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Heat Treatment of Flint at the Late Neanderthal Site Sesselfelsgrotte (Germany)

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Abstract: We examined lithic artifacts from the late Neanderthal site Sesselfelsgrotte (Bavaria, Germany) in order to evaluate the possibility of fire use and intentional flint heat treatment performed by late Neanderthals. We analyzed 1113 flint pieces from the G-layer complex (~60 to 45 kya; Micoquian) and 946 from the lower-layer complex (~115 to 70 kya; Mousterian). Based on macroscopic traits associated with the exposure of flint to heat and fire, we assigned artifacts to one of three groups: burnt, unburnt, and possibly intentionally heated. Our results show that while both complexes demonstrate the clear presence of fire, fire is more common in the younger G-layer complex. Moreover, possibly intentionally heated pieces are significantly more frequent in the G-layer complex, especially among the tools and specifically among side scrapers, suggesting a link between heat treatment and the production of these tools, most probably due to their functional and cultural significance. We therefore suggest that the flint in the G-layer complex of Sesselfelsgrotte underwent intentional heat treatment. The proportions of burnt flint artifacts in both complexes suggest an intensification in fire use at the site over time, while the appearance of possibly intentionally heated artifacts in the G-layer complex suggests the development of this advanced pyrotechnology by Neanderthals sometime between these two timeframes. Our results are supported by sedimentological and faunal data. We view these results as further indication of the advanced cognitive and technological capabilities of Neanderthals, which did not fall short of those of early modern humans.

Keywords: Neanderthals; fire use; heat treatment; lithics; Bavaria; Middle Paleolithic

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1. Introduction

Both the nature and the scope of fire use by Neanderthals in Europe are often debated, as some scholars advocate limited use, without the capability to produce fire at will and with full reliance on natural fire occurrences (e.g., [1–4]), while others suggest advanced use, including fire-production knowledge and the application of pyrotechnologies (e.g., [5–8]). Of special interest in this debate is the necessity, or lack thereof, of control over fire in northern latitudes, where harsher conditions occurred. While indeed considered important for coping with cold climatic conditions, the earliest sites in such regions currently lack evidence of fire use (e.g., [9,10]), with the first evidence of fire use dated to 400 kya onwards [8].

On the other hand, there are suggestions for the anthropogenic use of fire far earlier than this date in Africa. In Wonderwerk Cave (South Africa), for example, it was suggested, based on the identification of an ash layer and charred bones, that early humans were using fire for cooking already 1 mya [11]. There are other suggestions of fire evidence in Africa concerning Chesowanja [12] and Koobi Fora at site FxJj 20 [13,14], both of which are in

Kenya, dated to ~1.5–1.6 mya. In Swartkrans (South Africa), fire use by early humans is implied based on the presence of burnt bones dated to ~1.0–0.6 mya [15,16]. Yet, none of these cases provide direct evidence for the involvement of humans in the production or exploitation of these fires [8].

Outside Africa, early cases of human use of fire are known from Gesher Benot Ya'aqov (Israel) [17–19] and Cueva Negra (Spain) [20], both dated to ~780 kya. However, both cases are followed by a long time gap in which no fire use is currently known until around 400 kya, with the identification of fire at Qesem Cave (Israel) [21] in the Levant and Beeches Pit (England) [22] in Europe. Starting from this point, fire becomes more evident in the European and Levantine archaeological records [8,23].

Roebroeks and Villa [8] argue that Neanderthals had advanced fire-related capabilities, including the ability to produce fire at will, preserve it and transport it. Moreover, several studies demonstrate the application of pyrotechnology by Neanderthals for the production of composite tools (e.g., [5,6]), implying advanced technological knowledge among Neanderthals (however, see [24]). Based on this, Roebroeks and Villa [8] suggest that the nature of fire use among Neanderthals resembles that of Upper Paleolithic societies.

Contrary to this, Sandgathe et al. [3,4] suggest, based on the analysis of the stratigraphy from two Middle Paleolithic sites in France, Pech de l'Azé IV and Roc de Marsal, that well-preserved hearths can be found during periods of warm climatic conditions. Conversely, during periods of cold climatic conditions, evidence of fire becomes rare. They further argue that, while late Middle Paleolithic Neanderthals were indeed capable of using fire, at least some Neanderthals were unable to produce fire and therefore relied exclusively on natural fire occurrences. The link between warm climatic periods and fire use among Neanderthal populations in Europe is further advocated by Abdolahzadeh et al. [1] based on data collected from the Middle Paleolithic sites Abric Romani (Spain), Abri du Maras (southeast France), Kulna (Czech Republic) and Sesselfelsgrotte (Germany).

To further contribute to this ongoing debate, we present the results of a lithic analysis classifying flint artifacts from the late Neanderthal site Sesselfelsgrotte (Germany). We analyze flint artifacts found in the lower-layer complex and G-layer complex of the site, evaluating their possible exposure to fire via examining for macroscopic traits associated with exposure of flint to fire (see details below). Based on these traits, we divide the artifacts into three groups: unburnt, burnt (i.e., demonstrating unmonitored exposure to fire), and possibly intentionally heated (i.e., showing alterations which are associated with intentional heat treatment, but not alterations which are associated with thermal damage). The collected data are used to establish the frequency of fire in both complexes as well as the possible application of intentional heat treatment of flint. We then discuss the implications of these results for the understanding of fire use by late Neanderthals and their cognitive and technological capabilities in comparison with early modern humans.

1.1. The Site of Sesselfelsgrotte

Sesselfelsgrotte (Figure 1) is a Paleolithic rock shelter located in the valley of the lower Altmühl River (Bavaria), a tributary of the Danube, in southwest Germany. It was excavated by Gisela Freund from 1964 to 1977 and in 1981 [25]. About seven meters of sedimentary deposits were excavated [25]. The layers are mainly composed of limestone debris from the roof of the shelter and from the slope above the cave. The small rock shelter yielded a unique sequence of 22 Middle Paleolithic and several Upper Paleolithic occupations [25,26]. The lower-layer complex was occupied during MIS 5c to MIS 5a under moderate climatic conditions and yielded eight Mousterian assemblages, while the G-layer complex was deposited under the cool climatic conditions of MIS 3. The two stratigraphic complexes are separated by archaeologically sterile layers correlating to the cold and arid period of MIS 4. The onset of cold climatic conditions is indicated by the occurrence of mammoths in the uppermost part of the lower-layer complex (Layer M1 and M2: [27], close to the interface with the first glacial maximum of the Weichselian glaciation (MIS 4).

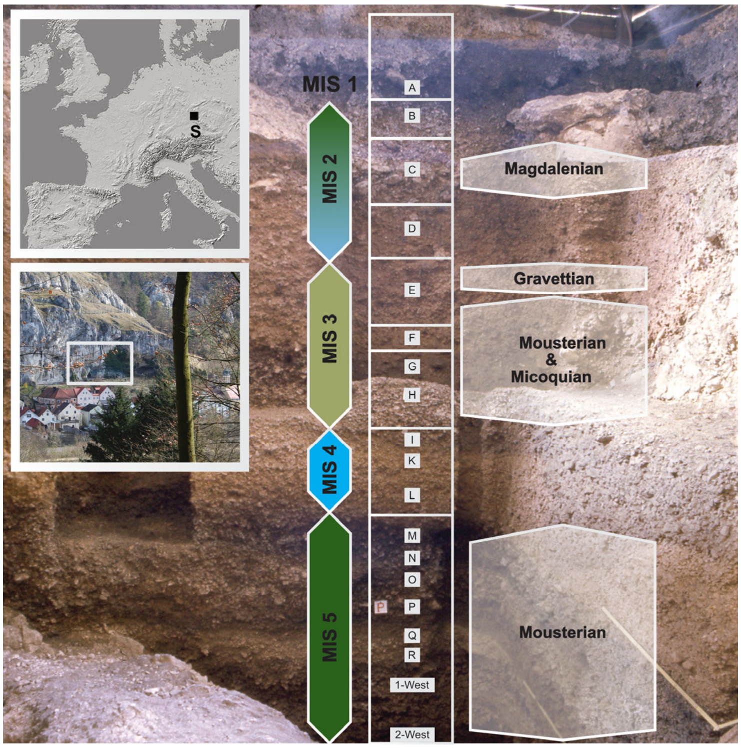

Figure 1. Location of the site (insert on the top left), view from South to the Jurassic limestone formation of the Sesselfelsgrotte with Sesselfelsgrotte in the center (white square in the insert on the left), and view into the section (with labels indicating geological layers of the Eastern profile) (photo: FAU Erlangen–Nürnberg).

The upper G-layer complex (which includes layers I, H, G5, G4, G4a, G3, G2 and G1) consists of a series of archaeological horizons containing approximately 85,000 lithic artifacts along with abundant faunal remains, consisting mainly of mammoth, reindeer, and horse remains [26]. The identification of the layers, including those which have yielded archaeological materials, was based on macroscopic sedimentological attributes observed during the excavations, such as the size and angularity of gelifraction debris, as well as the grain size of the sediment matrix and its color. The Label "G4a" indicates that, based on the criteria listed below, this layer was recognized in newly excavated parts of the site after the identification of G5. The archaeological finds are assigned to 13 assemblages (G-A01 to G-A13), all of which are classified as Mousterian or Micoquian [28,29]. Radiocarbon dating of charcoal and bone has yielded conventional (i.e., uncalibrated) ages of between ~48 ka BP (unit G4a/5) and ~40 ka BP (unit G2), with most of the Micoquian assemblages dating to 48–47 ka BP [29] (Figure 2). The chronological position of the G-layer complex being in an early part of MIS 3 is supported by TL dating on burnt flints, which gave a mean TL age (N = 4) of 56.0 ± 4.7 ka [29,30]. Several archaeological horizons of the G-layer complex represent living floors (i.e., layers G4 and G2), as indicated by evident features such as fireplaces [26].

The lower-layer complex consists of eight archaeological levels (3-West to M) and has yielded a total of 10,000 lithic artifacts (assemblages A01 to A08), all belonging to Mousterian production [31]. A mean TL age (N = 7) of 73.2 ± 11.7 ka for layer M [30] supports the assignment of the lower-layer complex to MIS 5. This chronological model is in accordance with a correlation of the overlying, archaeologically sterile deposits of units L and K, which separate the Lower-Levels complex from the G-layer complex, with MIS 4 (~71 ka) [29].

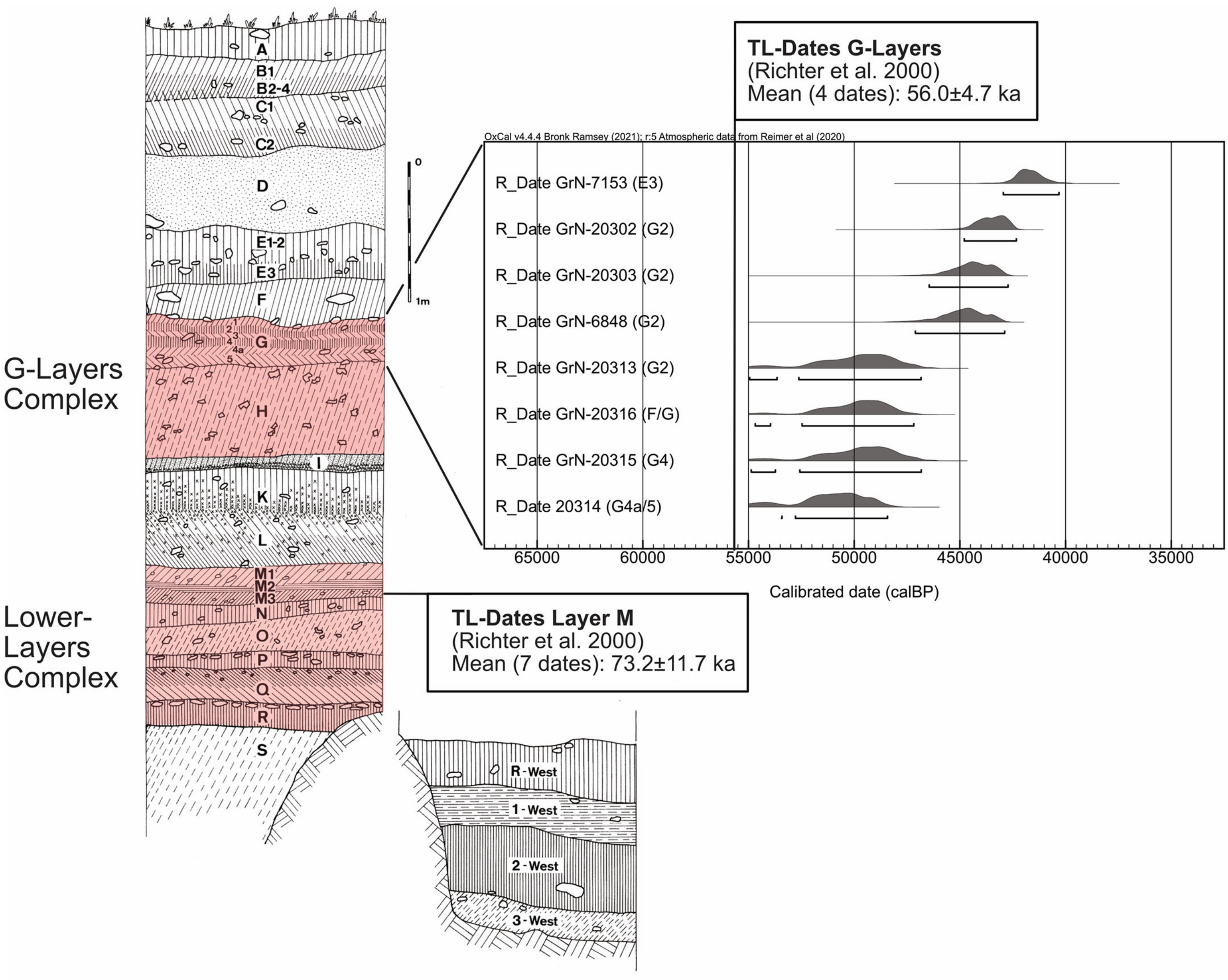

Figure 2. Absolute dates for the lower-layer complex and G-layer complex (highlighted in red) of Sesselfelsgrotte. AMS radiocarbon dates without contaminated outliers from the slope after the Richter [29] and calibrated with OxCal v4.4. Thermoluminescence (TL) dates as mean from several dates after Richter et al. [30].

Human remains found at the site include the remains of immature Neanderthal individuals [32,33]. These include two deciduous teeth from Layers G2 and M2, which seem to correspond to 12-year-old children, and 12 limb bones. Additionally, we found the ribs of a fetus or a neonate (Sesselfelsgrotte 1) in Layer G5. It has been proposed that the remains of the fetus/neonate may reflect an intentional burial [33].

1.2. On the Integrity of the Stratigraphic Units

The entire Sesselfelsgrotte sequence is mainly composed of local sediments and mostly includes limestone debris from the slope above the shelter and from the roof of the shelter. Occasionally, sedimentation was accompanied by humic and anthropogenic components. There was one large exception, and we discovered exogenous loess deposited during the last glacial maximum. The whole sequence shows a steady accumulation of sediments on top of layer E, with only one dramatic erosion event that has been recognized [25,34].

In the lower-layer complex, traces of human activity have been found in spots within sediment lenses limited to parts of the available horizontal surface [31]. Moreover, lithic artefacts, charcoal, and faunal remains, objects corresponding to one and the same human occupation stage, span some vertical distance, thus bracketing several sedimentary units [27,35,36]. With sedimentary units widely undisturbed, such observations indicate natural sedimentation, occurring very quickly, in parallel with human occupation. Human activities were limited to the exterior part of the present shelter, before the erosion of the previous dripline diminished the interior of the shelter to its present size [31]. The lower-layer complex consequently became sealed by more than half a meter of angular limestone debris, completely devoid of any traces of human activity, and rich in small animal bones, indicating that the cave was inhabited by owls [37–39]. It is currently correlated with the first maximum of the last glacial period (MIS 4) [29,30]. The debris layers, called L and K layers, horizontally cover the whole surface of the shelter, with no visible interruption on top of the lower-layer complex, and are continuously covered by the G-layer complex [28].

The artifact-bearing G-layer complex is clearly marked by two darkly colored horizons that cover the entire surface of the shelter. These are called the G4 layer and the G2 layer [25]. Much of those sediments display anthropogenic impact and show, or are altered by, traces of fire (cf. [35]). At the time of G4 and G2 accumulation, the sedimentation rate was low, thus allowing for the preservation of such occupation surfaces [28]. Layers G4 and G2 accordingly served the archaeologists as two darkish marker horizons, supporting the further subdivision of the G-layer complex. The sediments of the G-layer complex comprise the H and G5 layers; the G4a layer, limited to the front of the shelter; the G4 marker layer; the G3 layer, which is also limited to the front of the shelter; the G2 marker layer; and the G1 layer on top [28]. Layer G1 consists of light-colored limestone debris quite similar to the covering F and E layers [25]. Major events of erosion occurred after the deposition of layer E, the surface of which displays various signs of evacuation and the disturbance of sediments [34]. Sediments must have been washed out at this time, and eventually a deep erosional channel was left behind, cutting into the C/D line of square meters. It is difficult to estimate the date(s) and the duration of the erosional event(s). They postdate Layer E3 with the latest Middle Paleolithic occupation of the site (first half of MIS 3), and they predate the overlying loess deposits, indicating the second glacial maximum of the Weichselian (MIS 2). In absolute dates, this would comprise a time span of 20–30 ka, somewhere between 50–45 ka BP and 25–20 ka BP (cf. [29,34]). Because some Gravettian artefacts were found in the upper part of Layer E, the most serious erosional event must have occurred afterwards, perhaps roughly around 25 ka BP. The nearby "Abri-1" site, a large cavity only some meters east of Sesselfelsgrotte, yielded one human occupation, exclusively of Gravettian age [40], which was possibly connected to the Gravettian traces from Sesselfelsgrotte [34].

The subsequent deposition of loess ended in Layer D, which is completely void of any traces of human presence, much like the K/L layers. Layer D has thus been correlated with the 2nd glacial maximum (26–18 ka BP). The archaeological record resumed afterward with six occupations attributed to the Upper and Late Paleolithic, all of them connected by an uninterrupted sequence of deposits [41].

1.3. Regarding the Presence/Absence of Fire and the Climatic Conditions

As mentioned above, a link has been proposed between the frequency of evidence of fire in Neanderthal sites in Europe and the climatic conditions at the time of occupation (e.g., [1,3]). According to these suggestions, during warm climate periods, evidence of fire is more abundant than in layers associated with cold climates, at least in some Neanderthal sites.

According to Henry [42], such patterns may imply that the costs of fire maintenance exceeded the benefits of fire use and that therefore Neanderthals found other solutions to cope with the cold conditions. Sandgathe et al. [3,4], on the other hand, argue that Neanderthals, at least those of southwestern France, were incapable of producing fire, and instead relied entirely on the gathering of fire from natural fire occurrences. They propose this based on the possible higher frequency of natural fire events caused by lightning strikes during warmer and more temperate periods compared to colder and drier periods [2].

Sorensen [43] suggests, based on marine microcharcoal data from the Bay of Biscay (southwest France), that the frequency of natural fire events did not decline significantly during glacial periods compared to interglacial periods. Moreover, Sorensen et al. [44,45] argue, based on use–wear analyses of material from multiple Middle Paleolithic sites throughout Europe, as well as from experimental data, that Neanderthals were in fact capable of producing fire independently, as indicated by the use of pyrite in conjunction with flint, a procedure known to assist in the ignition of fire.

Given the inconsistency of the evidence for fire, Sandgathe et al. [4] and Dibble et al. [2,46,47] propose that the rarity of fire use among Neanderthals during cold climate periods may reflect a regional pattern relevant specifically to southwest France, rather than a pattern true to all Neanderthals, and suggest that Neanderthals were not "obligate fire users" [2]. On the other hand, Abdolahzadeh et al. [1], studying several Middle Paleolithic sites that span a territory of 900 km in latitude and over 1600 km in longitude, including Sesselfelsgrotte, advocate for a broader phenomenon, further stressing a possible link between the warm periods and Neanderthal fire use, a link that extends, in their view, beyond the region of southwestern France.

However, it is our view that the diachronic analysis of fire technology in general, and a comparison that aims at incorporating climatic and environmental conditions, as presented, for example, in Abdolahzadeh et al. [1], is difficult in several aspects. One problem lies in the need for long stratigraphic sequences, which often come from larger caves or rock shelters, such as Kulna Cave [48], Abri Pataud [49] or Combe Grenal [50]. In large Paleolithic sites that originate from processes of the dissolution of rock formations via gelifraction and/or karstic phenomena, long stratigraphic sequences are often complex and show local differences that make intra-site correlations difficult. In addition, the often-large amounts of excavated materials make the post-excavation analysis of the sedimentological record and the environmental data (such as large and small mammal fauna, pollen etc.) complex. However, sources of data other than the large mammal fauna, which often consist of species insensible to climatic changes, are needed for inferring causation rather than correlation between the archaeological and the environmental data.

Despite its long stratigraphical sequence, Sesselfelsgrotte offers an advantageous context for diachronic comparisons: (1) the site is a small rock shelter, measuring only ~40 square meters behind the dripline; (2) the complete site is in the daylight zone; (3) the steep limestone surrounding walls is almost devoid of large vegetation (affecting the analysis of malacofauna and small mammal fauna: see [37,51]), preventing the accumulation of guano or rotten vegetation and, thus, protecting the site from natural fires; and (4) the excavated area includes large parts of the potential occupation area in front of the dripline, minimizing the possibility of leaving parts used by prehistoric humans unexcavated. In addition, the stratigraphic sequence is highly resolved, with many layers being thinner than 10 cm. This includes several "living floors" excavated in natural layers wherever possible. After almost 40 years of research since the end of the last excavation campaign, the sequence has been integrated into a robust chronological model based on radiocarbon dates, TL dates and, equally important, environmental studies based on large mammal fauna [27], small mammal fauna [37], avifauna [39], and the analysis of pollen and the macro remains of plants [35].

2. Materials and Methods

Identifying early fire use is not an easy task due to the ephemeral nature of early fire remains [52] and the absence of constructed fire features [53]. Therefore, flint, a durable and resistant material with high visibility, is often used as an alternative substance for the identification and quantification of early fire presence and its frequency. The study presented here includes 1,113 flint artifacts from the G-layer complex of Sesselfelsgrotte dating to MIS 3, and 946 from the lower-layer complex dating to MIS 5, thus forming two large, statistically valid samples from two chronologically different contexts. The studied artifacts were selected by arbitrarily taking boxes of material from the storage at the

Erlangen campus of Friedrich-Alexander Universität Erlangen–Nürnberg. The storage of the lithic material from Sesselfelsgrotte is organized by assemblages (lower-layer complex assemblages U-A01 to U-A08, G-layer complex assemblages G-A01 to G-A13) and, within each assemblage, by raw material units stored in mini-grip bags. Each raw material unit consists of all artifacts larger than 3 cm of the respective petrographic unit without typological or technological differentiation. The sampling method applied in this study is therefore two-stage cluster sampling in which given subgroups (boxes with raw material units from different assemblages) are again sampled at random (artifacts are taken from raw material units without data concerning typology or technology).

As a result of this procedure, we obtained one sample from the G-layer complex with artifacts from Layer G2, which mainly belonged to assemblage G-A06. This sample correlates with the cold climatic conditions of MIS 3. Because of the much lower overall number of finds, the second sample from the lower-layer complex consists of artifacts from several assemblages, representing the moderate climatic conditions of MIS 5a to 5d.

As the material was not organized or labeled using typo-technological categories, each analyzed artifact was first classified into a typo-technological category (Table 1) and, whenever relevant, to a sub-category. Each artifact was then macroscopically evaluated using a yes/no indication according to the presence or absence of alterations associated with exposure of flint to fire: potlids, crazing, cracks, fractures, color change towards red/purple hues, gloss, and an oily texture. All parameters were evaluated via macroscopic examination, supported using a handheld lens. The first four parameters (i.e., potlids, crazing, cracks, fractures) represent thermal damage, which reduces the flint's knapping quality, and are therefore considered undesirable for the production of artifacts. The three remaining traits (i.e., color change, gloss, oily texture) are often associated with intentional lithic heat treatment (e.g., [54–61]). Based on this, the flint artifacts from both complexes were assigned to one of three groups: unburnt, burnt, and possibly intentionally heat-treated. For this division, we used the following logic: if an artifact presented one or more of the three latter traits (color change, gloss, oily texture), without any of the former four traits (potlids, crazing, cracks, fractures), it was considered as possibly being intentionally heat-treated; otherwise, if it had one or more of the four former traits, which are associated with fire damage, it was considered burnt; and finally, if it did not present any of the seven traits, it was considered unburnt. Additionally, an indication of patina differences (gloss contrast) between different surfaces was documented for each analyzed piece. This division allows for some artifacts that may belong to the possibly intentionally h heat-treated group to be "lost" into the other two groups, giving a minimal inclusion that keeps the findings on the "safe side".

Table 1. Division of the G-layer complex and lower-layer complex sequences by the presence of burnt, possibly intentionally heated, and unburnt flint pieces.

	Lower-Layer Complex	G-Layer Complex	Lower-Layer Complex	G-Layer Complex
Burnt	285	296	30.1%	26.6%
Possibly intentionally heated	8	127	0.8%	11.4%
Total of Artifacts Altered by fire	293	423	30.9%	38.0%
Unburnt	653	690	69.0%	62.0%
Grand Total	946	1113	100%	100%

The analysis of the data is performed by comparing the two complexes and by further looking at the typo-technological categories of the analyzed artifacts, pointing to the frequency of burnt artifacts and possibly intentionally heated artifacts within each category. The statistical significance of differences between the groups compared was tested using a Chi-squared χ^2 test.

The macroscopic classification of burnt/unburnt lithic artifacts has been used in previous studies as a reliable proxy for the identification and quantification of fire's presence and spatial distribution (e.g., [1–3,18,46,47,53,62–65]). Thermal alterations of silicious rocks are known to leave clearly visible and identifiable macroscopic changes, including color change, gloss, an oily texture, potlids, cracks, and crazing [1,66–69]. As for heat treatment, while macroscopically visible alterations cannot be unambiguously used to identify the intentional heat treatment of flint (see [70–72]), several studies have demonstrated the value of such alterations in the detection of heat treatment (e.g., [60,61,73]). Furthermore, macroscopic classification allows the use of a large sample, which may provide clear, statistically significant results. Arguably, it would be expensive and time-consuming to gather a similarly statistically valid sample size using high-resolution methods (e.g., paleomagnetism, UV-Raman, FTIR, etc.).

Given the just concerns brought up by Abdolahzadeh et al. ([1], see within for a debate on the topic), according to whom the easy breakage of burnt lithics may lead to an over-representation of burnt pieces, the analysis conducted here is presented in two levels: the first includes all identified categories, including debris artifacts, while the second excludes debris categories and includes only débitage artifacts. This is performed in order to avoid the loss of indicative data by any of the two resolutions, thus avoiding a potential under-representation of burnt pieces (see [43]), and to shed light concerning the possible impact of the inclusion or exclusion of debris artifacts on burning frequency calculations. The risk of the under-identification of burnt pieces is further enhanced by the possible obscuring of color change caused by burning due to patination processes [1], and also by the possible misidentification of artifacts that were exposed to fire but which do not bear macroscopically visible fire alterations (see [66]).

While misinterpreting marks such as gloss and oily texture as evidence for exposure to fire is possible, there is also the risk of overlooking such evidence, resulting in an additional reduction in estimations of the frequency of burning. Here, we preferred the minimizing approach and did not count artifacts for which the identification of the traits was not considered by us to be secure. Therefore, and given all the reservations made above, the proportions of burnt pieces presented here (as well as in other similar studies), as well as that of possibly intentionally heated artifacts, should be viewed as minimum estimations only (see [66,71]).

Lithic Heat Treatment

The monitored heat treatment of lithic materials is a procedure often associated with the improvement of the knapping properties of silicious rocks, the control of the knapper over the end-product (e.g., [66,74–76]), or with increases in edge sharpness [60]. In other cases, heat treatment is associated with aesthetic motivations (e.g., [77–79]). Some cases pointed to the monitored exposure of these lithic materials to indirect fire, usually at around 250–300°, most likely using a gradual cooling process [66,70,80]. For this, the lithic materials may have been placed in the vicinity of a fireplace or buried in the ground, with the fire placed directly above it or close by [56,81,82]. Knapping experiments have shown that the heating of flint enables the production of sharper active edges and thinner objects, therefore making the knapping procedure more efficient [66,81,83–86]. It has been argued that, in order to achieve beneficial monitored heating of lithic materials, fuel needs to be abundantly available around the site [74].

The deliberate and monitored heating of lithic materials is well-known from Neolithic (e.g., [60,61,80,87] and Mesolithic (e.g., [58,72]) sites, but was also demonstrated in Upper Paleolithic (e.g., [70,79]) and MSA (e.g., [69,88,89]) contexts. A recent study [66] pointed to the application of intentional heat treatment of flint, intended specifically for the production of blades, at the Lower Paleolithic Acheulo-Yabrudian Qesem Cave, Israel, more than 300 kya. To our knowledge, no report of lithic heat treatment at Neanderthal sites has been presented thus far.

3. Results

In the G-layer complex of Sesselfelsgrotte, 38.0% (n = 423; Figure 3) of the artifacts in the sample, including debris artifacts, present evidence for the exposure of flint to fire (either by intentional heating or burning), compared to 30.9% of the lower-layer complex (n = 293; Figure 4). This difference was found to be statistically significant ($\chi^2 = 11.15$, df = 1, $p < 0.05$). Possibly intentionally heat-treated artifacts are significantly more frequent in the G-layer complex (n = 126; 11.3%) than in the lower-layer complex (n = 8; 0.8%), a difference which was also found to be statistically significant ($\chi^2 = 93.16$, df = 1, $p < 0.05$).

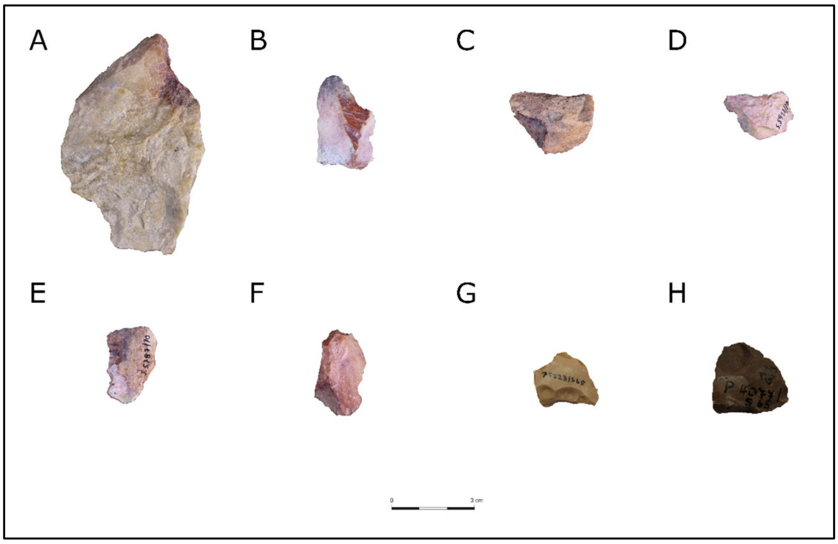

Figure 3. Flint artifacts from the G-layer complex showing evidence of burning: crazing, color change, potlids, fractures, and cracks. (**A**) Debris; (**B**) broken flake; (**C**) debris; (**D**) chip; (**E**) chip; (**F**) flake; (**G**) broken flake; (**H**) broken flake. A piece of debris is defined as an artifact missing any distinguishable typo-technological traits that is larger than 2 mm. A broken flake is defined as an artifact with a ventral face missing the bulb of percussion. A chip is defined as an artifact missing distinguishable typo-technological traits, smaller than 2 mm.

Patina differences between different surfaces of the analyzed artifacts appear with 7.5% of the analyzed artifacts of the G-layer complex (n = 84) and with 12.4% of the lower-layer complex (n = 119), implying that lithic recycling may have been more prominent in the earlier occupations at the site dating to MIS 5. The results of this aspect show no clear link to exposure to fire.

When excluding debris artifacts from the data, 39.8% of the G-layer complex (n = 301) shows evidence of burning compared to 30.5% (n = 149) of the lower-layer complex ($\chi^2 = 11.12$, df = 1, $p < 0.05$). This points to the minor impact of debris artifacts on the results described above. The proportions of possibly intentionally heat-treated artifacts increase in both assemblages when the debris categories are removed, but this occurs more so in the G-layer complex. In the G-layer complex (n = 115), 15.2% of artifacts are possible intentionally heat-treated artifacts. Conversely, in the lower-layer complex (n = 8), the frequency is no more than 1.6% ($\chi^2 = 61.36$, df = 1, $p < 0.05$).

It seems, then, that fire is present in both complexes, but is more frequent in the G-layer complex. Moreover, compared to the lower-layer complex, possibly intentionally heat-treated artifacts are significantly more frequent in the latter, providing evidence of more advanced fire use in the later assemblages.

Interestingly, the G-layer complex includes possibly intentionally heated pieces, which are especially common among the formal tools (28.8% of the tools; n = 61; Table 2, Figure 5a,b). Furthermore, when breaking down the types of tools into sub-categories, evidence for heat treatment is more frequently found among the side scrapers (12 out of 21; 57.1%; Table 3; Figure 6a,b and Figure 7), bifacial knives (3 out of 6; 50%), and notches

(7 out of 16; 43.8%). Most side scrapers were classified as convex side scrapers (Table 3), with 61.5% of them bearing evidence for possible intentional heating (n = 8). Six additional side scrapers from the G-layer complex show evidence of burning due to the presence of traits associated with thermal damage, bringing the proportions of scrapers exposed to fire, either due to intentional heating or burning, up to 85.7% (18 out of 21). This testifies to the common and repeated exposure of scrapers, or, more likely, of the raw material from which scrapers were produced, to fire. Given the technological and mechanical advantages of heating flint prior to tool production, it is our view that the exposure of flint to fire took place before scraper production, as part of material preparation, rather than by chance after production and possible use.

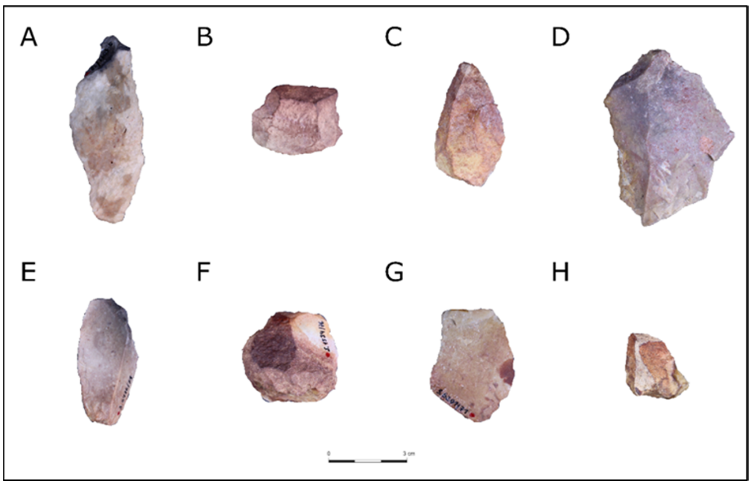

Figure 4. Flint artifacts from the lower-layer complex showing evidence of burning: crazing, color change, potlids, fractures, and cracks. (**A**) Flake; (**B**) debris; (**C**) debris; (**D**) debris; (**E**) flake; (**F**) debris; (**G**) broken flake; (**H**) debris. Debris is defined as an artifact missing any distinguishable typo-technological traits, larger than 2 mm. A broken flake is defined as an artifact with a ventral face missing the bulb of percussion. A chip is defined as an artifact missing distinguishable typo-technological traits, smaller than 2 mm.

Table 2. Breakdown of the G-layer complex by category and evidence of possible heating.

Category	Possibly Intentionally Heated	Not Heated	Total	% of Possibly Heated
Flakes	29	356	385	7.5%
Tools	62	152	214	29.0%
Broken Flakes	5	144	149	3.4%
Chips	3	93	96	3.1%
Cortical flakes	12	77	89	13.5%
Micro Flakes	4	58	62	6.5%
Debris	-	49	49	0.0%
Cores	2	17	19	10.5%
Core Trimming Elements	-	10	10	0.0%
Bladelets	2	7	9	22.2%
Cores-on-Flakes	1	7	8	12.5%
Special Waste	2	5	7	28.6%
Thinning Flakes	3	2	5	60.0%
Blades	1	4	5	20.0%
Cortical Blades	1	2	3	33.3%
Levallois Flake	-	2	2	0.0%
Recycling Products	-	1	1	0.0%
Grand Total	127	986	1113	11.4%
Debitage only	115	642	757	15.2%

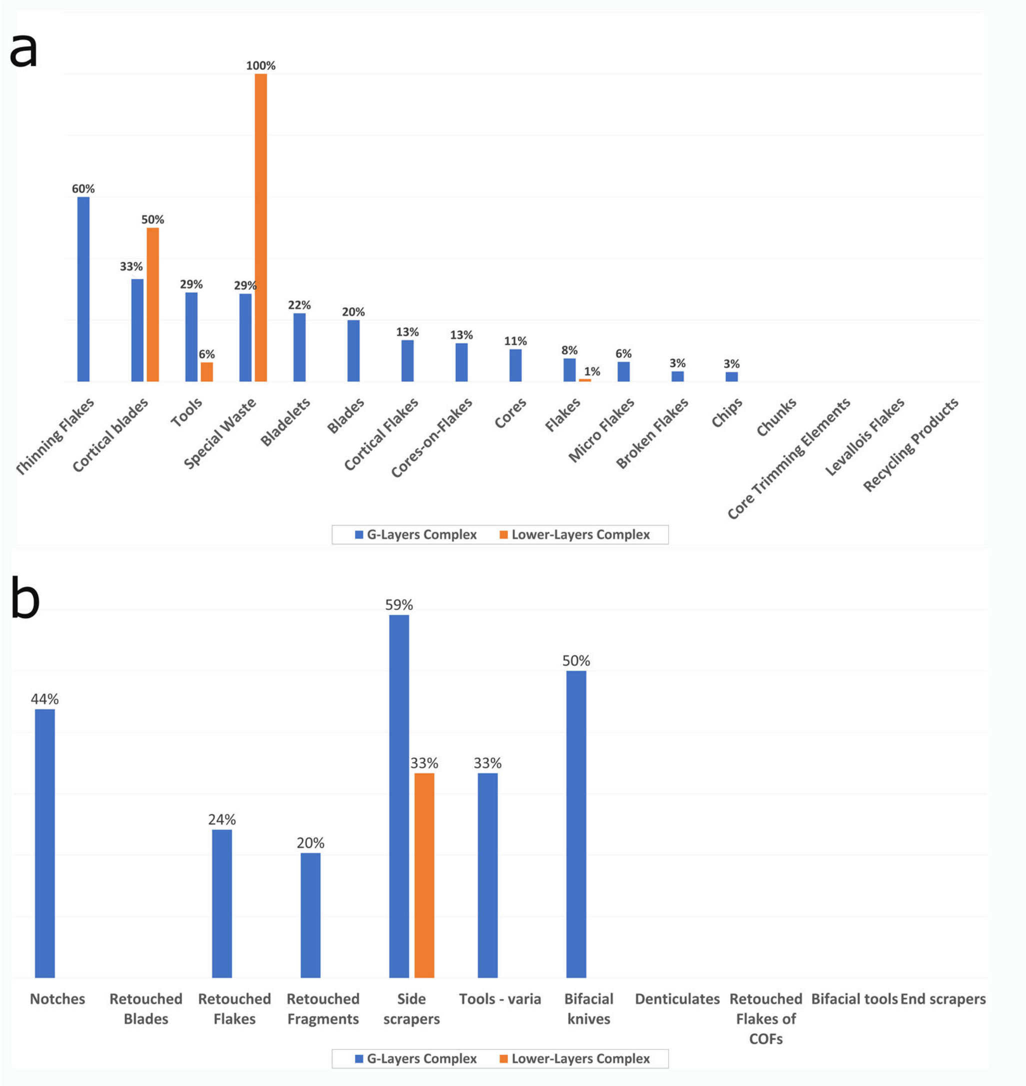

Figure 5. (**a**) The proportions of possibly intentionally heated artifacts by categories in both complexes. (**b**) The proportions of possibly intentionally heated pieces among the tools in both complexes.

Table 3. Breakdown of the side scrapers from the G-layer complex by type, and by indication of possible intentional heating.

Side Scraper Type	Possibly Intentionally Heated	Burnt	Unburnt	Total	% of Possibly Heated
Convex scrapers	8	5		13	61.5%
Double scrapers	2			2	100.0%
Straight scrapers		1	1	2	0.0%
Transversal scrapers			1	1	0.0%
Convergent scrapers			1	1	0.0%
Concave scrapers	1			1	100.0%
Angle scrapers	1			1	100.0%
Total	12	6	3	21	57.1%

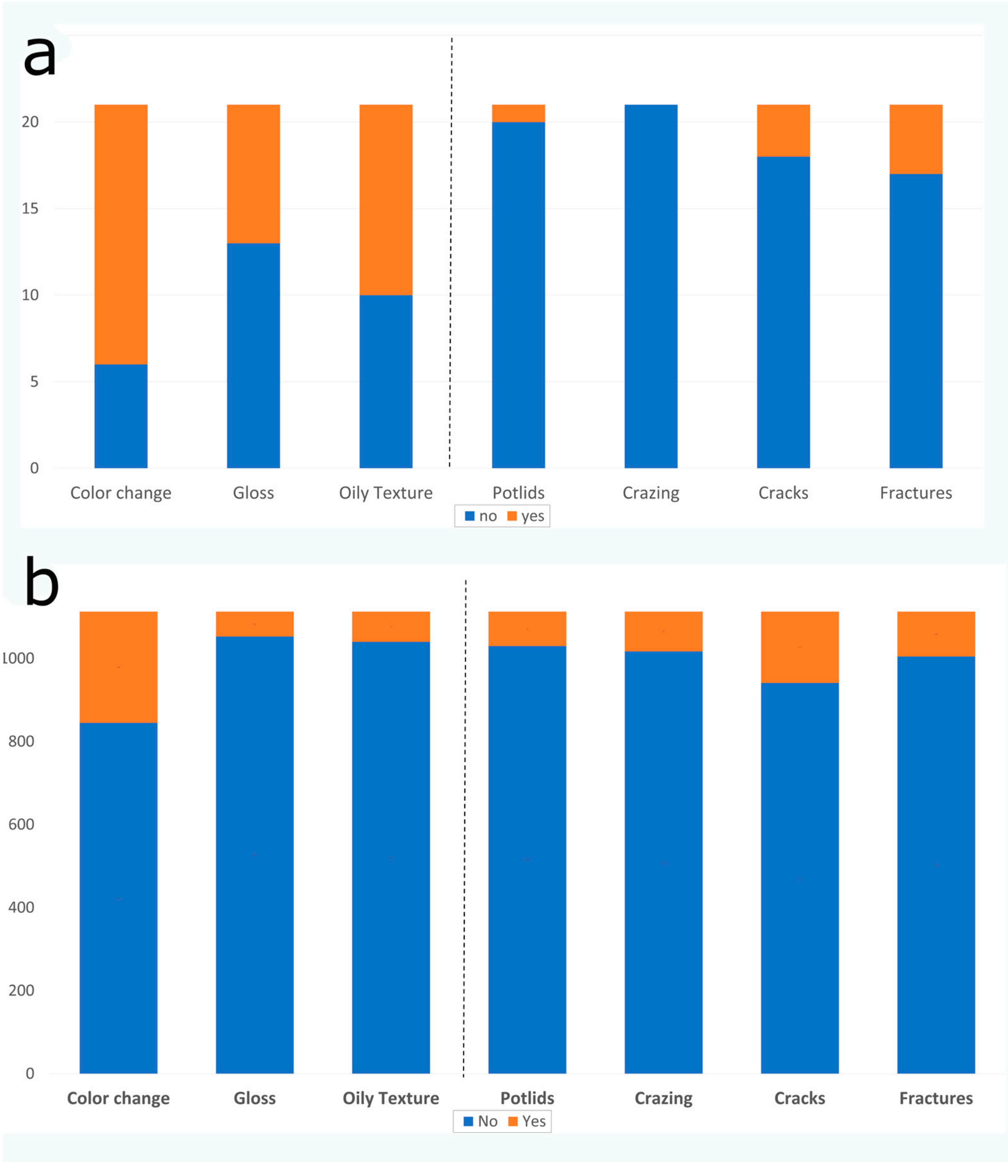

Figure 6. (**a**) The breakdown of each fire-associated trait among the 22 scrapers of the G-layer complex. The dashed line separates the heating-related traits from the traits associated with undesired thermal damage; (**b**) the breakdown of each fire-associated trait among the full sample of the lower-layer complex. The dashed line separates the heating-related traits from the traits associated with undesired thermal damage.

The presence of possible intentionally heat-treated items among the flakes, cortical flakes and blades may further testify to the heating of complete nodules prior to their knapping. A project evaluating the materials from Sesselfelsgrotte, including cores, using UV-Raman spectroscopy to test whether they were indeed heated, and at what temperature compared to experimental heating, is currently underway. The experimental project will allow us to evaluate the visual and mechanical impact of monitored heating on the locally used materials, providing us with more generalized insights.

It is worth noting that while possibly intentionally heat-treated pieces are rare in the lower-layer complex, three of the eight possibly intentionally heat-treated pieces are also side scrapers (out of nine side scrapers; 33.3%), implying that the intentional heat treatment of flint for the production of side scrapers may have, at least to some extent, begun already during the occupation of the lower-layer complex. Yet, given the small sample of side scrapers taken from the lower-layer complex, this observation should be treated with caution. The two other pieces from the lower-layer complex bearing alterations associated with heat treatment are a flake and a cortical blade (Table 4).

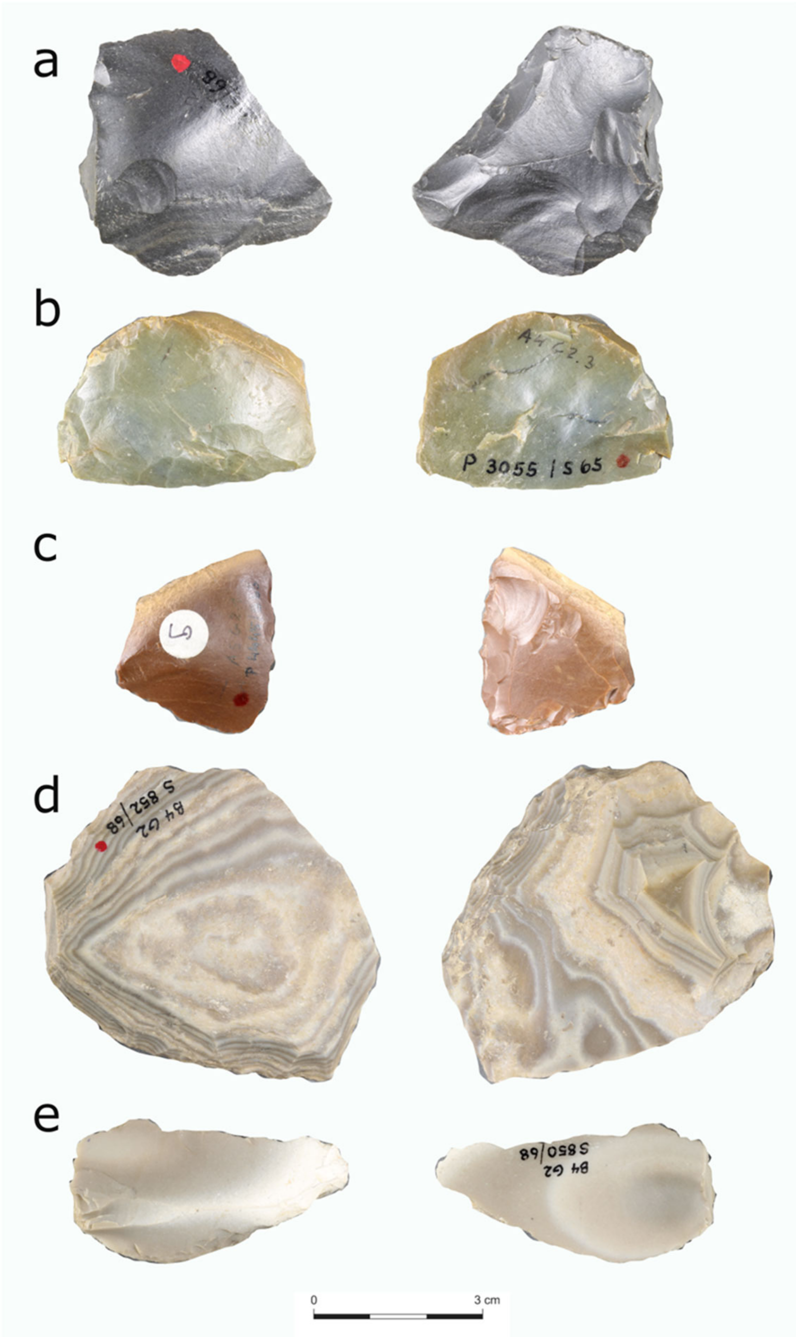

Figure 7. Possibly intentionally heated side scrapers side scrapers from the G-layer complex. Each letter represents both views—ventral and dorsal—of the same artifact.

While the use–wear analysis of side scrapers from the artifacts examined here has yet to be performed (see [90]), many studies testify to the significant functional role of side scrapers played during Paleolithic times in general (e.g., [91–93]), and specifically among Neanderthals (e.g., [94–97]). Past use–wear studies have shown that Middle Paleolithic scrapers were often used to process animal hides (e.g., [98–100]). The ethnographic record demonstrates a wide variety of animal hide uses (e.g., [101–106]), including significant roles in the cultural and cosmological realms (e.g., [105]). This may provide a possible justification for the great effort involved in the production of scrapers during Middle Paleolithic times, including the application of intentional heat treatment, as proposed here. Future research will explore the function of the potentially heat-treated side scrapers from Sesselfelsgrotte.

Table 4. Breakdown of the lower-layer complex by category and evidence of possible heating.

Category	Possibly Intentionally Heated	Not Heated	Total	% of Possibly Heated
Flakes	3	336	339	0.9%
Broken Flakes	-	146	146	0.0%
Chips	-	121	121	0.0%
Micro Flakes	-	110	110	0.0%
Debris	-	80	80	0.0%
Cortical Flakes	-	78	78	0.0%
Tools	3	45	48	6.3%
Cores	-	10	10	0.0%
Recycling Products	-	4	4	0.0%
Core Trimming Elements	-	3	3	0.0%
Cortical Blades	1	1	2	50.0%
Cores-on-Flakes	-	1	1	0.0%
Bladelets	-	1	1	0.0%
Blades	-	1	1	0.0%
Grand Total	**8**	**938**	**946**	**0.8%**
Debitage only	**8**	**481**	**489**	**1.6%**

To summarize, concerning the identification of the presence of fire, as well as the frequency of burnt artifacts, our results clearly demonstrate the presence of fire in both complexes, with a higher frequency in the G-layer complex. As for the identification of intentional and monitored heat treatment, it is certainly possible that not all artifacts that bear alterations associated with intentional heat treatment point necessarily to the application of heat treatment in the discussed contexts. Indeed, without further petrographic analysis (i.e., UV-Raman spectroscopy: [66]), we take into consideration that not all the artifacts which comply with the parameters established here for heat treatment were necessarily intentionally heated. Yet, given the significant differences between the two investigated complexes, in conjunction with the clear association between the evidence of possible heat treatment and specific typo-technological categories and sub-categories, it is our contention that the results presented here indicate the application of monitored heat treatment of flint, at least in the G-layer complex, specifically for the production of tools, and especially for the production of side scrapers.

The differences between the two complexes were found to be statistically significant. This clearly demonstrates the behavioral differences between the two occupation stages. While fire is evident within both complexes, heat treatment is clearly evident only in the G-layer complex. This implies that this technological innovation became well-established at the site sometime between the end of MIS 5 and the beginning of MIS 3.

Additional Evidence for Fire Use in Sesselfelsgrotte

The Middle Paleolithic layers of Sesselfelsgrotte yielded strong evidence for the use of fire in addition to, and methodologically independent from, the investigation of burnt lithics (Table 5). The evidence falls into three categories: (1) sedimentological features, (2) evident combustion features of anthropogenic fire use, and (3) burnt organic materials (in this case: burnt bones).

Table 5. Evident features in the Middle Paleolithic of Sesselfelsgrotte (green to blue colors indicate climatic interpretations derived from the sedimentology following Freund 1998; numbers in brackets indicate the source of the data compiled: (1) Freund 1998: 137–174; (2) Richter 1997: 38–42; (3) Freund 1998: 200–267; (4) Freund 1998: 268–288).

MIS	Layer	Thickness and Preservation	Sedimentological Features Indicating Fire Use	Features Related to Burning *	Dominant Remains of Fuel
MIS 3	G1	(1) 1 to 4 cm, in part up to 10 cm; original occupation surface (“sol d’habitat”)	High content of anthropogenetic matter, darker color caused by burnt bones.	(2) feature sq. A7: grayish-black concentration of ash (2) feature sq. C8: three small concentrations of burnt bones	Bone
	G2	(1) 10 cm (but in most areas further differentiated into G2 oben, G2 Mitte, G2 unten), original occupation surface (“sol d´habitat”)	(1) Black-grey color, ash/soot (“stark aschige Bestandteile”), high content of burnt bones; in some square meters, high content of charcoal.	(2) feature sq. A4: round concentration of ash with a diameter of 1 m (1, 2) feature sq. Z3: small concentration of ash/soot and charcoal	
	G3	(1) several cm	(1) High content of anthropogenetic matter, but lower content of burnt bones than in G2 and G4.		
	G4	(1) several cm, original occupation surface (“sol d´habitat”)	(1) High content of anthropogenetic matter, blackish color from ash and soot, high content of burnt bones.	(2) feature sq. B3: elongated concentration of ash	
	G4a	(1) up to 10 cm	(1) Charcoal pieces rare.		
	G5	(1) 5–8 cm	(1) High content of anthropogenetic matter, dark color from ash and soot.	(2) feature sq. X8: concentration of burnt limestone debris	
	H	(1) 30–60 cm	(1) Lenses of artifacts and faunal remain combined with burnt bones.	(2) feature sq. A2: small fireplace with sooty limestones	
4	Layers I, K, L (archeologically sterile)				
5a	M1	(3) 10–15 cm	(3) Dark color, high content of charcoal.	(3) feature sq. B4/A4: small fireplace surrounded by burnt limestones and lenses of burnt sediment below (3) feature sq. C6: small fireplace in an artificial pit surrounded by burnt limestones and burnt sediment below (3) feature sq. Z7: fireplace with charcoal and intensively burnt sediment below	wood
	M2	(3) 4–7 cm	(3) Dark color, lower content of charcoal, but in part large pieces.	(3) feature sq. Z9: fireplace with numerous large charcoal pieces, burnt bones, (in part vertical) burnt limestones and burnt sediment below (3) sq. B6: lens of dark (sooty) sediment	
	M3	(3) 2–9 cm	(3) Dark color, high content of charcoal, ash and soot (“Holzkohlenmehl”).	(3) feature sq. B7: small fireplace (3) sq. B5: dark color, high content of charcoal	
	N	(3) up to 10 cm	(3) Medium amount of charcoal.	(3) feature sq. B5: large concentration of large charcoal pieces (3) feature sq. A7: shallow fireplace with limestones blackened by soot (3) sq. A8: round concentration of charcoal (3) sq. C6: diffuse concentration of charcoal with hardened (burnt?) sediment below (3) sq. Z8: concentration of blackish sediment with burnt limestone	
	O1	(3) 3–7 cm	(3) Charcoal.	(3) feature sq. A9: large fireplace (3) feature sq. C7: fireplace with large amount of (also larger) charcoal pieces, burnt limestones and burnt faunal remains (3) feature sq. D7: fireplace (3) feature sq. Z8: fireplace associated with burnt limestone debris	
	O2	(3) 5 cm			
	O3	(3) 8 cm			

Table 5. *Cont.*

MIS	Layer	Thickness and Preservation	Sedimentological Features Indicating Fire Use	Features Related to Burning *	Dominant Remains of Fuel
5b	P	(3) 10–15 cm	(3) Single occurrences of larger charcoal pieces, in some areas high content of ash also in distance to fireplaces.	(3) feature sq. Z9: small but dense clusters of charcoal surrounding a fireplace with sooty limestones (3) sq. C9: small concentration of charcoal	
5c	Q	(3) 25–50 cm	(3) Single occurrences of larger charcoal pieces, in some areas high content of ash also in distance to fireplaces.	(3) feature sq. D7: large but diffuse concentration of ash and soot from two fireplaces (3) feature sq. D8: large fireplace with burnt limestones (3) sq. C8: concentration of charcoal	
	Bipartition of the excavation area by a limestone ridge at the base of the rock shelter into a western part (R-West, 1-West to 3-West) and eastern part (R, S); the size of the excavated surfaces decreases towards the base.				
	R	(3) 20 cm	(3) Pieces of charcoal and burnt bones.	(3) feature sq. C6: round fireplace with charcoal pieces and burnt sediment below, measuring 40 cm in diameter (3) feature sq. C7: round fireplace measuring 50 cm, with burnt limestones (3) feature sq. D7: fireplace with intense black sediment and charcoal pieces (3) feature sq. D8: large fireplace in artificial pit	
	S	(3) 25–30 cm	(3) Few traces of ash and soot.	(3) No evident fireplaces	
	R-West	(3) 30–38 cm	(3) Numerous pieces of charcoal.	(3) No evident fireplaces	
	1-West	(3) 40 cm	(3) Numerous pieces of charcoal.	(3) No evident fireplaces (3) A9: numerous dissoluted pieces of charcoal	
5d	2-West	(3) 55 cm	(3) Pieces of charcoal, numerous pieces of burnt bones.	(3) No evident fireplaces	
	3-West	(3) 20 cm	(3) Numerous pieces of charcoal.	(3) No evident fireplaces	

(1) [25]; (2) [28]; (3) [25]; (4) [25]; * sq. = square meter; features: fireplaces indicated by burnt sediments below concentrations of charcoal/bone coal; underlined features: evident fireplaces, coupled with concentrations of burnt artifacts; other evidence: concentrations of burnt materials lacking heat-altered sediments below.

In both the lower-layer complex and the G-layer complex, the amount of anthropogenic material (i.e., lithic artifacts and bones(is remarkably high in relation to sediment)such as frost debris or loess) and often includes small particles of burnt materials [25]. In some layers, sedimentological analysis revealed the dominance of anthropogenic material over geologic components, making it difficult to properly define the sediment [25]. This also applies for the description of the color of the sediment matrix which, in the following layers, went from dark gray to black due to the content of the products of dissolution of burnt organic material: G1, G2, G4, G5, M1, M2 and M3. All these layers are merely several centimeters thick, pointing to their being occupation surfaces. Therefore, the mixing of sediment and residues from burning (i.e., very small particles of burnt wood and burnt bones) is best explained by small-scale post-depositional processes such as trampling or the contribution of water saturation of sediments to the site formation process.

The small distance between the back wall of the rock shelter and the dripline, as well as the exposure of the entire shelter to daylight, underlines the fact that Sesselfelsgrotte is too small to be used as a homebase for bats. In addition, the analysis of the malacofauna [51] shows the far-reaching dominance of mollusk species that prefer a rocky environment at the time of the sedimentation of the base of the lower-layer complex. The small mammal fauna [37] of the Lower Layers is dominated by species that prefer an open habitat such as grasslands or a forest-tundra habitat, whereas those of the G-layer complex are indicative of cool glacial conditions with open habitats. In the face of a lack of large amounts of flammable materials in the sediment, such as guano, and on the steep limestone walls near the rock shelter, such as grass and bushes (such as patches of vegetation; see [107]), it seems highly unlikely that natural fires are the source of burnt materials.

Almost all layers of the lower-layer complex and the G-layer complex are reported to have yielded concentrations of burnt organic materials (Table 1; Figure 8). In the G-layer complex, the identification of fireplaces follows the procedure of Richter [28] and is based on the simultaneous presence of clearly confined concentrations of burnt bones, burnt artifacts and ash. In the lower-layer complex, the identification of fire is based on an assessment of the detailed descriptions (and in part interpretations) given by G. Freund (1998, 200–267). Following the suggestions of Mentzer [108], we only counted combustion features described as having a clear spatial boundary, with either lenses of burnt sediment below and/or an association with concentrations of heat-altered limestones (see also [109]). In Table 1, other features are also listed that were not counted as fireplaces. They may represent former fireplaces destroyed by post-depositional processes of different agency, or may result from the active cleaning of nearby fireplaces.

The total number of published fireplaces (Table 6) in the G-layer complex is 7 [28], and in the lower-layer complex 18 fireplaces are accounted for. However, any comparison must take into consideration the effects of time. There is a marked difference in the thickness of the layers between the lower-layer complex and the G-layer complexes. Both the analyses of the lithic assemblages conducted by W. Weißmüller (for the lower-layer complex: [31]) and J. Richter (for the G-layer complex: [28]) identified more than one occupation per layer. However, the G-layer complex contained 13 assemblages (A01 to A13), whereas the lower-layer complex yielded 27 (B001 to B027). Therefore, we calculated the mean number of fireplaces per cm of layer thickness (Table 6), excluding Layers R to 3-West at the base of the sequence, where only several square meters were excavated. For the overlying layers G1 to Q, the nonobservance of the size of the excavation area in the calculation is justified by the fact that it is consistently similar. The average numbers vary between 0.50 fireplaces per cm of layer thickness in Layer G1 and 0 fireplaces in Layer G3. Overall, the average in the G-layer complex of 0.10 fireplaces per cm is almost equivalent to the value of 0.11 fireplaces per cm calculated for the lower-layer complex. The lower-layer complex represents the moderate (but not interglacial) climatic conditions of MIS 5a to MIS 5d, whereas the G-layer complex, in an overall perspective, is characterized by the cooler conditions of the early part of MIS 3. However, the high stratigraphic resolution for some parts of the complex reveals more details. From a sedimentological point of view [25], the relative climatic minima and maxima for both the G-layer complex and the lower-layer complex are in fact identified in the lower-layer complex. Layer M1, with a value of 0.20 fireplaces per cm, represents the coldest environment within the archaeological layers (e.g., excluding the archeologically almost sterile layers I, K and L representing MIS 4). On the contrary, Layer M3 below, with a value of 0.11 fireplaces per cm, is the one with the most moderate climatic conditions. Again, the average number of fireplaces does not correlate with climatic variations.

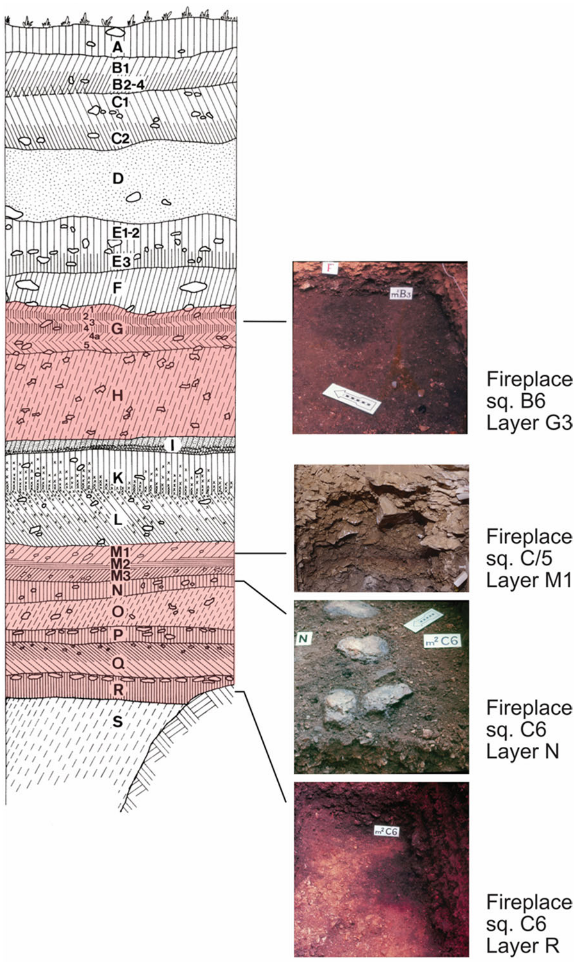

Figure 8. Examples of evident features from the lower-layer complex and G-layer complex interpreted as fireplaces. Except for the fireplace of Layer M1, which is shown in side view and was documented during sampling for micromorphological analysis in 2023, all features were documented in plane view during the excavations of G. Freund [25] (photos: archive of FAU Erlangen–Nürnberg).

In contrast with the almost identical relative average numbers of fireplaces in the G-layer complex compared to the lower-layer complex, the mapping of fireplaces reveals some differences (Figure 9). The task of performing a diachronic comparison of the locations of the fireplaces is made difficult by changes to the roof and the backwall during gelifaction. Although Weißmüller [31] underlines that changes to the dripline during the last glaciation were moderate due to the hardness of the limestone, numerous larger boulders in layers S to I indicate rock fall from the roof [25]. The dripline in Figure 7 represents the present-day status, which corresponds to the dripline position at the onset of the sedimentation of the G-layer complex. In earlier phases of human occupation, the dripline was situated further in the direction of the slope in front of Sesselfelsgrotte, falling within the excavated area (in square meter lines 9 and 8). Therefore, the overwhelming number of fireplaces from the lower-layer complex are situated below the current dripline. Conversely, the fireplaces of the G-layer complex are found near the backwall of the rock shelter.

Table 6. Number of fireplaces excavated in Sesselfelsgrotte, lower-layer complex and G-layer complex in comparison to the thickness of the layers. Note: the size of the excavated area is almost identical in Layers G1 to Q. In Layers R to 3-West at the base of the sequence, only a few square meters were excavated due to a limestone ridge at the basal bedrock that divides the excavated area into two parts, e.g., layers R and S in the east and R-West to 3-West in the west.

Layer	Max. Thickness in cm	Number of Evident Fireplaces	Fireplace Per cm
G1	4	2	0.5
G2	10	2	0.2
G3	3	0	0.0
G4	3	1	0.3
G4a	10	0	0.0
G5	8	1	0.1
H	30	1	0.0
sum/average	68	7	0.1
M1	15	3	0.2
M2	7	1	0.1
M3	9	1	0.1
N	10	2	0.2
O	20	4	0.2
P	15	1	0.1
Q	50	2	0.0
sum/average	126	14	0.1
R	20	4	
S	30	0	
R-West	38	0	
1-West	40	0	
2-West	55	0	
3-West	20	0	

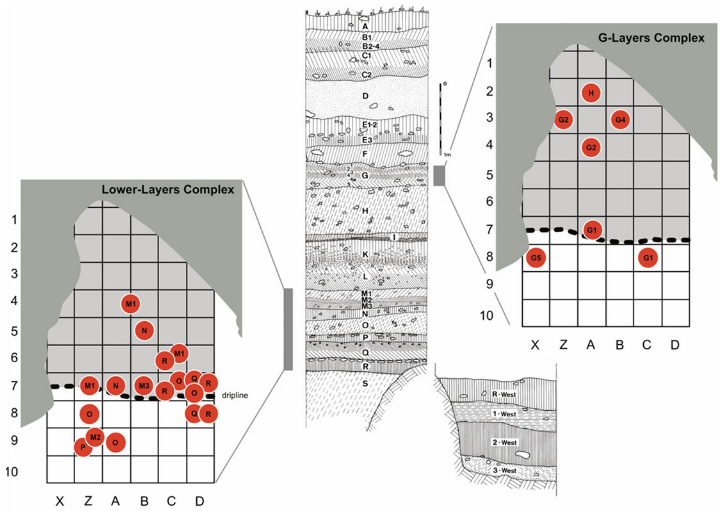

Figure 9. Schematic mapping of evident combustion features identified as fireplaces in the lower-layer complex and G-layer complex of Sesselfelsgrotte, with an indication of the layer. The resolution is one square meter. In cases of more than one fireplace per square meter, symbols were arranged to fit. In one case of the lower-layer complex, when dealing with fireplace in squares A4/B4 of layer M1, the feature was prominently larger than one square meter. Letters within the red markings of the combustion features identified represent their labelling.

Almost all layers contain considerable amounts of burnt bones. T. Rathgeber [27] distinguished between three categories: there was a category of identifiable bones (without quantifying burnt and unburnt pieces, even though an overwhelming number of bones are reported to be unburnt), and unidentified bone pieces were divided into burnt and unburnt items (Table 7). Many of the unidentified pieces are represented by a small fraction identified during the sieving procedure of the excavated sediment. Instead of being only black in color (see [110]), unidentified burnt faunal remains include all stages of heat exposure, from calcinated bone to only partly burnt pieces. In order to compare the number of burnt bones between the two complexes, we excluded the identifiable faunal remains from the calculations presented below. Instead, we only used faunal remains unequivocally classified as burnt or unburnt (e.g., the unidentified small fractions). Due to the small size of the items, we used the weight of the items to calculate the ratio between burnt and unburnt faunal remains. The results are shown in a boxplot (Figure 10). The majority of the instances of burnt items in the faunal assemblages of the G-layer complex range between 19.3% and 37.6%, with one outlier in Layer H of 16.7%. Contrarily, the relative instances of burnt remains in the faunal assemblages of the lower-layer complex never reach more than 8.7%, but this is an outlier as well. The majority of layers yield between 2.2% and 7.5% ratios burnt faunal remains. This value does not change significantly, even if the identifiable faunal remains are also taken into consideration and are counted as unburnt (Table 7). If numbers are used instead of weight, the ratios shift in the direction of burnt faunal remains (Table 7). It has already been mentioned that much of the burnt organic material in the lower-layer complex consisted of wood, which was sometimes preserved in large pieces. The preserved remains of combustion in the G-layer complex, on the contrary, mainly consisted of small fractions of burnt animal bone. While this is mainly reflected in the relative number of burnt bones, there are still some different ideas derived from the shift in combustion material. First, the use of fresh bones as fuel still needs wood to start the fire [111,112]. Therefore, planning is needed to provide a stock of both wood and bones when starting a fire. Second, the shift from wood to animal bone can be explained by a flexible response to the lower availability of wood. However, both aspects imply profound knowledge of combustion techniques and contradict a scenario of gathering fire from accidental natural fire occurrence.

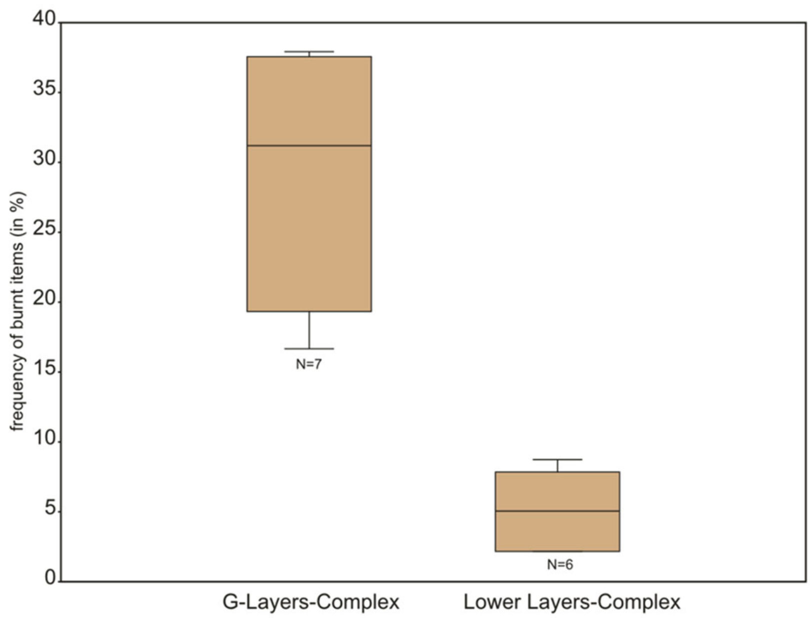

Figure 10. Boxplot of relative frequencies (percentages) of burnt faunal remains in the two studied complexes (whisker length: one sigma, quartile method: interpolation; data taken from [27], Tables 4 and 6 for the lower-layer complex and from Rathgeber, in preparation for the G-layer complex; for the complete data on burnt and unburnt faunal remains, see Table 5 of this article).

Table 7. Faunal data with information about exposure to fire ([17], Tables 4 and 6 for the lower-layer complex and from Rathgeber, in preparation for the G-layer complex) and calculation of relative frequencies within each layer (in grey: data used for the box plot in Figure 7).

Count						**Percentage Within Each Level, Unidentified**			**Percentage Within Each Level, including Identifiable (Counted as "Unburnt")**		
G-Layers Complex											
Layer	Unidentified, burnt	Unidentified, unburnt	Identifiable	Sum	Sum unidentified	Unidentified, burnt	Unidentified, unburnt	Sum	Unidentified, burnt	Unidentified & identified unburnt	Sum
G1	24,737	16,661	687	42,085	41,398	59.8	40.2	100	58.8	41.2	100
G2	22,254	18,375	568	41,197	40,629	54.8	45.2	100	54.0	46.0	100
G3	3041	2394	112	5547	5435	56.0	44.0	100	54.8	45.2	100
G4	11,490	8363	344	20,197	19,853	57.9	42.1	100	56.9	43.1	100
G4a	1864	2881	75	4820	4745	39.3	60.7	100	38.7	61.3	100
G5	2063	3998	99	6160	6061	34.0	66.0	100	33.5	66.5	100
H	442	2404	142	2988	2846	15.5	84.5	100	14.8	85.2	100
			Total	122,994	120,967						
Lower-Layers Complex											
M1	43	1113	99	1255	1156	3.7	96.3	100	3.4	96.6	100
M2	131	2352	50	2533	2483	5.3	94.7	100	5.2	94.8	100
M3	281	2343	48	2672	2624	10.7	89.3	100	10.5	89.5	100
N	114	1472	50	1636	1586	7.2	92.8	100	7.0	93.0	100
O	681	5115	75	5871	5796	11.7	88.3	100	11.6	88.4	100
P	269	3624	61	3954	3893	6.9	93.1	100	6.8	93.2	100
			Total	17,921	17,538						
Weight in gr						**Percentage Within Each Level, Unidentified**			**Percentage Within Each Level, Including Identifiable (Counted as "unburnt")**		
G-Layers Complex											
Layer	Unidentified, burnt	Unidentified, unburnt	Identifiable	Total sum	Sum unidentified	Unidentified, burnt	Unidentified, unburnt	Sum	Unidentified, burnt	Unidentified & identified unburnt	Sum
G1	9928	21,894	11,142	42,964	31,822	31.2	68.8	100	23.1	76.9	100
G2	10,765	22,762	4219	37,746	33,527	31.2	68.8	100	28.5	71.5	100
G3	1733	2,837	617	5187	4570	32.1	67.9	100	33.4	66.6	100
G4	5187	8,621	1646	15,454	13,808	37.9	62.1	100	33.6	66.4	100
G4a	667	2783	420	3870	3450	37.6	62.4	100	17.2	82.8	100
G5	748	3741	531	5020	4489	19.3	80.7	100	14.9	85.1	100
H	169	2303	404	2876	2472	16.7	83.3	100	5.9	94.1	100
			total	113,117	94,138						
Lower-Layers Complex											
M1	17	768	460	1245	785	2.2	97.8	100	1.4	98.6	100
M2	64	1682	630	2376	1746	2.2	97.8	100	2.7	97.3	100
M3	147	2135	165	2447	2282	3.7	96.3	100	6.0	94.0	100
N	92	961	882	1935	1053	6.4	93.6	100	4.8	95.2	100
O	342	4189	916	5447	4531	8.7	91.3	100	6.3	93.7	100
P	93	3425	890	4408	3518	7.5	92.5	100	2.1	97.9	100
			total	17,858	13,915						

4. Discussion

4.1. Fire Use among the Neanderthals of Sesselfelsgrotte

Based on the analysis of material taken from Sesselfelsgrotte, Abdolahzadeh et al. [1] suggest that fire use at the site was more frequent during the occupation of the lower-layer complex, when the climate was, according to their claims, warmer and more humid. Conversely, they assert that the G-layer complex, which was occupied when the climate was colder and drier, saw less fire use. Our findings, however, imply otherwise. Based on the data presented here, we suggest that fire was commonly used during both occupation phases. However, burnt flint is more evident in the G-layer complex, as indicated by both proportions of burnt material and by the evidence of heat treatment (see below). A scenario of natural burning at the site does not seem likely, in our view, given the common appearance of unburnt artifacts alongside burnt artifacts, and the selectivity in the exposure of artifacts to fire. In addition, Sesselfelsgrotte is not a cave, but a small rock shelter that has always been widely exposed to daylight, excluding the possibility of natural fires caused by the ignition of guano deposited by large numbers of bats. As mentioned above, the analysis of the malacofauna [51] and the small mammal fauna [37] have shown that the surroundings of Sesselfelsgrotte during the occupations of the lower-layer complex and the G-layer complex were characterized by limestone walls almost void of vegetation.

At Sesselfelsgrotte, differences in the intensity of fire use between the lower-layer complex and the G-layer complex are not only indicated by the varying amounts of burnt and/or heat-treated lithic artifacts. The analysis of the data collected by T. Rathgeber [27] provided above further demonstrates the differences regarding the combustion material. Whereas the lower-layer complex is dominated by burnt wood remains, combustion materials from the fireplaces of the G-Layer complex are characterized by large quantities of burnt bone. This reflects a flexible acquisition of combustion material related to the natural supply in the surroundings of the rock shelter. At the same time, it also suggests the application of more complex combustion methods in the G-layer complex, as the ignition of fire from bone is dependent on the use of wood as the ignition material [111]. Given all the above, our results imply that fire use was not less common during the later stage of occupation, but rather, as frequent and more variable.

Based on the archaeological record of the Paleolithic of Europe, Roebroeks and Villa [8] propose that fire use became habitual in Europe around 400 kya. Following this, they suggest that fire was an essential component in the lives of European Neanderthal populations. We view the results presented here as providing further evidence for the continual use of fire by European Neanderthal populations. Abdolahzadeh et al. [1] claim that the behavior of Neanderthals should not necessarily be viewed as a "species-level behaviour", and therefore that the evidence of fire use by a given Neanderthal group cannot be generalized to the entire human subspecies. However, it is our view that, given the broad appearance of fire in Neanderthal sites, and given the application of advanced fire technologies in several Neanderthal sites (e.g., [5,6,113]), Neanderthals as a species were capable of habitually using fire, including the capability to produce fire at will, and that fire knowledge was repeatedly transferred between Neanderthal groups throughout time and space. This suggests that the use, and probably also the production of fire, constituted regular, day-to-day procedures among Neanderthals. Ongoing work will explore the identification of fire and the intentional heat treatment of lithic raw materials at Sesselfelsgrotte, using Raman spectroscopy to further test the results presented here.

4.2. Evidence of Heat Treatment and Modern Human Behaviour

It has been often argued that the emergence of the European Upper Paleolithic reflects significant transformations in human behavior, strongly associated with the appearance of anatomically modern humans (AMHs) in Europe, some 40 kya (e.g., [114,115]). This set of behaviors and capabilities is known as modern human behavior (MHB), or behavioral modernity [116]. Behind the concept of the superiority of AMHs over Neanderthals stands the view according to which, as Breyl aptly phrased it, "our species dispersed out of Africa once it reached a fully modern cognition and consequently clashed with Neanderthals, quickly replacing them and thereby demonstrating that those modern humans were qualitatively superior in some or many cognitive domains" [117].

Among the transformations associated with MHB, the literature mentions language, the emergence of cave art, specialized and standardized tool production, the use of ochre, the manufacture of bone tools, the procurement of lithic materials from across great distances, the exploitation of aquatic resources, the formation of trade networks, and complex social organization, as well as other traits (see [118]). This view has further been expanded to the African continent, as several studies propose the existence of some of these traits among earlier AMH populations in Middle Stone Age sites throughout Africa (e.g., [74,119–121]). However, many recent studies point to the existence of such capabilities among Neanderthals as well (e.g., [122–125]), as well as among other pre-AMH species (e.g., [19,126,127]), suggesting that this view should be reconsidered (and see [117]).

In the case of fire use, MHB was often associated with the intensification of fire use, a higher degree of control over fire, and the application of pyro-technologies (e.g., [3,4,74,128]). For example, finds pointing to an advanced use of fire by AMHs during the Middle Stone Age in Pinnacle Point in South Africa, some 164 kya, including the application of pyro-technologies for the intentional and controlled heating of silcrete [74], have been used to raise claims concerning the alleged cognitive superiority of AMHs over Neandertals. According to Brown et al. [74], "as these early modern humans moved into Eurasia, the ability to alter and improve available raw materials and increase the quality and efficiency of stone tool manufacture may have been a behavioral advantage".

Yet, starting from the beginning of the Middle Paleolithic of Europe, there is evidence for the application of pyro-technologies among Neanderthals, mainly in the production of adhesive materials (e.g., [5,6,129]). In Middle Paleolithic Campitello Quarry (Central Italy), for example, two stone flakes partially covered in birch–bark–tar were found in association with the remains of a young adult female Palaeoloxondon antiquus in a layer older than 190 kya [6], providing evidence for an advanced use of fire by Neanderthals during cold climate periods. At the early Neanderthal site of Poggetti Vecchi (Italy), the production and use of "digging sticks" was suggested in a context dated to ~171 kya [113]. The manufacture of these "digging sticks" included processing by fire, most likely to lessen the effort involved in the scraping activities for which they were used. Koller et al. [5] suggest that in Königsaue, in a layer older than 80 kya a lignite open-pit mine located in the northern foothills of the Harz Mountains (Germany), Neanderthals were using pitch made of birch bark. They further claim that its production cannot be accidental, and that its existence therefore supports the claim of high technological capabilities.

In contrast to this, Schmidt et al. [24] claim that, while Neanderthals indeed engaged in the production of birch tar for the manufacture of hafted tools, it does not imply Neanderthal behavioral complexity. Rather, they say, birch tar might have been naturally deposited on vertical and sub-vertical stone surfaces located in adjacency to fire and collected from these surfaces, demonstrating a relatively simple production procedure. Therefore, they argue, the production of birch tar by itself cannot be used as evidence for modern cultural behavior and for high-level cognition and knowledge transmission.

Despite these specific discussions about the application of pyro-technologies for the production of adhesive materials, we see the ability to alter and improve the mechanical traits of lithic raw materials in order to increase the quality and efficiency of stone tool manufacturing. This is indicated by the findings from Sesselfelsgrotte Neanderthals, which demonstrate high cognitive and technological capabilities. Therefore, and in conjunction with the indications from the other European Middle Paleolithic sites mentioned above, advanced knowledge of fire technology cannot be considered as a characteristic unique to AMHs. We concur with the observation made by Brown et al. [74], according to which "heat treatment demands a sophisticated knowledge of fire and an elevated cognitive ability". However, we view this as a description fit for application to Neanderthals as well, reflecting their own high cognitive capabilities and advanced technological know-how. It is of note that the intentional heat treatment of lithic materials was also observed among other, earlier, non-AMH species [66], further implying that this capability is not exclusive to AMHs.

5. Conclusions

This study tackles two major topics concerning Neanderthal fire capabilities and knowledge. First, it examines the frequency of fire use among the Neanderthals of Sesselfelsgrotte and their dependence, or lack of thereof, on natural fire occurrences. Second, it evaluates the possibility of intentional lithic heat treatment conducted by the Sesselfelsgrotte Neanderthals. We propose that Neanderthals were regularly using fire and were not dependent on natural fire events for fire procurement. Rather, it is our view that the more likely scenario is that the Sesselfelsgrotte Neanderthals were capable of producing fire at will. We also suggest the intensification in fire use during the occupations of Sesselfelsgrotte, and the identification of intentional, monitored heat treatment of flint specifically for the production of side scrapers, starting at least during the Late Middle Paleolithic of MIS 3, provide the first currently known evidence for lithic heat treatment performed by Neanderthals.

The supposedly superiority of early modern humans over Neanderthals was long advocated, based on a list of traits that were originally associated only with AMHs and considered not to exist among Neanderthals. However, studies from the last two decades have demonstrated that many of these traits were not unique to AMHs at all (e.g., [125,130–132]; see especially the seminal publication by McBrearty and Brooks [133]). We view the results presented here as further evidence for the high cognitive and technological capabilities of Neanderthals, capabilities that did not fall, in our view, short of those of early AMHs.

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