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Reviewed Article:

A Spark of Inspiration: Experimentally Testing Manganese Dioxide as a Fire Lighting Aide

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Evidence for the production, use, and control of fire by Neanderthals in Europe ranges from the scale of ecosystems to microscopic alterations of artefacts. While there is a consensus that Neanderthals were skilled in the use of fire, there remains a dispute over whether they had mastered the ability to produce fire on demand. The unique discovery that Neanderthals

may have been utilising manganese dioxide as an additional component to their fire starting toolkits has opened the possibility that they had a novel level of understanding of inorganic materials. This paper aims to experimentally test the proposal that manganese dioxide is effective at improving the fire lighting capacity of different tinder using an actual methodology. The results suggest that it may be of use in a certain concentration, but that manganese dioxide may also possess interesting visual properties when added to flammable materials.

> “ While the actual experiments do not in themselves disprove the use of MnO_2 as a fire lighting aide, they do raise questions about the exact specifications of its use. Birch is an excellent firelighter (…) so it was surprising to see that it failed to catch a spark when combined with MnO_2, despite it lighting by itself in the same scenario.

Introduction

The debate surrounding the production, control, and use of fire by Neanderthals has diversified in recent decades, incorporating an increasing number of evidential classes. These include studies of dental calculus (Hardy *et al.*, 2012), traces of hearths (Courty *et al.*, 2012), the production of adhesives (Grünberg, 2002), fire-altered tools (Aranguren *et al.*, 2018), and use-wear analysis (Sorensen, Claud and Soressi, 2018). While few voices would now argue that Neanderthals possessed no capacities for a level of control and manipulation of fire, a point of contention still remains over their ability to create fire. At the ecosystem level the theory that human populations were able to produce fire has begun to be explored. The ‘null hypothesis’ of these studies remains that Neanderthals were unable to manufacture fire on demand, but were able to exploit naturally occurring spontaneous wildfires; this has been argued by Sandgathe *et al.*, (2011) demonstrating that long periods of occupation at Pech de l’Azé IV and Roc de Marsal in southwest France were maintained without evidence of fire use. The suggestion that Neanderthals inhabited cold European climates without the regular use of fire has been further explored and demonstrated by researchers, noting the absence of hearth features during the winter and potential adaptations to the cold weather (Daniau, d’Errico and Sánchez Goñi,, 2010; Dibble *et al.*, 2017, 2018; Sandgathe, 2017). In contrast a growing body of evidence suggests that hearth evidence during colder seasons is available (Sorensen, 2017), that polyaromatic hydrocarbon signatures can distinguish natural from anthropogenic fires in favour of Neanderthal production (Brittingham *et al.*, 2019), and that artifactual evidence supports the direct creation of fire (Sorensen, Claud and Soressi, 2018). Biochemical analysis of charcoal and plant residues such as triterpenoids infers that firewood selection was occurring and that certain non-local wood species were being brought to sites for the purpose of burning (Vidal-Matutano, Henry and Théry-Parisot, 2017; Leierer *et al.*, 2019). Proxies for the use of fire have also included the presence of cooked food trapped within Neanderthal dental calculus (Henry, Brooks and Piperno, 2011; Hardy *et al.*, 2012) and the alteration of wooden tools by intense heating (Aranguren *et al.*, 2018). One class of artefact in particular, birch tar adhesive, has been the subject of intense debate surrounding how technically and cognitively demanding is the process of distillation that Neanderthals employed (Roebroeks and Villa, 2011; Kozowyk *et al.*, 2017; Schenck and Groom, 2018). The experimental evidence was, until recently, fairly clear that tar distillation was a challenging enough process that Neanderthals would have needed extensive control and understanding of temperature, firewood, and weather conditions to be able to distill tar efficiently (Groom, Schenck and Pedersen, 2015; Kozowyk and Poulis, 2019). However, experiments conducted in the last few years have challenged this view and it may be that birch tar distillation is not as complex a process as previously believed (Schmidt *et al.*, 2019, 2020). A final piece of artifactual evidence under recent discussion is the discovery that Mousterian hand axes were possibly being employed as 'strike-a-lights', meaning that Neanderthals could have been striking pyrite nodules against the edges of flint hand axes to generate small sparks capable of lighting carefully prepared tinder (Sorensen, Claud and Soressi, 2018). The evidence for this comes from microscopic use-wear traces which purportedly show markings which concur with experimental wear traces of pyrite or marcasite rocks being repeatedly struck against the biface edge. This would seem to be a compelling argument for the use of specialised fire-lighting equipment by Neanderthal populations, but the occurrence of both pyrite/marcasite rocks and bifaces show no correlated association with hearth features that one would expect to see if they were being used to make fire regularly (Dibble *et al.*, 2018).

One addition to the potential toolkit of fire-lighting equipment has been suggested by the discovery of manganese dioxide (MnO_2) pieces at the site of Pech de l'Azé IV that revealed a number of surface modifications congruent with scraping or grinding (Heyes *et al.*, 2016). MnO_2 was previously suggested to have been used as a chemical powder for body or pictorial decoration; the lines of evidence for which were later published by Martí *et al.* (2019). What Heyes *et al.* (2016) proposed was that Neanderthals were selecting, grinding, and curating MnO_2 rich rocks in order to use them as aides for fire lighting. This was demonstrated through laboratory experimentation where ground MnO_2 was added to beech wood turnings and either heated from below or lit with sparks from a fire-steel. They concluded that the addition of MnO_2 reduces the ignition temperature of tinder by 100℃, something valuable to Neanderthals living in extremely cold conditions. The remarkable nature of this discovery was commented on by the authors who stated that this technique is unknown within the ethnographic literature and also would not fit with our understanding of the trial and error nature of prehistoric technological development. If it is true that Neanderthals were using MnO_2 to help light fires, it would appear to be a unique and sophisticated discovery on their part. The proposed mechanism by Heyes *et al.* (2016) is that MnO_2 begins to decompose at a low temperature, prompted by the release of wood gases as the tinder heats up. The decomposition produces oxygen which in turn enhances the combustion of the remaining tinder and small combustibles. The overall effect is to make the ignition process easier by generating additional oxygen at a micro level, not dissimilar to how blowing on a small fire can enhance the combustion. The sequence of events would appear thus:

1. A spark is generated
2. The prepared tinder/MnO_2 mixture receives the spark
3. The tinder begins to burn
4. The smoke and gases decompose the MnO_2, yielding additional oxygen
5. The oxygen is used to increase the combustion of the remaining tinder

This would imply that the MnO_2 alone would be incapable of receiving a spark and that its function is limited to assisting already lit tinder. The use of the MnO_2 powder must have been at a very small scale and may be required at a particular ratio or in combination with certain tinder materials. The laboratory experiments of Heyes *et al.* (2016) would seem to support this model of small-scale amounts being carefully applied to prepared tinder which are themselves capable of being lit with a spark. What is needed to validate this model is an actual experimental protocol which does not use heat coming from below the tinder but either from a small previously lit tinder source or from a hot spark in an outdoor setting.

Experimental Programme

In order to answer some of the questions that arose from a close examination of Heyes *et al.* (2016) the following experimental questions and programme were devised:

1. What effectiveness does MnO_2 have as a source of ignition within a tinder bundle?
2. What effectiveness does MnO_2 have as an aide to fire lighting?
3. Does the type of tinder make a difference when considering how effective MnO_2 is in either capacity?
4. How much MnO_2 should be added to be effective?

Here effectiveness is defined as making a noticeable difference to the act of fire lighting as compared to a tinder set up that contains no MnO_2. In addition to these considerations, the decision was made to design the experiments to be as realistic as possible, in order to complement the laboratory study. This would potentially validate or disagree with the theory based on a more imprecise and realistic fire lighting scenario. Measurements of tinder and MnO_2 were done by approximation and ratio rather than by a weighing scale. This actualistic approach necessarily lost elements of control, such as precision in measurement, but this improves the likelihood that the experiment was conducted under more realistic circumstances. The experiments were conducted outdoors at the York Experimental Archaeology Research Centre (YEAR) and tinder used were gathered and processed on site. The MnO_2 was purchased from a commercial supplier (minerals-water.co.uk) as a finely ground powder with no additional compounds present. A ferrocerium fire starting rod was used for some of the experiments. These can reach temperatures of 3000℃ which acted as a criteria of exclusion; since flint/pyrite sparks are much lower in temperature then it can be safely assumed that if the ferrocerium rod failed to light the tinder, then a pyrite spark would also fail. In the interests of environmental safety, the tinder was contained within a tin foil lined container which prevented the MnO_2 from entering the YEAR centre and contaminating or endangering local wildlife.

Methods

Three types of tinder were tested with different ratios of MnO_2: birch bark strips, ground birch bark and powdered charcoal. The charcoal was produced from burning and gathering a mixture of horse chestnut (*Aesculus hippocastanum*), elder (*Sambucus nigra*), and birch (*Betula pendula*). This tinder was chosen and is well documented in the archaeological record of the Middle Palaeolithic as well as being examples of both poor (charcoal) and excellent (birch bark) tinder materials. The experimental protocols were divided into two, the first being to test the ignition capacity of MnO_2 and the second to test the assistance of MnO_2 in helping a lit tinder to combust.

The ignition experiments were conducted using small amounts of tinder and MnO_2 powder, which was transferred from the bottle to the fire container using a spoon. An approximate amount was added to the tinder to make up the desired ratio. The amounts added to the birch were less than the charcoal since birch is a better tinder in its natural state. The ferrocerium rod was then used ten times to produce a spark (See Figures 1 and 2). Between each tinder type the tin foil was changed.

The combustion experiments were designed in a similar way, except that a lit match was introduced to the tinder instead of a spark. Birch strips were also used alongside ground birch bark. The tests were repeated three times with the match.

Results

The results of the two experimental procedures are reported in Tables 1 and 2. The ignition experiment demonstrated that MnO_2 has little efficacy as a source of ignition and failed to light, either by itself or in combination with the different tinder. The birch lit by itself but failed to do so with the MnO_2 in several different ratios. This would suggest that the inclusion of MnO_2 actually hindered the lighting of the tinder. The combustion experiment showed a similar level of efficacy with the charcoal, but a few different results for the birch tinder. At a ratio level of 10:1 birch:MnO_2, the birch did light, but in an 8:1 ratio the birch lit, died out, and then reignited several minutes later. Also observed was a thick blue smoke from the 8:1 ratio fire (See Figure 3) which was qualitatively different from the previous attempts. The smoke lasted for some time while the birch reignited.

Material	Action	Result
MnO2	10 strikes FC Rod	Didn't catch

Powdered Birch bark + MnO2 1:1	10 strikes FC Rod	Didn't catch
Powdered Birch bark + MnO2 2:1	10 strikes FC Rod	Didn't catch
Powdered Birch bark	10 strikes FC Rod	Caught a spark - flamed
Charcoal	10 strikes FC Rod	Didn't catch
Charcoal + MnO2 4:1	10 strikes FC Rod	Didn't catch
Charcoal + MnO2 2:1	10 strikes FC Rod	Didn't catch

TABLE 1. THE RESULTS FROM THE IGNITION EXPERIMENT SHOWING THE DIFFERENT TINDERS AGAINST THE USE OF A FERROCERIUM ROD (FC). ONLY THE BIRCH WITHOUT THE MNO2 MANAGED TO CATCH A SPARK. TABLE PRODUCED BY AUTHOR

Material	**Action**	**Result**
Charcoal + MnO2 4:1	Lit match	Didn't catch
Charcoal + MnO2 2:1	Lit match	Didn't catch
Birch bark strips + ground	Lit match	Slow combustion
Birch bark strips + ground + MnO2 10:1	Lit match	Combustion
Birch bark strips + ground + MnO2 8:1	Lit match	Combustion plus re-ignition

TABLE 2. THE RESULTS FROM THE COMBUSTION EXPERIMENTS. THE BIRCH BARK LIT WITH THE MATCH AND AT AN 8:1 CONCENTRATION RE-IGNITED. TABLE PRODUCED BY AUTHOR

Discussion

The results of the experiment failed to validate the model put forward by Hayes *et al* (2016). While the actual experiments do not in themselves disprove the use of MnO_2 as a fire lighting aide, they do raise questions about the exact specifications of its use. Birch is an excellent firelighter, due to the concentrations of triterpenoids within the bark, so it was surprising to see that it failed to catch a spark when combined with MnO_2, despite it lighting by itself in the same scenario. This indicates that there may be a critical threshold for the efficacy of MnO_2 within an amount of tinder, above which it hinders the reception of a spark. This may simply be due to the competition for surface area. The use of the ferrocerium rod also rules out the use of colder pyrite sparks as the mechanism of ignition. In contrast the reignition of the birch tinder in the second experiment does support the theory that heated MnO_2 generates additional oxygen which might slowly collect in pockets within the tinder, allowing for a cooler temperature of pyrolysis to rapidly increase and reignite. The smoke produced from the final round of birch tinder is an interesting phenomenal addition to any interpretation of MnO_2 use with fire, since it suggests that adding it may change the quality and colour of the smoke. This could be done deliberately in order to create a special or unusual effect, perhaps as part of a wider toolkit of artwork and body modification.

Overall then these results demonstrate the need for further experimental research into the potential uses of inorganic materials within Neanderthal pyro-technology. The sheer uniqueness of using MnO_2 as a fire aide means that we potentially know far less about the subtle and skilled uses of it than we do for more well characterised materials such as tinder fungus or flint/pyrite tool kits (Cave-Browne, 1992; Piqué *et al.*, 2020). It may be that other tinder materials perform better with the addition of MnO_2 and that more experimental data will validate this unusual and specialised form of fire production. In the wider context of Neanderthal pyro-technology, the use of MnO_2 for fire production still needs to be researched, especially in light of the fact that at Pech de L'Azė IV there is an inverse correlation between the deposition of MnO_2 pieces and evidence of fire (Dibble *et al.*, 2018). Integrating the wider datasets of Neanderthal hearth sites with the micro data of use-wear analysis and bioarchaeology is a major challenge in understanding exactly how and for what purpose Neanderthals were using fire.

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Keywords fire
methods & techniques

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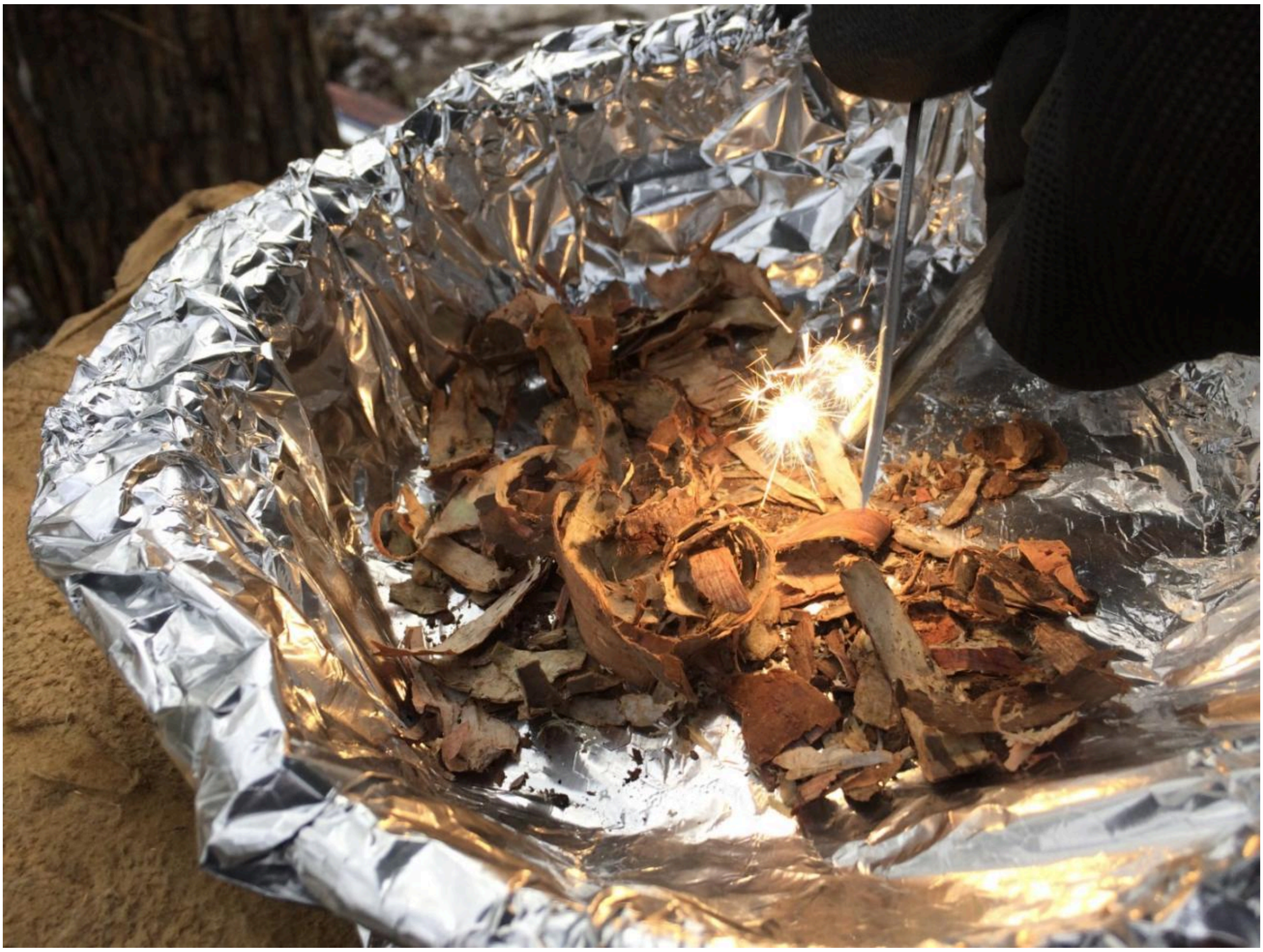

FIG 1. TESTING BIRCH BARK STRIPS. PHOTO BY ANDY LANGLEY

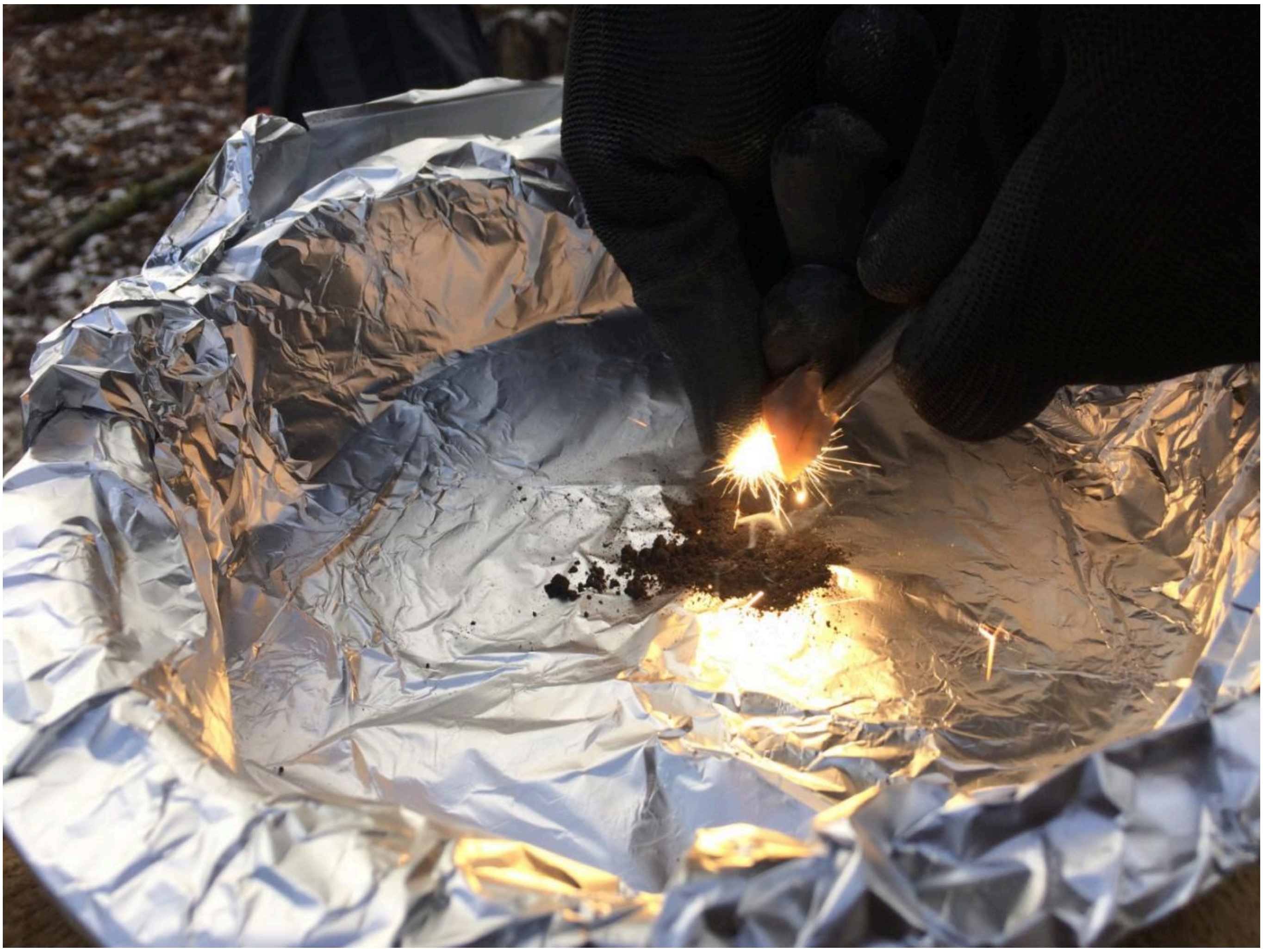
FIG 2. TESTING CHARCOAL AND MNO2. PHOTO BY ANDY LANGLEY

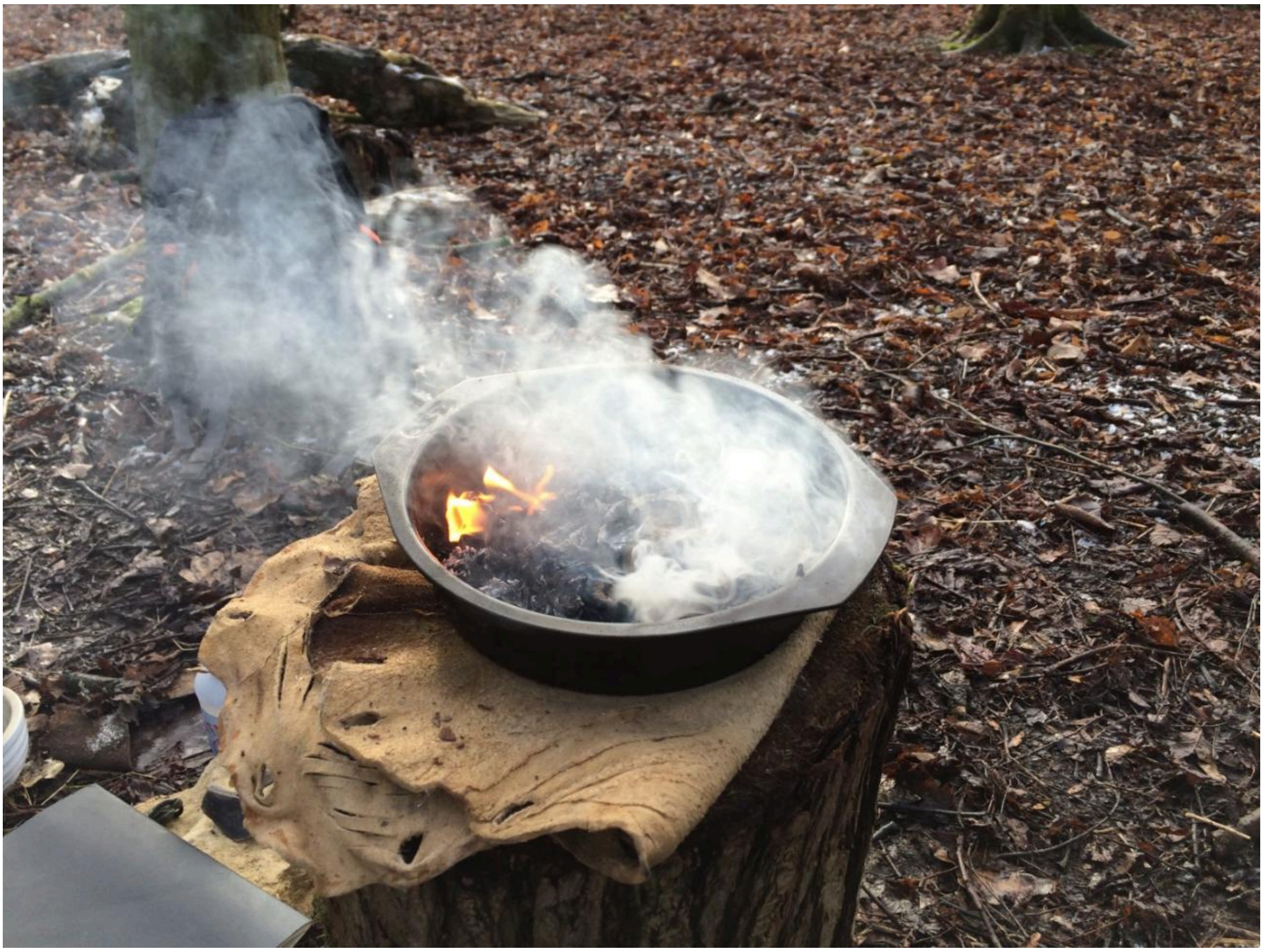

FIG 3. THE BIRCH BARK SHOWING RE-IGNITION AND SMOKE. PHOTO BY ANDY LANGLEY