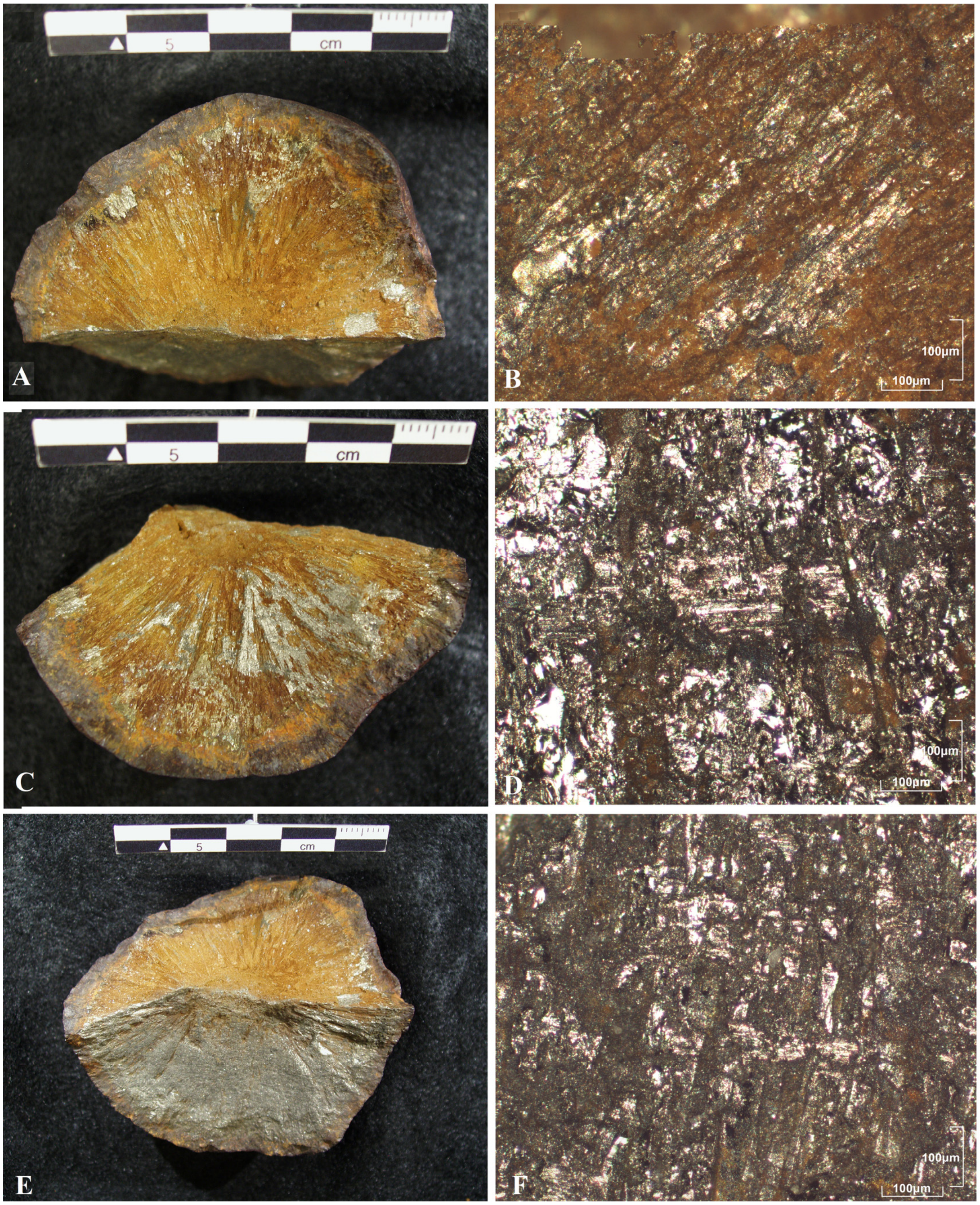

Figure 3.10. Photographs of unutilized (A, B) and utilized (C, D, E, F) sulphuric iron nodule fragments with mineralized fracture faces. Utilized fragment (C, D) subjected to 25 strokes using friction/transverse technique. Utilized fragment (E, F) subjected to over 600 strokes using all application techniques. Photographs B, D, and F taken at 100x magnification.

3.3. Strike-a-light effectiveness: a statistical approach

Preliminary statistical analysis was performed using the number of spark-generating strokes for each series to gauge the overall effectiveness of each experimental piece over the course of its early effective use life, in this case from one to four series of 25 strokes each (Table 3.2). These data were used to tease out possible trends between the experiments. The percentage of successful spark-generating strokes verses total strokes (% Success) were calculated per series, per experiment for individual experiments, as well as per application method: technique (friction or percussion)/orientation of the working edge (transverse or longitudinal). Any totals derived from these individual percentages were expressed as median values, as opposed to mean values (i.e. averages), because of their ability to attach less importance to statistical outliers, which can sometimes be a result of error and skew data. These data were analyzed in relation to other metric data including tool length and the straightness of the working edge in an attempt to identify possible relationships between these factors and how they affect tool success rates.

Not all of the experiments conducted completed all four series so that usewear at various stages of use would be preserved for future comparison and study. Unfortunately, this leaves holes in the data that need to be filled for more complex analysis. A complete data set would certainly have been preferable, but given the experimental nature of this statistical study as more of a 'viability test' for methods that could be used for future studies, extrapolated data inferred from actual data was inserted into these voids. This was accomplished by averaging the median value per series between experiments with the median value from series data per experiment for each application technique grouping (where applicable). This method helps to reflect both the nature of the strike-a-light being utilized, as well as how the edge of a tool reacts to being utilized over time. For example, only two of six experiments completed all four series within the friction/transverse group. Using the median of only these values to represent Series 4 for the whole group does not take into account the actual nature of any of the other tools, which could possibly have been much more or less successful at producing sparks in previous series, while the median values derived solely from other series within any one experiment only reflects the nature of the tool itself, and does not account for the possible diachronic trends in effectiveness possibly associated with any given application technique. Regardless of which configuration is used – whether the raw data or the different variations of data incorporating the extrapolated data – the relationships between the data and the trends extrapolated from these data do not change (Table 3.3).

It is hard to gauge the significance and reliability of the following statistical results and the interpretations derived from these results due to the small size of the data set, as well as the inequality in the number of experiments performed within the different application method groups. Nevertheless, interesting trends appear to emerge from this preliminary data that could provide insight into why different application methods are employed, the practical effects these application methods have on the tools used, and why tools with specific metric attributes might lend better to one method or another.

Application Technique (Method / Motion)	**Experiment**	**%* / Series / Experiment**				**% / Experiment**	**% / Total**
		Series 1	Series 2	Series 3	Series 4		
Friction / Transverse							23.5
	2000	36.0	44.0	48.0	34.0	40.0	
	2002	24.0	20.0	12.0	22.0	21.0	
	2005	4.0	16.0	21.0	17.0	16.5	
	2008	28.0	24.0	30.0	26.0	27.0	
	2010	16.0	36.0	32.0	24.0	28.0	
	2013	24.0	16.0	26.0	22.0	23.0	
	% / Series	24.0	22.0	28.0	23.0		
Percussion / Natural							14.0
	2006	8.0	4.0	20.0	20.0	14.0	
	% / Series	8.0	4.0	20.0	20.0		
Percussion / Transverse							9.0
	2003	4.0	0.0	20.0	6.0	5.0	
	2012	4.0	20.0	20.0	8.0	14.0	
	% / Series	4.0	10.0	20.0	8.0		
Friction / Longitudinal							8.0
	2009	8.0	12.0	8.0	8.0	8.0	
	% / Series	8.0	12.0	8.0	8.0		
Percussion / Longitudinal							7.0
	2001	8.0	4.0	12.0	10.0	9.0	
	2004	0.0	4.0	6.0	4.0	4.0	
	2007	8.0	16.0	12.0	6.0	10.0	
	2011	0.0	8.0	12.0	8.0	8.0	
	% / Series	4.0	6.0	12.0	8.0		

*Table 3.2. Spark production statistical data for experimental strike-a-lights. Extrapolated data was added to experiments with an incomplete compliment of series to round out the data set for analysis by averaging the median value per series between experiments with the median value from series data per experiment for each application technique grouping (where applicable). These extrapolated data are underlined. * % = Percent Success.*

		Median values determined by:				
		Raw Data*	**Series**	**Experiment**	***Combined***	**Relative rank**
% Success / Experiment	2000	44.0	40.0	44.0	*40.0*	1
	2002	20.0	22.0	20.0	*21.0*	5
	2005	10.0	20.0	10.0	*16.5*	6
	2008	28.0	26.0	28.0	*27.0*	3
	2010	28.0	28.0	28.0	*28.0*	2
	2013	28.0	24.0	20.0	*23.0*	4
% Success / Series	1	24.0	24.0	24.0	*24.0*	2
	2	20.0	20.0	24.0	*22.0*	4
	3	32.0	32.0	24.0	*28.0*	1
	4	24.0	24.0	22.0	*23.0*	3
% Success / Total		24.0	24.0	24.0	*23.5*	

*Table 3.3. Percentage success rates for the fiction/transverse group using different data configurations demonstrating comparable nature of trends (relative rank). The data in the 'Combined' column are extrapolated from both the series and experiment data, and these are the values represented in the text. * Raw data does not include any extrapolated data.*

3.3.1. Spark generation statistics

The analysis of the statistical variation per series between different functional groupings of experiments has allowed for the extraction of a number of perceived trends – both time-transgressive, and overall trends – related to the rate of success for the different application methods employed throughout the experimentation process. These results are displayed in Table 3.2. In the table, the individual strike-a-light experiments are segregated by application method, and fall into five groups: friction/longitudinal, friction/transverse, percussion/longitudinal, and percussion/transverse, with Experiment 2006 falling into its own percussion/natural category due to a naturally rounded exterior surface having been employed as opposed to an artificially created flake edge. Taking all experimental series within a particular group into account, of these five application methods, the most successful by a significant margin is the friction/transverse method with a success rate of 23.5%, which is followed by Experiment 2006 (percussion/natural) at 14.0%, the percussion/transverse method at 9.0%, the friction/longitudinal method at 8.0%, and finally, the percussion/longitudinal method at 7.0% success rate.

By comparing the median percentage of success of each series within an application method group, the effectiveness of the method can be assessed diachronically (Table 3.4). It was found that the best way to express these trends is to determine the median percentage of success between the first series and each subsequent series, with series 1 serving as a baseline for comparison. The equation for expressing this is as follows:

$$((\% \text{ success series } 2 - \% \text{ success series } 1) \div \% \text{ success series } 1) \times 100$$

For example, series 1 from the percussion/transverse group had a 4.0% success rate, while series 2 had a 10.0% success rate. When these values are entered into the above equation, one finds there is a 150.0% increase in the rate of success in series 2 from series 1:

$$((10-4)/4)100 = 150\%$$

Continuing with the percussion/transverse method, one finds there is an additional increase in effectiveness of 250.0% in series 3 to 400.0%, and then a fairly steep drop of 300.0% in effectiveness to 100.0% above the original median success rate of this method in series 4. The effectiveness of the friction/transverse method lowers slightly to 8.3%, then a modest increase to 16.7%, and finally dropping again in series 4 to 4.2% below the original rate of success for this technique. The rate of success for the percussion/longitudinal method increases to 50.0%, then to 200%, ultimately lowering to 100%. The friction/longitudinal method sees an initial 50.0% increase in effectiveness in series 2, but it then drops back to the original effectiveness in both series 3 and 4. Conversely, the lone member of the percussion/natural group (Experiment 2006), experienced a 50.0% drop in effectiveness in series 2, but then jumped to 150.0% above its original rate of success where it remained for the duration of the experiment.

Application Technique	Series 2	Series 3	Series 4
Friction/Transverse	-8.3	16.7	-4.2
Percussion/Natural (2006)	-50.0	150.0	150.0
Friction/Longitudinal	50.0	0.0	0.0
Percussion/Transverse	150.0	400.0	100.0
Percussion/Longitudinal	50.0	200.0	100.0

Table 3.4. Relative percentage of success per application method per series relative to series 1.

If the groups are broken up into their constituent variables, one will notice the closeness in the total effectiveness and the diachronic effectiveness trends by series between the friction method and transverse orientation, and the percussion method and longitudinal orientation (Table 3.5). This is very possibly a relict of the higher number of experiments performed using these two combinations in relation to the friction/longitudinal and percussion/transverse groups, rather than each variable being similarly weighted in how it influences the rate of success. Without having a data set with equal representation of each application method combination, the significance of these findings is questionable. As the data exists, however, it appears that the application method applied (i.e. friction verses percussion) is the more important factor to consider within these experiments than the orientation of the tool edge applied, though possibly not by much.

% Success / Variable	**Series 1**	**Series 2**	**Series 3**	**Series 4**	**Total % Success**
Longitudinal	6.0	9.0	10.0	8.0	8.0
Transverse	14.0	16.0	24.0	15.5	21.0
Friction	16.0	17.0	18.0	15.5	17.0
Percussion	4.0	6.0	20.0	8.0	8.0
Natural	8.0	4.0	20.0	20.0	14.0
Total % / series	8.0	10.0	20.0	8.0	9.0

Table 3.5. Percentages of success by application technique variable.

If one were to express the success rates for each group graphically as curves, the basic shape of these curves exhibited by the groups employing the friction or the percussion method would be fairly similar despite differences in values. However, it is these differences in the *degree* of change in success rates between the application techniques, and the possible reasons for these trends, that speak to the overall efficacy of each group. The slight 8.3% drop, and only modest 50.0% increase, in success for the friction/transverse and friction/longitudinal methods, respectively, appears less dramatic than the 50.0% increase for the percussion/longitudinal group, and 150.0% increases seen in the percussion/natural and percussion/transverse groups. This disparity is widened by the fall of the friction/longitudinal method in series 3 to its original rate of success, and only a slight increase in relative success to 16.7% by the friction/transverse method; in contrast to the jumps to 150%, 200.0%, and 400.0% above the original success rate of the percussion/natural, percussion/longitudinal, and percussion/transverse groups, respectively. If the original percentages of success for each series within these groups were unknown, these numbers would appear misleading giving an apparent functional advantage to the percussion technique. However, knowing that the numbers in fact suggest the friction/transverse method is the most successful overall, it could be explained that these tools started very near their ideal functional state only allowing for relatively minor perturbations in success rates for the course of the experiments. It is possible that this trend alludes to an early period of edge stabilization where weak and/or salient points are removed, thereby strengthening the utilized age and increasing efficacy. This is a phenomenon one could expect for most strike-a-lights early in their use lives. Seeing as the techniques utilizing the percussion methods had much lower rates of success overall – especially in the early series - they arguably had more room for improvement and required a higher degree of edge stabilization before attaining peak success rates.

The trend for Experiment 2006 appears to suggest a lower rate of success for producing sparks early in the experiment, but increasing and maintaining a 150.0% improvement in the rate of success for this strike-a-light. One way this could be interpreted is that the smooth, naturally-rounded surface was not adept at dislodging fragments of sulphuric iron to produce a spark until the working surface was sufficiently roughened and slightly flattened due to crushing. The overall homogeneity of this surface and the likelihood of it maintaining a fairly consistent geometry would suggest this type of strike-a-light would remain fairly consistent throughout its usage, as the numbers appeared to allude to in series 3 and 4. Being the only sample contained within the percussion/natural category, it is difficult to say without further experimentation if the trend exhibited by Experiment 2006 would hold true for other similar pieces.

The subsequent drop in rates of success seen in series 3 and 4 for friction/transverse, percussion/transverse, and percussion/longitudinal methods could be interpreted as the utilized edges losing some of their efficacy as they become more rounded or battered. Despite the relative similarity of these trends, the end results could ultimately have different interpretations for the friction and percussion techniques. The friction/transverse method, while still being more successful at producing sparks than either percussion method, is 4.2% less effective in series 4 from series 1. Conversely, the percussion/transverse and percussion/longitudinal methods both exhibit a 100.0% increase in success, so approximately twice as effective as they were in series 1 – an outcome similar to the 150% improvement in the final success rate of the percussion/natural category. Without knowing how these trends continue further into the use life of these experimental strike-a-lights, it is hard to say whether both the friction and percussion methods would continue towards a somewhat reduced efficiency ultimately reaching a level of stasis comparable to one another; or if one method or the other would end up reaching a level of stasis above or below the final or original success rates of the tool recorded here. In a personal communication with Jürgen Weiner, he stated that the efficiency of a strike-a-light employing the percussion technique tends to improve with use. Conversely, a number of internet posts by those using the friction technique have said the effectiveness of the friction method goes down with use. Factoring in these opinions, the numbers as they are could suggest a slow, gradual drop in effectiveness for the friction technique and an overall increase in effectiveness for the percussion method, at least in the short term. More series per tool would need to be conducted to see if this is the reality, however.

3.3.2. Quality verses quantity

It has already been shown that the friction/transverse method appears to be the more efficient method for producing sparks for a given number of total strokes. However, based on observation of online survivalists and primitive technology enthusiasts – not to mention personal experience – it is usually easier to execute more strokes in an allotted period of time with the percussion technique than the friction technique. Is it possible that the overall efficiency of the friction method could be negated by the rapidity with which the percussion method can be employed? To test this, approximate low and high range estimates for the number of strokes per technique, per minute were established. The low range was conducted using leisurely, controlled strokes for each technique; and the high range estimate was established using rapid strokes at a rate that felt to be just under what seemed practical for effectively producing sparks. Obviously, these rates would vary by individual. The ranges produced were 80 to 120 strokes per minute for the friction method, and 120 to 220 strokes per minute for the percussion method. Using the same equation used above to calculate the relative percentage of success between series, it was found that one could execute 50.0% more strokes per minute using the percussion method for the low end of the range, and 83.3% more strokes per minute for the high end. Assuming the percentage of success for each technique remain constant regardless of the speed at which the strokes are executed, one can quantify how the additional strokes executed by the percussion techniques relate, and possibly compensate, for the lower success rates realized by these groups when compared to the friction groups by calculating the effective relative success rate. In other words, if efficiency is gauged by time spent on a task rather than effort (arguably, a subjective term), then the total number of successful strikes within an allotted period of time can be compared to the (lower) number of strokes executed by the friction techniques within a given amount of time rather than the total strokes executed by the percussion technique in question, thereby increasing the relative effective success rate of that technique. If this new rate of success exceeds the rate of success for the friction technique, then the percussion technique in question is temporally more efficient at producing sparks than the friction technique. The equation used to find these values is as follows:

$$(\% \text{ success})(((\text{strokes/min perc} - \text{strokes/min fric}) \div \text{strokes/min fric}) + 1) = \% \text{ success/min}$$

Thus, the equation to determine the low end estimate for the percussion/longitudinal method is:

$$(7)(((120-80) \div 80) + 1) = 10.5$$

This shows that the percentage of success for the low-end range estimate of strokes per minute for the percussion/longitudinal method is 10.5%, and when calculated for the high-end range, the percentage of success further increases to 12.8%, a relative increase of 3.5–5.8 percentage points over the rate of success per number of strokes (Table 3.6). Following this process, the 9.0% success rate for the percussion/transverse method increases to 13.5–16.5% per minute, and the 14.0% success rate for the percussion/natural method increases to 21.0–25.7% per minute. These numbers show that when time is taken into account, the rate of success for a period of time for the percussion methods increase enough to surpass the rate of success for the friction/longitudinal technique for both the high and low end estimates. With regards to the friction/transverse group, however, only the percussion/natural specimen exceeds the rate of success for this group, but only at the upper range of strokes per minute. This helps to further demonstrate the friction/transverse technique is the most effective and the most efficient of the techniques employed in this study.

Total strokes / minute	Low rate	High rate
Percussion	120	220
Friction	80	120
% difference	50.0	83.3

Application technique	Original % success	Effective relative % success	
		Low rate	High rate
Friction/Transverse	23.5	23.5	23.5
Friction/Longitudinal	8	8	8
Percussion/Longitudinal	7	10.5	12.8
Percussion/Natural	14	21	25.7
Percussion/Transverse	9	13.5	16.5

Table 3.6. Relative effective success rates for application techniques per minute (as opposed to per series).

3.3.3. Factors affecting the rate of success for strike-a-lights

Paying close attention to variation between individual experiments allows for the deduction of possible reasons behind the intergroup trends highlighted in the section above. The following section outlines a possible avenue by which statistics could be used not only to explain the effectiveness of any one experimental strike-a-light by determining and quantifying the relationships between the success rate of the tool (per experiment and per series), the length of the tool, and the straightness of the utilized edge (‘edge straightness factor’), but also to act as a possible predictive model for how well an archaeological specimen might have worked or what forms of hypothetical tools would make the ‘ideal’ strike-a-light for a given application method.

The basis for this model stems from the desire to test three questions: 1) Do longer tools have higher rates of success? 2) Do tools with straighter working edges have higher rates of success? 3) How do these two variables, tool length and edge straightness, interact to affect spark production success rates? The questions were derived from general impressions gained from the rates of success for spark production of the experimental pieces, and by contemplating what quantifiable variables could differ between individual experiments that could affect these success rates. It seemed reasonable to hypothesize that a straighter working edge potentially allows for more points of contact with the sulphuric iron contact material, which would in turn likely increase the rate of success for spark-producing strokes. It also seemed logical while performing the experiments that success could be affected by the length of the flake or flint fragment used, with longer tools providing more of a ‘handle’ to grip, allowing for increased applied pressure and control due to increased leverage for friction application techniques, and greater distance between the contact surface and the knuckles of the user.

The friction/transverse method group was selected as the test group for a few reasons: 1) most importantly, it had the largest sample size of all the groups with six experimental pieces, 2) it had a fairly diverse array of success rates and different tool lengths, and 3) the friction method appears to have a higher degree of control, can be more easily replicated, and appears to sustain less edge failure and damage.

The straightness of the working edge of a tool was expressed using what has been termed the ‘edge straightness factor’. Edge straightness factors were calculated by measuring the total length of the effective working edge, and dividing that number by the distance measured directly between the two ends of the working edge (Figure 3.11: A), the baseline for a perfectly straight edge equaling one (1.0) with the number increasing as edges become less straight. For this study, a length of thin plastic string was used to gauge the length of the working edge by being applied to the edge surface so as to conform to the precise contours of the edge, and then straightened out and measured using a calipers. The calipers were also used to measure the distance between the ends of the working edge. The length of each strike-a-light was the maximal distance between the striking platform and the distal edge of the flake, measuring perpendicular to the surface of the striking platform (Figure 3.11: B). To try to determine the relationship of the interaction between these two variables, an interaction value was calculated for each experiment by multiplying the tool length by the associated edge straightness factor.

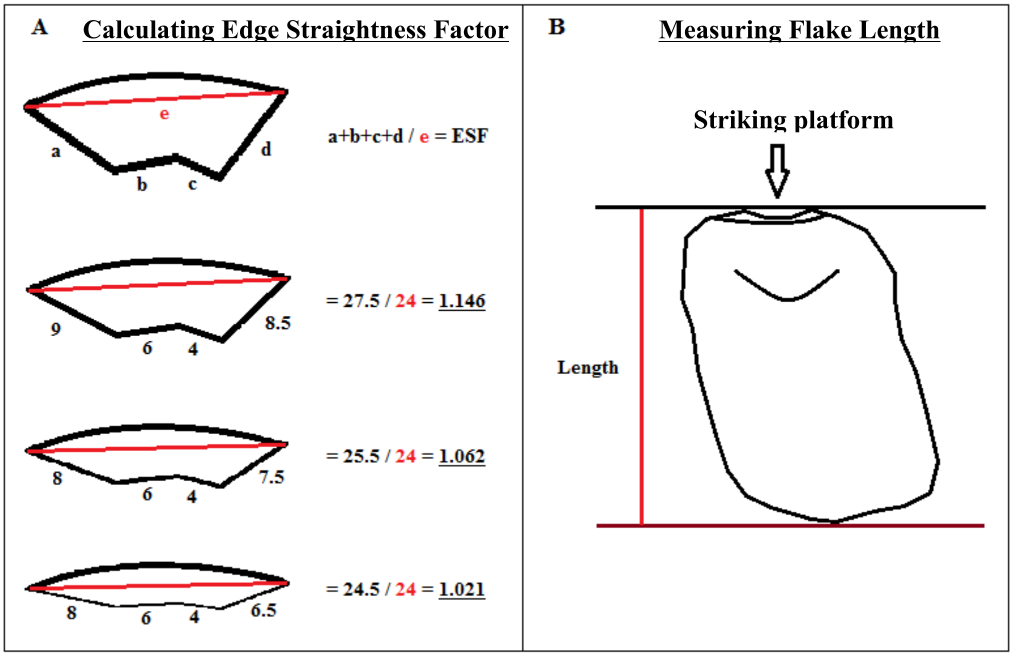

Figure 3.11. Diagrams of metric data collected: A) Edge Straightness Factor, and B) flake length.

These values were entered into a spreadsheet, along with the percentages of success per series, and median success per experiment (Table 3.7). These numbers were run through the program SPSS (Statistical Programming for Social Sciences) v.19 to determine the median probability of success for each of the three abovementioned variables: length, edge straightness, and the interaction between length and edge straightness. The resulting scatter plots for these variables depict the following possible trends. The length of the tool is positively associated with success, meaning longer tools may be a marker positively influencing rates of success, though the maximum length threshold was not determined (Figure 3.12: A). Edge straightness is positively associated with success, meaning a straighter working edge, so a lower edge straightness factor, may be a marker positively influencing success (Figure 3.12: B). The relationship of the interaction of tool length and edge straightness appears to be positively associated with success, so there may be an interaction between these variables influencing success (Figure 3.12: C). Unfortunately, the small and incomplete nature of the data set precludes any assignment of significance to these trends. Also, while it is likely these methods could be applicable to other non-flake tool forms, a practical problem to consider would be strike-a-light tools crafted with intentionally shaped edges (e.g. pointed or rounded) to correspond specifically shaped contact surfaces like large grooves (Figure 4.2: A). Perhaps alternative or supplementary metric data could be derived from measuring the total edge length affected by use. Nevertheless, the resultant trends of this preliminary study are intriguing, and appear to correspond to those initially hypothesized. More experiments will be necessary to see if these trends hold true for larger data sets, and to observe how they might develop after longer periods of use.

Table 3.7. Data table for friction/transverse group entered into SPSS to render scatter plots (below) in Figure 6. † Interaction = Length x Edge Straightness Factor

Experiment	Length	Edge Straightness Factor	Interaction†	Series 1	Series 2	Series 3	Series 4	Median % Success
2000	5.8	1.1	6.38	0.36	0.44	0.48	0.34	0.4
2002	2.6	1.3	3.38	0.24	0.2	0.12	0.22	0.21
2005	2.5	1.16	2.9	0.04	0.16	0.21	0.17	0.165
2008	2.3	1.04	2.39	0.28	0.24	0.3	0.26	0.27
2010	3.7	1.07	3.96	0.16	0.36	0.32	0.24	0.28
2013	6.6	1.12	7.39	0.24	0.16	0.26	0.22	0.24

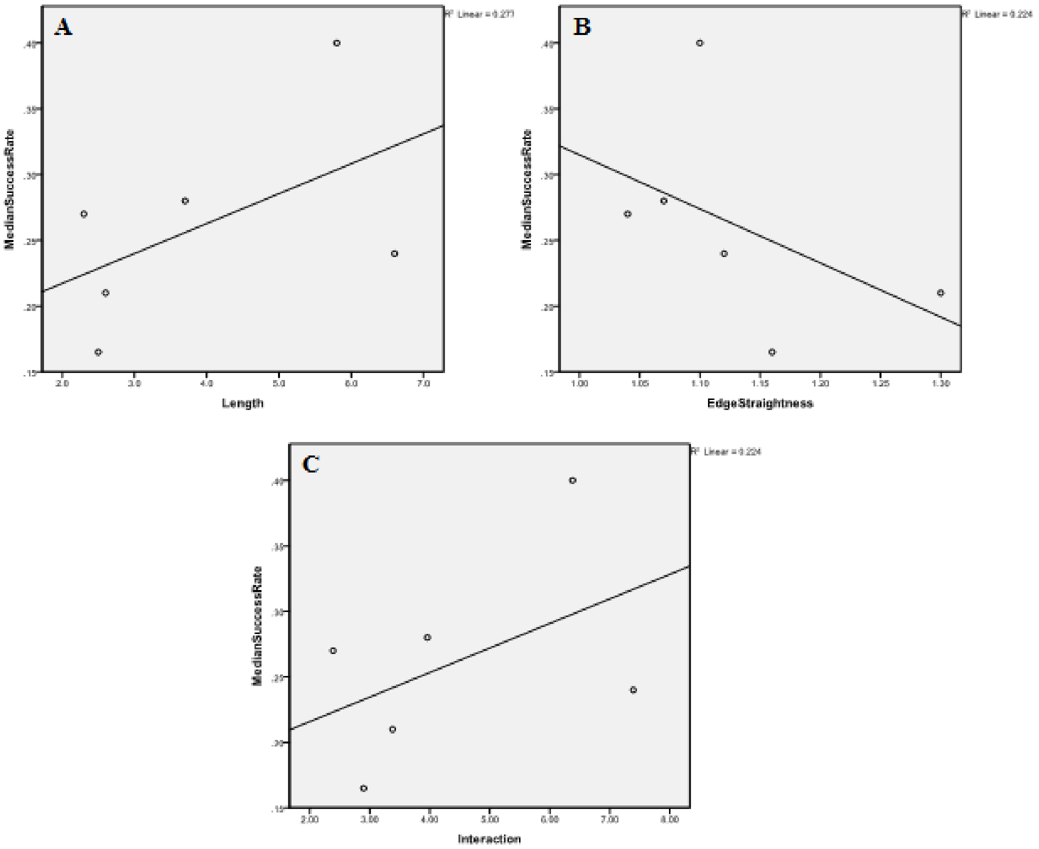

Figure 3.12. Scatter plots showing possible trends derived from median success rates of the friction/transverse group experimental strike-a-lights in relation to A) tool length, B) edge straightness, and C) the interaction between tool length and edge straightness. See Table 3.7.

4. VISIBILITY OF FIRE PRODUCTION IN THE EUROPEAN ARCHAEOLOGICAL RECORD

When it comes to evidence of burning on a site, presence, unfortunately, does not equate to production. Fire can arrive on site via both anthropogenic and natural vehicles, so it is to the tools of fire production that we must turn to in order to shed light on this vexing subject. Teasing out the earliest instances of fire creation in the Palaeolithic record requires looking beyond the expected forms and tell-tale signs seen in more recent strike-a-light specimens. Just as fire-making technology has manifested itself in different and novel ways in the recent past, so too, could one expect alternative methods outside the expected 'norm' to have been utilized in the very ancient past. The 'expedient strike-a-light' hypothesis offers a short-term use alternative to the heavily used, more 'formal' strike-a-light forms commonly encountered in later prehistoric periods. Nevertheless, familiarity with these later forms in the archaeological record provides not only affirmation that ancient peoples were indeed capable of employing fire production technology, but that this technology is still recoverable from deposits far removed from the present. Moreover, knowing when this technology first appears in the archaeological record provides a rough starting point in prehistory to look back from where alternative research strategies should be followed.

In the following sections, the oldest known possible examples of strike-a-lights and sulphuric iron contact materials so far recovered are listed to provide a foundation of plausibility for fire production in ancient times. Not only do these examples offer some guideline for what traces could be found on older specimens, but also – as the Neandertal affiliated La Cotte à la Chèvre sulphuric iron nodule discussed below elucidates – the presence of such items in strategic contexts can provide solid arguments for the probability of fire production on a site, vital for periods like the Middle Palaeolithic where doubt abounds due to the extreme rarity of such examples.

4.1. Flint strike-a-lights from the Upper Palaeolithic

The majority of the information presented in this section was compiled in a 1999 article by Stapert and Johansen after an earlier article of theirs (Johansen and Stapert 1995), in which they noted observing a number of odd flint implements with rounded ends at various sites in northwest Europe that reminded them of comparable rounded tools from later periods interpreted as strike-a-lights. The 1999 article is one of the few papers in the archeological literature focused on the subject of identifying strike-a-light specimens in the Palaeolithic archaeological record. A detailed discussion of all the possible Palaeolithic strike-a-lights covered in this article will not be restated here, but instead these have been compiled into a detailed list based on the text to facilitate quick referencing (Table 4.1). In this list of sites with possible and probable strike-a-lights, examples from both the Middle Palaeolithic and the first half of the Upper Palaeolithic are conspicuously absent. This may not surprise some for the Middle Palaeolithic, but the fact that none are listed for modern human groups prior to the Magdalenian is certainly perplexing given the commonly held belief that modern humans were fully capable of producing fire at will prior to colonizing Europe.

The Stapert and Johansen article includes discussions of specimens recovered from later periods, as well, including rare examples of Bronze Age daggers used as strike-a-lights (Petersen 1993), and Palaeo-Eskimo (1st Century Inuit) bifacial strike-a-lights from Greenland (Johansen and Stapert 1997a), but these are out of the purview of this thesis and were not included in Table 4.1. The Late Upper Palaeolithic examples listed are predominately fashioned from blades or blade fragments, a number of these being crested blades, which are thicker and sturdier than regular blades (Figure 4.1). This technology does not appear with any regularity until the Upper Palaeolithic.

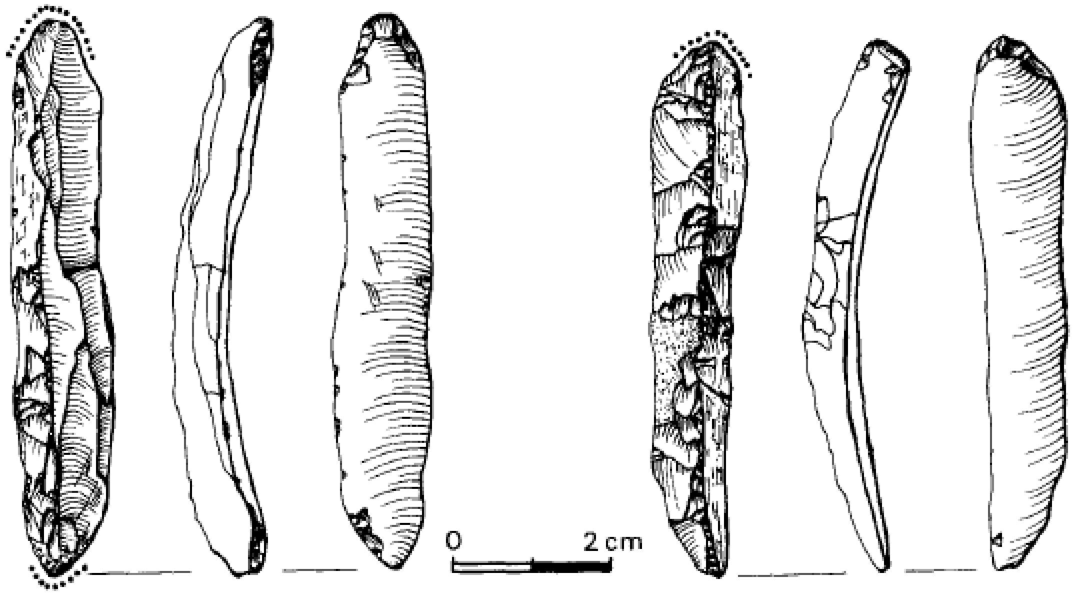

Figure 4.1. Examples of Late Upper Palaeolithic crested blades with markedly rounded ends from the Hambergian site at Sassenheim, Netherlands (after Stapert and Johansen 1999, Fig. 2, 769).

Only a portion of the examples in this list were examined personally by Stapert and Johansen for usewear traces, and even this was done only using low power stereomicroscopy. The others on the list were included based on descriptions of edge-rounding in the literature. Stapert and Johansen note that ‘strike-a-light’ is a tool type rarely incorporated into researchers’ typological lists, so these pieces could only be interpreted by the authors as possible strike-a-lights, pending further investigation. Stapert and Johansen are also right at pointing out that a heavily rounded tool edge may not necessarily be indicative of use as a strike-a-light, but could also have been used for other heavy activities on hard contact surfaces. An example they cite for this could be heavily worn flint tools recovered from Lascaux that may have been used to engrave the limestone walls of the cave (Leroi-Gourhan and Allain 1979). Nevertheless, detailed usewear studies and experimentation should allow one to distinguish between traces resulting from contact with these different materials.

Period	Industry, Culture, or Age	Site	Location	Striations Y/N/?	Description	Source(s)
Late Upper Paleolithic	Magdalenian	Andernach	Germany	?	Rounded crested blade	Bosinski & Hahn 1972
Late Upper Paleolithic	Magdalenian	Kniegrotte	Germany	?	Rounded crested blade	Feustel 1974
Late Upper Paleolithic	Magdalenian	Trou de Chaleux	Belgium	?	Rounded crested blade	Otte 1994
Late Upper Paleolithic	Hamburgian	Hasewich	Germany	?	One piece, with the rounded end opposite a scraper	Stapert and Johansen 1999
Late Upper Paleolithic	Hamburgian	Meiendorf 2	Germany	?	Rounded burin	Stapert and Johansen 1999
Late Upper Paleolithic	Hamburgian	Oldeholtwolde	Netherlands	?	Two rounded crested blades	Stapert et al. 1986; Staper and Johansen 1999 (fig 2: 1, 2)
Late Upper Paleolithic	Hamburgian	Poggenwisch	Germany	?	Rounded burin	Stapert and Johansen 1999
Late Upper Paleolithic	Hamburgian	Sassenheim	Netherlands	?	Four rounded crested blades	Stapert and Johansen 1999 (fig 2: 3-6)
Late Upper Paleolithic	Hamburgian	Teltwisch	Germany	?	One rounded blade and one rounded burin	Stapert and Johansen 1999
Late Upper Paleolithic	Hamburgian	Vledder	Netherlands	Y	Rounded blade fragment	Beuker & Niekus 1996; Stapert and Johansen 1999 (fig 3: 5; 4: B, C)
Late Upper Paleolithic	Hamburgian?	Ahrenshoft	Germany	?	Rounded tool?	Hartz 1987
Late Upper Paleolithic	Hamburgian?	Schalkholz	Germany	?	Rounded tool?	Tromnau 1974
Late Upper Paleolithic	Late Hamburgian	Sølbjerg 2	Lolland Island, Denmark	Y	One rounded tool	Petersen & Johansen 1996; Stapert and Johansen 1999 (fig 3: 3; 4: D)
Late Upper Paleolithic	Late Hamburgian	Sølbjerg 3	Lolland Island, Denmark	Y?	Nine rounded tools	Petersen & Johansen 1996; Stapert and Johansen 1999 (fig 3: 1, 2, 4, 6, 7)
Late Upper Paleolithic	Crestwellian	Gough's Cave	England	?	Two crested blades with rounded ends	Leroi-Gourhan and Jacobi 1986 (fig 3: 3, 4)
Late Upper Paleolithic	Crestwellian, ca. 12,190 RCYBP	Three Holes Cave	England	?	Two crested blades with "rubbed ends", associated with a hearth	Barton and Roberts 1996
Late Upper Paleolithic	Crestwellian?	Hengistbury Head	England	Y?	Several rounded flint tools described, with photos	Barton 1992
Late Upper Paleolithic	Late Ahrensburgian	Gramsbergen	Netherlands	Y	Strongly rounded blade	Johansen and Stapert 1997b; Stapert and Johansen 1999 (fig 2: 7; 4: E)
Late Upper Paleolithic	Federmesser	Usselo	Netherlands	?	Rounded crested blade	Stapert and Johansen 1999
Late Upper Paleolithic	Federmesser	Westelbeers	Netherlands	?	Rounded tool	Arts & Deeben 1976 (fig 20: 65)

Table 4.1. List of strike-a-lights from the Upper Palaeolithic (compiled from Stapert and Johansen 1999).

4.2. Sulphuric iron nodules as a proxy for Palaeolithic strike-a-lights

The presence of a sulphuric iron fragment within an archaeological deposit is lucky for any site, let alone very old sites dating to the Palaeolithic. This presence is significant not only due to the tendency of sulphuric iron to weather quickly when exposed to the elements, but also for the utility of the mineral for making fire in conjunction with flint. It is for this reason that any sulphuric iron recovered in association with archaeological find layers, especially those exhibiting evidence of burning, should be considered significant and signal researchers to be extra conscious of the possibility that at least one strike-a-light could be present on the site in question. A sulphuric iron fragment could itself exhibit traces of use, so it should therefore never be excluded from more detailed analysis.

4.2.1. Examples from the literature

A number of examples of sulphuric iron have been found in archaeological contexts dating to the Palaeolithic. Much like the archaeological strike-a-light examples above, a comprehensive list of such nodules has already been compiled and discussed at length in a paper by Weiner and Floss (2004), so in lieu of restating all of the findings contained therein, a table listing the finds (including the nodule from La Cotte à la Chèvre, absent in the Weiner and Floss article, but discussed below) has been produced to allow for quick referencing (Table 4.2).

Included in the table are both Middle and Upper Palaeolithic finds, mainly due to the meager sample of Middle Palaeolithic sulphuric iron finds in the literature. The higher frequency with which sulphuric iron is recovered from the Upper Palaeolithic verses the Middle Palaeolithic could be an indication of a higher frequency of use during this period. Another likely reason for this could be taphonomic attrition, an issue particularly relevant to a mineral like sulphuric iron that is prone to decay over time. It is significant to note that there is actually one more find listed from the Middle Palaeolithic than the Aurignacian, which helps to elucidate the point that sulphuric iron nodules appear to be just as sparse in early Upper Palaeolithic contexts as strike-a-lights.

Period	Industry, Culture, or Age	Site	Location	Usewear Y/N/?	Description	Source(s)
Middle Paleolithic	Mousterian	La Cotte à la Chèvre	St. Ouen, Jersey	?	Hen's egg sized nodule within a hearth feature and associated with Mousterian flint tools	Sinel 1912; Sinel 1914; Callow and Cornford 1986
Middle Paleolithic	Mousterian	Grotte de l'Hyène	Arcy-sur-Cure, Yonne, Burgundy, France	?	Two nodular pieces	Perles 1977; Leroi-Gourhan 1952; Leroi-Gourhan 1964; Weiner and Floss 2004
Middle Paleolithic	50,000 RCYBP	Drachenloch Cave	Tamina valley, south of Bad Ragaz, Switzerland	?	Halved nodule in association with a hearth feature; possibly artificially opened; probable modern use traces	Bächler 1940; Leuzinger-Piccand 2003; Weiner and Floss 2004
Upper Paleolithic	Aurignacian	Vogelherd	Near Heidenheim, Germany	Y	Full nodule with apparent band of crushing on exterior	Weiner and Floss 2004; Riek 1934
Upper Paleolithic	Aurignacian	Grotte du Renne	Arcy-sur-Cure, Yonne, Burgundy, France	N?	Three irregularly shaped fragments, described as apparently not utilitarian	Beaune 2002
Upper Paleolithic	Solutrean or Perigordian	Laussel	Marquay, Dordogne, France	Y	Fragment exhibiting many clear scratches	Mortillet 1909
Upper Paleolithic	Solutrean?	Grotte des Eyzies	France	?	No details	Perlès 1977
Upper Paleolithic	Magdalenian	Trou de Chaleux	Hulsonniaux, Belgium	Y and ?	Two pieces: one grooved (utilized) nodule; one piece remineralized to limonite (use unknown)	Collina-Gerard 1998 (Fig. 11); Dupont 1866; Dupont 1872; Prideaux 1977
Upper Paleolithic	Magdalenian	Trou de la Mere Clochettè	France	?	No details	Perlès 1977
Upper Paleolithic	Magdalenian, 12,650 RCYBP	Grotte du Bois Laiterie	Namur, Wallonia, Belgium	Y?	Four nodule fragments (refit?)	Lozouet and Gautier 1997; Otte and Strauss 1998 (C14 date)
Upper Paleolithic	Magdalenian	Pincevent	La Grande-Paroisse, France	?	Five fragments, not natural to the site	Leroi-Gourhan and Brézillon 1972
Upper Paleolithic (or Neolthic?)		Grotte d'Engis	Belgium	N	Full nodule, no noted signs of wear	Collin et al. 1991
Upper Paleolithic		Ottersum (Gennep), open air site	Limberg, Netherlands	?	Drilled?	Van der Lee 2000/2001

Table 4.2. List of sulphuric iron nodules recovered from Middle and Upper Palaeolithic contexts (compiled almost exclusively from Weiner and Floss 2004).

Of the sulphuric iron examples listed, only a few are accompanied in the literature with descriptions of definitive or possible usewear traces, all from Upper Palaeolithic contexts. These include nodules from Vogelherd in Germany, Trou de Chaleux in Belgium (Figure 4.2: A), and Laussel in France (Figure 4.2: B), and possibly Grotte du Bois Laiterie in Belgium. The rest listed either do not appear to exhibit use damage, or it is not mentioned in the literature. The halved nodule from Drachenloch Cave (Switzerland) is an interesting Middle Palaeolithic example in that it was found in association with a hearth feature that was dated to ca. 50,000 radiocarbon years BP (RCYBP), but also due to the unfortunate fact that the researcher who discovered the nodule may have tested it using flint to see if it was effective at generating sparks (Bächler 1940; Weiner and Floss 2004). In a photo of the nodule, there is what appears to be possible crushing near the center of the internal fracture surface, as well as a possible wide scratch that appears as a darker strip cross-cutting the radial crystal pattern on the lower portion of the nodule (Figure 4.3). To determine whether these marks are ancient or modern in origin could be very difficult. An alternative approach would be to look for possible impact scars preserved on the outer surface of the nodule that could be indicative of artificial forcible opening.

Figure 4.2. Images of utilized Upper Palaeolithic sulphuric iron nodules. A) Photograph of Trou de Chaleux (Belgium) nodule with deeply incised groove (Collina-Girard 1998), and B) drawing of Laussel (France) nodule exhibiting multiple linear usewear traces (Mortillet 1908 in Weiner and Floss 2004, 66). Images are not to scale.

Figure 4.3. Photograph of sulphuric iron nodule fragment from Drachenloch Cave (Switzerland). White arrow indicates possible linear usewear traces cross-cutting radial crystal pattern. Photo from Kantonsarchäologie St. Gallen.

4.2.2. La Cotte à la Chèvre, Jersey

La Cotte à la Chèvre is the name of a cave located in the Parish of Saint Ouen on the northwest coast of the island of Jersey, positioned approximately 18-m above mean tide level overlooking the rocky shore below (Figures 4.4 and 4.5). Flint artifacts were first discovered in the cave by Joseph Sinel in 1861, who performed the first excavations at the site in 1881 (Sinel 1912, 1914). The cave was subject to a series of excavations from this point through the latter half of the 19th century through the early 1910s, and then again in the 1960s (Callow 1986d; Mc Burney 1963; Sinel 1912, 1914). Artifacts recovered include poorly preserved animal bone, flint flakes and tools, the most common being notches and denticulates, but also various scraper forms and retouched cutting tools, along with Levallois flakes, cores, and points, and one small bifacially flaked, heart-shaped hand-axe measuring approximately 7-cm in length (Callow 1986d; Sinel 1912). It seems probable that this assemblage represents multiple occupations that could span the length of the Middle Palaeolithic, and seem to represent a few different Mousterian techno-complexes, with one of the later occupations possibly representing Mousterian of the Acheulian Tradition (MAT) as suggested by the presence of the hand-axe (Bordes 1961; Sinel 1912). The occupations at La Cotte à la Chèvre likely coincide to an extent with the succession of occupation layers, beginning with the earliest occupation (Layer H), at the much larger La Cotte de St. Brelade on the southwest coast of the island (Figure 4.2.2), which has over 200,000 years of episodic Neandertal occupations represented in its deposits, beginning at least 250 ka ago, based on an average thermoluminescence (TL) date of 238±35 ka for Layers C and D at La Cotte de St. Brelade (Huxtable 1986). Excavations have recently resumed at this site, with the bottom of the deposits not yet having been reached, so older dates and archaeological find layers could be possible (Elinor Croxall, personal communication, 2011).

Of particular interest for this study, however, is a set of findings from the original Sinel excavation of La Cotte à la Chèvre in 1881. In his 1912 report on the cave dwelling to the Société Jersaise, Sinel describes how he found "…near the middle of the cave, on the right hand side, and about 2 feet below the surface, a shallow hearth with wood ashes and carbonized wood. Among the ashes was a lump of nodular iron pyrites about the size of an ordinary hen's egg, which no doubt had been used in conjunction with a flint for striking fire, for similar nodules have been found under similar conditions in other caves" (210). Unfortunately, Sinel did not elaborate at all on which caves he was alluding to. The presence of this nodular piece of sulphuric iron in direct association with a hearth and Middle Palaeolithic artifacts is not only significant in the implications it could have for fire production by Neandertals at this site where at least a couple other hearths were observed, but also at La Cotte de St. Brelade, where evidence of burning is present in every archaeological level, and hearths are much thicker (Callow et al. 1986; Sinel 1912).

Figure 4.4. Photographs of La Cotte à la Chèvre cave exterior on Jersey. 'X' on left photo marks cave location. After Sinel 1914 (Plates IV and V).

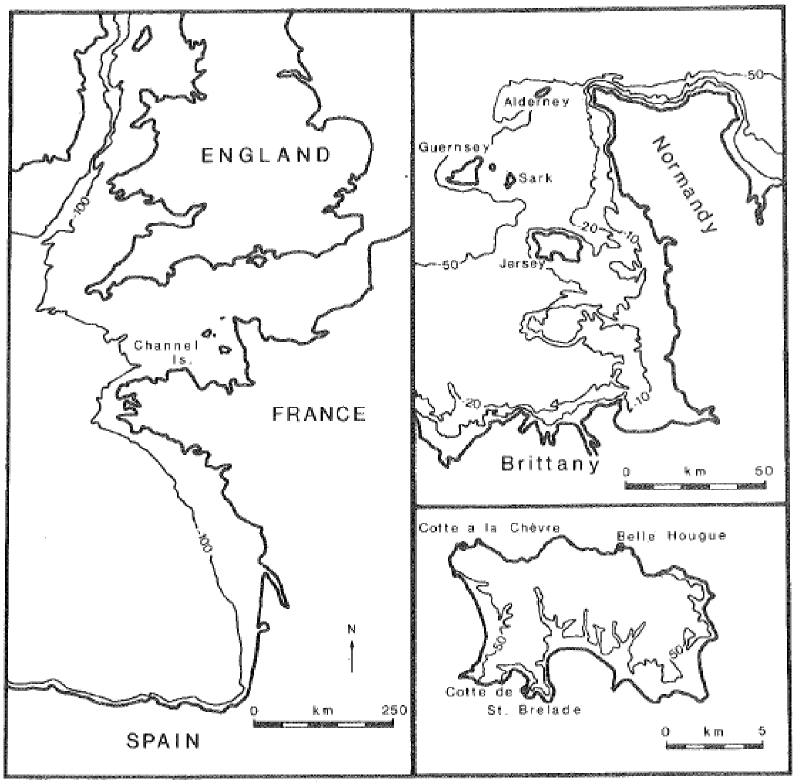

Figure 4.5. Map showing location of La Cotte à la Chèvre on Jersey, and topographic data indicating probable coastal margins with drops in sea level of 10, 20, and 100 meters (Callow 1986a, Fig. 1.1, 3).

The presence of sulphuric minerals including pyrite and marcasite is limited on Jersey Island, and is usually only present in hydrothermal veins and veinlets cutting into the granite bedrock in the northwest portion of the island where La Cotte à la Chèvre is located, and the Jersey Shale Formation to the south, where fine interstitial crystalline growths of the same minerals occur sparingly (Ixer 1992). These forms of sulphuric iron differ significantly from the nodular form described by Sinel (1912, 1914), which tends to form in calcium carbonate (i.e. chalk) host rock. Given the lack of carbonate bedrock on Jersey, it should not be surprising that there are no (modern) known local sources of flint or sulphuric iron nodules (Callow 1986b). Thus, it could be presumed both the flint and the sulphuric iron nodule recovered from La Cotte à la Chèvre were most likely brought to the island, but from how far away?

At the time of occupation, Jersey was adjoined to the European mainland as part of a peninsula during sea level low stands, as evinced by bathymetric data (Fig. 4.5; Callow 1986a, 1986c; Sinel 1912). The nearest known modern outcrops of chalks (possibly sulphuric iron-bearing, though not confirmed) are along the northwest coast of France approximately 150-km east of La Cotte à la Chèvre (Figure 4.6; French 2007). However, a few small chalk outcrops much closer to Jersey were probably exposed during sea level low-stands when Jersey was initially colonized by the inhabitants of La Cotte à la Chèvre: one located around 13-km to the north, another approximately 30-km south on the Minquiers Plateau (both requiring a drop in sea level of 25-m to be exposed, however), and another around 40-km north near the island of Guernsey, which would require a 50-m drop in sea level for exposure, and was probably not exposed during the time Jersey was occupied (Callow 1986b; Keen 1986). The majority of the flint found at both Chévre and St. Brelade appears to have originated as beach gravels (evinced by high percentages of water-worn cortex on dorsal surfaces of flakes and tools at St. Brelade) that, while still limited in supply, were likely located closer by. Local quartz and quartzite were also exploited with varying degree over the course of occupation of the island, often times comprising over a third of the lithic assemblage at St. Brelade (Callow 1986b). There is no mention of the abovementioned outcrops containing sulphuric iron nodules, however, and it is somewhat unlikely that these would preserve long enough to be washed up in secondary beach deposits, though it is certainly not impossible. It could be argued, nevertheless, that for a Neandertal to carry a nodule of sulphuric iron such distances would support the utilitarian nature of the piece. This functional interpretation is further supported by the primary context in which the nodule was found in association with a hearth feature and flint fragments and tools consistent with the Neandertal Mousterian Tradition.

By special request, a search was recently conducted by members of the Jersey Heritage Trust through the artifact collections there from La Cotte à la Chèvre in an attempt to locate the nodule for analysis. Unfortunately, their efforts have thus far proven unsuccessful, and the whereabouts of the nodule remain a mystery. Given the early excavation date for this site, it would not be surprising if the nodule was originally noted then discarded by Sinel, or simply lost or misplaced over the years. Nevertheless, the lithic assemblage from this site (and La Cotte de St. Brelade) would be ideal for analysis using the information contained herein to ascertain if any of the remaining flint artifacts bare traces of being used as a possible strike-a-light in combination with the sulphuric iron nodule.

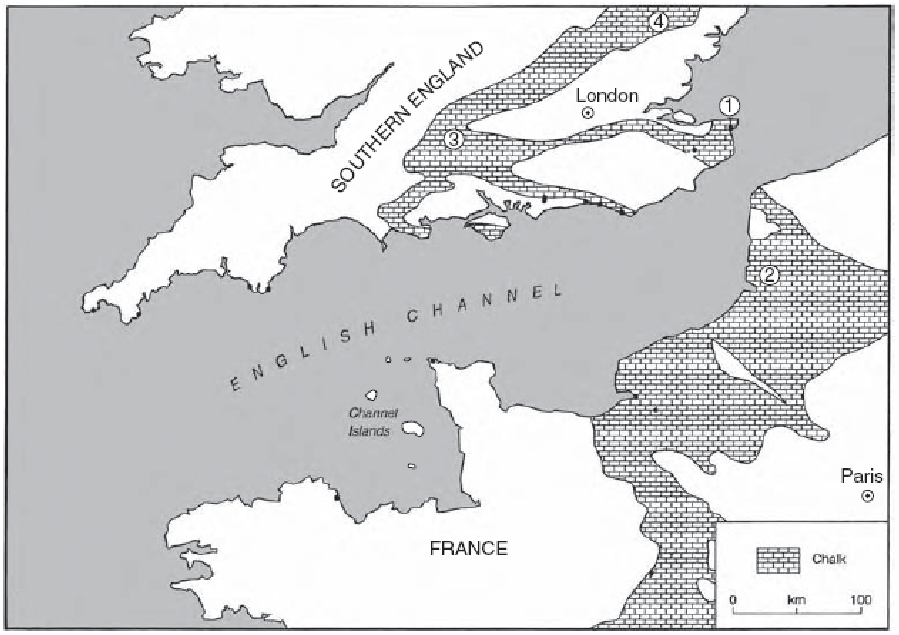

Figure 4.6. Map showing the extents of major modern chalk outcrops in northwest France, and southwest England (French 2007, Fig. 2.7, 25).

5. APPLICATION OF THE FINDINGS

Strike-a-lights are arguably one of the rarest artifact types recovered from the Palaeolithic archaeological record. This trend appears to directly translate to the extant literature on the subject, which is also very sparse. This scarcity of strike-a-lights in the archaeological record progressively dwindles to virtual non-existence the farther back one looks into the Upper Palaeolithic, and then seems to disappear completely during the Middle Palaeolithic (Stapert and Johansen 1999). A number of possible explanations for this can be proposed. The simplest explanation is, of course, that the group in question (in this case, Neandertals) did not possess the technology. Testing this hypothesis was, of course, the impetus for this thesis. Another explanation – the premise for this thesis – is the possibility that the typical tool form and associated wear patterns most researchers would expect to encounter based on archaeological strike-a-light specimens recovered from later periods is not how they appeared in the Middle Palaeolithic. A strike-a-light is a fairly distinctive, yet ephemeral tool type that may have only been needed once at a site to start a fire. After that point, the fire could be maintained until the camp was broken. This, of course, assumes that fire was not brought onto a site, or that another fire-producing method other than stone-on-stone friction or percussion was not used.

Whether due to absence or misidentification, it is this near invisibility of strike-a-lights in the Palaeolithic archaeological record that provided the impetus for this thesis. Rejecting the idea that Neandertals were incapable of utilizing fire production technology is not difficult when time and again instances are presented demonstrating Neandertals were capable and frequent users of fire, rarely less so than early Upper Palaeolithic modern humans (Roebroeks and Villa 2011a). The plausibility of this claim is augmented by the occasional presence of possible fire-making accessories found in fire-bearing contexts (i.e. the La Cotte à la Chèvre sulphuric iron nodule), with the only member lacking from the triumvirate of necessary variables for fire production being a strike-a-light exhibiting the requisite usewear traces. An apt analogy for this scenario could be a modern crime scene, where Neandertal man is the primary suspect with an established motive (i.e. fire for warmth, cooking, etc.), a long history of starting fires, and can be placed at the scene of the crime. The physical evidence includes the victim (the 'remains' of a hearth) and a spent shell casing (the sulphuric iron nodule); the only missing element is the presumed weapon (the strike-a-light). For most juries, this would in all likelihood be enough evidence to convict – especially if modern humans were the ones on trial. There exists, however, a double-standard with regard to Neandertal fire production that appears to demand the recovery of the strike-a-light ‘smoking gun’, and perhaps rightly so for the sake of due diligence. This is why the necessary knowledge and tools must be in place to aid in the recovery and identification of strike-a-lights from the Middle Palaeolithic.

To analyze a sample from an artifact assemblage is in all likelihood not an adequate research strategy when searching for strike-a-lights. A sampling provides an overall impression of a site, whereas seeking a specific tool type, especially one as uncommon as strike-a-lights, requires one to potentially observe an entire collection. Ideally, it would be most efficient in terms of time (and grant money) if whoever is cataloguing a collection be trained to keep an eye out for the tell-tale macroscopic traces that could correspond to an artifact having been used as a strike-a-light. This, of course, is only a viable strategy for future collections. For extant collections, focus should first be given to artifacts recovered from occupation levels with evidence of fire. Special attention should be paid to test units containing and directly adjacent to hearth locations (if present), and then expanding outward from there. For sites without formal fire locations, or open air sites without the convenience of the formal site boundaries that caves or rock shelters tend to afford, the process has the potential to be much more arduous. These were the precise conditions met when it was decided it could be worthwhile to test the ‘expedient strike-a-light’ hypothesis by examining the lithic finds from the Neandertal Last Interglacial site of Neumark-Nord (specifically findspot 2, horizon 2) in Germany.

5.1. Overview of evidence for identifying fire production

There are quite a few factors one must consider when attempting to infer whether or not a piece of flint or sulphuric iron has been used for the purpose of making fire. Making a determination such as this, as with all analysis, relies on multiple lines of evidence working in concert to form the basis for a convincing argument advocating such use. The majority of these attributes has already been discussed at length in earlier sections and will not be rehashed here in any detail. Please refer to Chapter 2.1 for a basic discussion of usewear traces and analysis; and Chapters 3.1, and 3.2 for more thorough descriptions of the usewear traces observed on experimental pieces. Those indicators of fire production or other supporting evidence noted in the literature but not specifically encountered during experimentation are elaborated on here in an attempt to provide a large pool of information to draw from for future studies.

The strike-a-light attributes discussed were directly applied to the Neumark-Nord 2/2 assemblage discussed below, while the sulphuric iron attributes should prove helpful for future analysis of ancient nodules: perhaps of the La Cotte à la Chèvre nodule, if it is ever recovered; or the Drachenloch Cave nodule (Figure 4.3, Table 4.2), which has not undergone any formal usewear analysis to date (Jürgen Weiner, personal communication 2011).

5.1.1. Strike-a-lights

For flint and other siliceous raw material types (e.g. quartz or quartzite), the identification of usewear traces that suggest a suspected strike-a-light has come into repeated contact with sulphuric iron is not terribly difficult if one is familiar with the character of these traces. Instead, it is the initial recognition that 'diagnostic' usewear traces *could* be present that is arguably the more difficult aspect of this process. More to the point, one must first discern (either macroscopically or under low magnification using a binocular microscope) edge-rounding that appears 'suspicious' when compared to the rest of an assemblage, and then use higher magnification to inspect the rounded surface for the presence of polish exhibiting the densely packed, deeply incised striations characteristic of forcible contact with sulphuric iron.

Edge-rounding is more often than not going to be the first indicator one will notice if an artifact has indeed been used as a strike-a-light. The degree of edge-rounding encountered can range from extensive – in which case identification is quite easy – to very slight (Figure 3.4). Unfortunately, it is very likely that in most instances, edge-rounding – specifically on the proximal dorsal edge of flakes or chips – is simply attributed to edge grinding or crushing for the purpose of preparing a striking platform. When this is the case, these flakes are relegated to a statistics table in someone's lithic analysis and forgotten, effectively quashing their true research potential. Given the possible subtlety of edge-rounding for pieces with short use-lives, researchers must remain vigilant and keep a careful watch for any flake or other implement exhibiting a degree of edge-rounding that could be considered 'greater than usual', and then set these pieces off to the side for closer scrutiny later on.

Without having extensively tested how every type of rock or mineral affects the surface of flint, it is impossible to say for certain that no other materials (especially fine-grained varieties of comparable hardness) are capable of leaving usewear traces very similar, if not identical, to those left by sulphuric iron (Figures 3.1 and 3.3). Therefore, context is key if use damage is present on a flint tool or flake that possesses qualities that could infer use as a strike-a-light. If an artifact is found in association with evidence of fire, and other attributes are present that appear to corroborate the argument for use as a strike-a-light as opposed to some other type of stone-working tool, then identification as a probable strike-a-light would be the most parsimonious explanation for those traces. Within the conversation of early fire, however, it is not uncommon for the most logical explanation to be overshadowed by the often long list of exceptions (Lewis 1989).

5.1.2. Sulphuric iron

There are a number of readily identifiable usewear traces that, if observed on an archaeological sulphuric iron specimen, could be suggestive of having been used as a contact surface for a strike-a-light (see Chapter 3.2). Furthermore, if these traces are lacking, there are still others that could in the very least be indicative of human alteration. The preservation potential for usewear traces on sulphuric iron nodules or fragments has the potential to be pretty low given the instability of this mineral when exposed to the elements. This is especially true for more subtle microscopic elements. However, multiple Palaeolithic examples have been recovered in archaeological contexts, demonstrating that depositional conditions can favor preservation in some instances.

Possibly the most blatant sign of use one could encounter would be a large groove cutting into the surface of a fragment or nodule, as seen in the Upper Palaeolithic Trou de Chaleux (Belgium) nodule (Figure 4.2: A), and a more recent nodule collected in the 19th century from the Indians of Fort Simpson, Mackenzie River district, British Columbia, Canada (Figure 5.1). Grooves such as these may have formed naturally during regular exploitation of a limited surface area, or they may have been intentionally carved into the surface. Some possible reasons for intentionally carving a groove are: 1) to expose fresh, unweathered interior material while preserving the integrity of the nodule to prevent weathering, avoid waste, or to maintain a shape easy to grip; 2) to increase control by acting as a guide for the strike-a-light and limiting the direction sparks can travel; and 3) to possibly increase the points of contact between the concave surface of the groove and the specially shaped edge of a strike-a-light tool (likely rounded or triangular/pointed). An excellent video demonstrating the effectiveness of this method can be viewed online (Labiste 2011).

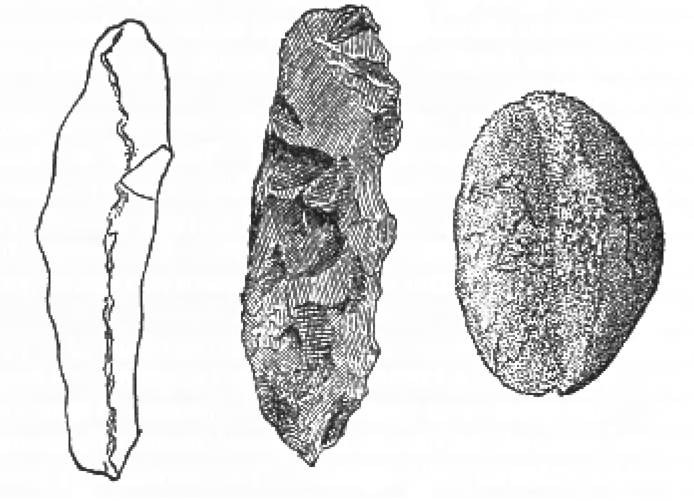

Figure 5.1. Flint strike-a-light and grooved sulphuric iron nodule collected in 19th century from Amerindians of Fort Simpson, Mackenzie River district, British Colombia, Canada. After Hough 1928 (Figure 40b, 56).

Scratches and crushing are to a degree less obvious than large grooves, but are the more common traces associated with the use of a sulphuric iron nodule in conjunction with a strike-a-light. Scratches can generally be expected to appear in parallel to subparallel and often intersecting linear traces incised into the surface (interior or exterior) of a sulphuric iron nodule or fragment (Figures 3.8 and 3.9). Longer scratches are somewhat more likely to manifest using the friction method verses the percussion method for applying a strike-a-light. Enough scratching along a consistent trajectory would likely begin to form a groove in the contact surface, especially if the working edge is applied longitudinally. Scratches on interior surfaces, even if not readily apparent due to limited use or surface weathering, can generally be seen cross-cutting the radiating crystal pattern exhibited by sulphuric iron nodules. Scratches are essentially a linear arrangement of crushed or planed sections of these individual needle-like crystals. As the contact surface becomes more heavily used, these individual scratches ultimately merge to form a continuous zone of crushing, though sometimes individual scratches can still be observed within these zones (Figure 3.10). If the percussion application method was employed, depending on the kinematics involved, it is possible for zones of crushing to develop with minimal observable scratching. Like scratches, crushing can be observed on interior and exterior surfaces. An Aurignacian nodule recovered from Vogelherd Cave (Germany) appears to exhibit a band of crushing on a portion of its exterior surface (Weiner and Floss 2004).

If a nodular fragment is present but does not appear to possess or retain any features indicative of use, it might still be possible to ascertain if the nodule was forcibly opened by examining the exterior of the piece for possible impact scars. These scars could be located both along the edge of the fracture plane (Figures 3.6 and 3.7), or possibly on any other point on the exterior surface. Multiple impact features could testify to their artificial origins, though they could suggest either the need for multiple strikes prior to breakage, or possibly that the nodule was used as a hammer stone prior to fracturing. This latter scenario could also be evinced by a concentrated zone (or zones) of crushing, especially if the positioning of these zones seems logical for this type of use when compared to other hammerstones. It could be possible for an impact scar to result from falling onto a hard surface, possibly from the ceiling of a cave or a rockshelter onto another rock fall, but geological data or sulphuric iron nodules observed *in situ* would be needed to support this claim. The argument for an anthropogenic origin of a sulphuric iron nodule is generally strengthened for sheltered sites like these when the mineral is not native to the host rock in which they are formed. This is also true for all sites in a region where there are no known local sources of sulphuric iron. This could suggest the piece was brought into the area with a specific purpose in mind, with making fire being arguably the most logical. A possible way to at least suggest whether a nodule broke open naturally by falling or fracturing due to frost or secondary mineral growth in fissures is to note whether the broken surface in question is either 'fresh' or heavily mineralized (Figure 3.9). A nodule containing fissures or fractures requires less force to break apart that an uncompromised nodule. The freshness of an exposed interior surface could testify to the amount of effort that was required to break the nodule, but if this was the case, the chances are good that other signs of forcible opening (i.e. multiple impact scars) will be present. Nevertheless, homogeneously mineralized interior surfaces like those observed in the experimental nodule can still belie possible utilization. Minimal usage is quite capable of removing these thin mineral deposits from the surface exposing fresh material (Figure 3.10). Even if scratches or crushing are faint, a disparity between affected and unaffected areas should be detectable. Much of this is speculation based on experimentation, however, since no archaeological specimens were available to test these hypotheses.

5.2. Fire production at Neumark-Nord 2/2?

Neumark-Nord 2/2, while not necessarily the ideal site for testing the 'expedient strike-a-light' hypothesis due to the lack of formal hearth locations, was selected nonetheless primarily owing to the fact that heated flint artifacts were recovered from the archaeological find layers, as well as the accessibility afforded by having a large portion of the collection in-house at Leiden University. The Neumark-Nord 2/2 assemblage was examined according to the guidelines and attributes laid out in Stapert and Johansen (1999), Van Gijn 2010, and Van Gijn et al. 2006, as the experimental strike-a-lights for this study had not yet been completed prior to examination. Other experimental strike-a-light specimens already in the Leiden Laboratory for Artefact Studies comparative collection also proved to be an invaluable resource. Nevertheless, keeping in mind the probable outcomes expected from the 'expedient strike-a-light' experiments, special attention was paid to specimens exhibiting what could be considered weak damage or wear consistent with possible short-term use as a strike-a-light.

5.2.1. Site overview

The excavation at Neumark-Nord 2 was just one facet of a larger 25 year undertaking in an opencast brown coal (lignite) mine approximately 10-km southwest of Halle (Geisel valley, Eastern Germany). The Neumark-Nord project has included multiple episodes of excavation and ongoing study performed by researchers and students from the State Office of Heritage Management and Archaeology of Saxony Anhalt, the *Römisch-Germanisches Zentralmuseum* (RGZM) in Mainz, and Leiden University. Archaeological deposits at what would be called Neumark-Nord 1 (NN1) were initially discovered in the area in 1985 due to large-scale mining activities. This site is a probable killing/butchery-site on the edge of a palaeo-lake basin that was believed to date at the time to a Middle Pleistocene Saalian interstadial, with excavations here continuing from this point through 1996 (Mania 1990, Brühl 2006, Brühl 2004, Brühl 2005). Towards the end of the excavations at Neumark-Nord 1, another palaeo-lake basin with associated deposits of Middle Palaeolithic flint and bone artifacts was discovered in 1995, called Neumark-Nord 2 (Laurat *et al.* 2008, Jurkenas *et al.* 2005, Laurat and Brühl 2006). The palaeo-lake basin was formed in depressed Saale till sediments that had subsided periodically due to the presence of a lignite diaper (Figure 5.2). The limnic sediments episodically infilling the depression and the archaeological deposits contained therein appear to securely date to the onset of the Eemian interglacial (ca. 121–110 ka), making it one of the few known Eemian archaeological sites, allowing for a unique and interesting insight into how Neandertals utilized this interglacial landscape. This date range is based on paleomagnetic testing at the site that happened to record the full Blake reversal event (ca. 121.5–118 ka), the dates extrapolated from this data further corroborated by TL dates obtained from burned archaeological flint specimens that yielded a weighted mean age estimate of 126±6 ka (Sier et al. 2010). The archaeological deposit was divided into three distinct horizons (NN2/2, NN2/1, and NN2/0), with NN2/2 subdivided into find layers A, B, and C along the outer shore. The stratigraphic layers became thicker, more numerous, and more complex moving south towards the center of the basin, with find layer B splitting into B1, B2, and B3 (though in some areas there is only a Bo [B-upper] and Bu [B-lower]), and layer B3 subdivided further yet into three sub layers: B3o (B3-upper), B3m (B3-middle), B3u (B3-lower). These stratigraphic relationships are best represented in *Hauptprofil* 7 from just south of the excavated area (Figure 5.3).

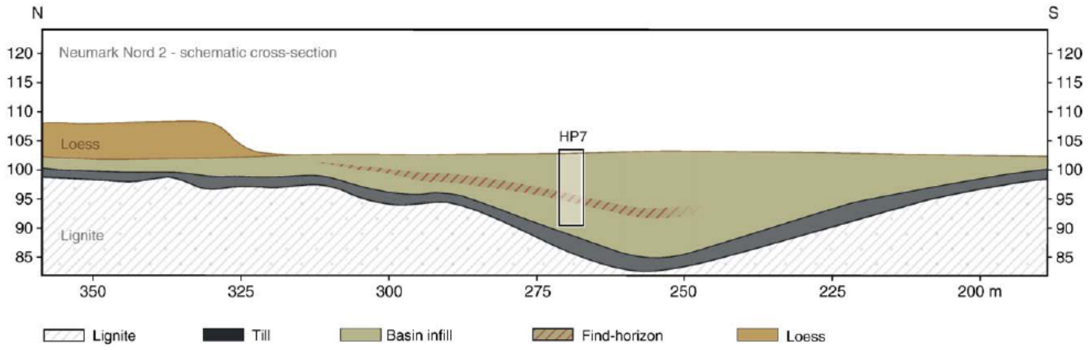

Figure 5.2. Schematic cross-section of Neumark-Nord 2, showing location of Hauptprofil 7 (Figure 5.3) and archaeological find layer (Sier et al. 2010).

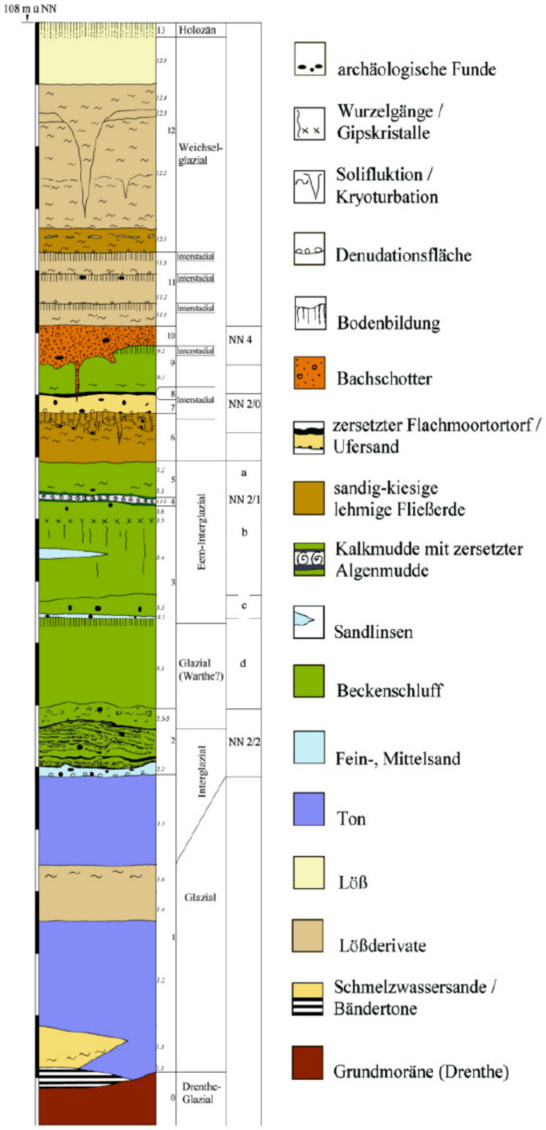

Figure 5.3. Representative profile (Hauptprofil 7) of Neumark-Nord 2 (Laurat et al. 2008).

A diverse array of faunal species were recovered from the site, including bank vole, deer, horse, large bovid, wolf, feline species, large hyena, and bear, with lesser numbers of megaherbivores like straight-tusked elephant and rhinoceros also represented in the assemblage (Kindler 2007), some of the bones exhibiting signs of human modification (12–14% of the bone material exhibiting cut marks and/or crushing, probably to facilitate marrow extraction). It is believed these animals lived alongside Neandertals in a rather open 'mosaic' landscape around Neumark-Nord 2 that was at this point not quite completely forested, as reflected in the pollen record (Sier et al. 2010). There are abundant traces of charcoal all through the infill, with large peaks coinciding with the peak in hominin presence (Wim Kipper, personal communication, 2011), including the charred remains of possible plant foods, including fragments of hazelnut (*Corals avellana*), of acorns (*Quercus* sp.), and of kernels of blackthorn (*Prunus spinosa)* (Figure 5.4; Roebroeks 2010). These, coupled with the occurrence of around 160 burned artifacts (Eduard Pop, personal communication 2011), could be the remnant traces of slightly reworked campfires, though no formal concentrations or hearth locations were observed.

At the conclusion of the excavations at Neumark-Nord 2/2, about 20,000 flint and 130,000 bone finds were recovered. The lithic materials from the site were split between the RGZM and Leiden University for lithic analysis, with the material primarily from the northern section (n~11,000) of the excavation housed at the RGZM, while the remainder from the southern part and a complete North-South trench (n~8700) is currently undergoing research at Leiden.

Figure 5.4. Photograph of charred Prunus spinosa *(blackthorn) kernel fragments from archaeological level at Neumark-Nord 2 (largest fragment ca. 0.5 cm). Photo by W. Kipper from Roebroeks 2010.*

5.2.2. Lithic technology overview

Overall, the lithic industry present at Neumark-Nord 2/2 is consistent with that of the Middle Palaeolithic Mousterian culture techno-complex (Jukenas et al. 2005). The flakes make up approximately 80% of the lithic assemblage, the majority being shorter than 20-mm, with few over 50-mm in length. In a recent study, dorsal face preparation was observed on upwards of 30% of flakes within the study sample: 20% via crushing, and 10% exhibiting faceted striking platforms or a combination of the two methods (Homelen 2011). The flakes often possess a glossy patina, but bear virtually no transport damage. This is consistent with the overall low-energy depositional environment of the lake basin. This also corresponds with the assumption that all larger stones found within the archaeological layers were most likely brought onto the site by its inhabitants. Cores make up approximately 5% of the finds, with discoid and levalloid forms dominating (Jukenas et al. 2005). The cores are quite small for the most part, ranging from 30 to 60 mm, possibly due to natural fissures and imperfections in the available material, which could also account for smaller, lower-quality nature of the tools recovered (Jukenas et al. 2005; Homelen 2011). A number of more 'formal' tool forms were identified, including Clactonian notches, a few retouched notches, Tayac points, and denticulates, while informal retouched tools, mainly for scraping or cutting with some indications of use, are more common. Definitive Levallois technology is represented in limited numbers, and includes some fine examples, but it is possible the best pieces were taken offsite to be utilized elsewhere.

5.2.3. Analysis of the lithic assemblage

A trait-specific cursory analysis was performed on *all* roughly 8,700 lithic artifacts (regardless of form) present in the Neumark-Nord 2/2 assemblage at Leiden using low magnification under a binocular microscope to look for edge-rounding and crushing that could be suggestive of use as a strike-a-light. Specimens exhibiting these 'suspicious' characteristics were pulled from the collection to be analyzed all at once in greater detail later on. Fragments deemed impractical for use as a strike-a-light, i.e. delicate artifacts smaller than 1–2 cm that would be difficult to grasp and/or would break easily, were only glanced at and not examined in any detail this study. Fewer than 40 pieces were initially segregated from the collection for to be looked at more closely. These archaeological specimens were subjected to further scrutiny and compared with experimental pieces using both low and high magnification. Most of the edge damage observed was present on the dorsal edge of flake striking platforms that appeared to be more or less consistent with that produced from light to moderate edge grinding, with edge-removals for most specimens propagating across the top of the striking platform as opposed to down across the dorsal surface. Edge grinding as a form of probable dorsal face preparation helps to homogenize and strengthen the striking platform by removing weak or salient points prior to the removal of a flake. Similar dorsal face preparation was noted in earlier studies of material recovered from Neumark-Nord 1, and have been interpreted a means to produce expedient end scraper-like tools (Brühl 2006; Mania 1990). Other pieces consisting of chunks, small core fragments, and natural gravels exhibited rounding that may have been caused by a few different processes. Some showed signs of possible grinding wear similar to that interpreted as dorsal face preparation seen on the flakes discussed above. Others exhibited edge-rounding and/or crushing associated with natural processes like post-depositional movement within the soil column, or extreme pressure caused by glacial stress. The latter was likely the cause for near ubiquitous rounding and crushing seen along salient ridges on the 'old surfaces' of probable till-derived specimens. All pieces indeed exhibited varying degrees of gloss patina, or 'soil sheen', as noted by Jurkenas and colleagues (2006). Ultimately, it was decided that, – save for one specimen – the probability of these artifacts being strike-a-lights was very low.

Figure 5.5. Photograph of flake NN2/2/425 from Neumark-Nord 2/2.

The remaining flake from square 2111, level B (*Befund nummer* 2111, B, 148; *Fund nummer* NN2/2/425) exhibited some interesting traces that gave pause for thought (Figure 5.5). Slight edge-rounding, yet 'more than the norm' when compared to other Neumark-Nord 2/2 flakes, is visible macroscopically along the dorsal edge of the striking platform. When viewed at low magnification, the degree of rounding appears to be akin to that seen in experimental samples having been subjected to a single series of 25 strokes or less, and appears more characteristic to traces left using the friction application method as opposed to the percussion method. Visible under the stereomicroscope, and made more clear at higher magnification, is what appears to be linear, parallel to subparallel grooves that suggests an oblique-transverse directionality approximately 20–40° off perpendicular to the edge (Figure 5.6: A, C). The overall character and distribution pattern of these striations suggests that they did not result from forcible contact with sulphuric iron, but some other hard material. The individual striations are of greater width and at a wider interval compared to the finer, more densely clustered striations observed on the experimental strike-a-lights, suggesting the contact material was more coarsely grained than sulphuric iron. The unidentified grooves also appear to be more deeply incised into the surface of the flint, suggesting either greater force was applied, or that the contact material or the individual grains comprising the contact material were of greater hardness than sulphuric iron, the latter being the most probable for this particular type of trace. Based on these attributes, the hypothesized contact material was quartz sandstone due to the more coarse-grained nature of this type of rock, and the greater relative hardness of its constituent mineral grains (7 for quartz, and 6–6.5 for sulphuric iron on the Mohs scale of mineral hardness). It is uncertain what effect gloss patina like that seen on the Neumark-Nord 2/2 specimen has on usewear traces like striations produced during contact with sulphuric iron. It is not inconceivable that finer striations could be destroyed during the creation of this post-depositional phenomenon (one common to sandy and silty sediments like those at Neumark-Nord 2/2), thereby creating a ‘grooved’ appearance by leaving only the larger and more deeply incised striations intact. This scenario seems unlikely, however, considering the common occurrence of what appears to be dorsal face preparation through edge grinding preserved on chips and flakes in the Neumark-Nord 2/2 assemblage, making it the more probable explanation. Therefore, the hypothesized cause of the usewear traces observed on flake NN2/2-2011/B-425 was dorsal face preparation of an edge using a sandstone abrader prior to removal the removal of the flake. The abrader was applied multiple times – probably fewer than 25 strokes – using an oblique transverse motion directed across the top of the platform.

To test this hypothesis, the process described above was emulated in an experiment using a flint flake of the same variety used for the strike-a-light experiments and a small, rounded quartz sandstone cobble as an abrader. The sandstone cobble was forcibly rubbed across the top of the dorsal edge of the flake striking platform using an angled transverse motion for a total of 25 strokes. The resultant usewear turned out to be remarkably similar to that observed in the NN2/2 specimen in type, degree and distribution of wear (Figure 5.6). Only a few minor differences were noted. The edge-rounding of the experimental piece is slightly less pronounced, while the perceived depth of the grooves on the archaeological piece is deeper on average. Together, these variables could suggest more pressure was applied to the archaeological piece. Distinct polish and fine, shallow striations are present within the larger grooves on the experimental piece, but are not visible on the NN2/2 piece. It is highly possible that these finer traces would be obscured or obliterated by the same 'soil sheen' present on the archaeological specimen if the experimental piece were to be buried in soil similar to that encountered at Neumark-Nord 2/2 and analyzed after 120,000 years.

Despite not having found a strike-a-light in the portion of the Neumark-Nord 2/2 assemblage present in Leiden, analysis of the other half of the total assemblage could prove to be more fruitful. Nevertheless, lessons learned from the experiments have led to understanding a little more about the technological methods employed at the site by interglacial Neandertals, possibly opening the door to another interesting avenue of research for the site with usewear analysis at the forefront.

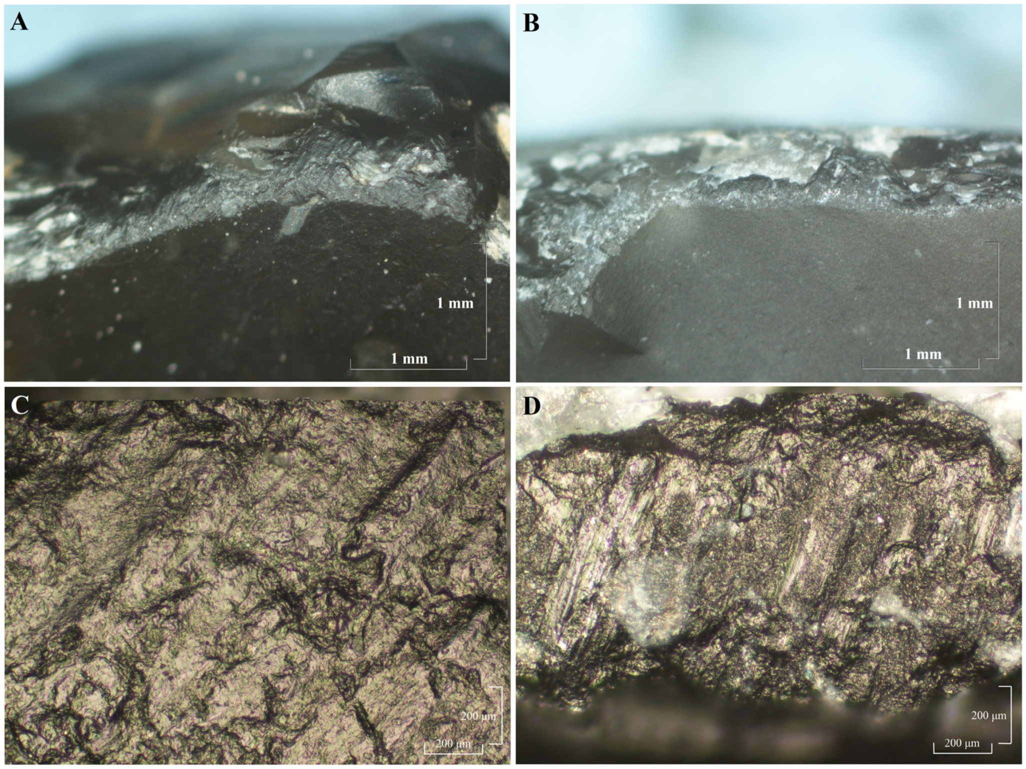

Figure 5.6. Photographs comparing usewear traces of archaeological specimen NN2/2/425 (A, C) with experimental sample (B, D) that was rubbed 25 times with a piece of quartz sandstone. Photographs A and B at 10x magnification; C and D at 200x magnification.

6. DISCUSSION & CONCLUSION

6.1. An alternative look at the 'expedient strike-a-light' hypothesis

In essence, the 'expedient strike-a-light' hypothesis is built upon the assertion that Neandertals regularly made simple yet versatile flake tools derived from relatively small and efficient prepared cores and flake cores that often doubled as tools. The oft considered quintessential method for fashioning these specialized cores and flakes during the Middle Palaeolithic was the Levallois technique – especially the *recurrent* form – that allowed for a more economic use of the raw material, which in turn reduced the amount energy required to carry a similar amount of 'cutting edges' (Roebroeks et al. 1988, 1997). This technology was employed (albeit rarely) at the various Neumark-Nord sites, sometimes coupled with dorsal face preparation directed across the top of the striking platform, which regularly produces edges approaching 90°. In this study, dorsal face preparation was noted on a number of flakes from Neumark-Nord 2/2. Instances of platform grinding being directed across the top of the striking platform are also alluded to in earlier studies of materials from Neumark-Nord 1. Here, the authors note this method as a possible means for producing an expedient, high-angle edge on a core prior to the removal of the flake, that once detached was suitable for use as an end scraper-like tool (Brühl 2006; Mania 1990). The utility of such a technique to possibly fashion readymade strike-a-lights – especially ones employing the friction method for producing sparks – from portable prepared cores cannot be overlooked, and aligns itself very nicely to the 'expedient strike-a-light' hypothesis.

The more regular appearance of possible strike-a-lights in the archaeological record – as suggested by the inventory of possible Palaeolithic strike-a-lights compiled by Stapert and Johansen 1999 (Table 4.1) – seems to correspond to the Magdalenian (beginning ca. 17 ka) as Mode V technology became more prevalent, and tool kits even more standardized. This apparent absence of strike-a-lights in the early Upper Palaeolithic could possibly be a relict of taphonomy; however, as several studies of the *chaîne opératoire* of lithics and bone/antler tools of the Aurignacian suggest, specific "formalized" tools for hunting vs. domestic tasks were present during this period, as well (Tartar et al. 2006). Strike-a-lights have appeared in a number of fairly regular forms: blades, especially sturdier examples like Upper Palaeolithic crested blades (Stapert and Johansen 1999); bifacially flaked implements like those found in a Neolithic grave at Schipluiden in the Netherlands (Smits and Kooijmans 2006; Van Gijn et al. 2006); very formalized, albeit rare, bifacial flint daggers recovered from Bronze Age graves in Denmark, that exhibit usewear on the butts of knives consistent with having been employed as strike-a-lights (Petersen 1993 in Stapert and Johansen 1999; Van Gijn and Niekus 2001); and unifacially flaked scraper-like pieces used in combination with firesteels during the modern era in Africa, and worldwide (Jeffreys 1955). However, to call most strike-a-lights seen in the archaeological record a 'formal' or 'standardized' tool type is a bit misleading. Rarely is there anything formal or standardized about the pieces of flint selected to function as strike-a-lights (Van Gijn et al. 2006). The real shift appears to lie in the extent of use these tools were subjected to, indicating long use-lives as integral components of later prehistoric tool kits. Therefore, it is possible the progression towards the 'one tool, one function' mentality seen through the early Upper Palaeolithic may not have caught up with strike-a-light technology until sometime during the Magdalenian. The lack of observed strike-a-lights in the archaeological record prior to this period could suggest it as a technological point of departure after which the practices outlined by the 'expedient strike-a-light' hypothesis possibly became marginalized.

Moving beyond strike-a-lights for the moment, over the past few decades there have been a number of challenges to the definition of the techno-typological variability in the Middle Palaeolithic based mainly on tools considered to be the predetermined final products of deliberate reduction sequences (Bordes 1961; Binford and Binford 1966). Instead, it is now being argued by some that these 'finished' pieces could in fact be the terminal forms of tools that have undergone multiple generations of use, retouch, changes in form and function, and upon exhaustion, were discarded (a.o. Dibble 1984, 1987; Roebroeks et al. 1997). Ultimately, it is in this final abandoned state that a tool is preserved for posterity, as are the usewear traces left by whatever happened to be the final task performed by the piece. This phenomenon is well-demonstrated by flint scatter 'Site J' (OIS 5) in the Maastricht-Belvéderé loess- and gravel pit in the southwest of the Netherlands (Roebroeks et al. 1997). An extensive refitting campaign at the site yielded very interesting evidence showing that whole reduction sequences are present at the site, from initial cortical flakes, up to the (very small) cores and the flakes that were turned into tools. A number of these tools were utilized and then extensively resharpened on site, in some instances gradually changing from one typological category into another (Figure 6.1).

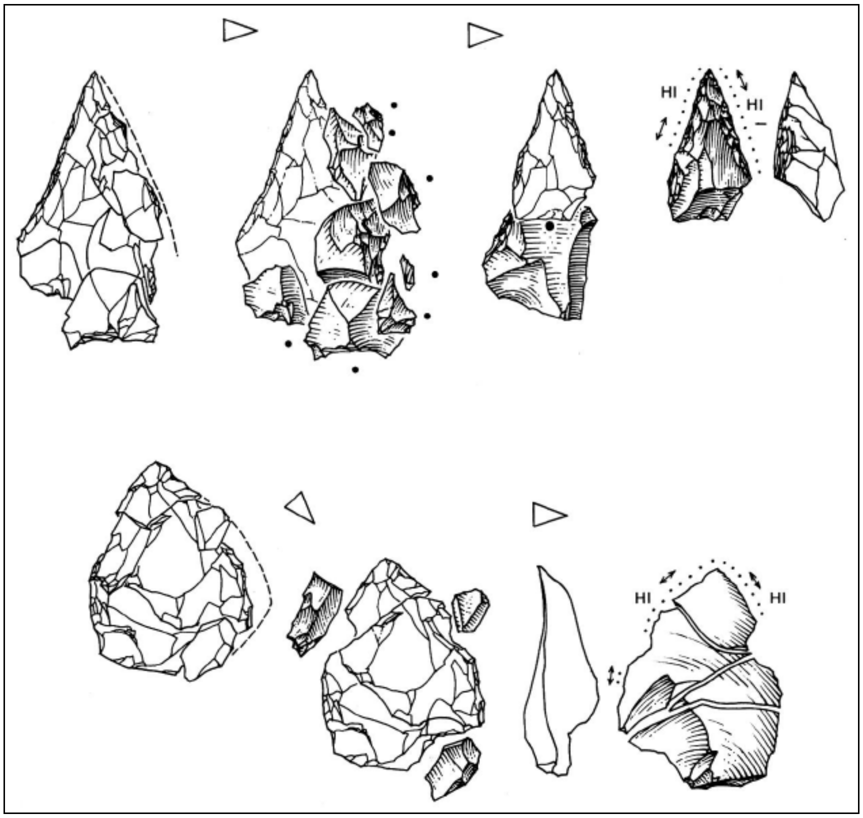

Figure 6.1. Schematic of refitting sequences showing extensive modification of two scrapers from Maastricht-Belvédère Site J: Above: Evolution of a double scraper. Below: Four flakes refit to form a double scraper, onto which three transverse sharpening flakes could be refitted. Both scrapers displayed traces of cutting hide on preserved lateral edges. After Roebroeks et al. 1997, 165.

Returning again to strike-a-lights: when a tool's sole or primary purpose is to be used as a strike-a-light, as is the case with the more recent examples discussed above, the chances of the tool being recognized as such are pretty good. However, what if the notion of a 'strike-a-light' during the Middle Palaeolithic was not as a formal tool *type* per se, but merely as one *task* among many executed by Neandertals on a daily basis using whatever multifunctional tool might have been readily available at the moment? Even prominent usewear traces resulting from a particularly difficult attempt at producing a fire could be instantly and completely erased from a tool with a few strategic flake removals. This process of use and reuse with minor retouching is likely to be extensive for individual tools in flint-sparse environments, where conservation efforts are likely to extend the use-life of a tool (Callow 1986c; Rolland and Dibble 1990). This could possibly reduce the number of larger flakes driven off a flake core to be used as expedient tools, including strike-a-lights. Nevertheless, if an individual flake exhibits traces suggestive of having come into repeated contact with sulphuric iron for the probable purpose of kindling a fire – especially if the usewear is present on the dorsal edge of the platform – it does not really matter whether the flake was created specifically for the purpose of producing a fire, or if it acquired the use traces prior to removal and its parent tool was being used as a part-time strike-a-light. Without knowing for sure how the usewear might differ between these two scenarios, it has been hypothesized that the traces would in all likelihood be quite comparable. It is for this reason that flakes of all shapes and sizes are so important within the framework of the 'expedient strike-a-light' hypothesis, even those counterintuitive to what one would expect when seeking out possible strike-a-lights. It could very well be the case that artifacts exhibiting traces consistent with those expected to be found on strike-a-lights are not necessarily the tools themselves, but instead are merely the remnants of a parent tool long since removed from the site, perhaps abandoned at another campsite awaiting discovery as a shadow of its former self when it was once used drive a spark.

6.2. Conclusion

To date, no tools possessing the requisite attributes to be considered a probable strike-a-light are known to have been recovered from a Middle Palaeolithic context, which some researchers take as a sign that Neandertals were obligate fire users and incapable of producing it themselves (Sandgathe et al. 2011a, 2011b). Conversely, no one really doubts that modern humans during the Upper Palaeolithic were capable of making fire at will despite the fact that strike-a-lights are just as absent from the first half of this period as they are from the Middle Palaeolithic. This apparent bias in favor of modern humans over Neandertals despite comparable evidence (or lack thereof) for fire production in the archaeological record is surely a relict of the concept of behavioral and cognitive 'modernity' that, for the most part, pervades the collective mindset of the archaeological and paleoanthropological community today.

The various histories of human evolution present in the modern discourse tend to read like narratives, usually progressing from an inferior being to a superior one (Landau 1991). The emergence of modern cognition is often inferred from behavioral innovations. However, it has been shown that there was great inter- and intragroup variability with regards to the emergence, disappearance, and re-emergence of various technological phenomena (e.g. art, bone technology, burials, or even fire) that significantly blurs the boundary between what or who is considered modern or archaic (d'Errico and Stringer 2011). Some authors believe this idea of behavioral modernity is the superimposition of a self-ascribed superiority complex onto the archaeological record, a practice limiting how we approach human origins, and one that should be discarded (a.o. Shea 2011). Shea goes on to argue that the plethora of means by which researchers try to identify and account for the appearance of modernity are not mutually exclusive, but instead allude to vast behavioral variability that has existed over the past 200 ka. This is surely a trend that has continued into the modern era.

This variation appears to be well represented within the archaeological record with regards to controlling, using, and producing fire, discussed earlier in Chapter 1.2. Given this variability, which is often intermingled with technological or behavioral parallels: could the 'expedient strike-a-light' hypothesis – though specifically geared towards Neandertal technological traditions in Middle Palaeolithic Europe – not also apply in principle to other contemporaneous hominin groups in Africa or Asia, where fire is present and often abundant, but the means of production conspicuously absent?

Sulphuric iron nodules as possible proxies for fire production are, strangely, more prevalent in earlier archaeological contexts than their more durable flint strike-a-light counterparts, as demonstrated by the virtual absence of these tool types until the latter half of the Upper Palaeolithic. Nodules with usewear traces suggestive of having been used as a contact material for strike-a-lights, though rare, are present in these earlier periods, while strike-a-lights are not. This is surely not solely due to the distinctive nature of sulphuric iron, which allows it to stand out in an artifact assemblage usually comprised of untold numbers of flint artifacts. More likely (and most importantly!), it is an indication that informal flint implements used as strike-a-lights (and the fragments possibly removed from some of these tools over the course of their use-lives) are not being recognized as such, but have instead been 'lost in the crowd', so to speak, amongst bucket loads of seemingly uninteresting and oft neglected debitage. It was for this reason that the 'expedient strike-a-light' hypothesis was developed. It is entirely possible that if the guidelines and methods described here in detail are employed during the study Palaeolithic artifact collections in the future, we might be surprised at how widespread this technology was in the past. This especially holds true for Neandertals in the Middle Palaeolithic. If they were indeed employing expedient strike-a-light technology to make fire for cooking their food, warming their bodies, and adding hours to their day, then this thesis provides the means for identifying this technological leap forward, further narrowing the perceived cognitive gap between our modern human ancestors and their not-so-distant hominin cousins, the Neandertals.

6.3. Suggestions for future research

All through the course of this study – during the experimentation process; analyzing the experimental and archaeological specimens; and interpreting the findings – it was exciting, and at times a bit overwhelming, to watch as the project seemed to take on a life of its own. As the research progressed, new ways of approaching the data and ideas for complimentary experiments and research projects were presenting themselves with a surprising rapidity. A number of these potential avenues for future research were touched on in the text, and could easily be built upon as independent research projects. These concepts are outlined below.

- A small practical project originally slated to be included in this thesis was to apply the findings to the lithic assemblage from the Neuwied 'volcano' sites in Germany. The assemblage is comprised of a group of exotic flint artifacts originating in the southwest of the Netherlands, over 100-km from where they were recovered. This area of Germany is lacking flint sources, which could increase the probability that one of the tools represented could exhibit usewear indicative of use as a strike-a-light. Moreover, the Middle Palaeolithic affiliation, accessibility, and small size of the collection fit nicely within the purview of this thesis, while at the same time having the potential to yield some very interesting data with minimal effort. This project is already in the planning stages, with research expected to be conducted in January 2012, followed by the possible inclusion of the findings in an article based on aspects of this thesis.
- Stemming from the assertions made in Chapter 6.1 concerning the alternative approach to the 'expedient strike-a-light' hypothesis, and utilizing similar experimental method as those applied in this study: it would be interesting to conduct a series of strike-a-light experiments applying a Levallois flake core, a small disc core, and a number of 'formal' Mousterian tool forms (e.g. various scraper types or a MAT hand-axe) to sulphuric iron to see how the resultant usewear traces compare with those observed on the experimental flake strike-a-lights from this study, both on the parent tool, as well as on flakes detached post-utilization. Effectiveness data could also be collected during the experimentation process and applied to the next research idea.
- A few different projects building onto the statistics section concerning strike-a-light effectiveness (Chapter 3.3) could be pursued by first adding a large group of

experiments conducted with more consistency, control, and duration (i.e. number of series performed) to the experimental data set used for this study to allow for more significant and reliable statistical data. Using similar methods outlined in Chapter 3.3, statistical effectiveness data could be applied to this extensive data set to assess the effectiveness of the various application techniques to any number of tool forms, sizes, edge shapes, etc. An increase in the number of series conducted could show how these various tools evolve in both shape (i.e. usewear) and effectiveness. Depending on different research questions, these data could be applied to, for example, comparing Upper Palaeolithic blade strike-a-lights to Bronze Age bifacial strike-a-lights to the Middle Palaeolithic strike-a-lights from above. These experiments should be performed in either a low-light setting, or with the aid of an infrared video camera, to ensure all strokes producing sparks are recorded – even small or low temperature sparks not readily visible, but hot enough to ignite tinder – thereby, improving the accuracy of the results.

- There are a number of site assemblages from closed systems (i.e. caves or rockshelters) that would be very interesting testing grounds for the 'expedient strike-a-light' hypothesis. Just drawing from this study, La Cotte à la Chèvre (Jersey) would be ideal since it is known a sulphuric iron nodule was recovered from a Middle Palaeolithic context there. It is made more attractive in that the cave is fairly isolated and self-contained, flint was sparse during the time of deposition, and the number of artifacts recovered is not all that high, so a comprehensive study would not be difficult. While on Jersey, it would also be a good idea to conduct a similar analysis one or a couple of the fire-bearing deposits at La Cotte de St. Brelade, which has one of the most extensive records of regular fire use by Neandertals in the Middle Palaeolithic. A couple of other sites pertinent to the early fire discussion are Peche de l'Azé IV and Roc de Marsal, France (Sandgathe et al. 2011a, 2011b). Not only do these sites have ample evidence of controlled use of fire over an extended period of time in the Middle Palaeolithic, but the recent nature of the excavations at these sites affords a level of spatial and stratigraphic control far better than that offered by earlier excavations. More to the point, the likelihood that not only the museum pieces, but *all* lithic artifacts were collected is particularly attractive, since it is amongst the debitage that the evidence for fire production by Neandertals is potentially hiding, as postulated in the 'expedient strike-a-light' hypothesis.

- A usewear project applying a number of rock and mineral types to flint as abraders/hammerstones being used for dorsal face preparation and reduction would serve the dual purpose of bolstering and diversifying the usewear comparative collection, while compiling a data set that could be applied to a dorsal face preparation usewear study of the Neumark-Nord 2/2 assemblage, which could provide insight into which rock types were preferred for knapping and platform preparation at the site, with this data compared to the manuports present on site – perhaps even being able to tie specific stones to specific scatters or areas of the site.
- Given the amount of gloss patina present on the Neumark-Nord 2/2 material, it would be interesting to perform a few experiments using simulated post-depositional processes to see how they might affect the usewear traces left on a strike-a-light. Specifically, it would be interesting to determine how much effort it might take to remove the deeply incised striations observed on the strike-a-light experiments, as well as comparing freshly utilized and post-depositional surface topographies to get an idea how these well-worn pieces might look and if any diagnostic traces or features would remain.
- Analysis of both these worn experimental pieces, as well as suspect pieces from any of the abovementioned projects, using SEM to look for sulphuric iron residue on surfaces and in recessed areas, after Stapert and Johansen 1999.
- Finally, a quick look at any and all Palaeolithic sulphuric iron nodules would be an excellent idea to see how well usewear traces preserve on this environmentally sensitive material. This would include the Drachenloch Cave (Switzerland) nodule despite the probable modern usewear on the interior surface. There may be a way to see a difference between older and younger traces. There may also be impact scars on the exterior surface of the nodule that could at least be indicative of artificial forcible opening.

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ABSTRACT

Tracing the origins of ‘modernity’ in the archaeological record has been an ongoing, and often heavily debated topic of discussion in the field of human origins for quite some time. Cognitive modernity – generally defined as the manifestation of complex language and abstract thought – is often inferred from various perceived innovations in material culture that are believed to indicate behavioral modernity (e.g. parietal art, personal adornment, bone tool technology, hafting technology, etc.). One of the more contentious facets of this debate is the subject of fire production during the time when controlled use of fire appeared to become a requisite component of the hominin technological repertoire: the Middle Palaeolithic. The mere presence of traces of fire on a site is not necessarily indicative that it was kindled by artificial means, however. To determine this, one must seek out the ‘tools of the trade’, which for this period were likely flint ‘strike-a-lights’ forcibly applied to fragments of sulphuric iron (more commonly known as marcasite or pyrite). Unfortunately, definitive examples of these tools are conspicuously absent in the archaeological record during the Middle Palaeolithic. Surprisingly, this trend appears to extend even into the early Upper Palaeolithic when modern human colonizers were pouring into Europe. In fact – contrary to the commonly held belief that modern humans were proficient fire-makers by this time – physical evidence of this technology does not appear with any regularity in the modern human tool kit until the mid- to late Upper Palaeolithic despite very regular use of fire by these peoples. One possible reason for this is simply hominids were obligate fire *users* (as opposed to *producers*) through the Middle Palaeolithic into the early Upper Palaeolithic. An alternate scenario advocated in this thesis is that both modern humans and Neandertals from the Middle Palaeolithic onward were likely able to make fire at will, but the tools they used to perform this task have not been recognized as such in the archaeological record. Drawing inspiration from the apparent ‘*ad hoc*’ nature of Middle Palaeolithic lithic technology, this thesis advocates what is called the ‘expedient strike-a-light’ hypothesis. It contends that early strike-a-lights were not formalized tools used to kindle numerous fires such as those recovered from later time periods. Instead, this study postulates strike-a-lights were either A) fashioned from simple, readymade flakes, utilized for only a short while – perhaps for just a single fire-making episode – and then discarded; or B) tools or small flake cores already on hand were expediently used as strike-a-lights. In this latter scenario, it is likely subsequent retouching of the tool would eliminate and evidence of it having been used to kindle a fire. An experimental usewear-based

approach to testing the viability of this hypothesis was employed by analyzing the traces left behind on flint flake tools forcibly applied to a nodular piece of sulphuric iron for short periods of time using a variety of techniques with the express purpose of generating sparks. The findings were then compared with archaeological specimens exhibiting seemingly similar wear patterns identified during a comprehensive, low-magnification examination of the lithic collection recovered from the Last Interglacial (~120 ka) site of Neumark-Nord 2/2 (Germany). More detailed analysis using higher magnification found that none of the segregated specimens exhibited the requisite usewear to be considered possible strike-a-lights. Nevertheless, it is the author's contention that this initial return of negative evidence in no way diminishes the value of this study. The rich and diverse body of data provided by this study, including detailed descriptions of usewear traces observed on both experimental flint strike-a-lights and the sulphuric iron contact material; supporting archaeological evidence culled together from extant literature; preliminary experimental statistical data concerning strike-a-light efficacy; and the novel methods outlined by the 'expedient strike-a-light' hypothesis, all combine to provide a solid foundation for future research seeking to shed light on the origins of man-made fire.

APPENDICES