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Were the Technological Innovations of the Gravettian Triggered by Climatic Change? Insights from the Lithic Assemblages from Hohle Fels, SW Germany

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ABSTRACT

During the Gravettian several innovations in lithic technology and typology appear. Blank production focuses on long, straight and narrow blades and bladelets. The preparation and maintenance of cores is frequent, and core exploitation is efficient. Often bladelets and smaller blades are transformed into standardized backed elements, among them the well-known Gravette and Microgravette points. Backed elements were often hafted. Many were parts of a modular projectile technology, but some probably served other uses such as cutting or perforating. These artifacts are part of a highly mobile toolkit, and their modular nature makes them especially convenient in terms of transport and maintenance. The Gravettian developed during a phase of constant cooling in Marine Isotope Stage (MIS) 3, which ultimately lead to the Last Glacial Maximum (LGM). Here we look at the lithic assemblages from the Gravettian of Hohle Fels Cave in southwest Germany and discuss the possible impact that climate change might have had on Paleolithic hunter-gatherer societies during the end of MIS 3. We examine the degree to which environmental development triggered some of the innovations that came with the Gravettian.

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INTRODUCTION AND BACKGROUND

This paper investigates the possible connection between environmental conditions in Southern Central Europe around and after 35 ka cal BP and the emergence of Gravettian lithic tool technology, which clearly differed from the preceding Aurignacian. The example of Hohle Fels Cave is especially well-suited to test this hypothesis, since the assemblages are from recent excavations with good stratigraphic resolution. Thirty radiocarbon dates from the Gravettian of Hohle Fels place it in late Marine Isotope Stage (MIS) 3 (Taller and Conard 2019; see below). To this end, we first conduct a detailed technological analysis of the Gravettian lithic assemblages. The results from these investigations are then contextualized with archaeological and chronostratigraphic data from the European Gravettian together with paleoclimatic data. In considering the argument further, we examine the processes of microlithization during the Pleistocene and Holocene in other parts of the world to identify the dynamics driving this development.

Hohle Fels is a large cave site in the Ach Valley of Southwestern Germany. It is situated on the right (i.e., the southern) flank of the valley, facing to the north. The Ach Valley is an archaeologically very rich micro-region with four key sites of Southern Central European Upper Paleolithic archaeology—Hohle Fels, Geißenklösterle, Sirgenstein, and Brillenhöhle, all located within a range of about five kilometres (Figure 1). The Lone Valley as the other important Paleolithic find region of the Swabian Jura—albeit apparently without layers from the Gravettian (cf. Taller et al. 2019)—is located about 30km northeast of the Ach Valley.

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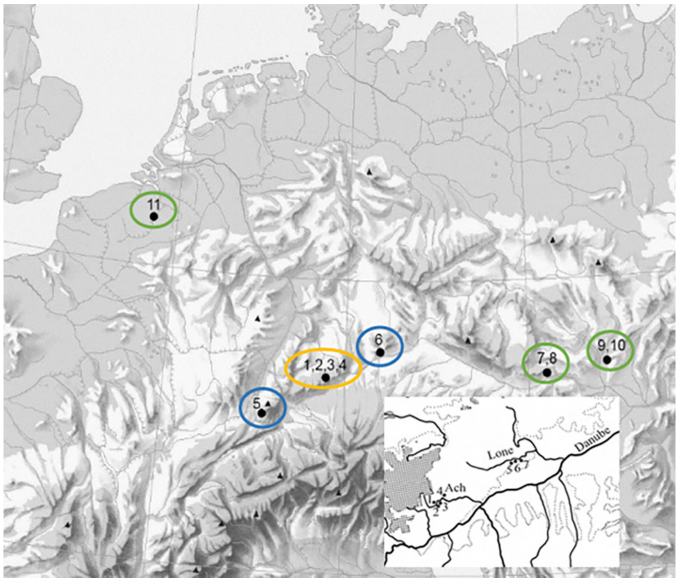

Figure 1. Selected sites of the earlier Gravettian. Green accentuation indicates an elevation of 0–300 meters above mean sea level (mamsl), blue indicates 300–500mamsl, yellow >500mamsl; 1: Hohle Fels, 2: Sirgenstein, 3: Geißenklösterle, 4: Brillenhöhle, 5: Steinacker, 6: Weinberghöhlen; 7: Willendorf II-5, 8: Krems-Wachtberg, 9: Dolní Věstonice, 10: Pavlov, 11: Maisières-Canal (created based on templates by the Instituto Geográfico Nacional de España, regional detail map after Conard and Bolus 2003).

Hohle Fels Cave is known for its outstanding Upper Paleolithic record including comprehensive assemblages from the Aurignacian (e.g., Bataille and Conard 2018; Conard and Bolus 2006, 2003), the Gravettian (Conard and Moreau 2004; Floss and Kieselbach 2004; Taller and Conard 2016; Figure 2), and the Magdalenian (Taller 2014).

The Aurignacian of the site is especially famous for its rich assemblage of ivory figurines and musical instruments (e.g., Conard 2009; Conard et al. 2009) as well as its early dates (Conard and Bolus 2003, 2008). The Gravettian of the Ach Valley also yielded comparatively early dates (Conard 2000, 2002; Conard and Bolus 2003; Taller and Conard 2016, 2019; for Geißenklösterle in particular: Higham et al. 2012; Moreau 2009a), which has led several researchers to postulate local origins of this Middle Upper Paleolithic entity out of the Aurignacian (Bolus 2010; Conard 2000, 2002; Moreau 2009a). The Gravettian assemblages of Hohle Fels show extensive similarities with those from Geißenklösterle, to the point that the dates from both sites are in good accordance (Higham et al. 2012; Moreau 2009a; Taller and Conard 2016, 2019). Objective evidence for a direct link of the Gravettian occupations of Hohle Fels and Geißenklösterle was obtained recently when a fragmented bladelet from Hohle Fels was refitted to a dihedral burin found in Geißenklösterle (Taller et al. 2019). The mosaic of Gravettian settlement in the Ach Valley was thus complemented in that it is now clear that three of the Gravettian sites (Hohle Fels, Brillenhöhle, and Geißenklösterle) were occupied simultaneously, and the fourth site, Sirgenstein, most probably was part of that settlement system too, as shared raw material units with all of the other sites are present, albeit without any direct refit yet (Moreau 2009a,b; Scheer 1990; Taller et al. 2019).

This means that the Hohle Fels-Gravettian is an important part of the Gravettian landscape in the Middle and Upper Danube region, alongside, in particular, sites such as Geißenklösterle, the Weinberghöhlen, and Willendorf II-5 (Moreau 2009a, 2010). Dates from Hohle Fels indicate a possible beginning of or transition towards the Gravettian here around or shortly after Greenland Interstadial (GI) 7 (Figure 3; cf. e.g., Svensson et al. 2006, 2008; Taller and Conard 2019). In GI 6, the Gravettian is already established in Hohle Fels (Jöris et al. 2010; Taller and Conard 2019); as is the case in Geißenklösterle (Higham et al. 2012; Moreau 2009a). This means an inception of the Gravettian sometime in the Denekamp-Interstadial (cf. also Bosinski 1989: 33).

Figure 3 moreover illustrates that in Hohle Fels the Gravettian ends shortly after the beginning of cooling phase Greenland Stadial (GS) 5, and well before the onset of Heinrich Event (HE) 3 later in this stadial. This led us to hypothesize a connection between environmental change and settlement activity in Hohle Fels and the Swabian Jura (Taller and Conard 2019). The Ach Valley Gravettian is thus especially well-suited to investigate the possible connection between paleoclimate, human behavior, and technological innovations. Here we address whether or not the innovations in the Gravettian lithic tool kits and technologies reflect reactions to a changing environment using archaeological data from Hohle Fels Cave.

THE CHANGING CLIMATE OF LATE MIS 3 AND ITS IMPACT ON PALEOLITHIC HUNTER-GATHERERS

The last few thousand years of MIS 3 were characterized by a series of abrupt climate changes (e.g., Rasmussen et al. 2014) that ultimately led to the maximum glaciation in MIS 2. Unfortunately, information on the vegetation development of late MIS 3 is scarce in southwestern Germany, as this sequence is not well represented in the regional geological record (Riehl et al. 2014). Studies are further hampered by erosion that affected some of the region's Gravettian deposits (Barbieri et al. 2017). Also, the closest big pollen profile in southern Germany in the Füramoos peat bog suffers from a hiatus between 40,000 and 14,000 ka BP (Müller et al. 2003), which means the critical part for our research is missing from this particular profile. We thus need to rely on information on paleoenvironments obtained from the sites themselves. For instance, a cooling trend is recognizable from the late Middle Paleolithic through the Aurignacian and especially towards the Gravettian in the faunal record of the Ach Valley caves (Münzel 2004, 2019). While during the Middle Paleolithic and Aurignacian prey species with quite different ecological requests, namely reindeer (*Rangifer tarandus*) red deer (*Cervus elaphus*), giant deer (*Megaloceros giganteus*), and roe deer (*Capreolus capreolus*), were present in Geißenklösterle Cave, during the Gravettian only red deer and reindeer remained, while the woolly rhinoceros (*Coelodonta antiquitatis*) appeared for the

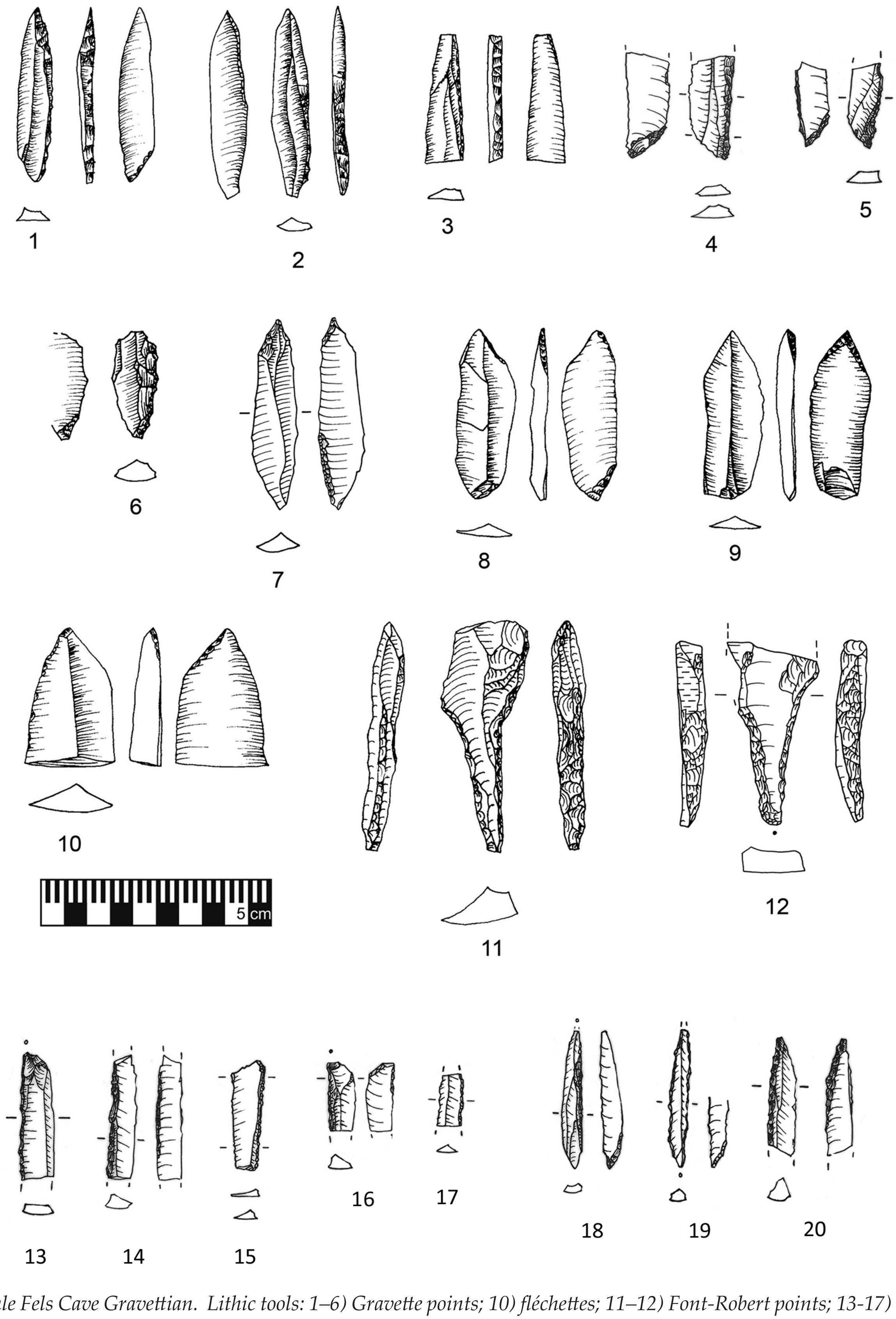

Figure 2. Hohle Fels Cave Gravettian. Lithic tools: 1–6) Gravette points; 10) fléchettes; 11–12) Font-Robert points; 13-17) backed pieces; 18–20) microgravette points (1: HF 56/2143, IIcf, 2: HF 55/1214, IIcf; 3: HF 79/1827, IIcf; 4: HF 32/253.1, IIc; 5: HF 77/955.19, IIcf; 6: HF 57/2493, IIcf; 7: HF 55/1259, IIc; 8: HF 67/1595, IIcf; 9: HF 68/1555, IIcf; 10: HF 57/2225, IIcf; 11: HF 77/621, IIcf; 12: HF 101/573, IIc; 13: HF 100/1079.3, IIcf; 14: HF 45/179.1, IIb; 15: HF 102/746.1, IIc; 16: HF 56/1900.1, IIc; 17: HF 56/848.4, IIc; 18: HF 100/891.1, IIc; 19: HF 56/1690.2, IIc, 20: HF 101/681.1, IIcf; modified after Taller and Conard 2016, Figures 6 and 7).

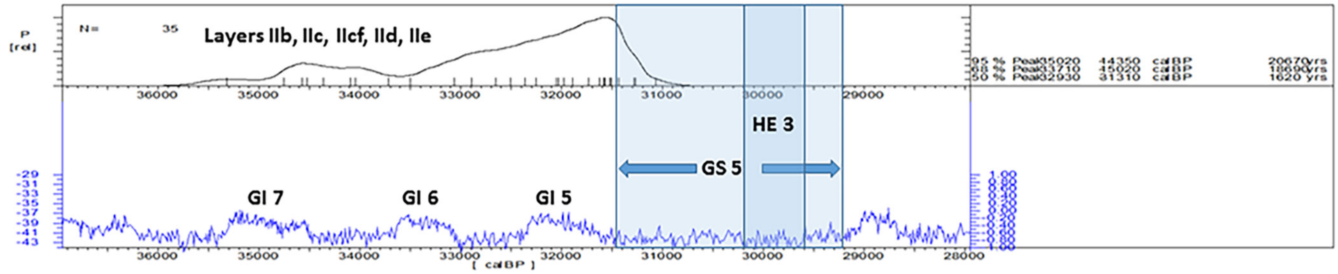

Figure 3. Hohle Fels Cave Gravettian. Radiocarbon dates cumulative graph (GI=Greenland Interstadial, GS=Greenland Stadial, HE=Heinrich Event; modified after Taller and Conard 2019). All dates calibrated with calpal (quickcal2007 ver.1.5, CalCurve: CalPal_2007_HULU), after Weninger et al. cal-pal online).

first time (Münzel 2019). These findings are complemented by an arrival of Saiga (*Saiga tatarica*) found at Brillenhöhle, indicating a shift towards cooler and more arid environmental conditions (Münzel 2004, 2019). The strong presence of hare/arctic hare (*Lepus europaeus/timidus*) during the Gravettian indicates a more open landscape at that time (Münzel 2019). Moreover, results from analyses of the avifauna from Geißenklösterle and Brillenhöhle support the model of an open, arid, and cool landscape during the Gravettian with abundant ptarmigan (*Lagopus*) and only few species indicating coniferous and mixed forest patches, which were presumably located along the river or in very protected areas (Krönneck 2019). During the Aurignacian on the other hand, avian species indicating the presence of deciduous forest (jay, *Garrulus glandarius* and hawfinch, *Coccothraustes coccothraustes*, Krönneck 2019), complement the finds of mammalian remains of *Capreolus capreolus*. Furthermore, micromorphological analyses in Hohle Fels and Geißenklösterle indicate cooler and drier conditions towards and particularly during the Gravettian as well (Miller 2015). Information from the record of small mammals documents a cooling trend during the Aurignacian in Swabia already (Rhodes et al. 2018, 2019).

In Hohle Fels Cave, constant cooling in the sense of increasingly cooler stadials as well as interstadials throughout the Gravettian up to HE 3 is apparent in the record of pollen and macro remains of plants (Riehl et al. 2014). At the end of the Gravettian, all indicators of arboreal plant vegetation have disappeared (Riehl et al. 2014). A regional signal from the Bergsee-pollen record in the Black Forest (ca. 200km southwest of Hohle Fels as the crow flies) complements the findings from Hohle Fels well in that it indicates very dry and cold conditions around 30 ka cal BP that probably mirror HE 3 (Duprat-Oualid et al. 2017). However, for the time preceding 30 ka cal BP, there is more or less evidence for an environment of a "boreal forest steppe" in Bergsee with *Pinus*, *Betula*, and some *Juniperus* (Duprat-Oualid et al. 2017: 1014), whereas in Hohle Fels arboreal indicators are already rare at the time and mostly consist of *Salix* and/or *Populus*, while pollen of *Artemisia* sp. are increasing (Riehl et al. 2014: 158 and 162). Also, the abundant use of bones for fuel in the Hohle Fels Gravettian suggests a reduced availability of woody plant vegetation (Riehl et al. 2014: 162); moreover, in Brillenhöhle extensive remains of burnt bones were found also in the Gravettian layers (Riek 1973). This discrepancy in both pollen records might be attributed to the location of the sites, or rather the altitude of their location. Hohle Fels is situated at 534m a.s.l. in the Swabian Highlands (Brillenhöhle at 600m a.s.l.), with the entrance of the cave facing northwards, whereas Bergsee lies considerably lower at only 382m a.s.l. and on a southern slope. It seems thus possible that the impact of a cooling climate is more pronounced or even drastic at the higher elevations of the Swabian Jura. The question is, why does the Gravettian settlement of the Swabian Jura end relatively abrupt around 31 ka cal BP, when the Gravettian as such continues in the west (Bosselin and Djindjian 1994; Bradtmöller et al. 2012; Djindjian and Bosselin 1994; Terberger 2003), the south (e.g., Mussi 2000, 2004) and the east (e.g., Reynolds et al. 2015) of Europe for several millennia (Figure 4). Even in neighboring eastern Central Europe, namely in Moravia, the Gravettian sequence extends to ca. 24 ka cal BP (e.g., Jöris and Weninger 2004; Wilczyński et al. 2019). Two scenarios are possible in that respect: either a depopulation of Southern Central Europe through migration (west-, east- or southwards) of the regional Gravettians, or even local extinctions of some of these groups (Maier and Zimmermann 2017); both are potentially possible as a result of the climatic deterioration at the end of the last Interpleniglacial when summer insolation started to drop significantly while temperature started to decline (Maier and Zimmermann 2017). A first negative peak was reached in GS 5 which coincided with HE 3, and later the climatic development culminated in the last glacial maximum (LGM) in GS 2 from ca. 26.5–19 ka BP (Clark et al. 2009). The Swabian Highlands are susceptible to continental climatic influences still today, as the Danube valley opens wide towards the east (Weniger 1982). This means that even today´s climate in the Swabian Jura is sometimes influenced by continental weather conditions and can be labelled as "moderately continental" (Eriksen 1991).

A migration to the South and Southwest of the continent will inevitably lead into an environment with a more clement kind of climate; indeed, the Southwest of France has to be viewed as a refugium in the time preceding and surrounding the LGM (e.g., French and Collins 2015; Jo-

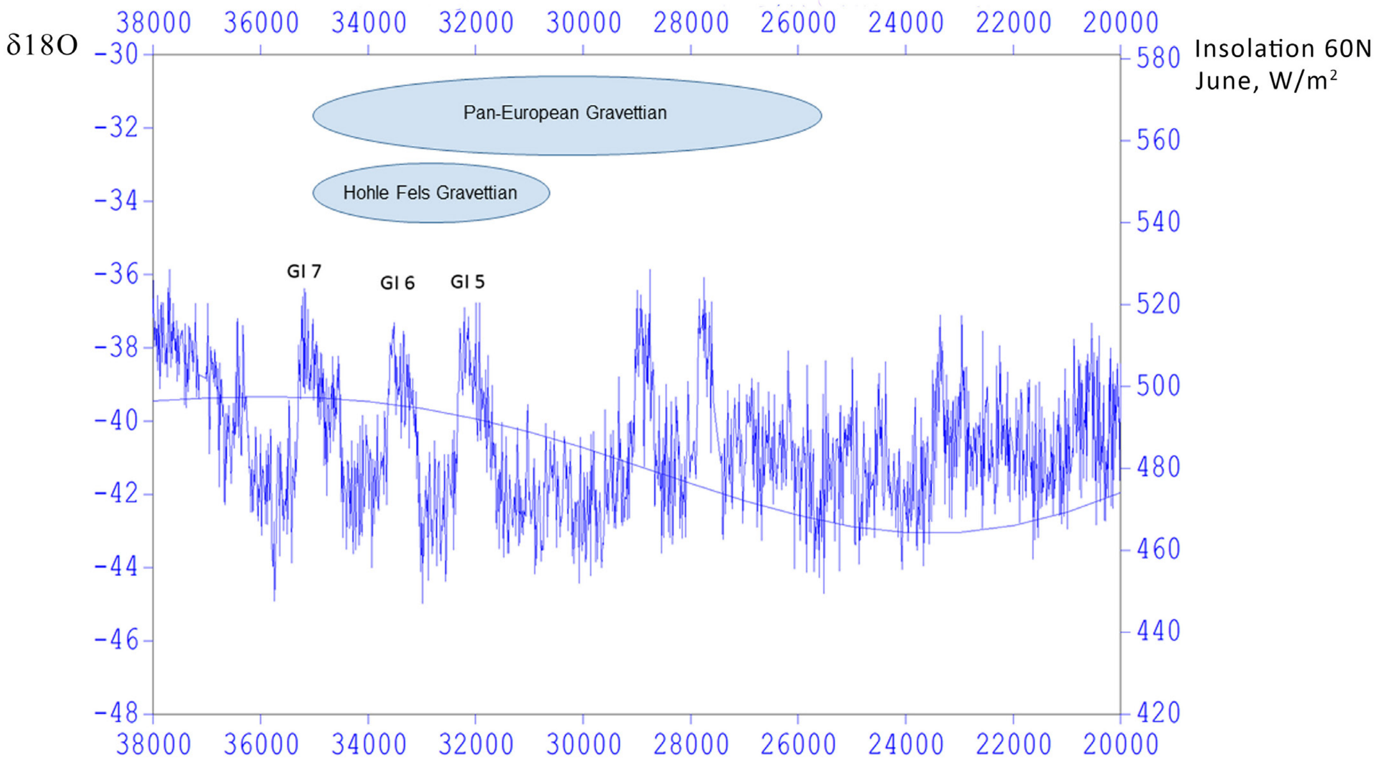

Figure 4. Climate and insolation during the Gravettian; ages are cal BP (data from calpal, after Weninger et al., cal-pal online; temperature indicated by $\delta^{18}O$-values from GISP-2 high, insolation shown as a line and indicated in watts per m^2 for 60°N.

chim 1987). Moreover, in most cases the Eastern and Western European sites are situated at considerably lower elevations than those of the Swabian caves. Concerning other Central European sites and site clusters of the earlier Gravettian (e.g., in Germany, Austria, and the Czech Republic, see Figure 1), they are largely situated along the river valleys, often of the Danube or its tributaries, and usually have an elevation of about 250m above mean sea level (amsl) or below (e.g., Svoboda et al. 2000); after 31 ka cal BP, no Gravettian sites are found above 500mamsl in Central Europe.

The sites of the Middle Danube area have consequentially already been highlighted as possible areas of "*a slight aggregation of the remaining population*" during the Gravettian of Central Europe (Maier and Zimmermann 2017: 584), and a continuous settlement throughout GS 5 is documented there (Jöris and Weninger 2004: 66). It seems thus possible that the milder climate of regions with a lower elevation and/or a more southerly location offered improved living conditions from GS 5 onwards compared to the situation on the Southern German Highlands. The only exception to this trend could—possibly—be Obłazowa Cave in Southern Poland, located at approx. 670mamsl on the Białka-pass in the Western Carpathians (Valde-Nowak 2015) and famous for the find of a boomerang made from a mammoth-tusk (Valde-Nowak et al. 1987). However, this site will not be considered in our assessment here since the Gravettian character of the assemblage of the site is questionable, as there are only 52 lithic artifacts, and none of them is diagnostic (Moreau 2009a). And the very old dates of up to 37–38 ka cal BP would not be out of place in a late Aurignacian context (Moreau 2009a: 300–302). Indeed, in the Swabian sites this is the time of the late Aurignacian (e.g., Bataille and Conard 2018; Conard and Bolus 2008). Whatever the cultural attribution of the remains dated in Obłazowa Cave, the timespan they belong to clearly offered more agreeable climatic conditions (cf. Figures 3 and 4) than the subsequent period during which the Central European Gravettian societies first thrived and later declined.

A primary settlement of areas with lower elevation after the onset of cooling phase GS 5 makes particular sense applied to the case of the region examined here, if we view (Southern) Central Europe as "*a narrow steppic belt that provided a corridor for communication between non-glaciated regions in the west and east of the continent*", as was proposed by J. Svoboda et al. (2000: 198). Since the role of river valleys as axes of communication in the Paleolithic is well established (e.g., Alvarez Fernandez 2001; Conard 2000; Conard and Bolus 2003; Floss 2000; Floss and Kieselbach 2004), it is also striking that most of the earlier Central European sites of the Gravettian lie directly on or at least in the vicinity of the east-west oriented Danube corridor (see Figure 1). While it is admittedly difficult to identify the equivalent of Heinrich 3, in the sense of the ice-calving events into the North Atlantic, at Paleolithic sites from southern Central Europe, it is clear that available local and regional paleoenvironmental data from the period in question indicate de-

TABLE 1. HOHLE FELS CAVE GRAVETTIAN (all lithics from all Gravettian layers).

Layer	Lithics >1cm (entered in database)	Modified Pieces (entered in database)	Inventory in Database Total	Pieces <1cm (only counted)	Total
IIb	2,926	392 (11.8% of all lithics >1cm; 3.4% of all lithics)	3,318	8,046	**11,364**
IIc	3,377	343 (9.2% of all lithics >1cm; 3.8% of all lithics)	3,720	5,288	**9,008**
IIcf	5,548	300 (5.1% of all lithics >1cm; 2% of all lithics)	5,848	8,704	**14,552**
IId	1,131	120 (9.5% of all lithics >1cm; 3.3% of all lithics)	1,251	2,368	**3,619**
Total	**12,982**	**1,155**	**14,137** (+166) =14,303	**24,406**	**38,543** (+166) =38,709

clining temperatures and changing compositions of flora and fauna. These findings are in accordance with the $\delta^{18}O$ records from Greenland ice cores (cf. e.g., Dansgaard et al. 1993; Svensson et al. 2006, 2008). Thus, we assume that the global climatic shift of MIS 3 is mirrored in paleoclimate in Central Europe and that the changing climate must have affected human populations from 35 ka cal BP onwards.

LITHIC TECHNOLOGY OF THE GRAVETTIAN IN HOHLE FELS CAVE

Here, we focus on the mode of production of lithic blanks used for tool manufacture. In Table 1 we give an overview for the upt to now more than 38,000 lithic remains from the Hohle Fels-Gravettian regarding their distribution in the stratigraphy. To these numbers, 166 lithics have to be added; these are pieces of unclear stratigraphic origin (regarding their exact original layer, but still clearly from the Gravettian strata, e.g., from profile collapse, see Table 1).

After evaluating the assemblage from Layer IId in the last publication on the topic (Taller and Conard 2016), it was concluded that these lithics indeed represent Gravettian as well, thus the assemblage was added to the compilation. And, even though, the artifact count from IId has grown significantly since then, the assemblage still clearly differs from all other layers with regard to artifact numbers. This is due to the fact that the sediments containing these pieces seem to have been subject to some reworking, which has led to an incomplete preservation of the layer and the associated artifacts (Taller and Conard 2016, Taller et al. 2019). Nevertheless, the assemblage is clearly of Gravettian character and must thus be included in the analysis. For the analysis, laminar blanks with a length equalling at least two times their width are classified as blades when the width exceeds 10mm, blanks with a width <10mm are categorized as bladelets. In the following section we introduce the assemblages from all four Gravettian layers of Hohle Fels, and after that we discuss the implications for the technological approach of Gravettians to lithic blank and tool production.

LITHIC ASSEMBLAGES FROM THE GRAVETTIAN

In this section, we will present short recapitulations of the Gravettian assemblages with some basic numeric information before discussing lithic technology in more detail in the following paragraph.

The assemblage of Horizon IIb. In IIb, 32 cores, 760 blades (97 complete), 769 bladelets (98 complete), 154 preparational flakes, 108 burin spalls, and 957 flakes were found; 392 blanks were modified and made into tools (Table 2). In this horizon, a mixing with Magdalenian sediments and artifacts is documented in the northeastern part of the excavation (Taller and Conard 2016, 2019). This intrusion is at least partly responsible for the massive amount of backed pieces in the tool spectrum.

Of the 392 tools (Table 3), 193 (49%) were made on local and regional Jurassic chert; radiolarite is the second most frequent lithic raw material with 87 (22%) pieces. Lydite (45 pieces; 11.5%) and pisolithic chert (*Bohnerzhornstein*, 30 pieces; 8%) are the third and fourth most abundant materials; other lithic materials include tertiary cherts, chalcedony, *Keuper*- chert, tabular cherts and quartzite (9.5% in total). The shares of lithic raw materials in the whole assemblage differ from that among tools in that Jurassic chert is considerably higher with 66%, whereas radiolarite pieces amount to 18%. Other raw materials present in comparatively noteworthy numbers are pisolithic chert (5%), tertiary chert (2%), and tabular chert (1%, cf. Taller and Conard

TABLE 2. HOHLE FELS CAVE GRAVETTIAN TOOLS OF LAYER IIb ACCORDING TO BLANK TYPE.

made on→ tools total ↓	Bladelets	Blades	Flakes	Preparation Waste Products	Burin Spalls	Indeterminant Blanks
392	153	147	48	14	17	13

TABLE 3. COUNT AND PERCENTAGES OF TOOL TYPES IN LAYER IIb.

Tool Type	Count	%
backed pieces	133	33.9
laterally retouched pieces	113	28.8
end retouched pieces	39	9.9
burins	28	7.1
perforators	16	4.1
endscrapers	14	3.6
Gravette points	4	1
microgravette points	15	3.8
fléchettes	6	1.5
Font-Robert points	1	0.3
pointed blades	3	0.8
combinations	8	2
splintered pieces	4	1
other	8	2
Total	**392**	

TABLE 4. HOHLE FELS CAVE GRAVETTIAN TOOLS OF LAYER IIc ACCORDING TO BLANK TYPE.

made on→ tools total ↓	Bladelets	Blades	Flakes	Preparation Waste Products	Burin Spalls	Indeterminant Blanks
343	82	152	66	23	8	12

2016).

The assemblage of Horizon IIc. In IIc, 54 cores, 846 blades (143 complete), 665 bladelets (98 complete), 199 preparational flakes, 112 burin spalls, and 1304 flakes were found; 343 lithics were modified and made into tools (Table 4). Of 343 tools (Table 5) 216 were made on Jurassic chert (63%), and 94 on radiolarite (27%). Other raw materials include *Keuper*- and pisolithic as well as tertiary cherts, plus a few pieces in quartzite and lydite, amounting to a total of almost 10%. The whole lithic assemblage is composed of 69% Jurassic chert, 25% radiolarite, and 3% pisolithic chert. The pieces of tertiary and tabular cherts as well as quartzite and lydite amount to about 3% in total (cf. Taller and Conard 2016).

The assemblage of Horizon IIcf. In IIcf, 67 cores, 1,021 blades (206 complete), 997 bladelets (156 complete), 331 preparational flakes, 79 burin spalls and 2,755 flakes were found; 300 lithics were modified and made into tools (Tables 6 and 7). The raw materials used for tool production are even less varied than in IIc: here, 241 (more than 80%) of all 300 tools were manufactured on local/regional cherts, whereas a mere 43 radiolarite-blanks (ca. 14%) were used. A few pieces of pisolithic and *Muschelkalk*- chert, lyddite, and quartzite amount to a total of about 6%. Regarding the whole assemblage, the picture becomes even more pronounced, as 91% of all lithics are Jurassic cherts. Radiolarite pieces amount to 5%, and pisolithic cherts provide 2% of the spectrum (cf. Taller and Conard 2016).

TABLE 5. COUNT AND PERCENTAGES OF TOOL TYPES IN LAYER IIc.

Tool Type	Count	%
backed pieces	55	16
laterally retouched pieces	113	32.9
end retouched pieces	49	14.3
burins	31	9
perforators	14	4.1
endscrapers	12	3.5
Gravette points	1	0.3
micrograpvettes	22	6.4
fléchettes	6	1.7
pointed blades	1	0.3
Font Robert points	2	0.6
combinations	22	6.4
splintered pieces	1	0.3
other	14	4.1
Total	**343**	

TABLE 6. HOHLE FELS CAVE GRAVETTIAN TOOLS OF LAYER IIcf ACCORDING TO BLANK TYPE.

made on→ tools total ↓	Bladelets	Blades	Flakes	Preparation Waste Products	Burin Spalls	Indeterminant Blanks
300	67	120	77	21	9	6

TABLE 7. COUNT AND PERCENTAGES OF TOOL TYPES IN LAYER IIcf.

Tool Type	Count	%
backed pieces	26	8.7
laterally retouched pieces	101	33.7
end retouched pieces	49	16.3
burins	29	9.7
perforators	5	1.7
endscrapers	10	3.3
Gravette points	8	2.7
Microgravettes	26	8.7
Fléchettes	12	4
pointed blades	3	1
combinations	9	3
splintered pieces	9	3
other	13	4.3
Total	**300**	

TABLE 8. HOHLE FELS CAVE GRAVETTIAN TOOLS OF LAYER IId ACCORDING TO BLANK TYPE.

made on→ tools total ↓	Bladelets	Blades	Flakes	Preparation Waste Products	Burin Spalls	Indeterminant Blanks
120	29	51	24	2	4	10

TABLE 9. COUNT AND PERCENTAGES OF TOOL TYPES IN LAYER IId.

Tool Type	Count	%
backed pieces	9	7.5
microgravettes	7	5.8
gravettes	1	0.8
fléchettes	4	3.3
splintered pieces	2	1.7
burins	31	25.8
endscrapers	9	7.5
pointed blades	1	0.8
end retouch	6	5.0
lateral retouch	41	34.2
perforator	1	0.8
sidescrapers	5	4.2
hammerstones	2	1.7
indet	1	0.8
Total	**120**	

The assemblage of Horizon IId. In IId, 19 cores, 253 blades (40 complete), 182 bladelets (29 complete), 32 preparational flakes, 56 burin spalls, and 245 flakes were found; 120 lithics were modified and made into tools (Tables 8 and 9). The lithic assemblage is dominated by Jurassic chert (91%), with only a few pieces of radiolarite (>5%) and pisolithic chert (2%; cf. Taller and Conard 2016).

LITHIC TECHNOLOGY: SUMMING UP

In this section, the focus will be on the process of lithic blank production. The lithics from all layers are treated as one analytical unit.

In the Gravettian layers of Hohle Fels, a total of 5,539 laminar blanks (2,905 blades, 2,634 bladelets) was found. However, among all of the 14,141 Gravettian lithics >1cm, only 7,107 artifacts are either complete or exhibit a proximal end, which means that this is the minimum number of knapped blanks. Of these, 3,107 belong to the laminar production chain in general, that is, including preparational products such as crested blades, core tablets, and removal surface renewals along the laminar blanks as such. Among the latter, there are at least 1,413 blades and 1,080 bladelets as the desired products with a preserved proximal end which thus amount to a total of 2,493 artifacts as a minimum number of laminar blanks in the site. The composition of the assemblage from Layer IIcf with its share of more than 90% of local and regional Jurassic chert and a large collection of small debitage and striking debris indicates comprehensive knapping activities of Jurassic chert at Hohle Fels. The fact that around half of all 4,564 pieces with cortex comes from IIcf strengthens this impression. So even though we cannot exclude that prepared cores or finished blanks or tools were brought into the site, processing of local and regional lithic raw materials seems to have been executed routinely during the Gravettian in Hohle Fels; even more so because a considerable 946 artifacts from all layers exhibit a cortex coverage of more than 50%. Initial preparation of the cores included decortication and the initialization of laminar blank production through the removal of a primary crested blade to create a ridge to guide further (blank) removals. Table 10 lists the 684 preparational removals categorized according to their function. Regarding the striking techniques, we found indications for the presence of soft direct percussion (with an antler hammer), soft mineral percussion (with e.g., a sandstone hammerstone) and hard direct percussion (with a hammerstone). Comprehensive knapping with an antler hammer is indicated in the 3,752 proximal parts of blanks that exhibit a continuous lip on the ventral side of the striking platform remains; 2,192 of these platform remains have a

TABLE 10. HOHLE FELS CAVE GRAVETTIAN TYPES OF PREPARATIONAL REMOVALS FROM LAYERS IIb, IIc, AND IIcf.

Type	N
natural primary crested blade	5
primary crested blade unilateral	182
primary crested blade bilateral	24
secondary crested blade unilateral	64
secondary crested blade bilateral	2
crested flake	10
core tablet	10
striking platform preparation	49
removal surface renewal	36
preparational flakes indet.	302
Total	**684**

smooth surface, while 2,124 show an elongated, often oval shape of the remaining platform. Platform edges are usually abraded to prevent the edge from splintering upon impact; proper dorsal reduction was visible on 1,475 pieces. The use of a soft mineral hammer is indicated in the presence of very narrow, abraded, basically edge-like or punctiform platform remains (n=2,229); these are sometimes accompanied by splintered bulbar parts (*esquillement du bulbe sensu* Pelegrin 2000: 79). In the Gravettian of Hohle Fels, this *esquillement du bulbe* is present in 56 of the aforementioned pieces thus substantiating the suspected use of a soft mineral hammer in these cases. In this context it is important to note that the stigmata created by either striking technique can be very similar and sometimes some attributes will overlap (Pelegrin 2000: 78). Finally, the use of a hard hammerstone is indicated in relatively deep platform remains (up to more than one centimeter), which are often facetted or cortex-covered, sometimes impact-rings are visible; pronounced bulbs are sometimes present on the ventral faces (more than 400). This striking technique was most frequently used in coarser actions such as decortication, core-shaping, core preparation, or initiation of the blank production process. In general, and regarding blank production specifically, soft organic and soft mineral hammers seem to have been the main tools in lithic reduction actions. From the Gravettian of Geißenklösterle, two sandstone-hammers with impact marks are direct evidence for the use of soft mineral percussion at that site (Moreau 2009a:107). Given that there is a direct refit of lithics between Hohle Fels and Geißenklösterle (Taller et al. 2019), we can extend this finding to Hohle Fels as well.

In Table 11, cores from all layers are listed according to the blank type that was produced; shape and organization of the cores is presented in Table 12.

Blade cores and cores with blade as well as bladelet-negatives in the cases of IIb and IId are even with each other; in IIc and IIcf the latter are more numerous (see Table 11). Cores with only bladelet negatives are few in all layers, with six as the highest count in IIb and a continuous decline down the stratigraphy (see Table 11). Cores in the initial stage of production or prepared nodules are rare, although the seven pieces from IIcf are notable in that respect. However, IIcf is very find-rich overall and displays evidence for extensive blank production, which in this case most probably accounts for the higher number of artifacts. Overall, cores with reduction faces showing negatives of blade- as well as bladelet removals are most frequent, closely followed by pure blade cores. In contrast to that,

TABLE 11. HOHLE FELS CAVE GRAVETTIAN CORE-TYPES ACCORDING TO BLANK PRODUCTION.

Layers→ Negatives ↓	IIb	IIc	IIcf	IId	All Layers
blades	9	18	19	8	**54**
blades and bladelets	9	25	21	8	**63**
bladelets	6	5	3	1	**15**
initial cores	2	1	7	1	**11**
indeterminate broken cores[1] (non-diagnostic)	6	5	17	1	**29**
Total	**32**	**54**	**67**	**19**	**172**

there are only few pure bladelet cores. Bladelet production seems to have been carried out in three different scenarios—first, in the course of an "embedded" production in the process of the laminar operation chain (*production lamellaire intégré,* after Moreau 2009a: 99). This implies that after the initialization of a given nodule as a laminar core and removal of blades with a subsequent reduction in size of the core volume, also the produced blanks became smaller and eventually have to be classified as bladelets. This mode of bladelet production has been detected as the paramount method in the Geißenklösterle-Gravettian, based on the disproportional relationship between the many blades in the assemblage and the very few actual blade cores and, on the other hand, very frequent and small bladelet cores (Moreau 2009a: 99). However, in contrast to that, in Hohle Fels we see an indication for a second mode of manufacture, namely, the so called "intercalated" production of bladelets (Bon and Bodu 2002; Digan 2006: 137–138; Klaric 2003: 358–362;), where bladelets are produced in the course of general laminar core reduction, but not necessarily as a result of core diminuition.

This results from—as becomes clear in Figure 5—the unfragmented blades and bladelets,which apart from the critical difference in width, differ significantly in length. Complete blades have a mean length of 44.4mm (median 42.3mm), the mean length of complete bladelets is 18.0mm (median 16.9mm); for complete burin spalls the values are 20.4mm (mean) and 18.7mm (median). And whereas the removal surfaces of cores and the blades fit well together regarding their respective length, bladelets are considerably shorter. Cores that fit the length of bladelet,s on the other hand, are very rare, which hints at an intercalated bladelet production in the course of the general laminar reduction chain and not necessarily exclusively due to a reduction of the core size. There is thus very little overlap in length distribution between blades and bladelets, which further supports the hypothesis of an intercalated production of bladelets, along with the fact that several blades display negatives of bladelets on their dorsal faces (Figure 6).

The third way to produce smaller, bladelet-like blanks is the detachment of burin spalls (n=359). These artifacts have repeatedly been used as blanks for tool production in at least 38 cases. Numerically, the blank production on burins is, however, only of relative significance and clearly less important than regular blade and bladelet production.

Figure 7 shows two important features of the lithic blanks produced in the Gravettian of Hohle Fels. First, in terms of the width-to-thickness ratio, there is indeed a perceptible degree of continuity between blades and bladelets, aside from their differences in length discussed above. In terms of width, blades have a mean value of 15.1mm (median 13.9mm), and bladelets have a mean of 6.7mm (median 6.8mm). Burin spalls however differ clearly from both blades and bladelets regarding blank calibre (mean: 5.3mm; median: 4.9mm). This feature, along with their often triangular cross-section and greater thickness predestines them as blanks for tools for perforating purposes, as has already been demonstrated for the Magdalenian of Hohle Fels Cave (Taller 2014: 117–118). Bosinski noted the modification of these blanks into perforators also for the Gravettian in the German Rhineland (Bosinski 2008: 255). Moreover, these burin-spall borers need little to no retouch, as the sturdy, tri-or rectangular cross-section is already suitable for perforating, and they often possess a natural point at the tapering distal end, being a detached edge of a blank.

Regarding the general layout of blank production, Table 12 presents the morphological differences of core types and layout in terms of numbers of removal surfaces and striking platforms.

Conical cores. All of the nine conical cores exhibit only one removal surface, although this face can span up to more than half of the circumference of the piece (Figure 8a). The unidirectional negatives in most cases form a more or less convergent pattern thus determining the shape of the core. The conical cores are the least frequent in the Gravettian of Hohle Fels, presumably because the blanks from such cores can sometimes be twisted, due to the convergent distal part; the blanks desired by the Gravettians were, however, supposed to be as straight as possible, which explains the relative infrequence of conical cores. In a few cases, however, it is not tapering negatives that are responsible for the conical shape, as sometimes this is determined by the morphology of the nodule, and in these instances the negatives show removals of straight and parallel rather than twisted, converging blanks (Figure 8b).

Cylindrical cores. The cylindrical cores are in some cases similar to the conical ones; namely, the removal surface can circulate around more than half of the volume. In these cases, only the general shape (i.e., lack of distal tapering due to converging negatives) distinguishes these cores from conical pieces; the technological approach is basically the same minus the tapered progression of blank removals. These cores, with their often prismatic appearance, are more apt for the production of straight blanks than the conical layout discussed above (Figure 9). In some cases, a second striking platform has been implemented at the foot of the core. These were either used for maintenance purposes or document an earlier cycle of blank removals (see Figure 9a).

Narrow faced cores. This second most frequent class of cores is characterized by the removal of laminar blanks on the narrow side of the volume, which in some cases consists of a thick flake or even debris. Most of these specimens (n=26/96%) exhibit a single removal surface, although in four cases (ca. 15%) a second striking platform at the distal end was used (e.g., Figure 10c). This second platform was typically used for purposes of core maintenance or for a second run of blank production after the first striking platform became unusable, as the refitting sequences in Figure 11 show.

Figure 11 also shows another connection between two core morphologies distinguished in Table 12—the remaining cores (without the refitted blanks and preparational removals) would classify as "cylindrical." However, as becomes clear when considering the whole refitting sequences, these cores would initially have to be classified as narrow faced cores.

TABLE 12. HOHLE FELS CAVE GRAVETTIAN LAMINAR CORE TYPES ACCORDING TO SHAPE AND PRODUCTION MODE.*

Layer→ / Core type↓	IIb (n=25)	IIc (n=53)	IIcf (n=50)	IId (n=19)	Total n=147
conical	n=1 RS: 1: 1x SP: 1: 1x	n=7 RS: 1: 7x SP: 1: 7x	n=0	n=1 RS: 1: 1x SP: 1: 1x	**n=9** RS: 1: 9x SP:1: 9x
cylindrical	n=5 RS: 1: 5x SP: 1: 5x	n=10 RS: 1: 7x; 2: 3x SP: 1: 3x; 2: 6x; 3: 1x	n=11 RS: 1: 10x; 2: 1x SP: 1: 6x; 2: 5x	n=2 RS: 1: 2x SP: 1: 2x	**n=28** RS: 1: 24x; 2: 4x SP: 1: 16x; 2: 11x; 3: 1x
removals on narrow face	n=8 RS: 1: 8x SP: 1: 7x; 2: 1x	n=6 RS: 1: 6x SP: 1: 4x; 2: 2x	n=5 RS: 1: 4x; 3: 1x SP: 1: 4x; 2: 1x	n=8 RS: 1: 8x SP: 1: 8x	**n=27** RS: 1:26x; 3: 1x SP: 1: 23x; 2: 4x
broad surface cores	n=3 RS: 1: 2x; 2: 1x SP: 1: 2x; 2: 1x	n=3 RS: 1: 2x, 2: 1x SP: 1: 1x; 2: 2x	n=7 RS: 1:6x; 2: 1x SP: 1:3x; 2: 4x	n=4 RS: 1: 3x; 3: 1x SP: 1: 2x; 2: 2x	**n=17** RS: 1: 13x; 2: 3x; 3: 1x SP: 1: 8x; 2: 9x
compact/multiple removal surfaces	n=8 RS: 1: 5x; 2: 2x; 3: 1x SP: 1: 4x; 2: 4x	n=27 RS: 1: 13x; 2: 13x; 3: 1x SP: 1: 5x; 2: 14x; 3: 8x	n=27 RS: 1: 3x; 2: 18x; 3: 5x; 4: 1x SP: 1: 3x; 2: 15x; 3: 9x;	n=4 RS: 1: 2x; 2: 1x; 3: 1x SP: 1: 3x; 2: 1x	**n=66** RS: 1: 23x; 2: 34x; 3: 8x; 4: 1x SP: 1: 15x; 2: 34x; 3: 17x
Total	**25**	**53**	**50**	**19**	**RS: 1: 95x; 2: 41x; 3: 10x; 4: 1x ------------- SP: 1: 71x; 2: 58x; 3: 18x**

*all layers; numbers of cores incorporated in the investigation per layer given in brackets, RS: removal surface, SP: striking platform

Broad surface cores. On these cores, blank production was carried out on a usually broad face of the volume, opposed by a flat, often cortical back (Figure 12). Still, there are a few pieces with more than one removal surface.

Compact cores/multiple removal surfaces. The cores of this largest category are relatively heterogeneous regarding their layout, and multiple removal surfaces are most frequent among these pieces (Figure 13), there are configurations with up to three or four removal surfaces (see Figure 13a, b). When two or more removal surfaces are present, they can be adjacent to each other, or on the opposite end of the volume. Multiple striking platforms can be opposed on the back and front of the core or on the proximal and distal end; perpendicular configurations are also possible (e.g., see Figure 13b). However, the reduction phases of the individual removal faces are exploited independently from each other and there usually is a chronological succession.

As Table 12 illustrates, the most common feature among the 147 cores suitable for a technological analysis is a configuration around one removal surface (n=95, this equals ca. 65%), and in 71 (or ca. 48%) cases, the single removal surface was exploited from only one striking platform. The fact that several cores with a single reduction surface exhibit a second striking platform does not necessarily imply a bidirectional removal of blanks (see above, this course of action was observed very rarely; see Figure

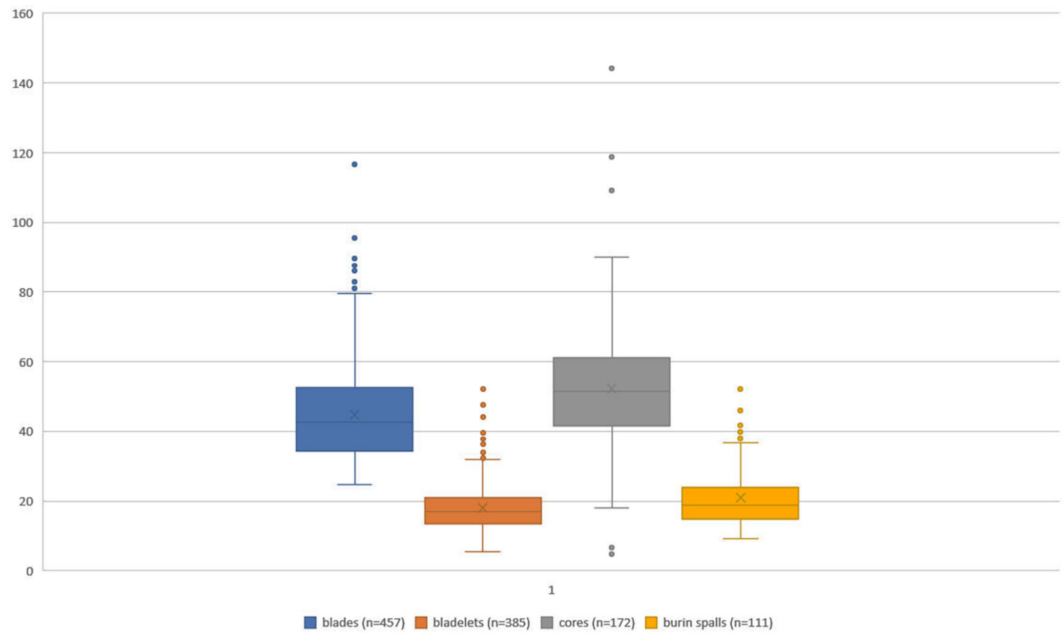

Figure 5. Hohle Fels Cave Gravettian. Boxplot of lengths of complete blades, bladelets, burin spalls, and removal surfaces of remaining cores from all layers.

6d), as often the second striking platform only served as a means of core maintenance in the distal part, e.g., in order to keep the frontal convexity pronounced enough to prevent overshooting of the termination (see Figures 6a, 9a, 10c; cf. also Moreau 2009a: 167). Moreau (2009a: 167–168) has observed and described a similar mode of conduct in the laminar blank production of Gravettian Geißenklösterle, where several cores showed two opposing striking platforms on a single removal surface, but where, in fact, only one of them was used in the actual reduction process, and the other served for core maintenance purposes. This means that the "logic of the core reduction" was unidirectional (Moreau 2009a: 167). This finding also holds true for core configurations with more than two striking platforms and removal surfaces—in virtually all of these cases, each configuration was used in a succession, and the goal seems to always have been to maintain the interplay between one removal surface and one striking platform for as long as possible. Indeed, 88% (n=4,225) of the record of dorsal faces of all blades and bladelets from the Hohle Fels-Gravettian (n=4,799) show negatives indicating unidirectional removals exclusively, which further supports the statement of a general pattern of blank production. If the combination of a removal surface and striking platform became exhausted (e.g., due to inapt angles or overshot removals), maintenance and repair were attempted; only if there was no way of restoring usability was the core turned and a new removal surface opened. And—again—only if that was not an option, either due to the small nodule size or for other reasons (e.g., maintenance and repair too difficult or costly regarding material loss), was the core discarded. That way, the highest potential yield in terms of blank production of a given raw nodule was possible, which is especially important when the raw blocs are as small as they are in the sites of the Swabian Jura (usually around ten centimeters, as has been observed, e.g., by Schmidt 1912; Schuler 1994; Moreau 2009a; Taller 2014). This is the reason why the core types or configurations (see Table 12) seem in fact to be secondary in the technological sense—the paramount goal of Gravettian knappers was to establish a sustainable combination of a striking platform and removal surface and work with it. If possible, this interplay was pursued to the exhaustion of the core nodule. However, if the interplay had to be abandoned, but the raw material nodule still allowed the implementation of a second removal surface due to size and/or shape, it was attempted. The shape of the remaining cores does thus not seem to be predetermined thoroughly by the technological course of action during blank production, but rather to depend on raw nodule size, shape, and properties. The fact that three distinct core morphologies seem to be interconnected technologically and, in fact, in some cases just represent different stages of core reduction/blank production, further supports this hypothesis. If the reduction process was successful, the remaining cores usually present one or several removal faces with prismatic surfaces, independent of the shape of the core.

DISCUSSION AND CONCLUSION: WERE THE GRAVETTIAN TECHNOLOGICAL INNOVATIONS TRIGGERED BY CLIMATIC CHANGE?

The production of standardized long, narrow and straight blades and bladelets opens up the possibility of a more or less thorough standardization of parts of the toolkit (e.g., Bolus 2012a; Moreau 2009a). The importance of the production of standardized laminar blanks on prismatic cores

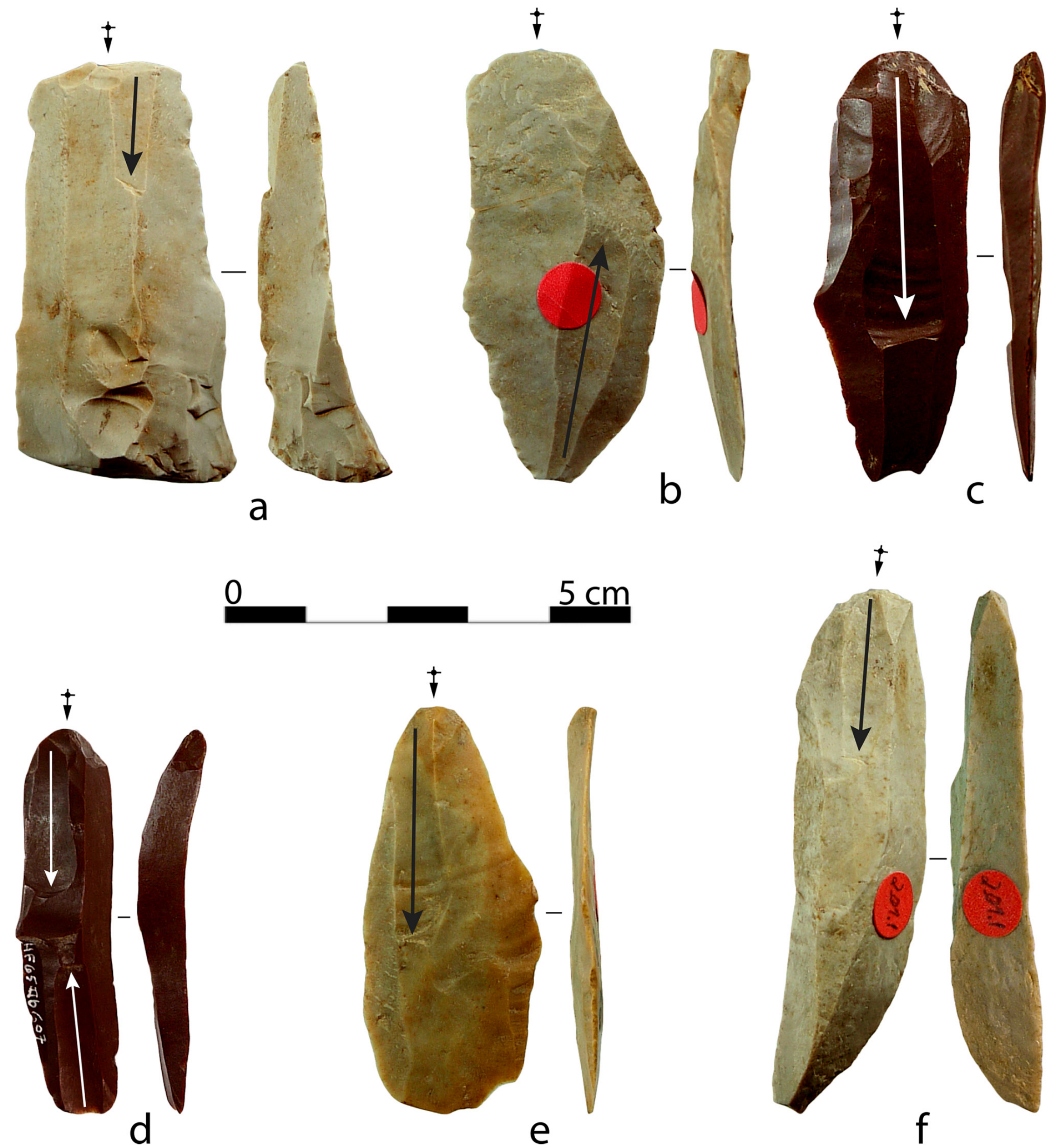

Figure 6. Hohle Fels Cave Gravettian. Blades displaying bladelet negatives on their dorsal face (a: HF 100/815, IIc; b: HF 58/711, IIc; c: HF 57/1002, IIc; d: HF 65/607, IIb; e: HF 58/1531, IIc; f: HF 67/1830, IIc; photograph by A. Falcucci).

for the manufacture of composite tools has been discussed before (e.g., Bar-Yosef and Kuhn 1999). The production of regular laminar blanks simplifies the maintenance of generalized tools as well as specialized hunting equipment. Moreover, the volumetric mode of blade- and bladelet-production also allows for an economic use of the core volume, which is of special importance considering the relatively small size of the lithic raw nodules used in the Swabian caves. In this context it is interesting to note the emergence of radiolarite as an important lithic raw material in the Gravettian of the Ach Valley compared to the preceding local Aurignacian, during which this raw material plays little to no role. This finding led L. Moreau (2009a: 91) to postulate a connection between technological sophistication and the increased knapping of this often very fine-grained and homogenous material, as it is well-suited for the standardized, serial production of the blanks used by Gravettian knappers at Hohle Fels and Geißenklösterle. Other explanations for the absence of radiolarite in the Middle Paleolithic and the Aurignacian of the Swabian Jura suggest a reduced accessibility of radiolarite in that time, probably because of denser vegetation or geomorphological change (Çep 2000; Hahn 2000).

So how do the findings from the technological analysis articulate with the larger topic of this paper, namely, the question of the extent to which these technological innova-

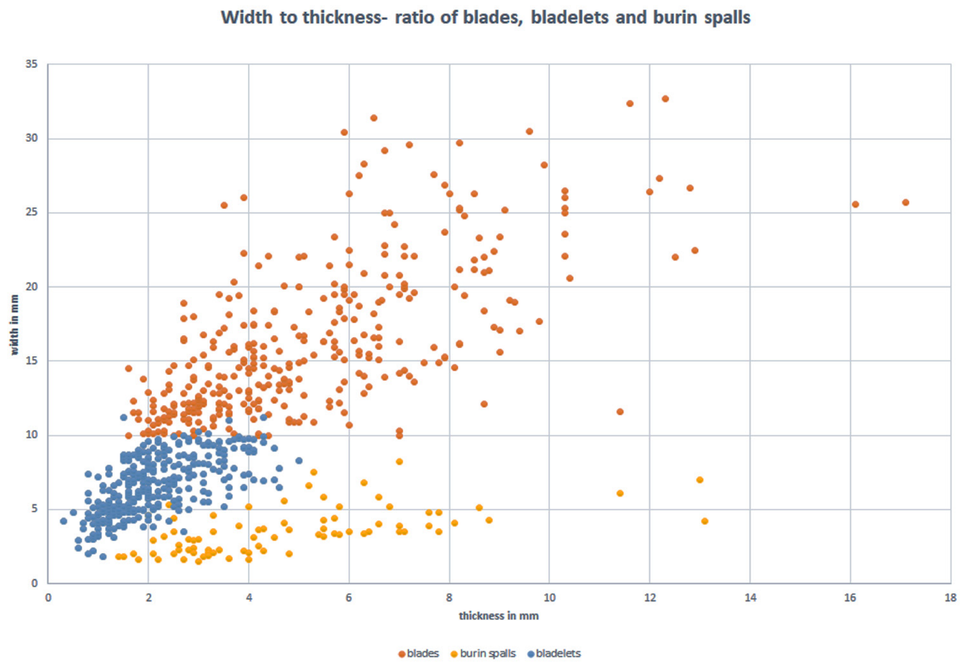

Figure 7. Hohle Fels Cave Gravettian. Width to thickness ratio in blades (orange), bladelets (blue), and burin spalls (yellow) for IIcf.

tions could have been triggered by the climatic development of the period? This is especially true for the plentiful appearance of regular and relatively standardized backed pieces—either as lithic points (Gravette- and Microgravette points), projectile inserts (backed pieces), or backed inserts in other composite tools—that marks a watershed in European Upper Paleolithic technology, as they indicate the fast spreading, large-scale use of a modular technological system all over Europe. The backed elements are complemented by the presence of *fléchettes* and Font-Robert-points (see Figure 2). In the context of the formation of the Gravettian technocomplex with its abundant appearance of backed pieces, Bosinski (1989: 33) spoke of an invention so meaningful that the technology in question spread very quickly over literally all of Europe and even beyond, and that this process led to a clearly perceptible break and change in the archaeological record[1]. Of course, the general reduction in size of many tools also means that they are easier to transport, maintain, and repair; this has been postulated before for backed pieces in other archaeological contexts (e.g., Clarkson et al. 2018a, b; Hiscock et al. 2011). These implements are also easy to manufacture in great number

Figure 8. Hohle Fels Cave Gravettian. Two examples of conical cores (a: HF 58/1243, IIc; b: HF 66/1191, IIc; photograph by A. Falcucci).

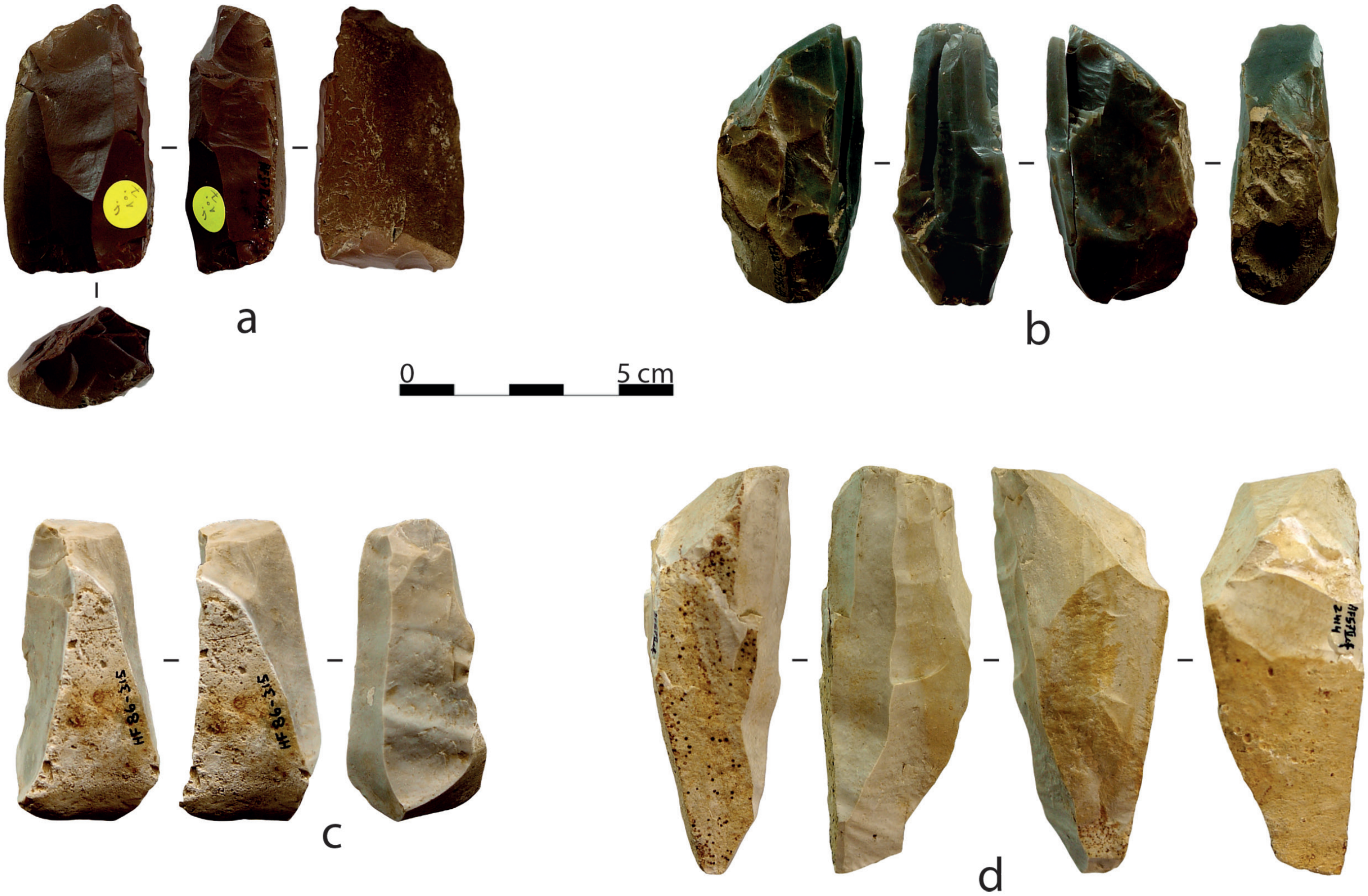

Figure 9. Hohle Fels Cave Gravettian. Cylindrical cores (a: HF 57/2466, IIc; b: HF 56/887, IIc; c: HF 86/315, IIb; d: HF 57/2414, IIcf; photograph by A. Falcucci).

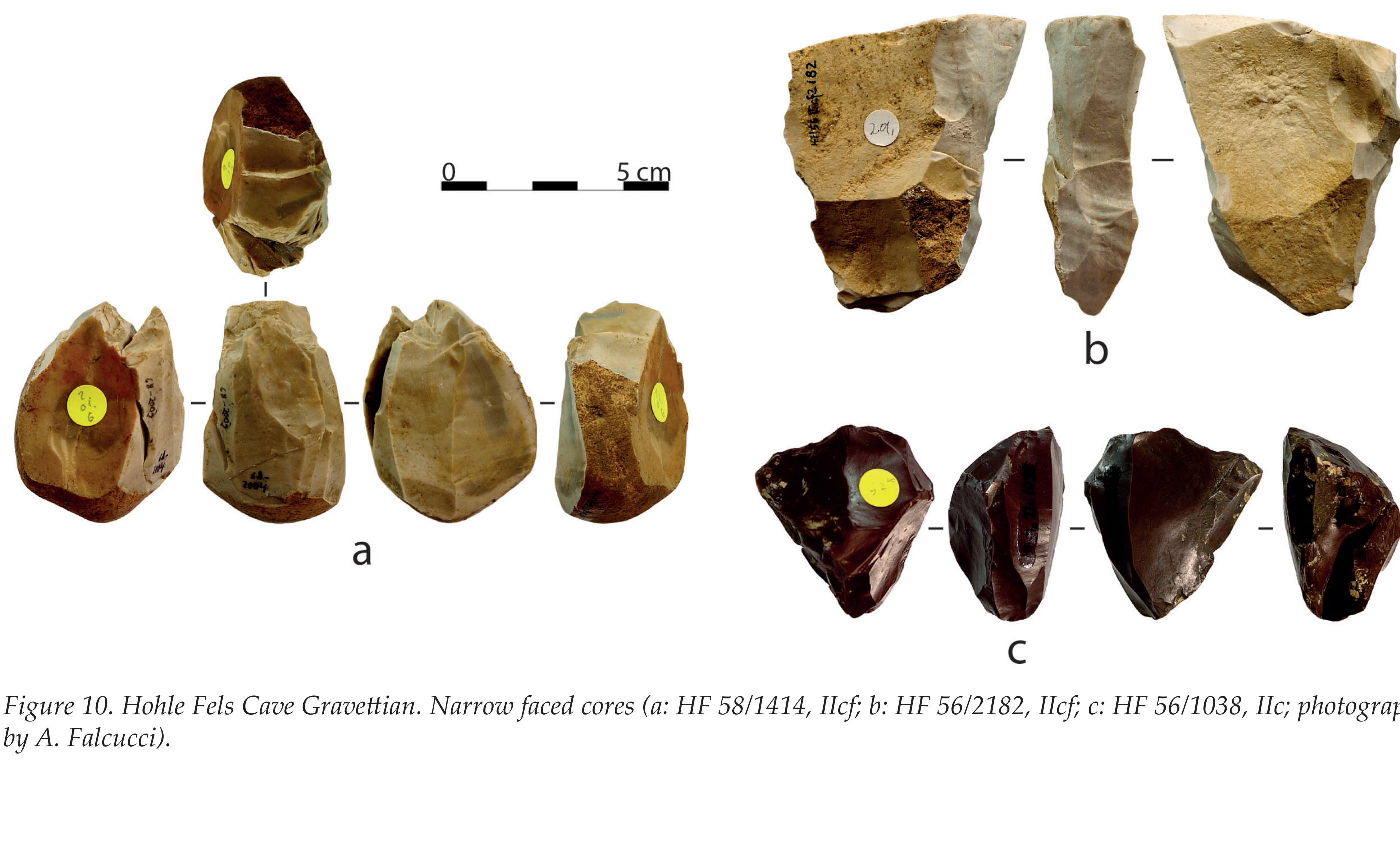

Figure 10. Hohle Fels Cave Gravettian. Narrow faced cores (a: HF 58/1414, IIcf; b: HF 56/2182, IIcf; c: HF 56/1038, IIc; photograph by A. Falcucci).

Figure 11. Hohle Fels Cave Gravettian. Refitting sequences involving two cores with removal surfaces on the narrow part; removals of core tablets on both striking platforms are visible (1: HF 56/2381, IIcf; 2: HF 56/1534, IIcf; after Taller et al. 2019, Figure 7).

in a standardized format, and the backing makes them less prone to bending snaps due to the thickening of the pieces relative to their widths (Clarkson et al. 2018a). Clarkson and colleagues (2018a) argue for the convergent emergence of small backed lithic implements across continents at different times, and, taking findings from east Africa into consideration, through hundreds of millennia and perhaps by different hominin species (Barham 2002). The discussion of this development in lithic technology often focuses on "backed microliths" (e.g., Belfer-Cohen and Goring-Morris 2002; Clarkson et al. 2018a; Hiscock et al. 2011; Petraglia et al. 2009). However, while backing as a technique to modify lithics is straightforward in the sense of blunting one edge of an implement to make it easier to haft or to handle, the question of what the term "microlith" implies is less clear[2] (e.g., Leplongeon 2014). It is highly debatable whether rare backed bladelets from the Last Interglacial complex (Conard 1992), the later Châtelperonnian or the *Mousterién de tradition Acheuléenne* (e.g., Bolus 2012b; Bosinski 1967; Bordes 1961; Roussel et al. 2016; Soressi 2005; Soressi and Roussel 2014) are comparable to the Gravettian and Magdalenian both in terms of numbers as well as production. Nonetheless, the backing of comparably small lithic implements occurred in several different geographical and chronological contexts, and varying explanations for these developments have been put forward (e.g., Blinkhorn and Petraglia 2014; Clarkson et al. 2018a, b; Hiscock et al. 2011; Jöris and Weninger 2004; Jöris et al. 2009; Mellars 2006; Svoboda et al. 2015).

There are two main competing models to explain the appearance of assemblages with backed lithics, at least regarding Africa, South Asia, and Australia. On one hand, there is the "dispersal"-hypothesis (after Mellars 2006, *contra*: Clarkson et al. 2018b), which argues for a dispersal of anatomically modern humans out of Africa along coastlines towards Southern and Southeast Asia and Australia carrying microlithic technology with them. On the other hand, there is the adaptive model (following, e.g., Clarkson et al. 2009) which suggests the convergent emergence of backed lithics as an adaptive reaction most probably in response to changing climatic and/or environmental conditions and the economic risk and uncertainty that these changes brought with them for hunter-gatherers (Clarkson et al. 2009, 2018a, b). The latter hypothesis has considerably greater explanation power, since the global record of backed lithics is patchy in terms of its temporal and spatial distribution, making a linear dispersal from Africa across Eurasia highly unlikely.

In South Asia, Petraglia and colleagues (2009) have suggested that an increase in population led to greater pressure on resources, which they hypothesize served as a trigger for innovations in lithic technology, including the rise of

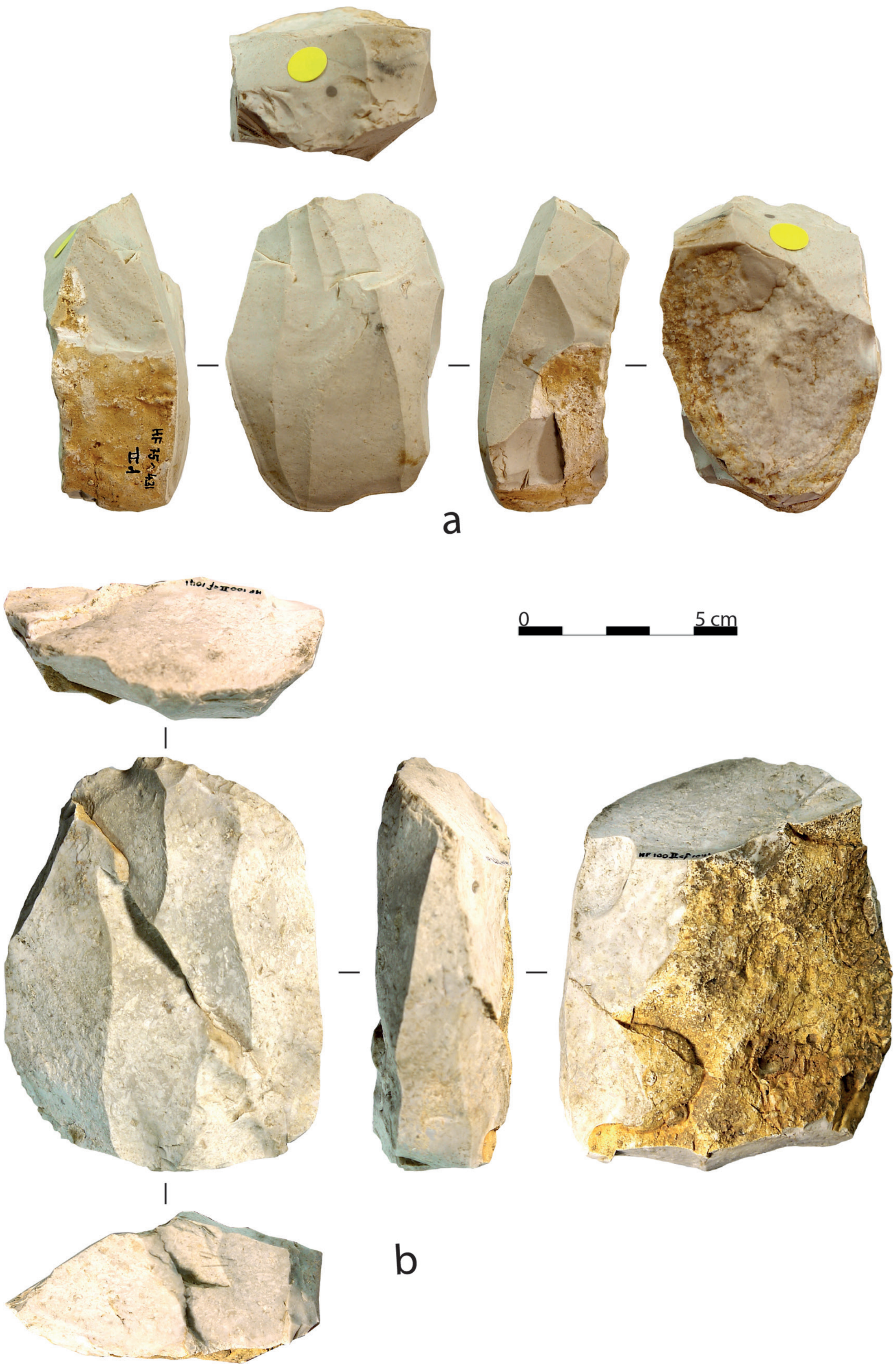

Figure 12. Hohle Fels Cave Gravettian. Broad surface cores (a: HF 75/431, IId; b: HF 100/1041, IIcf; photograph by A. Falcucci).

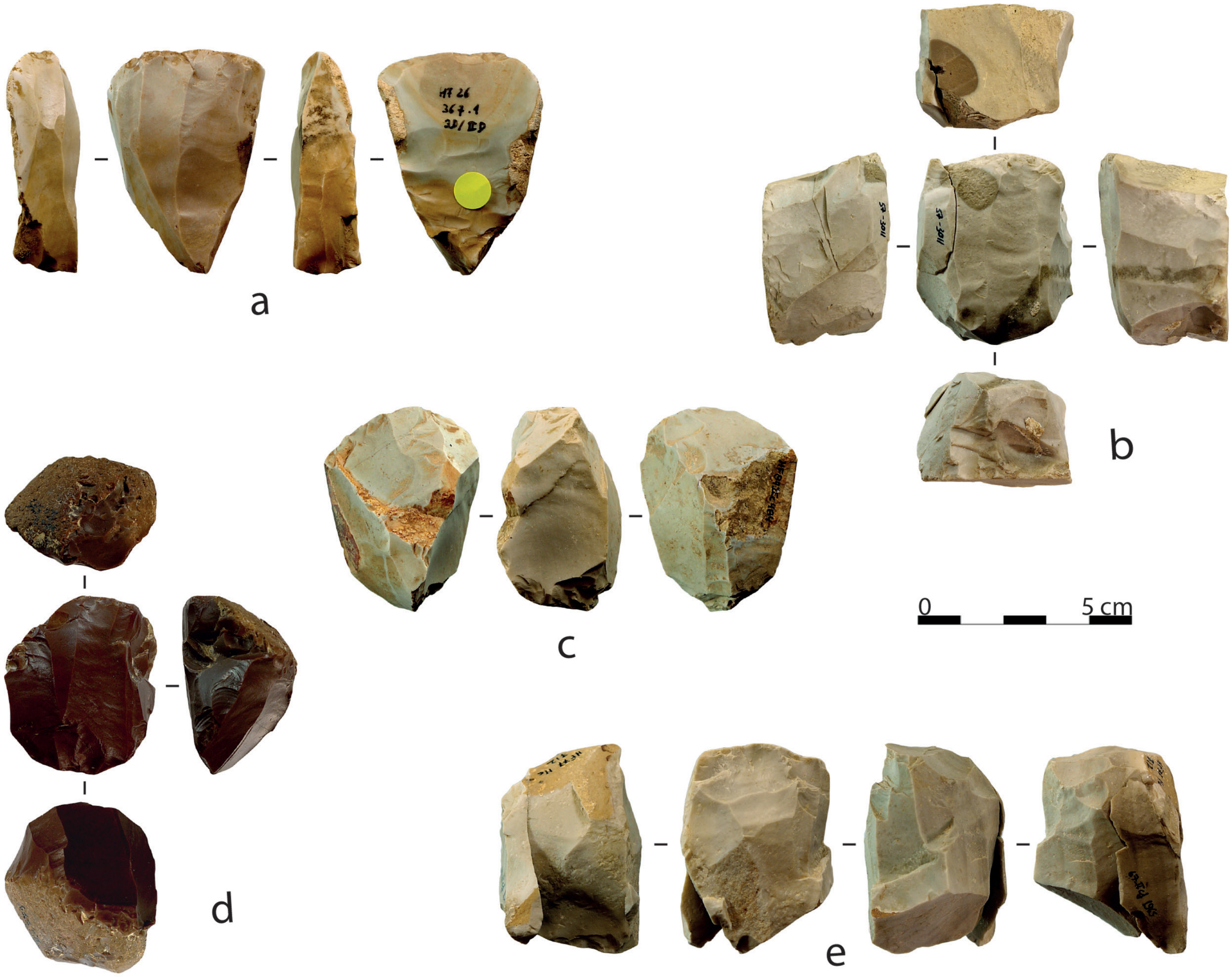

Figure 13. Hohle Fels Cave Gravettian. Compact cores (a: HF 26/367.1, IId; b: HF 57/2246, IIcf; c: HF 89/484, IIc; d: HF 67/575, IIc; e: HF 77/712, IIc; photograph by A. Falcucci).

backed assemblages. For this paper, we did not, however, consider this hypothesis further, as presently there are no real indicators in southern Central Europe suggesting that these dynamics might have been a driving factor of changes in lithic technology in the region and timespan discussed here[3].

The versatility of possible uses in composite instruments and their practicality in terms of manufacture, standardization, transportability, and maintenance represent crucial advantages of backed pieces, regardless of their source (e.g., Clarkson et al. 2018b; Christensen and Valentin 2004; Hiscock 2002; Hiscock et al. 2011; Moss and Newcomer 1982; Robertson et al. 2009; Taller et al. 2012), so that this technology reflects a positive adaptation for Stone Age hunter-gatherers when facing risky or unstable environmental conditions (Clarkson et al. 2018b; Hiscock 2002). Clarkson et al. (2018a: 178) state that the occurrence of backed lithics need not necessarily be connected to small laminar blank production. For example, the Howiesons Poort assemblages of southern Africa often contain relatively large backed tools, and these tools are often made from flakes. It is only with some assemblages of the LSA of southern Africa that we can speak of microlithic assemblages (Deacon 1982).

Returning to Europe and the Gravettian, the dynamic portrayed in the adaptive model is apparent here too. To make a case on this point considering the Swabian Gravettian in general and Hohle Fels cave specifically, we presented the whole laminar production chain and the aim of the blank manufacturing process. Here, we showed that the appearance of backed lithics is inseparably linked to a sophisticated laminar production system that focuses on straight, long, and narrow bladelets and blades. The over-emphasis of the link between backed pieces and microblade technology, stated by Clarkson and colleagues (2018a) regarding several technocomplexes in southern Africa is thus not true for the Swabian case. This finding applies for the whole pan-European Gravettian phenomenon, as these industries usually rely heavily on laminar blank production. For instance, the open-air-site Willendorf II-5 in Lower Austria shows extensive commonalities with the Gravettian in Swabia, both regarding the technology used for laminar blank production and subsequent tool manufacture (Moreau 2009, 2010; Taller and Conard 2016). Moreover, teardrop-shaped ivory pendants, typical for the Gravettian of Swabia, are also known from Lower Austria (Antl-Weiser 2008; Moreau 2009; Scheer 1985; Vercoutère and Wolf 2017). Additionally, Willendorf II-5 yielded early dates placing it in the same timeframe as Hohle Fels or Geißenklösterle (Haesaerts et al. 1996; Moreau 2009; Taller and Conard 2019). It thus seems that the makers of the Central European Gravettian occupied a vast territory, with relatively sparse settlement while nevertheless maintaining a high level of connectivity via social and economic networks (Moreau 2009; Taller and Conard 2016, 2019). Based on the consistencies Moreau identified when analyzing several assemblages from both regions, he highlighted the unity of the Upper Danubian and the Middle Danubian Gravettian (Moreau 2009a, 2010, 2012).

In this context, questions about the extent to which early Gravettian settlement clusters in Swabia, Lower Austria, and Moravia belonged to the same settlement system or were connected through direct or indirect contact remain of critical importance for our understanding of the Central European Upper Paleolithic. The Gravettian of Lower Austria and Moravia are sometimes associated with burnt clay figurines found in several Moravian sites, as well as in Krems-Wachtberg. Decorative engravings on ivory pieces are largely unique to this region and support the concept that Lower Austria and Moravia represent a single cultural region (e.g., Simon et al. 2014). These findings make the idea of a coherent Central European Gravettian phenomenon plausible for the Middle Danube region, however, there are unique aspects of the Gravettian settlement history of Swabia that also are important.

Moreau stresses the relative uniformity of Central European Gravettian assemblages between 30 and 27 ka (uncal.) BP (Moreau 2009a, 2010). Nonetheless, Moreau (2009a) sees notable differences between the regions arising with the so-called *evolved Pavlovian* (after Svoboda 1994, dating from 27–25 ka BP). This phase of the Gravettian postdates the Swabian phenomenon completely, since Southwestern Germany was uninhabited by Paleolithic hunters starting around 31 ka cal BP (Taller and Conard 2019). These younger dates for the Middle Danubian Gravettian are well-documented in Moravia and occur occasionally in Lower Austria (e.g., Antl and Fladerer 2004), and likely reflect the harsher climatic and environmental conditions in Swabia, which lies just north of the Würmian glacier. More work is needed to determine the degree to which the populations of these regions were in contact. Certainly, when we consider the media used for art and the iconography of the regions, the record of artistic and symbolic expression contrasts the Swabian Gravettian and the Gravettian of the Middle Danube. While the Middle Danube is best known for its female figurines, clay figurines, ivory and limestone sculptures and decorated faunal artifacts, as well as numerous burials (e.g., Einwögerer et al. 2006; Simon et al. 2014; Svoboda 2000, 2007), the Swabian Gravettian has a far poorer record with the stone phallus and engraved antler depiction of a quadraped being the best best known examples (Conard and Kieselbach 2006; Scheer 1994). To clarify the strength of the interaction between peoples of these regions we need still better regional chronologies. Additionally, one has to consider the major differences in duration of Gravettian settlement in the Upper and Middle Danube regions as a reflection of both the unique ecological and cultural histories of the two regions (cf. Taller and Conard 2019).

Returning to Gravettian lithics, at Hohle Fels we see a clear departure from the local Aurignacian lithic technology with its distinctive ways of producing blades on large, usually unidirectional cores and bladelets, often made using carinated scrapers and burins (Bataille and Conard 2018). The Gravettian differs from the Aurignacian both in terms of blank production and the toolkit, with the Gravettian assemblages exhibiting a strong focus on straight, narrow laminar blanks and high numbers of backed pieces. In contrast to the Aurignacian, the production chains for blades and bladelets are interlinked. Unlike Moreau (2009a), however, we see little evidence for techno-typological continuity, but rather a quick shift from the Aurignacian towards the Gravettian with changes on many levels (Taller and Conard 2019). A break between Aurignacian and Gravettian is also visible in the manufacture of organic projectile tips. While in the Aurignacian these were mainly made of antler (split base points) or ivory (massive base points), Gravettian hunters typically used mammoth ribs to manufacture massive points (Münzel 2019). Moreover, the rupture between Aurignacian and Gravettian is manifest in the techniques used to make ivory beads, as well as the in their form (Münzel et al. 2016). Also, the media and iconography of figurative art shifts radically between the Aurignacian and Gravettian, with carved ivory figurines that dominated the Aurignacian being absent in the Swabian Gravettian (e.g., Conard and Kind 2017).

Since in a cooler climate vital resources—in this case mostly animal biomass—are usually distributed unequally (Binford 1980; Kelly 1983, 1995: 72 ,111 ff.) especially compared to, e.g., tropical or subtropical environments[4] (Binford 2001: 100 ff.; Kelly 1983, 1995: 130), this correlation implies the necessity of a higher (especially logistical) mobility of the Gravettian hunters (cf. also Jöris et al. 2009; Svoboda et al. 2000). Even though the prevalent biome in Ice Age Central Europe during the late Pleistocene, the "mammoth steppe" *sensu* Guthrie (1990), is not directly comparable to present-day inland arctic regions as it is thought to have been richer in terms of vegetation, as well as offering warm daytime temperatures, probably similar to present-day alpine pastures in terms of plant production, this environment was the perfect habitat for grazing herbivores (Koenigswald 2002) and thus also Paleolithic groups as their hunters. As an outcome of this, the demands required from Paleolithic hunter-gatherer societies regarding technology, mobility, and social organization in order to thrive in these surroundings are assumed to have been similar to more recent hunter-gatherers of subarctic and arctic regions. For instance, the Nunamiut, caribou hunters of the North American arctic inland, possessed knowledge of resource distribution as well as tool and equipment caches in an area of almost 250,000km^2 (Binford 1984: 220), which indicates the high degree of mobility necessary for this kind of subsistence and the vastness of the territory that is ranged by such groups. The diminution of the lithic tool kit and the invention of modular combinations of the backed pieces in varying hafting systems could well be technological responses by these Pleistocene hunter-gatherers to subsistence-pressure caused by environmental shifts resulting from changing climatic conditions. The versatility of this technological system and the comparative ease in maintaining tool kits supports this hypothesis. The small size of the backed lithics means that the toolkit is light. Since large numbers of standardized backed artifacts could be made in advance, thus forming a reliable lithic endowment, the transport of larger, heavy quantities of raw materials decreased in importance (Clarkson et al. 2018a). The technology of organic projectile heads also mirrors the trend towards technological systems with easier manufacture and maintenance—here, the relatively complicated manufacture of split-based antler points and ivory points was abandoned in favor of massive points made from mammoth ribs, which also meant a change in raw material from antler and ivory toward bone, which is easier to work (Münzel 2019; Münzel et al. 2016). If people needed to broaden their range because of increasingly uneven distributions of game, and if they needed to be able to react quickly to challenging situations, we could expect a positive selection for lighter and more easily transported implements and for technologies that were versatile and easy to repair. All these qualities of the technological innovations mean that the toolkit became more portable and more reliable, at a time when hunter-gatherers in late MIS 3 were facing the need to change their land-use patterns in order to counteract the declining availability of food resources. Despite these important innovations the limits of the settlement and subsistence system were met in Swabia around 31 ka cal BP, when Gravettian populations largely abandoned the region, until ca 16 ka cal BP, when late Magdalenian groups were recolonizing the region (Maier 2015; Taller 2014, 2019; Taller et al. 2014).

In the Swabian Jura, we thus see two phenomena emerging near the start of the Gravettian. First, in the environmental realm, temperatures, vegetation and faunal resources declined steadily. Second, in the cultural realm, the Gravettian appears suddenly after the Aurignacian by 34 ka cal BP, and brings with it considerable change in lithic technology and tool design (Taller and Conard 2016, 2019). The organic technology, raw material choices, and the nature of artistic expression and beliefs also reflect considerable change during the shift from the Aurignacian to the Gravettian (Münzel 2019; Münzel et al. 2016). The question is whether or not there is a causal relationship behind these temporal coincidences, and we believe this to be the case. The emergence of Gravettian technologies seems to have been triggered and fuelled by the cooling climatic conditions from GS 7 onwards, in the sense of an "*innovative problem solving in connection with climatic stress*" (Conard and Bolus 2003: 363). This hypothesis for the emergence of the Gravettian proposed by Conard and Bolus in 2003 is supported by the evidence we now have, indicating an influence of climatic change on the development of the Gravettian. Kozłowski (2015) has proposed a scenario like this as a possible reason for converging developments of Gravettian technologies and toolkits.

While the more severe effect of climatic cooling on hunter-gatherer communities at that time in higher latitudes has been discussed by Maier and Zimmermann (2017), we suggest that the altitude of a given region also plays a substantial role in shaping the lifeways of Paleolithic hunters. As shown in Figure 4, the sites of the Swabian Jura are all situated above 500mamsl, and after 31 ka cal BP, there are no Gravettian sites above 500mamsl anywhere in Central Europe. This finding was described before for Moravia, where Gravettian sites are found at considerably lower elevations than Aurignacian ones (Klíma 1961, cited in Svoboda 1996). This relationship to elevation also points to gradual cooling as the reason why Gravettians left the Swabian Jura by 31 ka cal BP. In that sense, the climatic development of late MIS 3 seems to be at least partially responsible for both the rise and fall of the Gravettian in Southern Central Europe. That said, we need to bear in mind that the concrete socio-economic dynamics behind the sudden appearance and spread of the Gravettian, along with the equally sudden end of the phenomenon in Southern Central Europe around 31 ka cal BP remain largely unclear. Another thing to consider is that the climatic cooling at this time affected the inhabitants of all of Europe, even though most likely to a varying degree, depending on latitude and elevation. The introduction of new technologies to adapt new subsistence strategies might thus have been developed in different European localities as independent reactions towards these challenges resulting in a converging appearance of elements of the material culture (Kozłowski 2015: 12). The high mobility and large ranges of human populations could have fostered cultural contacts and facilitated the exchange of innovations and technologies despite the generally low population densities.

Many of the oldest sites of the Gravettian are located in Central Europe (e.g., Conard and Bolus 2003; Moreau 2009a; Otte and Keeley 1990; Taller and Conard 2019), and the possibility of an origin of the Gravettian in the region has accordingly been proposed repeatedly (e.g., Bolus 2010; Conard and Bolus 2003; Kozłowski 2015; Moreau 2009a; Otte and Keeley 1990). Still, the existence of a single "epicenter" of Gravettian origins in the form of one particular site or region anywhere in Central Europe seems unlikely. Such a hypothesis was postulated recently and the suspected road of colonization across Europe calculated using a least-cost-path-approach based on only the oldest single Gravettian date from different sites (Bicho et al. 2017). Consequently, Geißenklösterle was deemed as the "likely origin" for the Gravettian dispersal (Bicho et al. 2017). Although the Swabian Gravettian has long been seen as a very early manifestation of the Gravettian, and in the sense of the Kulturpumpe model has long been viewed as a key region for innovations, it is doubtful whether a single site or small region can be identified as the "exclusive" source of the Gravettian. The methodological problem with this approach is seen when considering the oldest Gravettian date from Geißenklösterle, which appears to be an outlier when compared to the other dates (cf. Higham et al. 2012). That is not meant to reject this early date altogether, but rather contextualize it with the rest of the dataset from this layer instead of picking it out singularly. To gain a more comprehensive and reliable picture of population dynamics and potential dispersal routes, we advise using larger bodies of contextualized AMS ^{14}C-dates (see, e.g., Maier and Zimmermann 2017).

It is also necessary to consider the importance of migrations and demographic processes, which likely played a crucial role in the evolution and spread of Paleolithic technocomplexes (e.g., Otte and Keeley 1990). Even though there is no proof for such a scenario (Taller and Conard 2019), the possibility of an immigration of peoples bearing Gravettian technologies, or at least bringing with them critical know-how, should be taken into consideration as a factor in the emergence of what we today call the Gravettian (as suggested by Svoboda 2007). We see the process of Gravettian genesis as a complex of adaptive reactions to climatic, demographic, and socio-economic challenges. Thus, Gravettian material culture likely reflects an archaeologically visible reaction of Ice Age European populations to changing environments. At the same time, we acknowledge that high mobility and population dynamics between regions may well have served as catalysts for the emergence of the Gravettian.

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ENDNOTES

[1]"*Der Beginn des Mittleren Jungpaläolithikums ist durch einige technische Neuerungen gekennzeichnet, die so sinnvoll waren, daß sie sich in kurzer Zeit über ganz Europa und die östlichen Mittelmeergebiete verbreitet haben und so zu einer deutlichen Zäsur und Änderung im Fundstoff führten.*" (Bosinski 1989: 33).

[2]In the analyses on the Hohle Fels material, the term "microlith" was not used at all, as in Central Europe it is applied mainly in a Mesolithic context (e.g., Heinen 2012). The laminar blanks used for the manufacture of backed pieces in Gravettian Hohle Fels were defined as a) being at least twice as long as wide, and, b) as either blades (width>10mm) or bladelets (with<10mm). Since of the almost 300 backed pieces from the Hohle Fels Gravettian more than 99% are under 50mm and 95% under 30mm in length while more than 85% exhibit a width of 8mm or under, the ensemble conforms to the use of the "microlith" notion by most publications on this topic, especially when considering the definition of a microlith given by J.D. Clark (1985, albeit in an African context) of pieces not exceeding 50mm in length and mostly being shorter than 30mm. Here it is worth noting that while in Africa backed artifacts such as MSA segments are often called microliths (McBrearty and Brooks 2000), in the European traditions backed artifacts that are not made from bladelets or small flakes are not considered to be microliths.

[3]In fact, there are only very few Gravettian sites especially in the Swabian Jura (namely, the four caves in the Ach Valley mentioned above in the introduction and background- section); they are even lower in numbers than in the preceding Aurignacian. There are studies considering demographic change and population increase in the timeframe and region in question (e.g., French 2015; Schmidt and Zimmermann 2019), but the results do not seem to justify the inference of concrete population pressure.

[4]This is, of course, a simplification, as the statement is only valid for hunters of comparably cold and arid regions with herds of large herbivores roaming, and not, e.g., inhabitants of the extreme Arctic who use a lot of aquatic resources located around their camp and are thus more similiar, in terms of mobility, to tropical hunters than to the inland reindeer hunting groups (cf. Kelly 1983, 1995: 129; also Binford 2001).

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