Establishing Contexts of Encounters: Radiocarbon Dating of Archaeological Assemblages With Implications for Neanderthal-Modern Human Interactions

The Harvard community has made this article openly available. Please share how this access benefits you. Your story matters.

<table>
<thead>
<tr>
<th>Citation</th>
<th>Alex, Bridget Annelia. 2016. Establishing Contexts of Encounters: Radiocarbon Dating of Archaeological Assemblages With Implications for Neanderthal-Modern Human Interactions. Doctoral dissertation, Harvard University, Graduate School of Arts &amp; Sciences.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citable link</td>
<td><a href="http://nrs.harvard.edu/urn-3:HUL.InstRepos:33493527">http://nrs.harvard.edu/urn-3:HUL.InstRepos:33493527</a></td>
</tr>
<tr>
<td>Terms of Use</td>
<td>This article was downloaded from Harvard University’s DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at <a href="http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA">http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA</a></td>
</tr>
</tbody>
</table>
Establishing contexts of encounters: radiocarbon dating of archaeological assemblages with implications for Neanderthal-modern human interactions

A dissertation presented by

BRIDGET ANNELIA ALEX

to

The Committee on Anthropological Archaeology and Human Evolutionary Biology

in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy
in the subject of
Anthropological Archaeology & Human Evolutionary Biology

Harvard University
Cambridge, Massachusetts

April 2016
Establishing contexts of encounters: radiocarbon dating of archaeological assemblages
with implications for Neanderthal-modern human interactions

ABSTRACT

This dissertation seeks to reconstruct the distribution of Neanderthals and modern
humans in time and geographic space in order to better understand the nature of
interactions between the groups. Because human fossils from the Late Pleistocene are so
rare, the biogeography of Neanderthals and moderns is primarily inferred from
radiocarbon dates of archeological industries, which are assumed to have been made by
one group or the other. Following this methodology, I critically reviewed published
radiocarbon dates and produced new dates from active excavations in three regions: the
Levant, Balkans, and Northeast Europe. The resulting regional chronologies were
compared to the distributions of Neanderthals and moderns predicted from interaction
models of no overlap, rapid replacement, and prolonged coexistence. The scenario of
prolonged coexistence was subdivided into models of integration, displacement, and
avoidance.

Informative archaeological chronologies were produced for each region. In
Northeast Europe, my new dates and site chronologies for Ciemna and Oblazowa Caves,
Poland, suggest that the Middle Paleolithic ended before 45 kcalBP. In the greater region,
a number of distinct assemblages appeared during Marine Isotope Stage 3 (MIS-3), but
the duration and sequence of these industries is not well resolved due to the large
uncertainties of the available chronometric dates. In the Levant, the dates and chronology reported here for Manot Cave, Israel, help to clarify the timing of Early Upper Paleolithic industries and test proposed migrations of modern humans between the Near East and Europe. Specifically, at Manot the Early Ahmarian industry was present by 46 kcalBP and the Levantine Aurignacian occurred between 37-35 kcalBP. However, it was the results from the Balkans that were most applicable to the interaction models proposed in this dissertation, and therefore most informative on the nature of Neanderthal-modern human interactions. The new dates from Pešturina, Hadži Prodanova, and Smolučka Caves, combined with published dates from other sites, suggest that Neanderthals and moderns overlapped for several thousand years in the Balkans. During this period of overlap the groups occupied distinct geographic zones, consistent with the models of prolonged coexistence by displacement or avoidance. The period of overlap ended by 39,000 calBP at the time of the Campanian Ignimbrite eruption and onset of the Heinrich Event 4 cold phase.
# TABLE OF CONTENTS

Chapter 1 – Introduction ........................................................................................................... 1  
1.1 The research question and approach .............................................................................. 1  
1.2 What ancient DNA can and cannot tell us ...................................................................... 3  
1.3 Using archaeological industries as proxies for human groups .................................... 8  
1.4 The biogeographic approach ......................................................................................... 12  
  1.4.1 Interaction Models .................................................................................................... 12  
1.5 Dissertation outline ....................................................................................................... 17  
1.6 References ..................................................................................................................... 17  

Chapter 2 – Radiocarbon dates from Manot Cave, Israel Establish Early Upper Paleolithic  
Chronology of Levant with Implications for Human Dispersals ........................................ 23  
  2.1 Abstract ........................................................................................................................ 24  
  2.2 Significance .................................................................................................................. 24  
  2.3 Introduction .................................................................................................................. 25  
  2.4 Manot Cave .................................................................................................................. 27  
  2.5 Results and Discussion ............................................................................................... 29  
    2.5.1 Chronostratigraphy at Manot ................................................................................ 29  
    2.5.2 Implications for regional chronology .................................................................... 34  
    2.5.3 Implications for the spread of modern humans and UP technology .................... 39  
  2.6 Methods summary ....................................................................................................... 40  
  2.7 Supporting information ............................................................................................... 42  
    2.7.1 Levantine Early Upper Paleolithic ........................................................................ 42  
    2.7.2 Manot Cave .......................................................................................................... 44  
    2.7.3 Geoarchaeological analysis .................................................................................... 46  
    2.7.4 Radiocarbon dating ............................................................................................... 50  
    2.7.5 Regional chronology .............................................................................................. 63  
  2.8 Acknowledgements ..................................................................................................... 70  
  2.9 References .................................................................................................................. 71  

Chapter 3 – Chronology of the Middle-Upper Paleolithic Transition in the Balkans based  
on Reliable Radiocarbon Dates .............................................................................................. 79  
  3.1 Abstract ........................................................................................................................ 80  
  3.2 Introduction .................................................................................................................. 81  
  3.3 Background .................................................................................................................. 82  
    3.3.1 Paleolithic research in the Balkans ........................................................................ 82  
    3.3.2 Biogeography and culture history .......................................................................... 85  
    3.3.3 CI eruption and H4 event ...................................................................................... 91  
    3.3.4 Reliable radiocarbon dates .................................................................................... 92  
  3.4 Materials and Methods ............................................................................................... 93  
    3.4.1 New radiocarbon dates .......................................................................................... 93  
    3.4.2 Review of published dates ................................................................................... 97  
  3.5 Results and Discussion ............................................................................................... 100  
    3.5.1 Chronology at Pešturina, Hadži Prodanova, and Smoučka ................................ 100  
    3.5.2 Regional Archaeological Chronology .................................................................. 103  
    3.5.3 Implications for Neanderthal-modern human interactions .................................. 106  
  3.6 Conclusion .................................................................................................................. 110
3.7 Supporting information ........................................................................................................ 113
  3.7.1 Regional Summary ........................................................................................................ 113
  3.7.2 Comparing dates ........................................................................................................... 145
3.8 Acknowledgements ........................................................................................................... 146
3.9 References ........................................................................................................................... 146

Chapter 4—Late Middle Paleolithic of Southern Poland: radiocarbon dates from Ciemna and Obłazowa Caves .................................................................................................................. 160
  4.1 Introduction ....................................................................................................................... 160
  4.2 Archaeological background .............................................................................................. 162
  4.3 Sites and samples .............................................................................................................. 164
    4.2.1 Ciemna ...................................................................................................................... 164
    4.3.2 Obłazowa .................................................................................................................. 167
  4.4 Methods ............................................................................................................................ 172
  4.5 Results .............................................................................................................................. 174
  4.6 Discussion ......................................................................................................................... 177
    4.6.1 Sample reliability ........................................................................................................ 177
    4.6.2 Chronology of Ciemna .............................................................................................. 179
    4.6.3 Chronology of Obłazowa .......................................................................................... 180
    4.6.4 Regional context ......................................................................................................... 180
  4.7 Conclusions ....................................................................................................................... 186
  4.8 Acknowledgements .......................................................................................................... 188
  4.9 References ....................................................................................................................... 188

Chapter 5—Conclusion ............................................................................................................. 195
  5.1 Reliable radiocarbon dates .............................................................................................. 195
  5.2 Major conclusions of case studies .................................................................................... 200
  5.3 Biogeographic approach applied to each region ............................................................... 204
    5.3.1 Northeast Europe ...................................................................................................... 204
    5.3.2 The Levant ............................................................................................................... 206
    5.3.3 The Balkans ............................................................................................................. 209
  5.4 Conclusion ......................................................................................................................... 214
  5.5 References ....................................................................................................................... 215

Appendix A ............................................................................................................................ 218
Appendix B ............................................................................................................................ 232
Appendix C ............................................................................................................................ 243
ACKNOWLEDGEMENTS

Graduate school has been a wonderful phase of my life and I am already nostalgic for it. This is primarily because of the people I have met, worked with, befriended, and best-friended through my time at Harvard. There are too many people to thank, but I’ll give it a shot.

Thank you to my committee members, beginning with my advisor, the wise and wonderful David Pilbeam. He taught me to ask big questions first, and to worry about feasibility and logistics later. I trust that he is omniscient and immortal, probably thanks to decades of taking-the-stairs and eating his own sandwich instead of Dial-A-Pizza. I aspire to one day, like him, introduce myself by saying, “I am interested in all aspects of human evolution.” Thank you to Elisabetta Boaretto who taught me that a radiocarbon date is not just a date, along with most of my other “practical knowledge.” Thank you to Richard Meadow, whose concern for students and careful reading of drafts is greatly appreciated. Harvard Archaeology would not be what it is without his sense of humor and institutional memory. Thank you to Dan Lieberman, who asks questions that push everyone’s research and interpretations. And to Christian Tryon for knowing about lithics, listening to my blabbering, and calling out my utilization of obfuscation.

Thank you to other Faculty members of the Archaeology Program: Ofer Bar-Yosef, Gary Urton, Matthew Liebmann, Rowan Flad, Jason Ur, C.C. Lamberg-Karlofsky, Bill Fash, and Jeffrey Quilter. You were extremely supportive and always made me feel like one of the gang. Thank you to Faculty members and affiliates of HEB: Maryellen Ruvolo, Tanya Smith, Richard Wrangham, David Reich, Terry Capellini, Peter Ellison, and Joe Henrich. I enjoyed taking your classes, teaching your classes, and hearing your thoughts at seminars. Thank you to the staff of Anthropology, HEB, and the Peabody Museum: Monica Munson, Karen Hendrickson-Santospago, Andrew Cepeda, Marianne Fritz, Judith Butler-Vincent, Gilmore Tamny, Lenia
Constantinou, Meg Lynch, and Karen Crabtree. You’ve made this whole getting-a-PhD thing go as smoothly possible.

I am eternally grateful to my community at Cabot House. Stephanie and Rakesh Khurana are making the mission of a transformative residential liberal arts & sciences education into a reality. They are selfless, tireless, inspirational leaders. It has been a pleasure to learn from and work with Tiffanie Ting. She has a thankless job, so here I thank her permanently in print for the thoughtfulness and dedication she puts into student wellbeing. The other tutors make a great team and the 300 undergrads keep life interesting.

Thank you to my research collaborators: Dušan Mihailovic, Stefan Miloševic, Omry Barzilai, Ofer Marder, Francesco Berna, Pawel Valde-Nowak, and Daniel Master. I am especially grateful to my colleagues and friends during my time in Rehovot: Eugina Mintz, Valentina Caracuta, John Kolinski, Michael Toffolo, the other Italian Michael, and Zach Dunseth.

And finally I have to thank my friends in Cambridge. Graduate school has been a blur of debilitating workloads, rehabilitating beers, and plenty of razzmatazz in between. I’m so lucky to have shared it with great friends. The Arch crew: Ari Caramanica, Max Price, Noa Corocoran-Tadd, Jeffrey Dobereiner, Yitzchak Jaffe, Nat Erb-Satullo, Emily Hammer, Michele Koons, and Ilaria Patania. The HEB crew: Sam Urlacher, Daniel Green, Alicia Breakey, Brian Addison, and Eric Castillo. Josh Walton, who I can count on to walk around Somerville cutting the stumps off Christmas trees with a handsaw so little girls can become scientists someday. Siavash Khosh Sokhan Monfared, the best boyfriend in Teele Square, who I met on a Monday at Cambridge Common—just like in the Fairy Tales. All my Dartmouth friends who were romping around Greater Boston at some point: Kristen Diede, Kat Rice, Meredith Gringer, Gabe Mahoney, and
Sarah Stern. And OF COURSE Bastien Varoutsikos, my best friend and worst exasperation, who will always be my plus-one, when I do not have a plus-one.

I also have to thank Jon Stewart and John Oliver, and *not thank* John Stamos.

Establishment wise, I have to thank Cambridge Common (the bar), Montrose Spa (for their breakfast sandwiches), and Otto Pizza.

Most of all I thank my parents, Howard and Peg Alex. They have been my biggest sources of support, comfort, and love since day one. I think they’re the best parents in the world.
CHAPTER 1 – INTRODUCTION

1.1 The research question and approach

During the Late Pleistocene there were several distinct types of humans inhabiting the planet. By 30,000 years ago, only modern humans, or *Homo sapiens*, were extant. Why did modern human survive while all other types of humans went extinct? This dissertation offers one approach to address this question. I reconstruct the distributions of Neanderthals and modern humans in time and space in order to identify contexts of their encounters. It is my underlying premise that only in such contexts—where the groups met and were exposed to the same conditions—will we be able to distinguish adaptations that allowed modern humans to outlast Neanderthals.

This work focuses on three contexts of potential overlap between Neanderthals and moderns: the Levant, Balkans, and Northeast Europe between 50,000-30,000 years ago. By this time Neanderthals and modern humans had diverged for hundreds of thousands of years and thus evolved distinct biological and cultural traits. I assume that the groups were allotaxa, undergoing parapatric speciation (Jolly 2002). Europe was the home range of Neanderthals, Africa was the home range of modern humans, and Southwest Asia was a contact zone. In order of increasing uncertainty, Neanderthal and modern humans can be distinguished by ancient genomes, skeletal anatomy, and associated material culture.

My first objective is to reconstruct human biogeography, simply defined as the spatial distributions of human taxa over time (Lomolino et al. 2010). Here, I am faced with two challenges. First, there are so few taxonomically unambiguous human fossils from this period that relying on fossils alone creates a poor and biased record of human
biogeography. Instead, like many paleoanthropologists, I have relied on the archaeological record of stone and bone artifacts to augment the data (Bar-Yosef & Belfer-Cohen 2011; Bar-Yosef & Pilbeam 2000; Jöris & Street 2008; Hublin 2015; Mellars 2006). At most sites there are no human fossils, but rather, there are artifact assemblages composed of distinct tools and technologies, which are assumed to have been produced by a particular human type. The new data presented in this dissertation are primarily radiocarbon dates of bones and charcoals that were associated with lithic assemblages, which serve as proxies for the presence of modern humans or Neanderthals. Links between the archaeological units and their assumed makers are tenuous and future discoveries will surely change our hypotheses. In this case the chronologies of archaeological industries will remain as accurate data, but the inferred human biogeography would be revised.

The second challenge concerns the reliability of radiocarbon dates. It is evident that many radiocarbon dates do not reflect the age of the event that archaeologists intend to date (Boaretto 2009; Higham 2011). This is due both to pretreatment procedures that fail to remove contamination and the selection of samples that were not deposited contemporaneously with the event in question (Pettitt et al. 2003; Waterbolk 1971). Evaluating published radiocarbon dates and producing new dates is not trivial and cannot be standardized. I disagree with metaanalyses that use “dates as data” from many sites, without consideration of the particularities of each sample, stratigraphic sequence, site excavation history, and archaeological question. Different samples provide different information: while a shell bead has a direct link to human activity, the shell may have sat on a beach for thousands of years before its modification by humans (Sivan et al. 2006).
Cave bear bones usually do not have a link to human activity, but a series of well-stratified cave bear bones can estimate the age of depositional layers, which contain artifacts. Radiocarbon dates should be interpreted within the framework: given everything that is known about a particular sample, what is the meaning of that date? Rather than following uniform quality control criteria, in this work I have established guidelines for evaluating dates, which are tailored to specific sites and archaeological questions (Boaretto 2015). Dates are classified as reliable, uncertain, or rejected based on explicit consideration of each sample’s stratigraphic context, taxonomic affiliation, taphonomic features, biochemical preservation, and pretreatment method.

1.2 What ancient DNA can and cannot tell us

As of April 2016, there is genome wide data from Neanderthals from three sites: a high coverage (52x) genome from Denisova Cave in the Altai Mountains, a low coverage (0.5x) genome from Mezmaiskaya Cave in the Caucasus, and a draft composite genome (1.3x) of three individuals from Vindija Cave in the Balkans (Prüfer et al. 2014; Green et al. 2010) (Figure 1.1). Denisova Cave is also the location of the only known Denisovan fossil remains, which have produced genome-wide data (Sawyer et al. 2015; Meyer et al. 2012). The Altai and Mezmaiskaya Neanderthals were not directly dated, but dates from associated materials suggest the depositional layers were formed >50 ka. Two of the specimens used to construct the Vindija genome produced direct radiocarbon dates between 49-39 kcalBP (Ua-?: 38310 ± 2130 14C yr BP; OxA-V-2291-18: 44450 ± 550 14C yr BP). Considering stratigraphic information, the Neanderthals providing genome wide data probably lived between 80-40 ka. Thus although the available Neanderthal genomes sample a wide geographic area, they represent an imprecise and limited
Figure 1.1: Neanderthal and modern human fossils older than 35 ka that have provided genome-wide data. Labeled with site name and approximate age in ka.
timespan—given that a Neanderthal lineage, distinct from both Denisovans and moderns, seems to have evolved before 400 ka, based on aDNA from the Sima de los Huesos hominins (Meyer et al. 2016).

Genome wide data is available from over 50 Eurasian modern humans over 7,000 years old (Fu et al. 2016). The data most relevant to Neanderthal-modern human interactions are: a 42-fold coverage genome from the Ust’-Ishim fossil from western Siberia directly dated to 47-43 kcalBP (combined OxA-25516: 41400 ± 1300 $^{14}$C yr BP/OxA-30190: 41400 ± 1400 $^{14}$C yr BP) (Fu et al. 2014); genome wide single nucleotide polymorphisms (SNP) from the Oase 1 fossil from the Balkans directly dated to 42-37 kcalBP (combined OxA-11711: >35200 $^{14}$C yr BP/GrA-22810: 34290 ± 970/870 $^{14}$C yr BP) (Fu et al. 2015; Trinkaus et al. 2003); and a 2.4-fold coverage genome of the Kostenki 14 fossil from the Don River, Russia directly dated to 39-36 kcalBP (OxA-X-2395-15: 33250 ± 500 $^{14}$C yr BP) (Seguin-Orlando et al. 2014; Marom et al. 2012).

These Late Pleistocene genomes reveal several important points about the nature of interactions between Neanderthals and modern humans. First, they provide unequivocal evidence that interbreeding occurred between Neanderthals and modern humans. The genomes of present-day non-Africans contain 1.6-2.1% Neanderthal DNA, the majority of which likely introgressed between 60-50 ka (Fu et al. 2014). This range is estimated from the length of the introgressed Neanderthal segments in Ust’Ishim and the recombination rate, under the assumption that only one admixture episode occurred. One introgression event is unlikely and the data are consistent with several episodes of interbreeding at different times and places (Fu et al. 2015; Kuhlwilm et al. 2016; Vernot
et al. 2016). The length of introgressed segments in the Oase 1 fossil suggests admixture 4-6 generations before this individual lived, in addition to a more ancient admixture event, which is observed in Ust’Ishim and present-day people (Fu et al. 2015).

Next, there appears to have been multiple dispersals of modern humans into Europe, some of which failed to lead to surviving lineages (Fu et al. 2016). The 42-37 kcalBP Oase 1 individual shares more alleles with non-Africans than Africans. However, among non-Africans, Oase 1 appears equally related to pre-agricultural Europeans as he does to present-day East Asians/Native Americans. In other words, Oase 1 shows no excess of shared alleles with subsequent Europeans. The pattern is the same for the 47-43 kcalBP Ust’Ishim individual, although this fossil may not be relevant to the colonization of Europe as it was found east of the Ural Mountains, over 1500 km from the geographically closest ancient European, Kostenki 14. Ust’Ishim and Oase are not more closely related to each other than to other ancient Europeans or present-day East Asians. This suggests there were populations of modern humans that inhabited Eurasia for some time, but failed to leave significant descendants. Although these populations likely interacted and interbred with Neanderthals in Europe, the legacy of these interactions is not preserved in the genomes of present-day humans.

In contrast, all ancient Europeans after 37 kcalBP that have been analyzed contributed to the ancestry of present-day Europeans (Fu et al. 2016). Those between 37-15 kcalBP likely descend from a single founder population. This striking population continuity begins with the Kostenki 14 individual, the oldest ancient individual to show greater affinity to present-day Europeans than to present-day East Asians. The trend
continues with GoyetQ116-1, a 35 kcalBP individual from Belgium, and all ancient samples following (Fu et al. 2016).

Lastly, Neanderthals may have been less fit evolutionarily than modern humans due to a prolonged period of low population size among Neanderthals. The demographic history of a population can be inferred from an individual by estimating the distribution of coalescent times between alleles across that individual’s diploid genome (Li & Durbin 2011). Applying this method to the Altai Neanderthal suggests that a prolonged bottleneck reduced the Neanderthal population to about 1/10th the size of modern humans ~350-50 ka (Prüfer et al. 2014). Simulations show that this population history would have allowed weakly deleterious mutations to rise in frequency among Neanderthals, while at the same time such mutations would have been selected out of the larger modern human population (Juric et al. 2015; Harris & Nielsen 2015). This theoretical prediction that purifying selection would be reduced in Neanderthals is supported by the empirical observation that Neanderthals have a higher proportion of nonsynonymous mutations, or mutations that change amino acids transcribed in coding regions (Castellano et al. 2014). Furthermore, the three Neanderthal genomes show remarkably low genetic diversity—lower than any living human population and among the lowest measured for any organism (Prüfer et al. 2014).

The Neanderthal-derived mutations would be effectively neutral among Neanderthals, but after 16,000 generations of isolation, the mutational load would cause the average Neanderthal to have an estimated 40% lower fitness than the average modern human (Harris & Nielsen 2015). Mutation-rich Neanderthal DNA would have caused strong selection against hybrids and depletion of Neanderthal ancestry from conserved
genomic regions. Again, the latter prediction is what is observed: introgressed Neanderthal DNA is significantly depleted in gene-rich regions of modern human genomes, implying purifying selection against Neanderthal material (Sankararaman et al. 2014). Relatively few introgressed alleles may have experienced positive selection, including some in genes associated with skin and hair traits (Sankararaman et al. 2016; Vernot & Akey 2014). Overall, observations of the Neanderthal genomes and the introgressed Neanderthal DNA in modern humans suggest that Neanderthals may have gone extinct because their breeding population was too small.

These three observations—that Neanderthals and moderns interbred during several episodes, that some modern human groups went extinct, and that Neanderthals had very low genetic diversity—highlight that interactions between the groups varied across time and space. Some moderns outcompeted Neanderthals, while others did not. The genetic results narrow the question of “why did modern humans outlast Neanderthals?” to “why did some modern human groups outlast Neanderthals, while others did not?” The successful modern human groups may owe their success to particular historical contingencies and cultural adaptations, beyond the biological adaptations shared by all modern humans. Genetics cannot identify the cultural adaptations; rather, we must rely on patterns of behavior preserved in the archaeological record.

1.3 Using archaeological industries as proxies for human groups

The archaeological record is used to infer human biogeography under the assumption that distinct groups make particular artifacts in particular ways (Bar-Yosef & Pilbeam 2000). Artifact assemblages are classified into units referred to as archaeological
industries, traditions, technocomplexes, or behavioral packages—terms that are inconsistently defined between scholars. I do not distinguish between these terms and take them all to mean suites of artifacts with shared features that appear at numerous sites. An archaeological unit is assumed to represent a socially connected human group and the distribution of that unit is used to infer the distribution of that human group (Bar-Yosef & Belfer-Cohen 2011). Furthermore, archaeological units are not fixed, but viewed in an evolutionary framework in which one industry evolves into another industry as features that define those industries are lost or gained across time and space (Tostevin 2009). In this analogy, archaeological industries, like human populations, belong to phylogenetic lineages. All industries have ancestors, but only some have descendants; others go extinct.

The validity of this methodology depends on the criteria used to define the archaeological units. Classification systems that rely primarily on artifact types (Bordes 1953; Bordes 1961) have been thoroughly criticized (Binford 1973; Tostevin 2013; Shea 2014; Dibble 1995; Clark 2015). Similar artifacts can arise from independent invention as distinct groups encounter similar environments and undertake similar tasks (Kuhn & Zwyns 2014). More socially meaningful archaeological units have been defined by considering other variables in addition to artifact type. In the production of material culture—from raw material selection, through tool manufacture, use, and disposal—there are many choices with equally valid solutions (Sackett 1982; Sackett 1992). These idiosyncratic choices are socially transmitted, and are partially preserved in the archaeological record (Crew 1975; Bar-Yosef & Belfer-Cohen 2011). When comparing two assemblages, the more shared features that reflect arbitrary choices, the more likely it
is that the assemblages were made by socially connected peoples. The interpretive challenge is setting some threshold, at which point the number of similarities between the assemblages is too high to be explained by chance or convergent evolution, but rather should be explained by cultural transmission (Tostevin 2013).

This methodology has been used to infer the distributions of populations across vast spans of time and space (Tostevin 2013; Kuhn & Zwyns 2014; Mellars 2006). Unfortunately the strength of the evidence supporting the links between industries and human groups varies considerably, especially regarding archaeological industries attributed to Neanderthals and moderns at their time of contact. In this work, I skeptically maintain a number of proposals that particular industries were produced by Neanderthals or modern humans. I consider these to be working hypotheses, which may be overturned by future discoveries. Once again, the chronology of archaeological assemblages presented in this dissertation is built on accurate data. The meaning of the chronology with regards to human dispersals and interactions is interpretation, subject to revision.

Generally, Neanderthals produced Middle Paleolithic (MP) industries, characterized by the use of Levallois and non-Levallois prepared core reduction methods (e.g. discoid, Quina) to make flake-based tools including sidescrapers, denticulates, and notches (Kuhn 2013; Klein 2009). Bone tools and ornaments were rare and largely disputed (Villa & Roebroeks 2014; Zilhao et al. 2010; Soressi et al. 2013). In contrast are Upper Paleolithic (UP) industries characterized by systematic blade and bladelet production, organic tools, personal ornaments, and art (Mellars 2005; Klein 2009). The earliest appearances of these UP traits provide the archaeological signal of modern humans.
It was long assumed that the Aurignacian industry was the earliest manifestation of UP traits and therefore the record of the earliest modern humans (Breuil 1913). The Aurignacian is an industry widespread in Europe after 35 ka, characterized by carinated and nosed scrapers/cores, large blades, systematic production of bone/antler tools including split-based points, and diverse personal ornaments (Bar-Yosef & Zilhão 2006). However a number of modern human fossils and industries with UP traits predate the Aurignacian, and therefore the Aurignacian probably does not represent the earliest modern humans in Europe (Teyssandier et al. 2010; Richter et al. 2008). Moreover in Southwest Asia between 130-75 ka there are fossils classified as anatomically modern humans associated with MP artifacts at Skhul and Qafzeh (Grun et al. 2005; Schwarcz et al. 1988).

There are numerous industries that do not conform to the broad division of MP and UP. I refer to these industries as “transitional” because they are found stratigraphically and temporally between clear MP and UP units. In my usage, transitional does not imply social or biological continuity between makers of preceding MP or subsequent UP. Rather, the relationships among MP, transitional, and UP industries is an open question. The transitional industries of each region are described in Chapters 2-4. Transitional industries are assumed to have been made by Neanderthals or moderns based on the following considerations:

1. The industry or some industry in its lineage is associated with human fossil remains that can be identified as Neanderthal or modern human by genetics or morphological features.
2. The industry was most likely produced by Neanderthals if it shows continuity with the underlying MP in terms of artifact types and technology, which reflect socially learned behaviors of material culture production and use. This applies to European contexts and the Levant during MIS-3.

3. Inversely, if a transitional industry does not show continuity of these features with the underlying MP, but rather shares these features with a nonlocal industry of the same age or earlier (the proposed ancestor industry), it was more likely produced by modern humans.

1.4 The biogeographic approach

In this dissertation I reconstruct Neanderthal and modern human biogeography, defined as the spatial distribution of the groups over time. While the current work is limited to spatial and temporal distributions, my long term research program aims to reconstruct Pleistocene human biogeography in a broader sense: human ecological niches in relation to other taxa and abiotic resources over time (Lomolino et al. 2010). Did Neanderthals and moderns maintain hybrid zones (Hewitt 1988; Jolly 2002)? How did the human taxa undergo dispersals, speciation processes, and extinctions (Stewart & Stringer 2012)?

For now, I compare the biogeography of human groups, as inferred from radiocarbon-dated archaeological assemblages, to the distributions of Neanderthals and moderns predicted by interaction models (Figures 1.2 & 1.3).
1.4.1 Interaction Models

1) *No overlap:* Neanderthals were locally extinct before modern humans arrived. There was no interaction between populations, and modern humans did not contribute to Neanderthal extinction.

- Neanderthal industries are stratigraphically and chronometrically earlier than modern human industries at all sites.
- There is a hiatus of greater than 1,000 years between the last appearance dated attributed to Neanderthals and first appearance date attributed to modern humans in the region. The 1,000 years cutoff is determined by the analytical uncertainty of radiocarbon dates from this period. It is our resolution limit and not related to human biological or cultural processes.

2) *Rapid replacement:* The arrival of modern humans coincided with Neanderthal extinction.

- Neanderthal industries are stratigraphically and chronometrically earlier than modern human industries at individual sites.
- The first appearance date attributed to modern humans occurs fewer than 1,000 years before the last appearance date attributed to Neanderthals in the region.

3) *Prolonged coexistence:* The prolonged presence of modern humans coincided with Neanderthal extinction (Figure 3).

- There are greater than 1,000 years between the first appearance date attributed to modern humans and the last appearance date attributed to Neanderthals.
3a) **Integration:** Neanderthals and modern humans occupied indistinguishable geographic space.

- Neanderthal and modern human industries are contemporaneous and distributed in similar geographic and ecological locations.
- The stratigraphic sequence of Neanderthal and modern human industries may vary between sites during the period of overlap.

3b) **Displacement:** Neanderthals distribution changed in response to modern humans.

- Modern human industries occur after Neanderthal industries at sites initially occupied by Neanderthals. These sites represent preferred territory.
- After the modern humans occupy the preferred territory, Neanderthal industries are found in less preferred territory.

3c) **Avoidance:** Neanderthal distribution remains constant despite the presence of modern humans in the region. Modern humans occupy geographic space not occupied by Neanderthals.

- Neanderthal industries are found within the same geographic or ecological space before and during the period of regional overlap.
- Modern human industries are found in previously unoccupied geographic or ecological space during the period of regional overlap.
- Modern human industries are found after Neanderthal industries at individual sites only after the last appearance date for Neanderthals in the region.
Figure 1.2: Interaction models based on regional chronologies of Neanderthal and modern human occurrence dates. Each column represents an archaeological site and the letters represent radiocarbon dates.
Figure 1.3: Overlap models of integration, displacement, and avoidance. Cartoons represent hypothetical region with Neanderthal (N) or modern human (S) sites at three time slices.
The models are imbalanced in terms of falsifiability (Shea 2011). Overlap cannot be rejected with certainty, while a model of no-overlap could be rejected by two contemporaneous sites with distinct assemblages. Moreover our ability to refute contemporaneity is limited by the uncertainty of radiocarbon measurements to about ±500 years. Nonsynchronous dates within 1000 years of one another may lead to false positives for overlap models.

1.5 Dissertation outline

In Chapters 2, 3, and 4 I produce chronologies of human fossils and archaeological industries for the Levant, Balkans, and Northeast Europe, which are based on review of published dates and the production of new dates from active excavations. Chapter 5 begins with a methodological discussion of radiocarbon dating: what is a reliable radiocarbon date and how can we design radiocarbon dating programs in order to produce accurate chronologies? I then summarize the dating strategies and major results from each region. Lastly I compare the regional chronologies to the interaction models, and evaluate how effective the biogeographic approach was at addressing the question of Neanderthal extinctions and modern human survival.

1.6 References


Fu, Q. et al., 2016. The genetic history of Ice Age Europe. *Nature*. doi:10.1038/nature17993


Grun, R. et al., 2005. U-series and ESR analyses of bones and teeth relating to the human


Prüfer, K. et al., 2014. The complete genome sequence of a Neanderthal from the Altai Mountains. 505, pp.43–49.


obstacles to investigating hominin evolutionary relationships in the Later Middle Paleolithic Levant. Quaternary International, 350(C), pp.169–179.


Vernot, B. et al., 2016. Excavating Neandertal and Denisovan DNA from the genomes of Melanesian individuals. Science. doi: 10.1126/science.aad9416


CHAPTER 2 – RADIOCARBON DATES FROM MANOT CAVE, ISRAEL
ESTABLISH EARLY UPPER PALEOLITHIC CHRONOLOGY OF LEVANT
WITH IMPLICATIONS FOR HUMAN DISPERSALS

Authors: Bridget Alex¹, Omry Barzilai², Israel Hershkovitz³,⁴, Ofer Marder⁵, Talia Abulafia⁵, Avner Ayalon⁶, Miryam Bar-Matthews⁶, Lauren Davis⁵, Daniella Bar-Yosef Mayer⁴, Francesco Berna⁷, Valentina Caracuta⁸, Amos Frumkin⁹, Mae Goder-Goldberger¹⁰, Mark G. Hans¹¹, Bruce Latimer¹¹,¹², Ron Lavi¹³, Lior Regev¹⁴, José-Miguel Tejero¹⁵,¹⁶, Gal Yasur⁶, Reuven Yeshurun¹⁷, & Elisabetta Boaretto¹⁴

Author affiliations: ¹Anthropology & Human Evolutionary Biology, Harvard University, 11 Divinity Avenue, Cambridge, MA 02138, USA. ²Israel Antiquities Authority, PO Box 586, Jerusalem 91004, Israel. ³Dan David Laboratory for the Search and Study of Modern Humans, Sackler Faculty of Medicine, Tel Aviv University, PO Box 39040, Tel Aviv 6997801, Israel. ⁴Steinhardt Museum of Natural History and National Research Center, Tel Aviv University, PO Box 39040, Tel Aviv 6997801, Israel. ⁵Archaeology Division, Ben-Gurion University of the Negev, PO Box 653, Beer-Sheva 8410501, Israel. ⁶Geological Survey of Israel, 30 Malkhe Israel Street, Jerusalem 95501, Israel. ⁷Department of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia V5A 1S6, Canada. ⁸Laboratory of Archaeobotany and Palaeoecology, University of Salento, Lecce 73100, Italy. ⁹Department of Geography, The Hebrew University of Jerusalem, Jerusalem 91905, Israel. ¹⁰Institute of Archaeology, The Hebrew University of Jerusalem, Jerusalem 91905, Israel. ¹¹Department of Orthodontics, Case Western Reserve University School of Dental Medicine, 10900, Euclid Avenue, Cleveland, Ohio 44106, USA. ¹²Department of Anatomy, Case Western Reserve University, Cleveland, Ohio 44106, USA. ¹³8 Dan Street, Modi’in 7173161, Israel. ¹⁴Max Planck-Weizmann Center for Integrative Archaeology and Anthropology, D-REAMS Radiocarbon Laboratory, Weizmann Institute of Science, Rehovot 76100, Israel. ¹⁵Centre National de la Recherche Scientifique de France (CNRS), UMR 7041, ArScAn équipe Ethnologie préhistorique, 92023 Nanterre, France. ¹⁶Seminar d’Estudis I Recerques Prehistòriques (SERP), Universitat de Barcelona, 08001 Barcelona, Spain. ¹⁷Sinman Institute of Archaeology, University of Haifa, Haifa 3498838, Israel.
2.1 Abstract

The Early Upper Paleolithic (EUP) sequence of the Levant has been used to form and constrain models of human dispersals and the spread of Upper Paleolithic traditions. However, the chronology and character of the Levantine EUP is itself debated. Of the two main EUP industries, the Levantine Aurignacian age is poorly established and the Early Ahmarian differs in age by several millennia between sites, clustering into early and late appearance dates. These uncertainties are largely due to the fact that many chronometric dates come from old excavations, unclear contexts, or outdated analytical methods. Here we present a chronology that does not suffer from these issues as it is based on a large sequence of radiocarbon samples dated by state-of-the-art analytical methods and collected from well-defined contexts of current excavations at Manot Cave, Israel. The radiocarbon dates are in good agreement with uranium-thorium (U-Th) dates and show that the Levantine Aurignacian occurred at least between 37,000-35,000 calibrated years before present (calBP) and the Early Ahmarian was likely present by 46,000 calBP. This strengthens the chronological placement of the Levantine Aurignacian and agrees with early appearance dates for the Ahmarian, also reported for Kebara Cave. This timing is consistent with proposed connections between the Near East and Europe, namely that the Ahmarian was related to the European Protoaurignacian and that the Levantine Aurignacian was related to the European Aurignacian through the spread of people or ideas.

2.2 Significance

The timing of Early Upper Paleolithic (EUP) traditions in the Levant is significant for understanding modern human dispersals. Despite intensive research, the Levantine
EUP chronology has not been resolved because most chronometric dates result from old excavations and outdated analytical methods. Here we report dates for Manot Cave, Israel, which constitute the largest series of EUP radiocarbon dates (n=55) from current excavations and state-of-the-art analytical methods. At Manot the EUP Levantine Aurignacian industry occurred at least between 37,000-35,000 calBP and the EUP Early Ahmariian was likely present by 46,000 calBP. This establishes a reliable EUP chronology for the Levant, which allows us to evaluate models of human dispersals and technological diffusion between the Levant and Europe.

2.3 Introduction

The timing and character of archaeological industries in the Levant between 50,000-30,000 years ago is significant for understanding the origin and spread of Upper Paleolithic traditions and peoples. During the temporal phase known as the Early Upper Paleolithic (EUP), there were two distinct cultural entities in the Levant: the Early Ahmariian and Levantine Aurignacian (Gilead 1981; Marks 1981). Early Ahmariian technology is characterized by blades/bladelets on elongated blanks made by soft hammer reduction of prismatic cores. The toolkit is dominated by el-Wad points, retouched blades, and endscrapers and burins on blades (Monigal 2003; Goring-Morris & Davidzon 2006; Gilead & Bar-Yosef 1993). It was distributed throughout the Levant, in the Mediterranean coastal woodlands as well as the arid zones (Sinai, Negev, Jordanian deserts) (Bar-Yosef & Belfer-Cohen 2010). Confined to Mediterranean cave sites, the Levantine Aurignacian is characterized by production of thick blade blanks and curved/twisted bladelets as well as a toolkit including thick endscrapers (nosed, shouldered, carinated), Aurignacian retouched blades, Dufour bladelets, and antler...
projectile points (Goring-Morris & Belfer-Cohen 2006; Tejero et al. in press). The Ahmarian and Levantine Aurignacian traditions may have coexisted, but the Levantine Aurignacian seems to have had a more limited temporal span and spatial distribution (Bar-Yosef & Belfer-Cohen 2010; Marks 2003). It is thought that the Early Ahmarian developed locally from the Initial Upper Paleolithic (IUP) (Kuhn 2013; Marks & Rose 2014), while the Levantine Aurignacian had nonlocal origins (Goring-Morris & Belfer-Cohen 2006; Williams & Bergman 2010).

The absolute chronology of these industries is debated (Douka 2013; Bosch et al. 2015a; Rebollo et al. 2011). Early Ahmarian assemblages have been intensively dated in recent studies, but the results differ by several millennia. Dates from Kebara, Israel begin the Early Ahmarian at 47/46 kcalBP (Rebollo et al. 2011), while those from Ksar Akil, Lebanon and Üçakızlı, Turkey begin the phase around 43 kcalBP (Bosch et al. 2015a) or 40 kcalBP (Douka et al. 2013; Douka 2013). The reason for this discrepancy between early appearance dates from Kebara and late appearance dates from Ksar Akil and Üçakızlı is disputed and may reflect the true timing of the industry across sites, issues of characterizing assemblages, or errors in radiocarbon dating. Regarding the Levantine Aurignacian, most dates were produced decades ago, associated with large error ranges or unreliable methods (Mellars & Tixier 1989; Bar-Yosef et al. 1996; Hedges et al. 1992). As such, the timing of this industry is not known with precision.

The ages of the Early Ahmarian and Levantine Aurignacian have implications beyond the local chronology because the occurrence of these industries has been used to argue for the spread of peoples or ideas between the Near East and Europe (Hublin 2015; Tostevin 2013). Specifically it has been proposed that the Early Ahmarian in the Levant
led to the Protoaurignacian in Europe (Mellars 2006), and that makers of the European Aurignacian back-migrated to the Near East, producing the Levantine Aurignacian (Goring-Morris & Belfer-Cohen 2006). The likelihood of these scenarios depends on both the affinities between industries and their relative ages.

2.4 Manot Cave

Manot is an active karstic cave in northwest Israel, about 10 km east of the present day Mediterranean Sea (Figure 2.1). The site has been excavated for six seasons from 2010-2015 (Barzilai et al. 2012; Marder et al. 2013; Barzilai et al. 2014). Manot sediments include reworked soil containing artifacts and ecofacts that entered the cave through at least two now-sealed entrances, as inferred by the presence of west and east taluses. There are rich deposits of Early Ahmarian and Levantine Aurignacian material, as well as less abundant Epipaleolithic, Initial Upper Paleolithic (IUP), and Middle Paleolithic (MP) finds. Human fossils of several individuals have been found, including Manot 1, an anatomically modern human calvaria U-Th dated to a minimum age of 54.7 ± 5.5 ka (Hershkovitz et al. 2015).

Excavations have focused on Areas C and E (Appendix A). At the top of the west talus slope, Area E has preserved occupational deposits recognized by semi-brecciated sediment, concentrations of artifacts, and in situ occupational surfaces defined by intact hearths (Appendix A). Unit 1, the uppermost, is a thick archaeologically sterile deposit. Unit 2 Layers I-III contain relatively low artifact yields comprising endscrapers, burins, and partially retouched twisted bladelets. Artifacts in these layers probably represent a post-Aurignacian tradition. In contrast, the richer assemblage of Unit 2 Layers IV-IX has artifacts characteristic of the Levantine Aurignacian with osseous tools and lithics.
**Figure 2.1:** Map of Levantine Early Upper Paleolithic sites mentioned in text: 1) Üçağızlı, 2) Ksar Akil, 3) Manot, 4) Kebara, 5) Wadi Kharar 16R, 6) Hayonim, 7) Meged, 8) Raqefet, 9) Qafzeh, 10) Nahal Ein-Gev I, 11) Mughr el-Hamamah, 12) Tor Sadaf, 13) Boker A/Boker Tachtit, 14) Qadesh Barnea, 15) Lagama VII, 16) Abu Noshra II. Sites included in regional chronology are in red. Manot Cave indicated by star.
including nosed and carinated scrapers, blades with Aurignacian retouch, and massive tools. The base of occupational layers in Area E has not been reached.

In Area C, near the bottom of the west talus, no clear-cut occupational surfaces were observed during excavation or by micromorphological analysis (Appendix A). However, Area C yielded abundant anthropogenic material that was likely redeposited in sequence from primary contexts higher on the slope. The stratigraphic sequence here includes: Unit 1, a talus deposit with no UP material. Units 2–4 have typical Levantine Aurignacian artifacts including carinated and nosed endscapers on Aurignacian blades, curved-twisted bladelets, bone and antler tools, and shell ornaments (Appendix A). In Units 5–6 both Aurignacian and Ahmari elements are prevalent. There is no discrete boundary between these cultural phases evident from the sediments or artifacts. Units 7–8 contain a predominately Early Ahmari assemblage with long and narrow blades, uni- and bidirectional cores, endscrapers, burins, and el-Wad points (Appendix A). IUP and MP layers have not yet been uncovered, but the presence of these phases is suggested by a small number of finds at the base of the excavated sequence: IUP pieces include endscrapers on unprepared flakes, uni- and bidirectional blade cores with wide removal surfaces, and blades with wide faceted butts resembling Levallois blades. The MP pieces are a few Levallois cores and flakes (Hershkovitz et al. 2015).

2.5 Results and Discussion

2.5.1 Chronostratigraphy at Manot

A total of 55 AMS radiocarbon dates of 41 charcoals (several with replicate measurements) and 6 sediment samples were produced in this study (Figure 2.2, Appendix A). All dates in the text are reported as calibrated 68% highest probability
Figure 2.2: Radiocarbon dates from Area E and Area C-J squares shown as probability density functions (pdfs) calibrated with OxCal v4.2 (Bronk Ramsey 2009) and IntCal13 (Reimer et al. 2013). Dates are listed in stratigraphic sequence by laboratory code followed by absolute elevation or the elevation range of the sample’s excavation basket.
density functions (pdfs). In Area E charcoals were dated from 3 confirmed combustion features (Appendix A). The combustion features (Loci 500, 501) in Unit 2 Layer I, associated with a post-Aurignacian industry, dated to 34-33 kcalBP. Lower in the stratigraphic sequence, a combustion feature (Locus 502) dated to 37-36 kcalBP in Unit 2 Layer IV, which contains Levantine Aurignacian artifacts. An additional charcoal from 10 cm above Locus 502, in the Unit 1 archaeologically sterile colluvium, produced a date of 34 kcalBP.

In Area C, a relatively homogenous sedimentary composition and structure was indicated by field observations, FTIR of sediments, and micromorphological analysis. The area comprises reworked terra rossa soil of silty clay loam with abundant biogenic and anthropogenic materials (Appendix A). There is no evidence of in situ combustion features or other unambiguous indication of anthropogenic occupational surfaces. However, the area exhibits a cultural sequence and chipped stone from all stages of the reduction process. These observations suggest that archaeological material was redeposited in sequence over time, after primary deposition upslope. This conclusion is supported by the radiocarbon and U-Th dates, which are in agreement and show increasing age with depth. Speleothems from four flowstone layers were U-Th dated, with the uppermost lamina producing a date of 20 ka and the lowermost lamina producing a date of 42 ka (Hershkovitz et al. 2015). Charcoals (n=4) collected from between these flowstones produced radiocarbon dates of 31-27 kcalBP.

A nearly continuous ~1.5 meter sequence of 30 radiocarbon dates was produced from 23 charcoals in Area C (squares J64, J65, J66) (Figure 2.2, Appendix A). The dates from Unit 4 (n=7) ranged from 38-34 kcalBP. Dates from Units 5-6 (n=14) covered a
wider timespan from 49-33 kcalBP, but most dates show increasing age with depth, belonging to a younger or older cluster. The two lowest dates in the sequence came from Unit 7 and ranged from 46-44 kcalBP. Three samples (RTD7783A, RTD7785, RTD7786) from the boundary of Units 5/6 produced dates suggesting reversed stratigraphic order. In the same area of the section, there appears to be a gap in dates from 41-39 kcalBP. The Unit 5/6 boundary is characterized by many rocks, possibly indicating stronger water activity, which could have led to mixed and missing sediments. The interstratified dates and temporal hiatus likely reflect the complicated depositional history of this portion of the sequence.

Conservative estimates for the timing of cultural phases were based on samples from the following secure contexts (Table 2.1): post-Aurignacian material was deposited 34-33 kcalBP in Area E Unit 2 Layer I (combustion features Loci 500 and 501); Levantine Aurignacian material dates to 38-34 kcalBP in Area E Unit 2 Layer IV (combustion feature Locus 502) and Area C Unit 4; Early Ahmarian material dates to 46-44 kcalBP based on two samples from Area C Unit 7. These dates provide the ages of charcoals securely associated with archaeological industries, but probably do not capture the full span of the industries. Our dates from secure contexts represent moments within cultural phases that lack stratigraphically bound start/end dates.

The dates from Area C Units 5-6, which contain a mixture of Aurignacian and Ahmarian artifacts, were excluded from the conservative age estimates described above. Dates from this portion of the sequence cluster into a younger group from the top of Unit 5 and an older group from the bottom of Unit 6. The younger dates overlap in age with the secure Aurignacian dates, while the older dates overlap in age with the secure
Ahmarian dates from Unit 7. It is our hypothesis that the younger dates from Unit 5 belong to the Aurignacian phase and the older dates from Unit 6 belong to the Ahmarian phase. One date from this extended dataset was significantly older than others: RTD7116 from midway through Unit 6 produced a date >48 kcalBP (RTD7116: 48,700 ^14C yr BP). This may be the oldest date for the Ahmarian at Manot or it may belong to an earlier phase, as artifacts suggestive of the IUP and MP were recovered from the base of the sequence.

Table 2.1: Ranges of dates assigned to archaeological phases in Manot Cave.

<table>
<thead>
<tr>
<th></th>
<th>Ahmarian</th>
<th>Levantine Aurignacian</th>
<th>Post-Aurignacian</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Secure</strong></td>
<td>Contexts</td>
<td>Area C Unit 7</td>
<td>Area E Unit 2 Layer IV L. 502; Area C Unit 4</td>
</tr>
<tr>
<td></td>
<td>Calibrated range</td>
<td>45,870- 44,200</td>
<td>38,260- 34,050</td>
</tr>
<tr>
<td></td>
<td>Modeled range</td>
<td>45,939- 43,923</td>
<td>36,786- 34,934</td>
</tr>
<tr>
<td><strong>Expanded</strong></td>
<td>Contexts</td>
<td>Area C Units 6 &amp; 7</td>
<td>Area E Unit II Layer IV L. 502; Area C Units 4-5</td>
</tr>
<tr>
<td></td>
<td>Calibrated range</td>
<td>49,440- 41,560</td>
<td>38,260- 34,050</td>
</tr>
<tr>
<td></td>
<td>Modeled range</td>
<td>45,551- 42,048 or 49,356- 41,903</td>
<td>37,229- 35,497</td>
</tr>
</tbody>
</table>

Bayesian models were produced to estimate the span of archaeological phases and test for outliers (Table 2.1, Appendix A). Model 1 only includes dates from secure contexts, which provide accurate occurrence dates for the industries, but probably do not represent the full spans. Model 2 also includes dates from Units 6 and 7 that overlap in age with the secure Aurignacian and Ahmarian dates. A shortcoming of both models is that there are no clear stratigraphic boundaries for the start/end of the Ahmarian and the start of the Aurignacian. Our phase estimates may therefore underestimate the full span of industries. Models 1 and 2 produce consistent results for the modeled spans of the post-Aurignacian from 34-33 kcalBP and Levantine Aurignacian from 37-35 kcalBP. The
outputs for the Ahmarian differ, with Model 1 producing a span of 46-44 kcalBP and Model 2 producing a longer span of 46-42 kcalBP. This difference is likely due to the fact that Model 1 only has two dates for the Ahmarian phase, while Model 2 has nine dates. The only sample identified as an outlier by either model was RTD7116, which was ~2000 years older than any other dates. If this sample is included then the Ahmarian could be >48 kcalBP. However we believe that it is more likely that this charcoal intruded from an earlier phase.

Based on our interpretation of the radiocarbon dates and stratigraphic sequence, we propose the following chronology of minimum spans for archaeological phases: a post-Aurignacian industry 34-33 kcalBP, Levantine Aurignacian 37-35 kcalBP, and Early Ahmarian 46-42 kcalBP.

2.5.2 Implications for regional chronology

It is difficult to construct a regional chronology due to the variable quality of assemblages and absolute dates. In addition to Manot, there are only four sites with large sequences of radiocarbon dates produced by state-of-the-art analytical methods (Figure 2.1). Three of these are caves or rock shelters along the Mediterranean coast: Üçağızlı in Turkey (Kuhn et al. 2009), Ksar Akil in Lebanon (Douka et al. 2013; Bosch et al. 2015a), and Kebara in Israel (Rebollo et al. 2011). The fourth is Mughr el-Hamamah in the Jordan Valley (Stutz et al. 2015). Other sites in the southern arid zone (Negev, Sinai, Jordanian deserts) have fewer than 10 dates published, which were produced in the 1970s and early ‘80s (Phillips 1994; Goring-Morris & Belfer-Cohen 2003). These include Abu Noshra I-II (Phillips 1994), Boker A (Marks 1983), Qadesh Barnea (Gilead 1991) and the Lagaman sites (Bar-Yosef & Phillips 1977). With limited data from the arid zone, the
regional chronology is based on the Mediterranean coastal sites, which have similar ecology, preservation conditions, and archaeological sequences. This coastal sample is probably not representative of the technological and behavioral variability exhibited by Levantine people between 50-30 ka. Relations between coastal and arid sites are unclear, and the timing and character of industries may have differed between these zones.

Among the chronologies of the Mediterranean coastal sites, there are some consistencies and some disagreements (Figure 2.3, Appendix A). The few dates produced for Levantine Aurignacian assemblages (sensu Williams & Bergman 2010) are in broad agreement, although most of the previous measurements were made in the 1980s and ‘90s and have large error ranges (Douka 2013). A rich Levantine Aurignacian assemblage was found at Hayonim (Belfer-Cohen & Bar-Yosef 1981), but the radiocarbon dates were produced from charred bones and are probably unreliable (Hedges et al. 1992). At Raqefet, the only sample securely associated with Levantine Aurignacian artifacts produced a date of ~34 kcalBP (RTT-4945: 30,540 ± 440 BP) (Lengyel et al. 2006). Thus the span reported here of 37-35 kcalBP for Manot Cave offers the largest reliable radiocarbon sequence for a Levantine Aurignacian assemblage.

The Early Ahmarian appears to have begun by 47.5/46 kcalBP at Kebara (Rebollo et al. 2011) and Manot, and then around 43 kcalBP (Bosch et al. 2015a) or 40 kcalBP (Douka 2013) at Ksar Akil and Üçağızlı. This 3,000-7,000 year difference may be because the people at Manot and Kebara produced the Early Ahmarian several thousand years earlier than people at Ksar Akil and Üçağızlı. However, this possibility is weakened by the observation that these assemblages show a high degree of techno-typological similarity within a narrow geographic and stratigraphic range, corresponding to the
Figure 2.3: Regional chronology of radiocarbon dates for stratified EUP sites between 50-30 kcalBP. Vertical lines are charcoal dates and crossed lines are shell dates. Dates are shown calibrated at their 68.2% highest probability density function using OxCal2.4 software (Bronk Ramsey 2009) and the IntCal-Marine13 calibration curve (Reimer et al. 2013). Dates are color coded by associated archaeological industry and organized into columns by site and study. Within a given study dates are ordered in stratigraphic sequence (lowest elevation or layer on the left to highest on the right), as precisely as this information is known. The shaded blocks represent phase ranges reported by particular studies after Bayesian modeling. M&T stands for Mellars and Tixier (Mellars & Tixier 1989), MHM stands for Mughr el-Hamamah. Dates assigned to “other or undetermined” do not necessarily represent the same industry between sites or strata. Site and date information in Appendix A.
northern early Ahmarian” (Kadowaki et al. 2015). The Early Ahmarian likely developed in situ from the IUP based on sequences in the Negev (Boker Tachtit-Boker) (Marks 1983), Üçağızlı (Kuhn 2013), and Ksar Akil (Ohnuma & Bergman 1990). The more southern sites of Manot and Kebara do not have stratified IUP assemblages, but the well-dated Early Ahmarian layers are earlier than or contemporaneous with the IUP at Ksar Akil and Üçağızlı. In this case, the people of Ksar Akil and Üçağızlı would have gradually developed an industry 3,000-7,000 years after it was fully developed less than 400 km to the south. We believe that this is unlikely and therefore maintain an assumption that the Early Ahmarian assemblages of Kebara, Manot, Ksar Akil and Üçağızlı were produced by contemporaneous, socially related people. We emphasize that this assumption is fundamental to our arguments, but cannot be sufficiently evaluated until the assemblages are described in commensurate detail and analyzed within a comparative framework (Tostevin 2013).

Alternatively, the discrepancy may be explained by differences in the reliability of radiocarbon dates. Ksar Akil is generally regarded as the reference sequence for the UP of the Levant, but the EUP and earlier layers were excavated in the 1930s and 40s (Ewing 1947; Williams & Bergman 2010). Materials were collected in levels that could be 1-2 meters thick and samples may have been contaminated and/or mislabeled in the decades since (Douka et al. 2013; Douka 2013). Two recent studies dated shells from Ksar Akil collections, using differing sample selection and model parameters (Douka et al. 2013; Bosch et al. 2015a). Focusing on shell ornaments, Douka and colleagues modeled the Ahmarian starting 41.6-40.9 kcalBP and ending 39.0-37.5 kcalBP (Douka et al. 2013). Bosch and colleagues dated dietary shells and reported significantly older (2,000-5,000 y)
age estimates of 43.3-43.0 kcalBP start and 43.1-42.8 kcalBP end (Bosch et al. 2015a). Although the chronologies differ, both propose start dates for the Early Ahmarian that are several thousand years younger than the start of the Early Ahmarian at Manot.

At Üçağızlı a series of charcoals (Kuhn et al. 2009) and shells (Douka 2013) were dated from IUP and Early Ahmarian layers. The charcoal dates show a broad trend of increasing age with depth from 32 to 45 kcalBP, although individual dates are markedly interstratified. The authors suggest the oldest charcoal dates are closest to the age of the deposits, but are probably still minimum age estimates (Kuhn et al. 2009). Adding eight shell dates and stratigraphic constraints, Douka modeled the Early Ahmarian span between 39-36 kcalBP (Douka 2013).

In the most recent study of Kebara, the authors reopened an excavation area in order to collect fresh charcoals that were prepared by ABA and ABOx-SC (Rebollo et al. 2011). The authors modeled the start of the Early Ahmarian by 47.5/46 kcalBP. These dates are consistent with earlier studies that reported ABA-prepared charcoals (Bar-Yosef et al. 1996) and thermoluminescence dates of heated flints (Valladas et al. 1987). However, it has been suggested that the relatively old Early Ahmarian dates are due to intrusive charcoals from the lower MP layers (Douka et al. 2013; Zilhao 2013).

The late appearance dates for the Early Ahmarian from Ksar Akil and Üçağızlı were produced primarily from shells, while the early appearance dates from Manot and Kebara were produced from charcoals. Shell and charcoal are both problematic materials in terms of the radiocarbon community’s ability to detect and eliminate contamination (Busschers et al. 2014; Rebollo et al. 2011). However, because a small fraction (<1%) of modern carbon can make a Late Pleistocene sample appear thousands of years younger
(Bronk Ramsey 2008), it is common practice to regard older dates as more reliable (Higham et al. 2011; Higham 2011). It is therefore likely that the early appearance dates produced from charcoals from Manot and Kebara are closer to the true age of the Early Ahmarian.

2.5.3 Implications for the spread of modern humans and UP technology

The EUP chronology of Manot has implications for dispersals of modern humans and the spread of Upper Paleolithic traditions. It has been argued that the Early Ahmarian spread through human migrations or technological diffusion to Europe, where the traditions manifested as the Protoaurignacian (Mellars 2006). This model has been challenged because late appearance dates for the Ahmarian of ~40 kcalBP from Ksar Akil and Üçağızlı (Douka 2013) are younger than the earliest Protoaurignacian dates of 44-41 kcalBP from sites including Isturitz, Riparo Mochi, L’Arbreda, and Fumane (Douka et al. 2012; Wood et al. 2014). In contrast, early appearance dates from Manot and Kebara begin the Ahmarian by 46 kcalBP, securely before the earliest Protoaurignacian, and therefore do not refute the proposal that the Ahmarian of the Levant gave rise to the Protoaurignacian of Europe.

It has also been proposed that the Levantine Aurignacian was a nonlocal industry, introduced by European Aurignacian people (Goring-Morris & Belfer-Cohen 2006; Garrod 1953). The secure Levantine Aurignacian dates from Manot of 37-35 kcalBP are contemporaneous with or slightly later than the 39.5-35.5 modeled start dates of the Evolved Aurignacian in Southwest France/Northern Iberia at L’Arbreda, La Viña, and Abri Pataud (Wood et al. 2014; Higham et al. 2011) and substantially later than Proto/Early Aurignacian assemblages, which begin between 44-41 kcalBP across Europe.
at sites including Isturitz, Riparo Mochi, and Willendorf II (Douka et al. 2012; Nigst et al. 2014; Wood et al. 2014). The osseous industry at Manot in particular shows similarities with the Evolved Aurignacian (Tejero et al. in press). Thus the artifacts and dates from Manot allow for the possibility that the Levantine Aurignacian developed from a European Aurignacian precursor.

Testing proposed affinities between the Ahmarian and Protoaurignacian as well as the European Aurignacian and Levantine Aurignacian will require systematic comparisons of the material cultural remains (i.e. lithics, shells, bone, and antler artifacts) from each region. However ancestor-descendent relationships cannot be evaluated without accurate dates. Our results greatly inform this effort by providing a reliable Levantine EUP chronology, based on a large number of radiocarbon samples collected from well-characterized contexts of current excavations and prepared with state-of-the-art analytical methods.

2.6 Methods summary

The objective of radiocarbon dating was to establish the EUP chronology of the site and the age of in situ hearths. Samples were chosen for radiocarbon dating based on characterization of their context and preservation state. Contexts were evaluated by micromorphological analysis, Fourier Transform Infrared Spectrometry (FTIR) of associated sediments, and U-Th dating of speleothems and calcite crusts on artifacts. Charcoals were taxonomically identified (Appendix A) and their preservation was characterized by microscopy, FTIR of untreated and pretreated samples, and %C upon combustion (Cohen-Ofri et al. 2006; Rebollo et al. 2008) (Appendix A). Charcoal samples were prepared for radiocarbon dating by standard acid-base-acid (ABA)
procedures at the DANGOOR Research Accelerator Mass Spectrometry Laboratory (D-REAMS), Max Planck-Weizmann Center for Integrative Archaeology and Anthropology, Israel (Rebollo et al. 2011; Yizhaq et al. 2005; Boaretto et al. 2009). Graphite samples with laboratory code RTD were measured by AMS at the D-REAMS Laboratory and those with the code RTK were measured at the NSF-AMS Radiocarbon Laboratory in Tucson, Arizona. δ^{13}C was measured at the Geological Survey of Israel, Jerusalem. Dates were calibrated using OxCal version 4.2 software (Bronk Ramsey 2009a) and IntCal13 atmospheric or Marine13 curves (Reimer et al. 2013) and are reported as radiocarbon years (^{14}C yr BP) or calibrated years (calBP) at the 68.2% highest probability density function (pdf).

The charcoals were prepared with acid-base-acid (ABA) pretreatment (Rebollo et al. 2011). Numerous studies have shown that the harsher ABOx-SC pretreatment (Bird et al. 1999) can produce older dates that are more consistent with other chronostratigraphic data (Wood et al. 2012; Douka et al. 2010). However other studies have found that ABA-treated samples produced older dates and better preservation parameters, suggesting those particular ABA samples had proportionately less contamination that their corresponding ABOx-SC replicates (Rebollo et al. 2011; Stutz et al. 2015). We believe that the proper pretreatment for fossil charcoal depends on the particular depositional and diagenetic histories of samples as well as laboratory procedures (Rebollo et al. 2011; Rebollo et al. 2008; Haesaerts et al. 2013). Therefore, strict quality control standards are the best indicator of reliable dates rather than assuming that the harsher treatment always produces more reliable dates. All of the Manot charcoal samples that we consider reliable were visually identified as well-preserved Amygdalus sp. wood charcoal, had %C in the
acceptable range (>50%), and had FTIR spectra that displayed peaks consistent with pretreated charcoal (Appendix A). Moreover, contamination predominately makes dates younger, and the Manot charcoals are significantly older than dates for similar assemblages at other sites.

2.7 Supporting information

2.7.1 Levantine Early Upper Paleolithic

The Early Ahmarian and Levantine Aurignacian are two distinct cultural entities (Gilead 1981; Marks 1981), which are assumed to have coexisted in the Levant for some time during the Early Upper Paleolithic (EUP) (Bar-Yosef & Belfer-Cohen 2010; Belfer-Cohen & Goring-Morris 2003). In Early Ahmarian assemblages prismatic core reduction was used to produce elongated blanks with a soft hammer (Meignen 2012; Marks 2003). The toolkit features retouched and backed blades, bladelets, endscrapers, burins, and el-Wad points. Bone tools and shell ornaments have been found in coastal cave sites conducive to organic preservation (Newcomer 1974; Kuhn et al. 2009; Douka 2013). The industry has been documented throughout the Levant, in caves of the Mediterranean woodlands and open-air sites of the arid regions. There is variability between assemblages classified as Early Ahmarian, which may correspond to different ecological zones or chronological changes (Goring-Morris & Davidzon 2006; Kadowaki et al. 2015; Stutz et al. 2015). The Early Ahmarian is best documented at Ksar Akil XX-XVI (Azoury 1986; Ohnuma 1988), Üçağızlı B3-B (Kuhn et al. 2009), Kebara IV-III (Bar-Yosef et al. 1996), Boker A (Monigal 2003), Abu Noshra II (Phillips 1988; Phillips 1991), Qadesh Barnea (Gilead & Bar-Yosef 1993), Lagama VII (Bar-Yosef & Phillips 1977), and Tor Sadaf EUP (Fox 2003). The easternmost Early Ahmarian assemblage was found in Syria.
at Wadi Kharar 16R (Kadowaki et al. 2015). A juvenile skull and postcranial remains (“Egbert”) were recovered from Early Ahmarian levels at Ksar Akil, at the boundary between levels XVI-XVII, and identified as modern human based on casts (Stringer & Bergman 1989). Early Ahmarian layers at Üçağızlı have produced isolated teeth with ambiguous taxonomic affinities (Kuhn et al. 2009). Despite the weak fossil evidence, the Early Ahmarian is widely thought to have been developed locally from IUP traditions by modern humans (Bar-Yosef 2000; Marks 2003; Kuhn 2013).

The Levantine Aurignacian appeared in the region, contemporaneous with, but distinct from the Early Ahmarian. Strictly defined, the Levantine Aurignacian is characterized by flake production with hard hammer percussion, carination, and Aurignacian retouch, and different reduction sequences were used for flakes, blades, and bladelets (Williams 2003; Marks 2003; Goring-Morris & Belfer-Cohen 2006). Typologically, the assemblages are dominated by thick endscrapers (nosed, shouldered, carinated varieties) and also include burins, Aurignacian retouched blades, el-Wad points, and Dufour bladelets. There are personal ornaments, portable art, and bone and antler tools (Bar-Yosef & Belfer-Cohen 2010). The best-described assemblages are from Ksar Akil VII-VIII (Williams & Bergman 2010), Kebara II-I (Bar-Yosef et al. 1996; Tostevin 2013; Bar-Yosef & Belfer-Cohen 1996), and Hayonim D (Belfer-Cohen & Bar-Yosef 1981). The Levantine Aurignacian sensu stricto was a stratigraphically and geographically limited industry that appears intrusive within the local UP sequence (Williams & Bergman 2010). Based on this observation and the industry’s strong typo-technological similarities with classic Aurignacian assemblages of Europe, some have argued that European modern humans spread Aurignacian traditions to the Levant.
2.7.2 Manot Cave

Located ~220 m asl in a hilly woodland, Manot Cave is in the western Galilee region of Israel, about 10 km north of Hayonim Cave and 40 km northeast of the Mt. Carmel caves (Marder et al. 2013; Barzilai et al. 2012; Hershkovitz et al. 2015; Barzilai et al. 2014). The cave comprises an elongated main hall (80 m long, 10-25 m wide, 20 m deep) and two lower chambers connected north to south (Appendix A). The original cave entrance was likely blocked by roof collapse around 30 ka. Twelve excavation areas (Areas A-L; Appendix A) have been opened and excavations are ongoing. Most work has concentrated on the stratified sequences in Areas C and E.

Area E is at the top of the talus slope near the modern and presumed ancient cave entrances. The area contains occupational deposits and localized surfaces that likely eroded into a steep slope covered by relatively recent colluvium (Appendix A). When excavated, the occupational deposits have emerged as partially eroded terraces, defined as archaeological horizons based on the recognition of compact semi-brecciated sediment, combustion features, and concentrations of artifacts. Between the archaeological horizons the sediment is looser and artifact-poor. At the top, Unit 1 is the archaeologically sterile colluvium: loose, damp soil with many rocks. Unit 2 comprises ~2.5 meters divided into nine archaeological layers (I-IX). The upper Unit 2 Layers I-III have low artifact density, but contain a series of well-preserved combustion features. For instance Locus 500 in Unit 2 Layer I (Appendix A) is a 0.6 m diameter hearth with white, calcified wood ash surrounded by a layer of burnt heated clay. Burnt flints, charcoal
pieces, and bone fragments excavated from a ~0.1 m thick layer adjacent to the hearth indicate a living surface. Lithic artifacts from Unit 2 Layers I-III include endscrapers, various types of burins (including one on a Clactonian notch), and partially retouched twisted bladelets. The assemblage is similar to post-Aurignacian industries found at Meged Rockshelter Unit 3 (Kuhn et al. 2004), Nahal Ein-Gev I (Belfer-Cohen et al. 2004), and Ksar Akil VI Phase 6 (Bergman 1987). It seems that Unit 2 Layers I-III contain an unnamed UP tradition, distinct from the Levantine Aurignacian.

The lower Unit 2 Layers IV-IX contain a greater number of artifacts and numerous combustion features, which appear as oval patches of white calcified ash containing burnt bones, flints, and charcoals, surrounded and underlain by reddish then blackish sediment. The flint artifacts from Unit 2 Layers IV-IX are characteristic of the Levantine Aurignacian industry with nosed and carinated scrapers, blades displaying Aurignacian retouch, and massive tools (denticulates and retouch pieces). A few el-Wad points were found within these layers. The osseous tool assemblage consists of awls on bones and projectile points on antlers (Tejero et al. in press). A perforated red deer (Cervus elaphus) canine is also documented from Unit 2 Layer V. Red deer canines were among the most frequently used personal ornaments in the European Aurignacian (Vanhaeren & d'Errico 2006; White 2007). The few marine shell beads (less than 10) are Columbella rustica, Nassarius gibbosulus, and Antalis sp. Large local land snails, Levantina caesareana, may have been consumed (Bar-Yosef Mayer pers. comm.). The material culture from Unit 2 Layers IV-IX is similar to Hayonim Cave Unit D (Belfer-Cohen & Bar-Yosef 1981), Kebara I-II (Bar-Yosef & Belfer-Cohen 1996), Raqefet III (Lengyel 2007) and probably to Ksar Akil VII-VIII Phase 5 (Williams & Bergman 2010).
A different depositional history led to the formation of Area C near the base of the talus slope (Appendix A). The area was divided into 8 units based on changes in abundance and character of geologic and anthropogenic materials. The sediment consists of dark brown to reddish brown clay to silty clay loam with varying compactness and density of stones. Several channels were observed that follow the natural slope of the talus. No occupational surfaces were identified. Units 2-4 contain an Aurignacian flint assemblage and antler projectile points (Tejero et al. in press) (Appendix A). Units 5-6 have a mix of Aurignacian and Ahmarian elements. In Units 7-8 Ahmarian elements dominate the flint assemblage (Appendix A), although Initial Upper Palaeolithic (IUP) and Middle Palaeolithic (MP) components were also identified (Hershkovitz et al. 2015). Numerous blades and bladelets produced from single or opposed platform cores were recorded. The Ahmarian tool kit consists of retouched blade and bladelets, el-Wad points, scrapers on blades, and burins. Similar assemblages have been found in Kebara III-IV (Bar-Yosef et al. 1996), Qafzeh E (Bar-Yosef & Belfer-Cohen 2004), Ksar Akil XVI-XX Phase 2 (Ohnuma 1988; Williams & Bergman 2010), and Üçagizli B1-3 (Kuhn et al. 2009). The shell assemblage from Area C includes *Columbella rustica*, *Nassarius gibbosulus*, and a few other gastropods used for personal ornamentation as well as *Pattela* sp., probably consumed as food (Marder et al. 2013).

2.7.3 Geoarchaeological analysis

2.7.3.1. Methods

In conjunction with geoarchaeological work at Manot Cave, focused mineralogical analyses were conducted to support radiocarbon sampling and interpretation. The analyses included micromorphology, loose sediment characterization,
and experimental heating of local control sediment. For micromorphological study, intact sediment blocks were taken from throughout the vertical section of Area C (Appendix A) and from specific features in Area E. Air-dried blocks were impregnated with polyester/styrene resin, cured, cut with a rock saw, and sent to Spectrum Petrographies (Vancouver, WA), where they were prepared into 30 µm thin sections. The thin sections were analyzed with a petrographic microscope and described using conventional criteria and terminology (Bullock 1985; Stoops 2003). Loose sediment samples were collected from surfaces, sections, and with radiocarbon samples, then analyzed by Fourier Transform Infrared Spectrometry (FTIR). For all FTIR measurements, a few milligrams of sample were ground and homogenized with an agate mortar and pestle. Approximately 0.2 mg sample was mixed with ~50 mg KBr powder and pressed into a 7-mm pellet with a hand press (Qwik Handi-Press, Spectra-Tech Industries Corporation) or a manual hydraulic press (Specac). FTIR spectra were measured at 4 cm⁻¹ resolution for 32 scans between 4000-400 cm⁻¹ (Weiner 2010; Toffolo et al. 2012). Spectra and photographs of thin sections are available upon request.

Control sediment was collected from the surface of the cave base (Area A) for an experimental heating study (Berna et al. 2007). The sediment was heated to set temperatures and analyzed by FTIR to determine the temperature-related transformations of the clay minerals contained in the local sediment. This calibration was then used to estimate the temperatures reached by sediment associated with putative combustion features. 50 g of sediment was homogenized and separated into ten 5 g samples. The samples were placed in ceramic crucibles and heated to different temperatures (0°C and 200-1000°C at 100°C increments) for four hours in a muffle furnace (Adam Mandel, T21
type coupled with an Eurotherm 3216 temperature programmer). After heating the sediments were analyzed by FTIR as described above.

2.7.3.2 Results

In Area E, mineralogical analysis focused on characterization of the combustion features from which charcoals were collected for radiocarbon dating (Loci 500, 501, 502). The results of the experimental heating of control sediment show that sediment heating can be detected above 500°C, at which point the infrared OH stretching absorption band of the kaolinite lattice (3695 cm\(^{-1}\)) disappears (Appendix A). At 800°C the shoulder corresponding to the infrared OH stretching absorptions of the mica-smectite lattice (3620 cm\(^{-1}\)) disappears. Also, the major infrared Si-O silicate absorption (usually 1035 cm\(^{-1}\)) shifts to increasingly higher wavenumbers (>1070 cm\(^{-1}\)) due to increased concentration of amorphous silica derived by the dehydroxylation and melting of the clay minerals.

Because the sediment used in this experiment was from the cave base (Area A), it was particularly enriched in clay fraction and clay minerals. This sediment was chosen because it was archaeologically sterile and we were interested in transformations of the clay minerals contained in the cave sediment. Although sediment from other areas of the cave contains larger amounts of sand and silt than the control sediment, the heating experiments indicate that the clay minerals composing the substratum and sediment fragments of the combustion features were locally transformed by temperatures ranging approximately 500-800°C.

The combustion features also all contain wood ash, which was identified through microscopy as well-preserved oxalate pseudomorphs (Appendix A) and through FTIR as
calcite with atomic disorder consistent with that of wood ash (Regev et al. 2010).

Micromorphological analysis for Area E is ongoing. However, preliminary results show that Locus 500 is a moderately well preserved in situ combustion feature. Locus 501 appears to be the remains of a combustion feature that cracked and shifted slightly. We are thus confident that the features result from human-made fires on occupational surfaces of Area E, which were probably used at the same time as associated artifacts.

In Area C the sediment contains clay (kaolinite and illite/smectite), quartz, and carbonate-hydroxylapatite minerals (the primary component of bones, coprolites, and authigenic minerals). The same general fabric was observed throughout the section (Appendix A). The sediments have a subangular blocky microstructure with crumb microstructure in mm-cm scale passage features and burrows. The dominant mineral inclusions are sand and silt sized quartz and mica, in addition to gravel-sized brecciated soil aggregates, phosphatic nodules, phosphatized limestone fragments, coprolites, and abundant anthropogenic material (bones, flints, and charcoals). There is considerable clay translocation, levigation (b-fabric), and calcification (micritic calcite coatings, hypocoatings, impregnation, and infillings). The large quantity of apatitic coprolite fragments indicates an intense local use of the cave by carnivores (probably hyena).

Interestingly, in situ formation of aluminum or iron phosphates was not detected, indicating that Area C did not witness extensive guano accumulation. Some phosphatized sediment and coprolites formed upslope and relocated downslope to Area C. There is no evidence of anthropogenic occupational surfaces, but sedimentary surfaces are indicated by several features. These include flowstones, localized cm-thick silty clay crusts that were likely puddles, and a thin (~1 cm) layer of calcite-rich sediment overlying layer 7,
which has been interpreted as a depositional unconformity. Area C was likely formed by colluvial deposition and periodic surface stability.

2.7.4 Radiocarbon dating

2.7.4.1 Methods

We tested over 40 bones in varying taphonomic states from all excavation areas of the cave. No bones from Manot yielded collagen, the target molecule for radiocarbon dating, which has been the case at many Mediterranean Paleolithic cave sites (Douka et al. 2013; Douka et al. 2011; Rebollo et al. 2011). Although dietary and ornamental marine shells were recovered we did not date shell because it is unclear if diagenetic carbonate can be separated from original biogenic carbonate (Busschers et al. 2014). Therefore our radiocarbon samples were restricted to taxonomically identified charcoal (Appendix A). In Area E the charcoal samples were selected from combustion features, whereas in Area C charcoals were chosen to cover as much of the sequence as possible. Charcoal pieces were collected by hand during excavation or from exposed sections and wrapped in aluminum foil with associated sediment. Several charcoals were collected from micromorphology blocks as the blocks were cut and removed. Charcoals were identified by V.C. using a metallographic microscope (Nikon Eclipse LV150N). The vast majority of pieces were *Amygdalus* sp. (almond) and all dated specimens belonged to this taxon.

Samples were characterized and prepared for radiocarbon dating based on routine procedures at the DANGOOR Research Accelerator Mass Spectrometry Laboratory (D-REAMS), Max Planck-Weizmann Center for Integrative Archaeology and Anthropology
Before and after pretreatment samples were analyzed by FTIR to test the purity of the material. Approximately 50 mg of each charcoal piece was cleaned of sediment with a scalpel and homogenized by crushing with an agate mortar and pestle. Most samples were then treated with the following acid-base-acid (ABA) procedure: a) acid treatment in 1 N HCl (3 mL) for 30 minutes followed by rinsing with Nanopure water until pH 6, b) base treatment of 0.1 N NaOH (3 mL) for 15 minutes followed by rinsing until pH 6, c) acid treatment in 1 N HCl (3 mL) for 1 hour in a water bath of 80ºC followed by rinsing with until pH 6. Alternatively, four charcoals were treated with a water-base-acid (WBA) regime, which followed the same procedure except that the first acid treatment was replaced by a wash with Nanopure water. One charcoal piece was homogenized, divided, and treated with both the ABA and WBA procedures.

Samples were dried overnight at ~60ºC then combusted to CO$_2$ with ~200 mg CuO at 900ºC and reduced to graphite in a vacuum line. Four samples were divided and underwent graphitization on the standard vacuum line as well as an ultraclean line, dedicated to samples over 30,000 $^{14}$C yr BP. Samples with laboratory code RTD were measured by AMS at the D-REAMS radiocarbon laboratory, while those with RTK were measured at the NSF-AMS radiocarbon laboratory, Tucson, Arizona. Stable isotope measurements were conducted at the Geological Survey of Israel, Jerusalem.

We also produced radiocarbon dates for sediment in order to evaluate the effect that unremoved sediment may have on the radiocarbon dates of charcoal. Four sediment samples were directly removed from charcoal pieces that were dated from Area C-J squares. Two sediment samples were collected from the section in Area C square I65.
The sediment samples were crushed and homogenized, then dissolved in 1 N HCl followed by three rinses with Nanopure water. This remaining fraction contained the total organic carbon (TOC) and was prepared into graphite as described above.

2.7.4.2 Results

The FTIR spectra of untreated samples all showed strong carboxylate \((\text{COO}^-)\) absorptions around 1590 cm\(^{-1}\) and 1385 cm\(^{-1}\), characteristic of fossil charcoal (Appendix A) (Rebollo et al. 2008; Cohen-Ofri et al. 2006). Some untreated samples also showed absorptions indicating the presence of clay, such as the silicate absorption at 1035 cm\(^{-1}\). However these peaks were eliminated or significantly reduced in spectra after ABA treatment. The post-ABA spectra showed the pattern expected for pretreated fossil charcoal: carboxylic acid \((\text{COOH})\) absorptions at 1715 cm\(^{-1}\) and 1245 cm\(^{-1}\) as well as carboxylate absorptions at 1600 cm\(^{-1}\) and 1400 cm\(^{-1}\).

The %C upon combustion measurements of nearly all charcoals were greater than 50%. A value less than 50% suggests that the material may not be pure charcoal (Rebollo et al. 2011; Braadbaart & Poole 2008). Five samples did not meet this requirement, but other lines of evidence suggest that these dates are reliable: the %C values are still above 40%, the FTIR spectra indicate pure pretreated charcoal, and the dates are consistent with the samples’ stratigraphic positions. We note that 3/5 of the charcoals with <50% C came from combustion features. It is possible that the microenvironment of the combustion features is less conducive to charcoal preservation than the general sediment of Manot Cave.

The samples treated with WBA produced dates consistent with dates from samples treated by the standard ABA procedure. Statistically indistinguishable
radiocarbon dates were produced for fractions of the one charcoal treated by both methods (RTD7088). The WBA fraction had higher % efficiency and %C values. Samples divided and graphitized on the ultraclean and standard lines produced consistent results. The exception was sample RTD7884, which had a significantly older radiocarbon date for the ultraclean line fraction (RTD7884.1).

Radiocarbon measurements were also produced on the total organic carbon (TOC) of sediment samples removed from 4 dated charcoals in the J transect. The TOC reflects any organic carbon in the sediment, which is a mixture of clay, degraded organic matter, and recent organic growth. Inorganic carbon from carbonate minerals and bones was removed by acid dissolution. The sediment TOC ages range from 35-29 kcalBP, or 16,000-10,000 years younger than the associated charcoals. Therefore if any sediment survived the pretreatment procedure, we would expect this contamination to make the charcoal radiocarbon dates younger than their true age. However the TOC was very low, constituting only ~0.8% of the insoluble fraction of clay.

All dates from Manot were calibrated with OxCal4.2 (Bronk Ramsey 2009a) and the IntCal13 curve (Reimer et al. 2013) (Appendix A).

The chrono-cultural sequence is based on charcoals from combustion features of Area E and the J squares in Area C. Additional dates were produced from two other contexts to answer questions about site formation processes. Charcoals (n=5) and sediment (n=2) were measured from Area C Square I65 (between the J square sequence and cave wall) in order to assess the degree of mixing and potential noise in the sequence. The artifacts in I65, while representative of Ahmariian and Aurignacian, reflect size sorting due to higher water energy near the cave wall. The charcoals dated to 39-31
kcalBP. This is a wider span, but overlaps with dates from the equivalent elevation in J65 (Appendix A). This supports our assumption that mixing is more significant in the I squares and that the J squares have a better-preserved archaeological sequence. However, the degree of mixing in I65 is still surprisingly low for a Pleistocene deposit at the bottom of a talus next to the cave wall.

In order to compare the age results of U-Th and radiocarbon dates, several charcoals (n=4) were dated from between flowstone layers in Area C Square M65 (Hershkovitz et al. 2015). The area represents a channel and was not assigned to an archaeological unit, although artifacts were recovered. Speleothem samples were collected from four flowstone layers. The uppermost lamina of the top flowstone (sample 1023) layer produced a U-Th date of 20 ± 0.3 ka, while the lowermost flowstone (sample 1028) produced a U-Th date of 42.0 ± 1.8 ka. Charcoal samples were collected from between the base of the top flowstone (sample 1024: U-Th date of 32.4 ± 1.1 ka) and the next lowest flowstone (sample 1054: U-Th date of 32.1 ± 0.5 ka). The radiocarbon dates ranged from 31-27 kcalBP. Thus the U-Th and radiocarbon results are in good agreement.

2.7.4.3 Bayesian modeling

Bayesian modeling can be used to constrain the likelihood of dates by prior information such as stratigraphic position and to formally test for outliers (Bronk Ramsey 2009b; Bronk Ramsey 2009a). We constructed two models of cultural phases: Model 1 based on samples from the most secure contexts and Model 2 based on an expanded dataset. All dates were set with the standard 5% prior likelihood of being an outlier in a t-
type outlier model (Appendix A). The OxCal Date command was used to estimate the
age ranges of the phases.

Model 1 constrains dates to three sequential cultural phases (Early
Ahmarian>Levantine Aurignacian>post-Aurignacian) (Table 2.1). The post-Aurignacian
assemblage is dated by samples from two combustion features (Loci 500 & 501) in Area
E Unit 2 Layer I. Levantine Aurignacian dates come from a combustion feature (Locus
502) in Area E Unit 2 Layer IV as well as Area C Unit 4. Dates for the Early Ahmarian
come from Area C Unit 7.

Model 1 OxCal code:

Plot()
{
  Outlier_Model("General",T(5),U(0,4),"t");
  Sequence()
  {
    Boundary("Start Ahmarian");
    Phase("Ahmarian")
    {
      R_Date("RTD7196", 41100, 454)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTD7115", 42210, 385)
      {
        Outlier("General", 0.05);
      };
    }
    Boundary("End Ahmarian");
    Boundary("Start Aurignacian");
    Phase("Aurignacian")
    {
      R_Date("RTK6305", 32135, 500)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTK6624", 33290, 505)
      {
        Outlier("General", 0.05);
      };
    }
  }
}
}; R_Date("RTK6304", 32135, 500)
{ Outlier("General", 0.05);
}; R_Date("RTK6307", 32730, 530)
{ Outlier("General", 0.05);
}; R_Date("RTK6303", 31870, 500)
{ Outlier("General", 0.05);
}; R_Date("RTK6306", 30865, 420)
{ Outlier("General", 0.05);
}; R_Date("RTK6308", 30390, 400)
{ Outlier("General", 0.05);
}; Line( ); R_Date("RTD7247", 32272, 192)
{ Outlier("General", 0.05);
}; R_Date("RTD7246", 32685, 200)
{ Outlier("General", 0.05);
}; Boundary("End Aurignacian"); Boundary("Start Unit 2 Layer I"); Phase("Unit 2 Layer I")
{ R_Date("RTD7089", 29720, 150)
{ Outlier("General", 0.05);
}; R_Combine("RTD7088-combine")
{ R_Date("RTD7088A", 29230, 200);
 R_Date("RTD7088B", 29060, 145);
 Outlier("General", 0.05);
}; R_Date("RTK6847.1", 29488, 383)
The modeled spans for cultural phases were: 33.8-33.4 for the post-Aurignacian, 36.8-34.9 for the Levantine Aurignacian, and 45.9-43.9 for the Early Ahmarian. The model produced consistent results with repeated runs. The posterior outlier likelihoods of all dates were below 10% and therefore no dates were identified as outliers. However,
this model may not capture the full span of the archaeological phases. Based on stratigraphy there is not a clear boundary between the Aurignacian and Ahmarian phases. In Area E there are occupational surfaces associated with Aurignacian artifacts, but the base of this phase and the beginning of Ahmarian layers was not reached. In Area C, Unit 4 can be classified as Aurignacian and Unit 7 can be classified as Ahmarian, but Units 5 and 6 are an accumulation of both industries. There is no sterile layer, unconformity, or discrete change in artifacts to demarcate a boundary. Therefore the spans modeled from secure contexts represent some portion of Aurignacian and Ahmarian occupations, but the durations are probably longer.

To better estimate the duration of these phases, Model 2 includes dates from more contexts. In addition to the secure contexts contained in Model 1, Model 2 has dates from Area C Units 5 and 6, which overlap in age with the secure dates from overlying Aurignacian and underlying Ahmarian layers. Specifically, the Ahmarian phase includes dates from the bottom of Unit 6 (below z=205.35) and the Aurignacian phase includes dates from the top of Unit 5 (above z=205.50). We reiterate that there was no clear stratigraphic or artifact based boundary between these phases in Area C. However it is our assumption that the younger dates from the top of Unit 5 that overlap in age with dates from Aurignacian contexts belong to the Aurignacian phase. Likewise we assume that the older dates from the bottom of Unit 6 that overlap in age with dates from the underlying Ahmarian unit belong to the Ahmarian phase. Stratigraphically between these included dates is the boundary between Units 5/6 and three dates that show reversed stratigraphic order (RTD7783A, RTD7785, RTD7786). This portion of the sequence appears to be more mixed due to water activity and therefore these dates were omitted.
from the model. Usually dates should not be eliminated “by hand” when using outlier
analysis (Douka et al. 2015). However, we consider this portion of the sequence to be
disturbed and not reflective of the chronology of human occupations.

Model 2 Oxcal code:

Plot()
{
  Outlier_Model("General",T(5),U(0,4),"t");
  Sequence()
  {
    Boundary("Start Ahmarian");
    Phase("Ahmarian")
    {
      R_Date("RTD7196", 41100, 454)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTD7115", 42210, 385)
      {
        Outlier("General", 0.05);
      };
      R_Combine("RTD7197-combine")
      {
        R_Date("RTD7197.1", 37332, 300);
        R_Date("RTD7197.2", 37118, 299);
        Outlier("General", 0.05);
      };
      R_Date("RTD7117", 41610, 540)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTD7119", 42310, 375)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTD7118", 40280, 320)
      {
        Outlier("General", 0.05);
      };
      R_Date("RTD7116", 48705, 700)
      {
        Outlier("General", 0.05);
      };
    }
  }
}
R_Date("RTD7087", 41790, 380)
{
  Outlier("General", 0.05);
};
R_Date("RTD7086", 38875, 305)
{
  Outlier("General", 0.05);
};

Boundary("End Ahmarian");
Boundary("Start Aurignacian");
Phase("Aurignacian")
{
  R_Combine("RTD7784-combine")
  {
    R_Date("RTD7784.1", 33743, 289);
    R_Date("RTD7784.2", 32920, 145);
    Outlier("General", 0.05);
  };
  R_Date("RTD7816", 33207, 157)
  {
    Outlier("General", 0.05);
  };
  R_Combine("RTD7194-combine")
  {
    R_Date("RTD7194.1", 32241, 191);
    R_Date("RTD7194.2", 32543, 201);
    Outlier("General", 0.05);
  };
  R_Combine("RTD7195-combine")
  {
    R_Date("RTD7195.1", 33129, 210);
    R_Date("RTD7195.2", 32382, 201);
    Outlier("General", 0.05);
  };
  R_Date("RTK6305", 32135, 500)
  {
    Outlier("General", 0.05);
  };
  R_Date("RTK6624", 33290, 505)
  {
    Outlier("General", 0.05);
  };
  R_Date("RTK6304", 32135, 500)
  {
    Outlier("General", 0.05);
  };
}
};
R_Date("RTK6307", 32730, 530)
{
    Outlier("General", 0.05);
};
R_Date("RTK6303", 31870, 500)
{
    Outlier("General", 0.05);
};
R_Date("RTK6306", 30865, 420)
{
    Outlier("General", 0.05);
};
R_Date("RTK6308", 30390, 400)
{
    Outlier("General", 0.05);
};
Line();
R_Date("RTD7247", 32272, 192)
{
    Outlier("General", 0.05);
};
R_Date("RTD7246", 32685, 200)
{
    Outlier("General", 0.05);
};
Boundary("End Aurignacian");
Boundary("Start Unit 2 Layer I");
Phase("Unit 2 Layer I")
{
    R_Date("RTD7089", 29720, 150)
    {
        Outlier("General", 0.05);
    }
    R_Combine("RTD7088-combine")
    {
        R_Date("RTD7088A", 29230, 200);
        R_Date("RTD7088B", 29060, 145);
        Outlier("General", 0.05);
    }
    R_Date("RTK6847.1", 29488, 383)
    {
        Outlier("General", 0.05);
    }
    R_Date("RTD7242", 29458, 154)
Model 2 produced consistent phase estimates for the post-Aurignacian industry from 33.8-33.4 kcalBP and the Aurignacian between 37.2-35.3 kcalBP (Appendix A).

The model produced inconsistent results for the start of the Ahmarian due to RTD7116, a sample from midway through Unit 6 that is 48,700 $^{14}$C yr BP, or ~2000 years older than any other radiocarbon date from Manot. Outputs of the model either: 1) estimate the Ahmarian from 46-42 kcalBP and identify RTD7116 as an outlier with >50% likelihood
or 2) estimate the Ahmarian from 49-42 kcalBP and do not identify RTD7116 as an outlier (Appendix A). Sample RTD7116 may belong to Ahmarian deposits or have intruded from an earlier phase such as the IUP or MP. We believe that the latter scenario is more likely. In either case, we can say confidently that the Ahmarian begins at least by 46 kcalBP.

2.7.5 Regional chronology

2.7.5.1 Methods

Our regional chronology was constructed from published radiocarbon dates from Üçakızlı, Ksar Akil, Kebara, and Mughr el-Hamamah in addition to the new dates for Manot Cave reported here (Figure 2.3, Appendix A). Included dates were produced from charcoals and shells. No bones from these sites produced sufficient collagen for radiocarbon dating. We treated dates that were reported, but rejected in the original publications as follows: dates that were rejected because they failed predetermined preservation standards or came from poor contexts (e.g. a burrow or subsurface layer) were not depicted in Figure 2.3. Dates that were rejected because they were identified as outliers by the authors’ Bayesian models were included Figure 2.3. Individual dates were calibrated with Intcal13 for terrestrial samples (charcoal) and Marine13 for marine samples (shell) using Oxcal version 4.2 (Bronk Ramsey 2009a; Reimer et al. 2013). Some authors have applied a Mediterranean local reservoir correction to marine samples (ΔR=58 ± 85 14C years). Because it has not been demonstrated that this correction is appropriate for samples older than 6000 calBP (Reimer & McCormac 2002), we did not use it.
We also display authors’ reported phase ranges produced by Bayesian modeling (Figure 2.3). The calibration and phase modeling procedures differ between studies and are reviewed in the following subsections. Some of the ranges were produced with the previous calibration curve IntCal-Marine09 (Reimer et al. 2009) and/or the Mediterranean reservoir correction (Reimer & McCormac 2002). We did not recalibrate and recalculate the phases because for some studies the models were not described in sufficient detail to be reproduced. We prefer to compare the reported ranges, which are influenced by the assumptions and choices of the authors, as well as the unmodeled calibrated dates, which are less subjective.

2.8.5.2 Sites

Üçağızlı Cave in southern Turkey was first excavated by Minzoni-Deroche in the 1980s and then by a team from Ankara University and the University of Arizona in the late 1990s/early 2000s (Kuhn et al. 2009; Kuhn 2004). The more recent excavations revealed a 3.5-meter sequence of terra rossa clay and silty clay. As the lithology of the sediments was relatively homogenous, stratigraphic units were defined by changes in the abundance and character of anthropogenic material. The upper layers (B1-B3) appeared to represent a massive accumulation of artifacts, while in the lower layers (H, H1-3, I) anthropogenic material was in thin, discrete lenses. Layers B-C, classified as Early Ahmarian, were characterized by an abundance of narrow, regular blade blanks removed from bi-directional prismatic cores. The dominant tools were endscrapers, retouched blades, and pointed blades including el-Wad points. Layers D-E had low artifact yields but were most similar to the Early Ahmarian layers. Layers F-I were classified as IUP with high frequencies of wide, flat blades with facetted platforms, which were mostly
produced from unidirectional parallel or convergent reduction with likely hard-hammer percussion. Endscrapers were the most abundant tool. Bone tools were found throughout the sequence, although relatively rare. Shell beads were abundant in all layers, becoming more diverse in type through time.

Radiocarbon dates were reported by Kuhn et al. (2009), produced from mostly “what appeared to be carbonized plant material” as well as two marine mollusk shells, which were confirmed to be aragonite by FTIR spectroscopy (Kuhn et al. 2003). Ten charcoals were prepared by ABOX and the three samples that survived produced indistinguishable dates from those prepared by ABA. The dates generally showed increasing age with depth between 45-35 kcalBP, but samples from the lowest layers were widely dispersed. An additional eight dates were produced from shells (Douka 2013). Douka combined both sets of dates into a Bayesian model of ten contiguous phases based on excavation layers. Under this constraint, the IUP ranged from 45/43-39/38.5 kcalBP and the Early Ahmarian followed until 36.5/35.5 kcalBP. Eleven of the 32 dates were outliers. Our regional chronology displays calibrated dates of all charcoals and shells produced in both studies (Kuhn et al. 2009; Douka 2013). Dates from layers D-E were assigned as “other” industry because the artifacts were too few for distinction between IUP or Early Ahmarian according to the authors. Our regional chronology also shows the phase ranges reported by Douka (Douka 2013) based on the modeled start and end dates (68.2%) for the IUP and Ahmarian (including layers D-E) phases using IntCal-Marine09.

Most attention has focused on Ksar Akil, Lebanon as its 23 meters of stratified archaeological deposits serve as the reference sequence for the Levantine UP and modern
human remains were found in IUP and EUP layers (Stringer & Bergman 1989; Douka et al. 2013). The rock shelter was excavated between 1937-1938 and 1947-1948 under Doherty, Ewing, and Murphy (Ewing 1947) as well as between 1969-1975 under Tixier (Tixier 1974). The earlier excavations did not apply modern excavation methods and Tixier’s excavation did not reach EUP or earlier levels (Douka et al. 2013). The sequence has been divided into eight main archaeological phases: Mousterian (excavation levels XXXVII-XXVI), IUP (XXV-XXI), Early Ahmarian (XX-XVI), a possible occupational hiatus (XV-XIV), UP Phase 3 (XIII-XI), UP Phase 4 (X-IX), Levantine Aurignacian Phase 5 (VII-VIII), UP Phase 6 (VI), and Epipaleolithic (V-I) (Marks & Volkman 1986; Ohnuma 1988; Bergman 1987; Williams & Bergman 2010). The IUP levels contained blade cores with faceted platforms and converging sides that were used to produce elongated blanks likely by soft hammer percussion. The toolkit included chamfered pieces, end scrapers, and burins. In the Early Ahmarian levels parallel-sided cores with opposed platforms were used to produce thinner blade blanks, again, likely by soft hammer direct percussion. The toolkit included end scrapers, retouched blades and bladelets, and el-Wad points (Bergman 1988). The remaining UP levels have been difficult to classify, but Phase 5 layers VIII-VII are thought to be Levantine Aurignacian (Williams & Bergman 2010). Phase 5 is characterized by flake production, thick nosed and shouldered scrapers, invasive retouch, and a large number of bone/antler tools. Occurring at lesser frequency, blades and bladelets were mostly straight or curved, but sometimes twisted.

During the 1938 excavation season a human skull and postcranial remains were recovered within Early Ahmarian levels XVII or XVIII. The fossils have been lost, but
based on descriptions and reconstructed casts of the skull, they are believed to represent a juvenile modern human, known as Ksar Akil 1 or “Egbert” (Stringer & Bergman 1989). A partial maxilla from a separate individual, Ksar Akil 2 or “Ethelruda,” was discovered in the 1947-1948 excavation in the level XXV, associated with the IUP industry. The specimen was originally described as “Neandertaloid” (Ewing 1963), but it has since been argued to represent a modern human (Douka et al. 2013).

Mellars and Tixier reported radiocarbon dates produced from charcoal and clay as well as Uranium series dates of bones (Mellars & Tixier 1989). Two recent studies (Douka et al. 2013; Bosch et al. 2015a) dated marine shells and combined the new dates with the previously published ones in Bayesian models. Douka and colleagues (Douka et al. 2013) dated mostly ornamental shells, while Bosch and colleagues (Bosch et al. 2015a) dated dietary shells. Our regional chronology presents the dates reported in these three studies (Mellars & Tixier 1989; Douka et al. 2013; Bosch et al. 2015a), but we exclude the U-series dates and radiocarbon dates of clay, land snail, and bone prepared without ultrafiltration. Phases 3-4 and 6 contain UP industries that we classify as “other or undetermined.” We present the modeled phase ranges produced by the Douka and Bosch studies from the beginning of the reported start dates to the end of the reported end dates (68.2%). In the Douka study, the end dates (their model 2) were 43.2-42.5 kcalBP for the Mousterian, 41.6-40.9 kcalBP for the IUP, 39-37.5 kcalBP for the Early Ahmarian, and 35-34 kcalBP for the Levantine Aurignacian (Phase 5) using Intcal-Marine09 with the Mediterranean reservoir correction. The start of the IUP and MP are reported as unknown. Nine out of 39 dates were identified as outliers. In the Bosch study (their model 1), the IUP occurred between 44.6-43.2 kcalBP and the Early Ahmarian
occurred between 43.3-42.8 kcalBP using Intcal-Marine13 with the Mediterranean reservoir correction. In this model 6/16 dates were determined to be outliers and then removed from the model. The models have been debated (Douka et al. 2015; Bosch et al 2015b).

Kebara Cave in Mt Carmel, Israel was excavated in multiple campaigns during the 20th century and most recently between 1982-1990 by Bar-Yosef and Vandermeersch (Bar-Yosef et al. 1992). The 14 layers identified in the most recent excavations include Mousterian (V-XIV), Early Ahmarian (III-IV), and Levantine Aurignacian (I-II) assemblages. No diagnostic IUP artifacts were recovered and the missing phase may be explained by an unconformity between the final MP and first Early Ahmarian layer. A Neanderthal burial was discovered in layer XII. The Mousterian layers VI-XII have been dated by TL measurements of 38 burnt flints (Valladas et al. 1987).

Radiocarbon dates have been produced for Kebara by several laboratories using different protocols (Bar-Yosef et al. 1996; Rebollo et al. 2011; Brock & Higham 2009). When the same charcoal pieces were subjected to ABA and ABOx-SC pretreatments, Brock & Higham (2009) found no difference in the resulting ages, while Rebollo and colleagues (2011) produced older dates and better preservation parameters with the ABA treatment. This pattern is the opposite of what is usually found (Wood et al. 2012; Douka et al. 2010) and the authors propose that siliceous aggregates in the sediment may have allowed modern atmospheric CO₂ or CO to adsorb to the charcoal samples. Because ABOx-SC treated charcoals are generally smaller, any contamination would have a larger effect on the date. Using ABA and ABOx-SC samples that passed preservation parameters, Rebollo et al. modeled the end of the MP at 48/49 kcalBP and the start of the
Ahmarian at 47/46 kcalBP (68.2%). These relatively old dates for the Early Ahmarian (compared to Üçağızlı and Ksar Akil) have been questioned on the basis that the samples may have intruded from the lower final MP layer (Zilhao 2013; Douka et al. 2013).

Our regional chronology excluded Kebara dates from charred bone and charcoals that had %C upon combustion <50%. When an individual charcoal was prepared by different procedures, we combined the dates unless a replicate failed preservation parameters (%C<50) or had a significantly worse precision. Figure 2.3 shows the modeled end date for the MP and start date for the Ahmarian (68.2%) produced by Rebollo et al. (Rebollo et al. 2011) using IntCal09.

Mughr el-Hamamah in the Jordan Valley was excavated in 2010 by Stutz (Stutz et al. 2015). Two test trenches inside Cave 2, totaling an area of 8 m², contained mixed modern/Pleistocene Layer A above Pleistocene Layer B. Ongoing lithics analysis suggests that the Layer B assemblage is EUP, but does not fit into the categories of IUP or Early Ahmarian, as defined by the Mediterranean coastal sites (Belfer-Cohen & Goring-Morris 2003; Kuhn & Zwyns 2014). The Layer B assemblage includes Early Ahmarian core reduction strategies and tools including el-Wad points, in addition to IUP technological characteristics and tool types such as Emireh points and chanfrein pieces. According to the authors, “it is yet unclear whether the assemblage is best described as a variant of the Initial Upper Paleolithic/Emiran, the Early Ahmarian, or a third Levantine EUP industry or industrial facies that combines elements of the former” (Stutz et al. 2015: 161). Charcoals were collected from within or under ash lenses associated with hearths or from under what the authors describe as anthropogenic limestone slabs and a basalt cobble manuport. Charcoals were prepared by ABA (Stutz et al. 2012) and ABOx-
SC (Stutz et al. 2015). For individual charcoals prepared by both treatments, the ABA
dates were significantly older. However, the authors favored the ABOx-SC dates and
report a single-phase occupation between 45-39 kcalBP using their own calibration
method and the CalPal-Hulu 2007 curve. We included both sets of dates (ABA and
ABOx-SC), but calibrated with IntCal13. We excluded the date on humics (Aeon-1038).

2.8 Acknowledgements

We thank Eugenia Mintz for laboratory assistance, Steve Weiner and Meg
Thibodeau for microarchaeology work, and Clara Klöcker, Jeannie Kakayuk, and Priya
Sathyanarayan for carrying out the sediment heating experiment. We also thank David
Pilbeam, Ofer Bar-Yosef, and Christian Tryon for their comments on this paper.
Analytical work was funded by National Science Foundation (NSF) Doctoral Dissertation
Improvement Grant #1334615, Fulbright Student Scholarship from the US-Israel
Educational Foundation, and NSF Graduate Research Fellowship Program Award DGE-
1144152. AMS dates were funded by the Exilarch’s Foundation, the DANGOOR
Research Accelerator Mass Spectrometry Laboratory (D-REAMS), and the Max Planck-
Weizmann Center for Integrative Archaeology and Anthropology. The Manot Cave
excavation is funded by the Dan David Foundation, the Israel Antiquities Authority, Case
Western Reserve University, the Leakey Foundation, the Irene Levi Sala CARE
Archaeological Foundation, the Keren Kayemet L’Israel, and the Israel Science
Foundation. Geoarchaeological work was supported by the Social Sciences and
Humanities Research Council of Canada and the Bertha and Louis Weinstein Research
Fund.
2.9 References


Meignen, L., 2012. Levantine perspectives on the Middle to Upper Paleolithic


Tejero, J.-M. et al., in press. The osseous industry from Manot Cave (Western Galilee, Israel): Technical and conceptual behaviours of bone and antler exploitation in the Levantine Aurignacian. *Quaternary International*.


CHAPTER 3 – CHRONOLOGY OF THE MIDDLE-UPPER PALEOLITHIC TRANSITION IN THE BALKANS BASED ON RELIABLE RADIOCARBON DATES

Bridget Alex¹,², Dušan Mihailović³, Stefan Milošević⁴, Elisabetta Boaretto⁵

¹Department of Anthropology, Harvard University, Cambridge, Massachusetts, United States of America

²Department of Human Evolutionary Biology, Harvard University, Cambridge, Massachusetts, United States of America

³Department of Archaeology, Belgrade University, Belgrade, Serbia

⁴Laboratory for Bioarchaeology, Belgrade University, Belgrade, Serbia

⁵Max Planck Society-Weizmann Institute for Integrative Archaeology and Anthropology, D-REAMS Radiocarbon Laboratory, Weizmann Institute of Science, Rehovot, Israel
3.1 Abstract

This study produced a chronology of human fossils and archaeological assemblages in the Balkans between 50,000-25,000 years ago, which has implications for the nature of interactions between Neanderthals and modern humans. The chronology is based on newly produced radiocarbon dates from three sites in Serbia (Pešturina, Hadži Prodanova, and Smolućka) as well as critical review of published dates. The results show that between 45-40 kcalBP the Balkans and adjacent regions were characterized by a number of distinct archaeological industries in different geographic zones: Middle Paleolithic in the western mountains, Uluzzian on the southern Mediterranean coast, and Bachokirian/Early Upper Paleolithic along northern river valleys of the Danube Corridor. After 39 kcalBP, the calendar age of the Campanian Ignimbrite eruption, only Early Upper Paleolithic industries have been found until ~30 kcalBP when Gravettian appeared throughout the region. Assuming that Middle Paleolithic industries were made by Neanderthals and Bachokirian/Early Upper Paleolithic industries were made by modern humans, it is likely that Neanderthals and modern humans coexisted in the Balkans. During the period of overlap Neanderthals were concentrated in the western mountains, while modern humans were along aquatic routes, suggesting a coexistence characterized by avoidance and territoriality. However, the duration and stability of their coexistence is unclear, due to uncertainties of the available chronometric dates. This study highlights the need for a greater number of reliable chronometric dates for the Balkans during Oxygen Isotope Stage 3 (OIS-3) of the Late Pleistocene.
3.2 Introduction

Between 60-30 thousand years ago (ka), modern humans colonized Europe, Neanderthals became extinct, and Middle Paleolithic (MP) archaeological traditions were replaced by Upper Paleolithic (UP) ones. The interrelatedness of these biological and cultural processes is greatly debated (Mellars et al. 2007; Bar-Yosef 2002). Genetic evidence shows that Neanderthals and modern humans likely interbred between 60-50 ka in Southwest Asia (Fu et al. 2014) and ~40 ka in Europe (Fu et al. 2015). However there may have been other interbreeding events, which are not preserved in our genetic heritage, or contact without genetic exchange. Identifying these episodes of contact and correlating them with changes in the archaeological record is dependent on an accurate chronology of the distribution of human populations and archaeological cultures. Producing such a chronology, however, has been hindered by the fact that many radiocarbon dates are inaccurate due to inappropriate sample selection and pretreatment procedures (Higham 2011). Efforts to amend the radiocarbon record have transformed our views of this period, but have mostly focused on Western Europe or a few key human fossil bearing sites elsewhere (Bosch et al. 2015; Pinhasi et al. 2012; Higham et al. 2014).

The Balkans is an understudied but critical region for understanding modern human dispersals, Neanderthal extinctions, and coincident changes in material culture. Considering directly dated fossils, Neanderthals from Vindija, Croatia (Green et al. 2010; Higham, Ramsey, et al. 2006) and a modern human (Oase 1) from Peștera cu Oase, Romania (Trinkaus et al. 2003) could overlap in age around 40 ka. Ancient DNA from Oase 1 indicates Neanderthal-modern human admixture occurred 4-6 generations, or less than two centuries, before the individual lived (Fu et al. 2015). Based on the
archaeological record, UP modern humans spread into Europe along both the Danube Corridor and Mediterranean coast (Conard & Bolus 2003; Mellars 2006a), while MP Neanderthals persisted in the central/western mountains (Bar-Yosef 2011). Lastly, faunal and botanical records suggest that the Balkans may have been buffered from severe climate oscillations, offering a refugium for humans during glacial periods (Miracle et al. 2010; Tzedakis 2002). However, most sites in the Central Balkans have low artifact yields and abundant carnivore remains, which may reflect ephemeral human occupations (Dogandžić et al. 2014; Kuhn et al. 2014). The population and culture history of the Balkans in the Late Pleistocene are not well understood.

Here, we produce the first regional chronology of human fossils and archaeological industries in the Balkans between 50-25 kcalBP, which is based on reliable radiocarbon dates. Using explicit guidelines, we evaluated dates from publications and produced new dates from three stratified sites in Serbia: Pešturina, Hadži Prodanova, and Smolućka. Chronologies were created for each site, using Bayesian modeling when appropriate, and the site-specific chronologies were combined into a regional chronology. The results show that between 45-39 kcalBP the Balkans was home to several biological and cultural human groups, which seem to have occupied distinct geographic zones.

3.3 Background

3.3.1 Paleolithic research in the Balkans

The Balkans peninsula is bound by the Adriatic, Mediterranean, Aegean, and Black Seas, as well as the Danube River and Sava River valleys to the north (Figure 3.1). The territory comprises European Turkey, Bulgaria, Greece, Albania, and the countries of
the former Yugoslavia. Although not part of the Balkan Peninsula, sites in southern Italy and southern Romania were included in this study.

As a crossroads between the Near East and Europe, the Balkans has long been a contact zone between different species and cultures (Griffiths et al. 2004; Kozlowski 1992). Owing to its diverse topography and rich biodiversity, the Balkans may have supported sympatric populations of large-bodied omnivores—i.e. Neanderthals and modern humans—through niche partitioning or notions of territoriality. In addition to these theoretical reasons to assume to Balkans as a human contact zone, the fossil of a recently admixed human has been found (Fu et al. 2015). However, the Paleolithic archaeological record of the Balkans during is not well known. This is partially due to low levels of research during the early 20th century (Mihailović et al. 2011), but over the past few decades interest in the Paleolithic of the Balkans has risen and led to numerous projects (Mihailović 2014). Nevertheless, the expanding archaeological record appears relatively meager compared to other regions of Europe at the same time. It is unclear whether these patterns reflect human history (low population density, ephemeral site use, cultural buffer zones) or depositional history, in which periods of time are missing from stratigraphic sequences (Dogandžić et al. 2014).

Reconstructing human biogeography in the Balkans Late Pleistocene is especially challenging because the majority of sites are shallow palimpsest deposits with low artifact yields and evidence for abundant carnivore activity. However, the region cannot be ignored because the sites do not provide deep sequences with thousands of artifacts. The apparent ephemeral nature of many sites in the Balkans may be a reflection of the way in which humans used this landscape (Kuhn et al. 2014; Dogandžić et al. 2014). It is
critical to include these sites in our synthesis, but in a manner that accounts for the variable quantity and quality of data between sites.

3.3.2 Biogeography and culture history

There are few directly dated human fossils from the Balkans between 50-25 kcalBP (Figures 3.1 & 3.2). Three Neanderthal specimens from Vindija, Croatia have been dated during genetic analyses to 39 kcalBP or older (Green et al. 2010; Krings et al. 2000). Another Vindija Neanderthal (Vi-208), from higher in the stratigraphic sequence, produced a date of 39-35 kcalBP (OxA-X-2089-06: 32,400 ± 800 $^{14}$C BP) (Higham, Ramsey, et al. 2006). A modern human mandible (Oase 1) was found without associated archaeology at Peștera cu Oase, Romania. The specimen produced a radiocarbon age of 42-37 kcalBP (combined OxA-11711/GrA-22810: 34,950 +990/-890 $^{14}$C BP (Trinkaus et al. 2003)) and aDNA that suggests Neanderthal admixture no more than 200 years prior (Fu et al. 2015). Additional modern human fossils have been dated from the Romanian sites of Peștera Muierii (Soficaru et al. 2006) and Cioclovina (Soficaru et al. 2007) to between 34-32 kcalBP.

Because human fossils are rare, human biogeographic history is often inferred from the distribution of archaeological units in time and space (Higham et al. 2014; Jöris & Street 2008). Archaeological units, variably referred to as industries, traditions, or technocomplexes, are defined based on assemblages of distinct and frequently associated technologies and artifact types. When an archaeological unit is found in association with human remains of a particular type, it is often assumed that wherever that archaeological unit is found, that particular human type was once present. In this way the Mousterian or MP has long stood as a proxy for European Neanderthals (Higham et al. 2014; Bordes...
Figure 3.2: Calibrated radiocarbon dates of human fossils from the Balkans compared to faunal bones dated in this study. Highest probability density functions (pdfs) shown and calculated with OxCal2.4 software (Bronk Ramsey 2009a) and the IntCal13 calibration curve (Reimer et al. 2013). Dark gray pdfs represent bones with signs of human modification. Light gray pdfs represent bones with no signs of human modification. Colored pdfs represent directly dated fossils of modern humans (red) and Neanderthals (blue). Infinite dates are indicated by solid bars.
1961), and the Uluzzian has recently been argued to represent early modern humans in Europe (Benazzi et al. 2011). This culture-historical approach has been criticized (Shea 2014) and revised (Tostevin 2013), but continues to be widely employed, albeit more explicitly (Bar-Yosef & Belfer-Cohen 2011; Nigst et al. 2014; Bosch et al. 2015).

Before 50 ka the archaeological record of the Balkans was characterized by widespread MP industries, including Charentian, Typical Mousterian, Denticulate, and Micro-Mousterian (Mihailović et al. 2011; Mihailović 2014). However, many MP assemblages, especially in the Central/Western Balkans, are difficult to characterize because the artifact yields are very low, comprised mostly of ad hoc quartzite pieces and a small number of nonlocal flint tools or Levallois flakes. The relative abundance of quartzite pieces likely reflects raw material availability and short-term site use, rather than cultural differences (Mihailović et al. 2011). For this study all MP variants have been condensed into a single analytical unit of MP, which we define as assemblages containing Levallois and other prepared core reduction methods used to make flake-based tools including sidescrapers, denticulates, and notches (Kuhn 2013). There is a consensus that all MP assemblages in Europe were made by Neanderthals (Higham et al. 2014).

A distinct archeological unit, known as the Uluzzian, appeared between 45-39 ka in coastal Greece and Italy (Riel-Salvatore 2007; Douka et al. 2014; Peresani et al. 2016). The Uluzzian has been described as transitional between MP and UP industries due both to its place in stratigraphic sequences and its techno-typological components. It is characterized by flake production from a variety of cores including bipolar, unipolar, discoid, and centripetal. The lithic artifacts are mostly MP tools (sidescrapers, denticulates, notches) and splintered pieces, as well as some UP tools (endscrapers) and
lunates, or crescent-shaped microliths considered the *fossiles directeurs* of the industry. Uluzzian assemblages also include worked bone, shell beads, and pigments. The Uluzzian and preceding MP are distinguishable, but share a number of features, which renders ambiguous the relationship between these industries (Peresani et al. 2016). The Uluzzian and subsequent Protoaurignacian are markedly distinct (Riel-Salvatore 2007; Kaczanowska et al. 2010). The Uluzzian was generally assumed to have been made by Neanderthals until reanalysis of two deciduous molars found in Uluzzian layers at Cavallo Cave, Italy (Benazzi et al. 2011). Using enamel thickness and geometric morphometric outline analyses, the authors concluded that the specimens were modern humans, prompting assertions that the Uluzzian was made by modern humans (Higham et al. 2014; Ronchitelli et al. 2014). Although on average Neanderthals have thinner enamel than modern humans, the ranges overlap and are determined by a small number of specimens (Smith et al. 2012; Olejniczak et al. 2008). Moreover, the Cavallo molars are worn, which leads to uncertainty and subjectivity in shape and thickness reconstructions (Martin 1983). Others have accepted that the molars come from modern humans, but challenge the stratigraphic association between the teeth and the Uluzzian assemblage (Zilhão et al. 2015).

Also dated to ~45 ka, the Bachokirian is another industry described as transitional and was defined based on the assemblage found in Layer 11 of Bacho Kiro Cave, Bulgaria (Kozłowski 1982a). Other possible occurrences of the Bachokirian (i.e. Temnata TD-II Layer VI and TD-I Layer 4) are uncertain (Tsanova 2008; Tostevin 2013: 434). The eponymous Bacho Kiro Layer 11 assemblage contains few cores or pieces illustrative of the reduction sequence, but appears to be a technology focused on the
production of convergent blanks and points through direct hard hammer percussion, which some authors argue was derived from a Levallois method (Tsanova & Bordes 2003; Teyssandier 2003; Kozłowski 2004). It shows discontinuity with underlying Mousterian in terms of raw materials selection as well as discontinuity with overlying Aurignacian in terms of techno-typology. Many archaeologists have subsumed the Bachokirian into a larger tradition of Levallois-derived blade industries including the IUP of the Near East and the Bohunician of Central Europe (Kuhn & Zwyns 2014; Kozłowski 2004). Consequently, it is often assumed that the Bachokirian was made by modern humans from the Near East or their descendants (Hublin 2015), although the only associated human remain is a mandible fragment, which was lost before its taxonomic identity could be established (Glen & Kaczanowski 1982).

The Aurignacian technocomplex, widespread throughout Europe after 35 ka, is traditionally seen as the first fully UP tradition produced by European modern humans (Hublin 2015; Mellars 2006b). In the broadest sense, Aurignacian assemblages have shared features of systematic production of blade and bladelets, bone and antler tools, and diverse personal ornaments (Teyssandier 2008; Bar-Yosef & Zilhão 2006). Two geographically distinct traditions appeared before 40 ka in Europe: the Protoaurignacian along the Mediterranean and the Early Aurignacian in Central and Western Europe (Wood et al. 2014; Nigst et al. 2014). In Protoaurignacian assemblages, blades and long, straight bladelets were produced from the same method of continuous reduction of unidirectional cores that were often pyramidal. Early Aurignacian assemblages are characterized by two core reduction methods: robust blade blanks were removed from cores with a prepared single striking platform, whereas curved bladelets were removed
from carinated cores (Teyssandier et al. 2010). These differences in technological behavior may represent northern and southern migration routes of modern humans and/or strategies developed in response to differing environments (Mellars 2006b; Nigst et al. 2014). The Kozarnikian assemblage found in Layer VII of Kozarnika cave, Bulgaria is similar to Protoaurignacian assemblages, and it has been suggested that both developed from Early Ahmarian traditions found in the Near East (Tsanova et al. 2012; Tsanova 2008; Mellars 2006b). In our synthesis, Proto/Early Aurignacian assemblages and the Kozarnikian assemblage have been combined into the analytical unit of Early Upper Paleolithic (EUP). It is widely believed that EUP industries were made by modern humans, although there are few associated human skeletal remains (Hublin 2015; Bailey et al. 2009). Two deciduous incisors from Protoaurignacian layers at the Italian sites of Grotta di Fumane and Riparo Bombrini have been characterized as modern humans based on mtDNA and enamel thickness, respectively (Benazzi et al. 2015).

The Gravettian is a European UP technocomplex characterized by distinctive backed blades/bladelets, diverse organic artifacts, and extensive use of symbolic objects including ornaments and figurines, which exhibit strong stylistic similarities across Europe (Svoboda 2012). It has been proposed that the Gravettian arose in Danubian Central Europe, from Protoaurignacian traditions in the Mediterranean, or from other backed-blade traditions outside of Europe, such as the Ahmarian (Kozłowski 2015; Svoboda 2012). Gravettian traditions appeared widely across Europe by 30 ka (Talamo et al. 2014) and have been found with modern human skeletal remains (Trinkaus et al. 2000).
3.3.3 CI eruption and H4 event

A volcanic eruption in Late Pleistocene southern Italy, known as the Campanian Ignimbrite (CI or Y5) eruption, is critical to understanding population histories in the Balkans because 1) the tephra deposits correlate stratigraphic sequences between sites and 2) the event may have impacted the local environment. The most widely used age estimate, based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating, is 39,280 ± 110 yr BP (De Vivo et al. 2001; Bronk Ramsey et al. 2015). Unequivocally identifying CI tephra at different localities is challenging because the composition of the expelled material varied over the course of the eruption and on average is quite similar to other volcanic eruptions in the region (Pyle et al. 2006). However, convincing cases have been made for CI tephra or cryptotephra at numerous sites relevant to this paper (Giaccio et al. 2008; Lowe et al. 2012; Morley & Woodward 2011; d'Errico & Banks 2015).

The impact of the CI eruption on the environment and human populations has been widely debated (e.g. Lowe et al. 2012; Costa et al. 2012; Fedele et al. 2008). There is no doubt that it was among the largest known volcanic eruptions in the Quaternary, comparable to Toba (~73.5 ka) or Bishop Tuff (~770 ka) (Fedele et al. 2008). The ash fall covered at least 5,000,000 km$^2$ east of the source, as distal tephra has been found across the Eastern Mediterranean and Eastern Europe (Giaccio et al. 2008). Based on sulphate concentrations in the Greenland ice core record, the eruption may have caused a global cooling of 1-2°C (Costa et al. 2012) or 3-4°C (Fedele et al. 2008) for 2-3 years. The CI eruption coincided with the onset of Heinrich Event 4 (H4), a millennial-scale period of cooling within the milder interglacial conditions of Oxygen Isotope Stage 3 (OIS-3) (Hemming 2004). H4 and the CI eruption may have interacted through positive feedback
mechanisms, the effects of which are difficult to reconstruct at a global, let alone regional scale. In the Balkans, centennial-scale pollen records show a marked increase in grasses and decline in tree taxa (Müller et al. 2011; Tzedakis 2002), while some mammal assemblages seem to remain stable through this period (Miracle et al. 2010). It is possible that the ecological impact of the CI eruption and H4 varied across the Balkans due to local topography and precipitation patterns.

3.3.4 Reliable radiocarbon dates

It has been thoroughly demonstrated that many published radiocarbon dates do not reflect the age of the event that archaeologists wish to date (Higham 2011; Boaretto 2009). The discrepancy can result from insufficient pretreatment procedures that fail to remove contamination and/or from inappropriate sample selection that fails to identify dateable materials deposited contemporaneously with the event in question. Over the past decade, the largely unreliable radiocarbon record for Paleolithic Europe has been improved through critical review of published dates (Jöris & Street 2008; Higham et al. 2014) and the production of new dates by state-of-the-art procedures (Marom et al. 2012; Higham, Jacobi, et al. 2006; Rebollo et al. 2011). Moreover, the precision of calibrated dates has been improved by updated calibration curves (Reimer et al. 2013; Hogg et al. 2013) and the use of Bayesian modeling, which allows for the integration of chronometric and relative dating information (Bronk Ramsey 2009a).

The reliability of a date should be evaluated based on the sample’s context, taxon, taphonomic features, biochemical preservation, and pretreatment method (Waterbolk 1971; Pettitt et al. 2003). However, there are no uniform quality control criteria for all radiocarbon dates; instead guidelines must be tailored to the research question and
archaeological context (Boaretto 2015). Different samples provide different kinds of information: while a cave bear bone does not directly date human presence, a sequence of well stratified cave bear bones can estimate the age of depositional layers. An in situ hearth directly dates human activity, but may not be convincingly associated with a lithic assemblage. Radiocarbon dates should be interpreted within the framework: given everything that is known about a particular sample, what is the meaning of that date?

3.4 Materials and Methods

3.4.1 New radiocarbon dates

3.4.1.1 Sites

Pešturina is a medium-sized karstic cave in southeast Serbia near the Nišava river (Mihailović & Milosevic 2012). Between 2006-2014 an area of over 22m² was excavated, revealing four lithostratigraphic layers with material culture characteristic of the MP and UP (Appendix B). The uppermost Layer 1 comprised Holocene loose humic silts. The underlying Pleistocene Layers 2-4 are characterized by compact, fine-grained silt with minor clay and fine stones. Signs of erosional truncations and rodent borrows were observed during excavation, indicating that the sequence is both incomplete and disturbed. Layer 2 contained about 100 chipped stone artifacts of mostly flint and high quality chalcedony. The toolkit, dominated by backed pieces, retouched blades and flakes, and truncated pieces, is classified as Gravettian. Layers 3 and 4 contained flake-based industries made mostly from local quartzite, typical of the Balkans Late MP. The tools include retouched flakes, notches, sidescrapers, and denticulates. The few cores suggest production of flakes by Levallois, centripetal, recurrent, and discoid methods. Layer 3 is classified as Denticulate Mousterian and Layer 4 as Charentian with Quina
elements. For the purposes of this study, the archaeological material from Pešturina can be separated into two analytical units: a MP quartzite flake assemblage and a UP flint backed blade assemblage.

A similar geologic and archaeological sequence was found at Hadži Prodanova, a cave ~150 km west of Pešturina in the Rašćanska River valley (Mihailović 2008). The cave consists of a ~20 meter corridor opening to a large room, ~50 meters long by 15 meters wide. Rescue excavations in 2003 and 2004 uncovered an area of 16m² to a maximum depth of 2.5 m, which contained 5 lithostratigraphic layers (Appendix B). Layer 1 was loose, mixed Holocene deposits. Layer 2 contained a small number of artifacts resembling Gravettian pieces. Layer 3 was archaeologically sterile and reflected carnivore occupations. Layer 4 did not contain lithic artifacts, but human presence was indicated by bones with anthropogenic modifications. Layer 5 had MP artifacts, including Levallois flakes and blades. Retouched tools were made from flint and quartzite. The flint tools were retouched and heavily used, suggesting the pieces had been transported and curated. Hadži Prodanova had the same broad pattern as Pešturina of a quartz-dominated MP assemblage overlain by an UP Gravettian assemblage. However, Hadži Prodanova had an archaeologically sterile layer between these cultural layers. Although only ~100 chipped stone artifacts were recovered from Hadži Prodanova, faunal remains were well preserved with clear signs of human modification.

Smolućka Cave in southwest Serbia was excavated between 1984-1987 by Kaluderović (Dimitrijević 1991). Excavations to a depth of 2.20 m revealed 6 lithostratigraphic layers without reaching bedrock (Appendix B). The uppermost Layers 1 and 2 consisted of loose, heterogeneous brown clay with mixed Holocene and Pleistocene
fauna and artifacts. Layers 3-6 were Pleistocene deposits with differing sedimentary and faunal characteristics. Only MP artifacts were found in the Pleistocene layers. One previously dated charcoal from Layer 3 produced an infinite age of >38,000 $^{14}$C yr BP (OxA-1251) (Hedges et al. 1990). The context is poorly described, but because only MP artifacts were found in the Pleistocene layers, we include the date in this synthesis.

3.4.1.2 Sampling strategy

Samples were chosen for radiocarbon dating by a series of criteria related to context, taphonomy, preservation, and pretreatment. The strategy differed between Pešturina, an active excavation, and Hadži Prodanova and Smolućka, for which sampling was restricted to collections materials. At Pešturina loose sediment samples and micromorphology blocks were taken in order to better define layers. No charcoal samples were recovered or available in collections from the sites. As the bioturbated, palimpsest nature of the sites was evident during excavations and from reports, greater priority was given to sampling bones with signs of human modification over bones associated with lithic artifacts (Appendix B). Most samples were medium and large mammal long bone shafts, which tend to have the best collagen preservation. Cut marks were identified using binocular light or scanning electron microscopy. Three-dimensional copies of the marks were made with polysiloxane dental mold (Pearson Dental 3M Poly Vinyl Express Garant). Impact fractures were identified by breakage patterns as described by Villa and Mahieu (Villa & Mahieu 1991).

Bone samples underwent prescreening procedures at the DANGOOR Research Accelerator Mass Spectrometry Laboratory (D-REAMS) at the Weizmann Institute of Science, Israel (Yizhaq et al. 2005; Boaretto et al. 2009). Percent collagen was estimated
by percent insoluble fraction after acid dissolution (1 N HCl). Insoluble fractions were analyzed by Fourier Transform Infrared (FTIR) spectrometry in order to evaluate the preservation of bone collagen and screen for possible contaminants. Samples with spectra indicative of pure, well-preserved collagen were selected for radiocarbon dating (Appendix B).

Bone collagen was purified for radiocarbon dating by Acid Base Acid (ABA) treatment, gelatinization, and filtration following the procedures presented by Yizhaq et al. and Boaretto et al. (Yizhaq et al. 2005; Boaretto et al. 2009). For each sample ~500 mg of bone powder was treated with 0.5 N HCl until the mineral was dissolved (~1 hour) and then washed with Nanopure water until pH= 7. To remove humics, samples received 0.1 N NaOH (30 minutes) and were washed until pH= 7. A final acid treatment of 0.5 N HCl (5 minutes) was followed by washing until pH= 3. Solutions were gelatinized in a vacuum oven for 20 hours at 70°C, and then passed through Eezi-filters™ and ultrafilters (Vivaspin™15, 30kD MWCO), cleaned by established procedures (Brock et al. 2007). Purified gelatin samples were lyophilized for 24 hours and again analyzed by FTIR to ensure that the material was pure collagen. The freeze-dried collagen was combusted with ~200 mg CuO in sealed quartz tubes and reduced to graphite in a vacuum line. Three samples (RTD7226B, RTD7228B, RTD7229B) were graphitized in an ultraclean vacuum line dedicated to samples over 30,000 ¹⁴C yr BP. Samples with laboratory code RTD- were measured by accelerator mass spectrometry (AMS) at the D-REAMS radiocarbon laboratory. Samples with laboratory code RTK- were measured at the University of Arizona NSF-AMS laboratory. Dates were reported as radiocarbon years
(14C yr BP) and calibrated years (calBP) with OxCal v4.2 (Bronk Ramsey 2009a) and IntCal13 (Reimer et al. 2013).

### 3.4.2 Review of published dates

We reviewed the published record of human fossils and stratified archaeological assemblages for the Balkans between 50-25 kcalBP (Appendix B). Twenty-two sites and nearly 200 radiocarbon or thermoluminescence (TL) dates were reviewed to produce regional chronologies of a) dated archaeological assemblages and b) stratified assemblages with and without dates. Our primary research question is: when were particular human types or archaeological industries present at sites within the study region? Within the framework of this question, we classified dates as “reliable,” “uncertain,” or “rejected.” Reliable dates likely reflect the age of a human fossil or a named archaeological assemblage based on subjective, but explicit consideration of the available site and sample information. Our definition of reliable combines both analytical uncertainty (pretreatment and measurement parameters) and archaeological uncertainty (stratigraphic context, integrity of the assemblage). Uncertain dates do not have enough sample information to accept or reject. Rejected dates failed one or more selection criteria, indicating that they likely do not reflect the age of the fossil or archaeological assemblage.

The guidelines for classification were:

1) **Context:** The radiocarbon sample was a human fossil or associated with an archaeological assemblage with diagnostic artifacts. In the latter case, the sample came from a secure location in a well-described stratigraphic sequence.
2) **Material:** The sample was charcoal or bone collagen. The taxon, when known, is consistent with occupation by Pleistocene humans. For example, botanical remains from domesticated plants would fail this criterion. Shell samples were considered uncertain because it is unclear if diagenetic calcite can be fully identified and removed (Busschers et al. 2014).

3) **Human association:** The sample was likely deposited by humans. At a site that was intensively occupied and has a well-preserved stratigraphic sequence, samples belonging to an archaeological layer likely date the human activity that deposited materials in that layer. Numerous samples should be dated to identify potential outliers. However, many sites in this study were occupied ephemerally by humans and intensively by carnivores. In this case it is important to link dated samples to human activity. Bone samples should show human modifications such as cutmarks or impact fractures. Charcoal samples should come from *in situ* hearths.

4) **Preservation:** Measured preservation parameters were within known biological ranges for the material. As different laboratories report different measurements, a number of complementary parameters can be considered:

For charcoal:

- %C by weight upon combustion to CO₂ was >50% (Braadbaart & Poole 2008)
- Fourier Transform Infrared spectrometry (FTIR) shows absorption peaks characteristic of untreated fossil charcoal (COO- at 1590 cm⁻¹ and 1385 cm⁻¹) and pretreated fossil charcoal (COOH peaks around 1715 cm⁻¹ and 1250 cm⁻¹; COO- peaks around 1600 cm⁻¹ and 1400 cm⁻¹) (Rebollo et al. 2008; Ascough et al. 2011). There are no peaks indicating the presence of sediment or minerals.
For bone collagen:

- the % insoluble fraction after pretreatment was >1% by weight of starting bone powder (Van Klinken 1999), unless other measurements (e.g. FTIR) show that the material was well-preserved collagen
- upon combustion to CO₂ the %C was 30-50% weight of the purified collagen or the C:N atomic weight ratio was 2.9-3.5 (Brock et al. 2010; Van Klinken 1999)
- FTIR of the material after pretreatment showed a spectrum for pure, well-preserved collagen (absorption peaks with characteristic height ratios at 1650 cm⁻¹ for amide I, 1540 cm⁻¹ for amide II, 1455 cm⁻¹ for proline) (Yizhaq et al. 2005; Weiner 2010)

5) Pretreatment: Bones were prepared by a method that isolates a particular biological molecule, such as ultrafiltration of collagen (Brock et al. 2010; Boaretto et al. 2009) or single amino acid extraction (Marom et al. 2012). Charcoal was prepared by some form of acid-base-acid (ABA) treatment (Rebollo et al. 2011), including wet oxidation, stepped-combustion procedures (e.g. ABOx-SC) (Bird et al. 1999).

For each site we produced a chronology based on the reliable and uncertain chronometric dates. The dates were calibrated using OxCal 4.2 software (Bronk Ramsey 2009a) and the IntCal13 atmospheric or Marine13 marine curves (Reimer et al. 2013) and shown as 95.4% highest probability density functions (pdfs) in calibrated years BP (calBP). When sites had sufficient numbers of dates and stratigraphic information, Bayesian models were produced to reduce the uncertainty of dates and estimate the ranges of particular phases (Appendix B). The models constrained dates to priors such as a series of stratigraphically defined phases or known-age tephra within the sequence.
However, there were *not* sufficient dates and prior information for most sites and therefore we did not produce Bayesian models for most sites. When no dates were available for a particular phase at a site, we indicated the approximate timing of that phase based on the site’s stratigraphic sequence and chronologies produced for other regions of Europe (Wood et al. 2014; Higham et al. 2014; Talamo et al. 2014). The relative order and temporal overlap of dates between sites was estimated with Oxcal functions (Appendix B).

### 3.5 Results and Discussion

#### 3.5.1 Chronology at Pešturina, Hadži Prodanova, and Smolučka

In total 25 bones from Pešturina (n=8), Hadži Prodanova (n=11), and Smolučka (n=6) passed our selection criteria and were measured by AMS (Figure 3.2, Appendix B). The new dates from Smolučka, as well as the previously measured charcoal, produced infinite dates or finite dates beyond the calibration curve. The samples came from three layers (3-5) considered to be Pleistocene and associated with MP artifacts. The samples did not have signs of human modification and therefore were classified as uncertain dates for human occupation. MP occurrences in Smolučka date to 42 kcalBP or older.

The dates from Pešturina have been published in an edited volume (Alex & Boaretto 2014). Samples excavated from Layer 2 range from >37,800 $^{14}$C yr BP to 13,440 ± 60 $^{14}$C yr BP; samples from Layer 3 range from 40,230 ± 3600 $^{14}$C yr BP to 28,680 ± 180 $^{14}$C yr BP; and the one sample from lithostratigraphic Layer 4 (RTD7149) dates to 40,500 ± 590 $^{14}$C yr BP. Generally, the samples demonstrate increasing age with depth. However, stratigraphic mixing is evident at the transition between Layers 2 and 3, and within Layer 2 two samples recovered from the same 5 cm spit in adjacent squares
differ in age by over 12,000 years (RTD7148 at 13,440 ± 60 $^{14}$C yr BP and RTK6446 at 26,120 ± 620 $^{14}$C yr BP). The dates from Hadži Prodanova range from 18,730 ± 80 $^{14}$C yr BP to beyond the background. There is increasing age with depth, but certain samples deviate from this pattern, indicating that materials in Hadži Prodanova also experienced stratigraphic mixing.

Due to the documented stratigraphic mixing at Pešturina and Hadži Prodanova, the age of artifacts should not be inferred based on their lithostratigraphic layer or associated radiocarbon samples. We believe that further dating would only corroborate this pattern of mixing. Although we cannot securely date archaeological layers at Pešturina and Hadži Prodanova, we can confidently state dates of human presence, based on the bones with human modifications (Figure 3.2). These samples provide direct evidence for human occurrences at several points between 52-39 kcalBP and 34-28 kcalBP. There were also humans present at Hadži Prodanova at ~22 kcalBP and at Pešturina at ~16 kcalBP.

These dates represent the error ranges of point occurrences and we assume that humans were present at other times. However, our discussion must focus on the available data—on which archaeological industries were deposited during these known occurrence dates. The only archaeological industries identified at Pešturina and Hadži Prodanova were MP and Gravettian. Based on the ages of these industries at other sites (Higham et al. 2014; Jöris & Street 2008; Talamo et al. 2014), it is most likely that the human modified bones deposited between 52-39 kcalBP were left by MP people, while those from between 34-28 kcalBP were left by Gravettian people. We believe that this is the case even for four samples that were recovered from layers that do not correspond to
these archaeological assignments. For example, because sample RTD7275 dates to ~33 kcalBP, we assume that it was deposited by Gravettian people, despite the fact that the bone was recovered from Hadži Prodanova Layer 5, which contained predominately MP artifacts. It is likely that this bone infiltrated from higher layers considering that it is ~10,000 years younger than other dated samples from Layer 5. The same reasoning can be applied to sample RTD7231, which dates to ~33 kcalBP and is from Pešturina Layer 3 with predominately MP artifacts. Layer 4 of Hadži Prodanova did not contain diagnostic artifacts, but had bones with human modifications. From this layer, one cutmarked bone dated to ~28 kcalBP (RTD7481) and probably represents Gravettian occupations, while another cutmarked bone dated to ~40 kcalBP (RTD7276) and probably represents MP occupations.

The assignment of human modified bones older than 39 kcalBP to MP and those younger than 34 kcalBP to Gravettian at Pešturina and Hadži Prodanova is our inference, supported by the following observations. There are no convincing MP assemblages in the region younger than 39 kcalBP (discussed below) and Gravettian assemblages are documented by 33 kcalBP in the northern Adriatic (Talamo et al. 2014), Middle and Upper Danube (Higham et al. 2012; Einwogerer et al. 2009), and Western Europe (Wood et al. 2014). Alternatively, it is possible that human modified bones were deposited by people of an undetected tradition, who did not leave diagnostic artifacts at these two sites. In this case we would expect the people to be makers of Uluzzian, Bachokirian, or EUP industries based on the culture history of the greater Balkans. These industries are absent from Pešturina and Hadži Prodanova and they have not been found anywhere in central or southern Serbia (D. Mihailović & B. Mihailović 2014; D. Mihailović 2014). It is also
possible that the dates do not reflect the age of human occurrences due to misidentification of human modifications or sample contamination. In sum, the assignment of bones dated between 52-39 kcalBP to MP and 34-28 kcalBP to Gravettian is the most parsimonious explanation for the dates, but alternative explanations cannot be rejected.

3.5.2 Regional Archaeological Chronology

Our review of the Paleolithic of the Balkans comprised twenty-two sites and nearly 200 chronometric dates. We classified 28 radiocarbon dates as reliable. An additional 64 radiocarbon dates were included in the synthesis, but classified as uncertain. Our newly produced dates constitute nearly half of the reliable dates and over one quarter of the total dates used to construct the regional chronology. Figure 3.3 shows the regional chronology of a) directly dated human fossils or samples associated with archaeological assemblages and b) archaeological assemblages found in stratigraphic sequence with and without chronometric dates.

MP assemblages characterized the Balkans before 45 kcalBP. Between 45-39 kcalBP the region had numerous distinct industries including MP, Uluzzian, Bachokirian, and EUP (Kozarnikian and Proto/Early Aurignacian). The industries were geographically patterned with MP in the central/western mountains, Uluzzian on the Mediterranean, and Bachokirian along the Danube Corridor (Appendix B). Proto/Early Aurignacian has been found in both the Mediterranean and Danube zones. There are no reliable dates for MP, Uluzzian, or Bachokirian assemblages after ~39 kcalBP in the region. EUP industries persisted until ~34 kcalBP, but remained restricted to the northern rivers and Mediterranean coast. UP industries (Gravettian) occurred across the region by 30 kcalBP.
Figure 3.3: Chronologies displaying a) reliable and uncertain chronometric dates b) chronometric dates and archaeological phases found in stratigraphic sequence. Solid lines represent dates estimated by radiocarbon dating at 95.4% highest probability density functions. Lines with stars are directly dated human fossils. Lines with circles are TL dates at two standard deviations. The color code is MP-blue, Uluzzian-purple, Bachokirian-pink, EUP-orange, UP-green, industry undetermined-gray, human fossil-black. Opaque lines are reliable dates and semi-transparent lines are uncertain dates. Gray horizontal bars represent known-age tephra identified in stratigraphic sequences. For Pešturina and Hadži Prodanova only samples with human modification are shown. In 3b colored areas indicate estimated age ranges of archaeological phases. The ranges of colored ovals with discrete borders were estimated by Bayesian models. The ranges of colored areas with faded borders were estimated based on stratigraphy and synthetic ranges from other regions of Europe (Wood et al. 2014; Higham et al. 2014; Talamo et al. 2014). Archaeological sites are listed approximately from northwest to southeast, but grouped by country.
This pattern is corroborated when undated assemblages in stratigraphic sequence are also considered (Figure 3.3b). Uluzzian or Bachokirian assemblages have been found above MP layers along the Mediterranean and Danube corridor. On the Adriatic coast and central/western mountains no Uluzzian, Bachokirian, or EUP assemblages have been identified (D. Mihailović & B. Mihailović 2014). At these sites the MP is followed by Gravettian.

There is no convincing chronostratigraphic evidence for the persistence of MP, Uluzzian, or Bachokirian industries in the Balkans after the CI eruption. Where the tephra has been properly identified, the deposits are above final MP, Uluzzian, or Bachokirian layers (Morley & Woodward 2011; Lowe et al. 2012; Giaccio et al. 2008). The tephra deposit generally marks a discontinuity in cultural sequences, and in the cases of putative continuity—where material culture appears the same below and above the tephra—the assemblage is ambiguous or EUP. For instance, at Franchthi, CI tephra is found within Aurignacian layers (Douka et al. 2011; Lowe et al. 2012). At Tabula Traiana, CI cryptotephra was identified within a layer thought to be UP, but the industry was not defined further due to the small number of artifacts (Borić et al. 2012). CI cryptotephra was reported within an “early UP” archaeological layer at Golema Pesht (Lowe et al. 2012), but the stratigraphic position of the samples was not provided, nor has the assemblage been sufficiently described (Salamanov-Korobar 2008). Likewise, at Kozarnika, CI cryptotephra is said to lie within an early UP layer without any further information about sample location (Lowe et al. 2012). Thus, at sites where both the archaeological assemblages and the CI tephra are well characterized, MP, Uluzzian, and Bachokirian traditions end before the CI eruption. Furthermore, at sites where the CI
tephra has not been identified, there are no reliable dates for these industries after 39 kcalBP, the calendar age of the CI eruption.

3.5.3 Implications for Neanderthal-modern human interactions

In the Balkans the first appearance date for a modern human is 42-37 kcalBP (OxA-11711/GrA-22810: 34,950 +990/-890 \(^{14}\)C yr BP) from the Oase 1 fossil, Oase, Romania (Trinkaus et al. 2003). This individual is a recent hybrid, showing genetic evidence for Neanderthal admixture no more than 200 years prior (Fu et al. 2015). The last appearance date for a Neanderthal is 39-35 kcalBP (OxA-X-2089-06: 32,400 ± 800 \(^{14}\)C yr BP) from the Vi-208 individual, Vindija, Croatia (Higham, Ramsey, et al. 2006).

We estimated how close in age these fossils were using the Oxcal Difference command, which calculates a probability range for the difference in age between two calibrated dates (Appendix B). If zero falls within the range, the dates cannot be distinguished statistically and could be the same age. Oase 1 is between 5740 to 20 years older than Vindija Vi-208 at 95% confidence. If both of these fossil dates are accurate, the first appearance date for a modern human was sometime within 6000 years before the last appearance date for a Neanderthal in the Balkans. We classify the Oase 1 date as uncertain because it is the combined estimate of an infinite date produced by ultrafiltration (OxA-11711) and a finite date produced without ultrafiltration (GrA-22810). Therefore the Oase 1 individual could be older than 42-37 kcalBP, which would prolong the period of overlap. We classify the Vindija Vi-208 ultrafiltration date (OxA-X-2089-06) as reliable because the bone collagen was prepared by ultrafiltration and met quality control parameters for C:N and % collagen (Higham, Ramsey, et al. 2006). The X in the laboratory code indicates that the specimen was prepared by non-standard or
experimental methods (Brock et al. 2010), which in this case refers to the use of a small amount of starting bone powder (230 mg for several fractions). The small sample size did not seem to affect the reliability of the date. Nevertheless, others have classified this date as a minimum age without explicate explanation (Pinhasi et al. 2011). Comparing Oase 1 to the next-youngest Neanderthal, Oase 1 is between 1,300 years older to 12,000 years younger than Vindija Vi-80 (Ua-?: 38,310 ± 2130 ^{14} \text{C yr BP}). If these individuals were contemporaneous they would have coexisted sometime between 42-39 kcalBP. Due to the uncertain date of Oase 1, disagreement over the reliability of Vi-208, and large error range of Vi-80, the fossil record provides poor resolution on the overlap between Neanderthals and modern humans.

Considering the archaeological record, the length and nature of overlap becomes clearer, although the improved resolution is contingent on the assumption that archaeological industries represent human groups. We propose the following hypotheses to link observed variability in the archaeological record with human population history in the Late Pleistocene Balkans: MP industries were produced by Neanderthals. Bachokirian, Temnata TD-I Layer 4, EUP (Proto/Early Aurignacian, Aurignacian, and Kozarnikian), and UP (Gravettian) assemblages were produced by modern humans. The makers of the Uluzzian is undetermined. These archaeological units subsume and ignore a great deal of inter-assemblage variability, but offer hypotheses for archaeological proxies for human populations. We emphasize that links to the assumed makers are tenuous and future discoveries may change our assumptions about the human groups responsible for them. In this case the spatial and temporal distributions of the
archaeological assemblages will remain as accurate data, but the implied human biogeography would be revised.

Given these assumptions, the following population history can be reconstructed for the Balkans between 50-25 kcalBP (Figure 3.4). Only Neanderthals were present until ~45 kcalBP when modern humans began to appear along the northern river valleys and Mediterranean coast. Considering only dates classified as reliable, the first appearance date for a modern human industry is 45-40 kcalBP, coming from the Bachokirian layer of Bacho Kiro Cave (OxA-3138: 37,650 ± 1450 14C yr BP). The last appearance date for MP was produced in this study: a cutmarked bone from Layer 4 of Hadži Prodanova dated to 41-39 kcalBP (RTD7276: 35,495 ± 276 14C yr BP). The Bachokirian date is between 5000 years older to 700 years younger than the Hadži Prodanova Layer 4 date, with a 95% probability of the Bachokirian date being older (Appendix B). The second-to-last appearance date for MP was also produced from Hadži Prodanova in this study: a cutmarked bone from Layer 5 dated to 44-43 kcalBP (RTD7270: 39520 ± 540 14C yr BP). The Bachokirian date is between 1860 years older to 4000 years younger than the Hadži Prodanova Layer 5 specimen.

Dates classified as uncertain—meaning that there was not enough information to accept or reject the dates—are also consistent with modern human presence for several thousand years prior to Neanderthal extinction. We performed pairwise comparisons between dates attributed to Neanderthals and the earliest dates attributed to modern humans, which determined the relative order of dates within each pair (Appendix B). For pairs in which the modern human-attributed date had >20% probability of being older than the Neanderthal-attributed date, we also calculated their difference in age.
Figure 3.4: Time series maps of Neanderthal and modern human occurrences inferred from radiocarbon dated fossils and archaeological industries. Points represent individual radiocarbon dates. The size of the point is proportional to the likelihood of the date. Blue points represent Neanderthal fossils or MP assemblages assumed to have been made by Neanderthals. Red points represent modern human fossils or assemblages assumed to have been made by modern humans (including Bachokirian, Temnata TD-I layer 4, Proto/Early/Aurignacian, Kozarnikian, Gravettian). Purple points represent Uluzzian assemblages. At most sites other archaeological industries are observed in stratigraphic sequence, but this figure only displays assemblages with associated radiocarbon dates.
(Appendix B). Fifty of the pairs produced a difference range that contained zero, indicating that the radiocarbon dates cannot be statistically distinguished and could be contemporaneous. For the remaining twenty-six pairs, the modern human attributed date was unambiguously older. Nearly all of the modern human dates had >90% probability of being older than the Vi-208 Neanderthal from Vindija and a MP associated charcoal date from Mujina Pećina (OxA-8150). If these dates are excluded as possible outliers or minimum ages, there still remains several dates attributed to modern humans that have >50% probability of being older than Neanderthal-attributed dates. These include dates from TD-I Layer 4 at Temnata and the EUP Kozarnikian Layer VII from Kozarnika, which occurred sometime between 45-40 kcalBP.

During the period when Neanderthals and modern humans may have overlapped, there was a geographic pattern to the groups’ distributions. Dates attributed to modern humans come from sites along the Danube corridor and Mediterranean Coast, while those attributed to Neanderthals come from sites in the central/western mountains. After ~39 kcalBP there is little evidence of Neanderthal presence, aside from the date for the Vindija Vi-208 fossil (OxA-X-2089-06), which we consider to be reliable, but others have questioned (Pinhasi et al. 2011; Higham, Ramsey, et al. 2006).

3.6 Conclusion

Through the production of new radiocarbon dates and review of published dates, this study has generated a reliable chronology of fossil and archaeological occurrences in the Balkans between 50-25 kcalBP. New dates came from three sites in Serbia (Pešturina, Hadži Prodanova, and Smolućka) and constitute nearly half of the reliable dates for the region. The sites contained material culture attributed to the MP and UP (Gravettian) and
lacked elements suggesting Uluzzian, Bachokirian, or EUP occurrences. Although the sites experienced considerable stratigraphic mixing, the dates of human-modified samples allow us to state with confidence that humans were present in this area at some points between 52-39 k calibrated before present (kcalBP) and 34-28 kcalBP. It is most likely that MP peoples were present between 52-39 kcalBP and Gravettian people were present between 34-28 kcalBP.

Considering the full chronology of the Balkans and adjacent areas, it appears that MP, transitional, and EUP industries occurred between 45-40 kcalBP, but in distinct geographic zones. This period of archaeological diversity ended by 39 kcalBP at the time of the CI eruption, after which there is no convincing evidence for MP, Bachokirian, or Uluzzian traditions and only EUP and UP assemblages have been identified. We recognize that absence of evidence does not provide evidence of absence for these industries in the Balkans after 39 kcalBP. However, as Paleolithic research in the Balkans has intensified over the past decade, we can no longer attribute this pattern to a lack of research and must consider alternatives (D. Mihailović 2014). There may have been a substantial reduction or local extinction of some human groups after the CI eruption. This proposal is consistent with genetic evidence that the earliest modern humans in Eurasia did not lead to surviving lineages, whereas modern humans after ~37 kcalBP show population continuity with subsequent ancient and present-day Europeans (Fu et al. 2016). The reduction or disappearance of human groups may have left a relatively open landscape for later groups of dispersing humans.

With the available dates the duration of Neanderthal-modern human overlap cannot be determined with precision. Of the directly dated Neanderthals from Vindija, the reliability of the youngest fossil (Vi-208) has been questioned and the error range of the
next youngest fossil (Vi-80) is nearly 9,000 years. The first appearance date for a modern human (Oase 1) may be a minimum age. Under the assumption that Neanderthals produced MP industries and modern humans produced Bachokirian, Temnata TD-I Layer 4, EUP, and UP industries, radiocarbon dates suggest Neanderthal-modern human overlap for some period between 45-39 kcalBP. The duration of overlap inferred from archaeological industries cannot yet be determined due to uncertainties associated with the available dates. The analytical error ranges of the reliable dates allow for coexistence ranging from several thousands years to several decades, with a small probability of no overlap. Dates classified as uncertain augment the case for prolonged overlap, but their uncertainty is not reflected in the analytical error range, as it is due to subjective evaluation of sample selection and pretreatment procedures.

Regardless of its duration, the period of potential overlap indicates segregation: Neanderthals were in the central/western mountains and modern humans were along the Mediterranean and northern rivers between 45-39 kcalBP. It seems that coexistence was characterized by avoidance and territoriality, as was proposed by Mihailović a decade ago (Mihailović 2004). This proposal is very much in line with the conclusion drawn for Western Europe (Higham et al. 2014). However, in Western Europe the timing and nature of overlap has been established by combined estimates of hundreds of dates from intensively occupied sites. In the case of the Balkans, the conclusion hinges on several dates from sites with low artifact densities, and will remain speculative until a greater number of reliable dates are produced. Nevertheless, this study establishes a foundation for building a robust chronology of population and culture history for the Balkans.

Combining the improved chronology with other lines of evidence, such as faunal records,
technological studies, and ancient DNA, may reveal how Neanderthals and modern humans coexisted, and what ultimately enabled our ancestors to survive as Neanderthals went extinct.

3.7 Supporting information

3.7.1 Regional Summary

For each site we summarize the excavation history, stratigraphic sequence, and chronometric data. We explain our classifications of dates as reliable, uncertain, or rejected. When a Bayesian model was used, the model is described and the OxCal code is included. All calibrated dates (calBP or kcalBP) are reported as 68.2% and 95.4% highest probability density functions using the IntCal13 or Marine13 calibration curves (Reimer et al. 2013) in OxCal v4.2 software (Bronk Ramsey 2009a). Full sample information and dates are available upon request.

3.7.1.1. Croatia

Vindija Cave: Vindija Cave in northern Croatia has yielded important archaeological assemblages and human fossils, including the specimens used to construct the draft sequence of the Neanderthal genome (Green et al. 2010). The major systematic excavations occurred between 1974-1986 under M. Malez (Janković et al. 2011; Karavanić 1995). The 9-meter profile of over 20 strata included MP, Aurignacian, Gravettian, and Holocene layers. Level G1 contained directly dated Neanderthal specimens, EUP bone points, and a lithic industry that was mostly a non-Levallois Mousterian tradition, with some bifacial and blade technology (Karavanić & Smith 2013). The ambiguous assemblage has been explained as a result of site formation processes (stratigraphic mixing, palimpsest deposition (Zilhão 2009)) or cultural
processes (innovation by Neanderthals, cultural transmission between Neanderthals and modern humans (Ahern et al. 2004)). Stratigraphic mixing is evidenced by lithic refits, taphonomic analysis, and radiocarbon dates that are inconsistent with their stratigraphic positions (Karavanić & Smith 2013).

Because the stratigraphy and archaeology of Vindija are debated, only dates from human fossils were included in this synthesis. Neanderthal remains from Vindija have been dated in several studies (Green et al. 2010; Smith et al. 1999; Higham, Ramsey, et al. 2006; Krings et al. 2000; Serre et al. 2004). A Neanderthal parietal (Vi-208) from Level G₁, dated by multiple procedures, yielded the best preservation parameters and the oldest date of 32,400 ± 800 \(^{14}\text{C}\) yr BP (OxA-X-2089-06) after undergoing the ultrafiltration procedure at Oxford (Higham, Ramsey, et al. 2006). This sample fell within acceptable ranges for preservation, but has been described as a minimum age (Higham, Ramsey, et al. 2006; Pinhasi et al. 2011). A second Neanderthal sample (Vi-207) was prepared by the same method in the same study, but deemed unreliable based on unacceptable values for C:N, \(\delta^{13}\text{C}\), and \%N. Two Neanderthal specimens (Vi-75 and Vi-80) from lower Level G₃ were dated during mtDNA studies (Krings et al. 2000; Serre et al. 2004) and it is possible that the bones came from the same individual. One of the samples dated to 38,310 ± 2130 \(^{14}\text{C}\) yr BP (Ua-?, (Serre et al. 2004)) and the other produced an infinite age of >42,000 \(^{14}\text{C}\) yr BP (Ua-13873, (Krings et al. 2000)).

Although the studies did not report conventional parameters for radiocarbon dating, results from prescreening for aDNA showed that the samples had amino acid compositions consistent with human bone collagen. A final Neanderthal bone was dated in constructing the Neanderthal genome (Green et al. 2010). The specimen (Vi33.26)
came from an unknown sublayer of Level G and dated to 44,450 ± 550^{14}C yr BP (OxA-V-2291-18).

We include these human remains in our synthesis as reliable calibrated dates. Three of the fossils are greater than 39 kcalBP and may extend beyond the calibration curve. The fossil from layer G1 dates between 39-35 kcalBP.

**Mujina Pećina:** Systematic excavations in **Mujina Pećina** on the Adriatic coast of southern Croatia yielded a fairly homogenous Mousterian assemblage distributed through five lithostratigraphic units (Rink et al. 2002). The assemblage, which is dominated by denticulates and notched pieces, strongly resembles that found in Crvena Stijena Level XIII. One faunal bone from each Pleistocene layer of excavation square F9 was dated at the Groningen AMS facility. Ranging from ~50-42 kcalBP, the dates fall in stratigraphic order and are consistent with ESR dates on teeth. However, most of the dates extend beyond the calibration curve and the bones were not prepared with ultrafiltration so it is possible that they underestimate the true ages. One charcoal sample (OxA-8150) was measured from combined pieces in an apparent hearth midway through the sequence of an adjacent excavation square (G9). This date is over 1000 years younger than any of the measured bones, which is opposite the pattern expected if the bones were contaminated by modern carbon. Because the charcoal date is anomalous and the bones were not prepared by ultrafiltration, the dates from Mujina Pećina are included as uncertain calibrated dates. The bone dates range from beyond the curve to 41.5 kcalBP and the charcoal dated to 40-37 kcalBP.
3.7.1.2 Montenegro

**Crvena Stijena:** Crvena Stijena in southwest Montenegro was systematically excavated in the 1960s and 70s (Basler 1975) and studied in a renewed campaign in 2004 (Baković et al. 2009). The >20-meter sequence contained archaeological materials spanning from the MP through the Neolithic. Overlying the final Mousterian Layer XII was a tephra deposit assigned to the CI eruption (Morley & Woodward 2011). Above this layer the sequence contained only UP material, beginning with a backed point industry in Layer X. This layer was originally classified as Aurignacian (Basler 1975; Benac & Brodar 1958), but has since been convincingly reinterpreted as Gravettian or Epigravettian (Mihailović & Mihailović 2007). The single radiocarbon date published for Crvena Stijena is a charcoal from the final Mousterian Layer XII dated to 40,770 ± 900 \(^{14}\text{C} \text{yr BP (GrN-6083)} \) (Vogel & Waterbolk 1972). Because insufficient sample information was reported, we classified this date as uncertain and plotted its calibrated age along with the age of the CI eruption. The charcoal from the final MP layer dated to 46-43 kcalBP and the CI eruption provides a *terminus ante quem* of 39 ka for the MP at Crvena Stijena.
Table 3.1: Layer classifications according to Baković et al. 2009 with the exception of Layer X, which is according to Mihailović and Mihailović 2007.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Bronze Age</td>
</tr>
<tr>
<td>II-III</td>
<td>Neolithic</td>
</tr>
<tr>
<td>IV</td>
<td>Mesolithic</td>
</tr>
<tr>
<td>VIII-IX</td>
<td>Late UP (Epipalaeolithic)</td>
</tr>
<tr>
<td>X</td>
<td>Backed point; Gravettian or Epigravettian</td>
</tr>
<tr>
<td>XI</td>
<td>CI tephra</td>
</tr>
<tr>
<td>XII</td>
<td>Late Mousterian</td>
</tr>
<tr>
<td>XIII</td>
<td>Denticulate Mousterian</td>
</tr>
<tr>
<td>XIV-XVII</td>
<td>Mousterian</td>
</tr>
<tr>
<td>XVIII</td>
<td>Pontinian</td>
</tr>
<tr>
<td>XIX-XX</td>
<td>Mousterian with triangular points</td>
</tr>
<tr>
<td>XXI-XXII</td>
<td>Pontinian</td>
</tr>
<tr>
<td>XXIII-XXIV</td>
<td>Mousterian</td>
</tr>
<tr>
<td>XXV-XXVIII</td>
<td>Protomousterian</td>
</tr>
<tr>
<td>XXIX-XXXI</td>
<td>Premousterian</td>
</tr>
</tbody>
</table>

3.7.1.3 Serbia

Šalitrena Cave: Šalitrena Cave is considered the richest Paleolithic site in Serbia, but has only been described in cursory reports (Mihailović 2008; Mihailović et al. 2011; Mihailović & Mihailović 2014; B. Mihailović et al. 2014). Excavations and analyses are on going and thus far have revealed Gravettian, Aurignacian, and MP layers both within the cave and on the river terrace opposite the cave. The MP assemblage contains Levallois flakes produced by preferential method, atypical Mousterian points, and few sidescrapers and denticulates. The Aurignacian assemblage is characterized by wedge-shaped and burin cores, carinated endscrapers, burins, and retouched blades. Radiocarbon dates produced by Beta Analytic place MP Layers 6a-6d between 43-41 kcalBP and Aurignacian Layer 5 between 37-34 kcalBP (Mihailović & Mihailović 2014). However, no sample information has been published for these dates. We include them as uncertain.
calibrated dates until additional information is available clarifying the samples’ contexts, taphonomic conditions, and pretreatment procedures.

**Table 3.2:** Layer classifications according to Mihailović and Mihailović 2014 and Mihailović et al. 2011.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Later prehistory, historic</td>
</tr>
<tr>
<td>2</td>
<td>Starčevo</td>
</tr>
<tr>
<td>3</td>
<td>Gravettian</td>
</tr>
<tr>
<td>4</td>
<td>Gravettian</td>
</tr>
<tr>
<td>5</td>
<td>Aurignacian</td>
</tr>
<tr>
<td>6a-d</td>
<td>MP</td>
</tr>
</tbody>
</table>

**Tabula Traiana:** On the Danube in northeast Serbia, Tabula Traiana has been excavated from 2004-2005 and 2008-2009 (Borić et al. 2012; Borić & Jevtić 2006). Two Pleistocene lithostratigraphic layers were identified: an upper layer (207/217) consisting of 20-60 cm of thick gray-brown calcareous silt, and a lower layer (206/209) consisting of yellow-brown calcareous silt. The “modest assemblage” (Borić et al. 2012) of chipped stone artifacts from the lower Layer 206 has been classified as late MP based on the presence of Levallois flakes and predominance of local, low-quality quartz and quartzite. The upper Layer 207 contained a blade with bilateral continuous retouch, an unretouched bladelet, and a bladelet with marginal retouch, suggesting prismatic-core reduction typical of the Protoaurignacian. More artifacts are needed for cultural classification, but the authors consider Layer 207 to be EUP. Although five faunal bones from Layer 207 dated between 41-35 kcalBP, the radiocarbon dates have only been published for the two samples with cutmarks (OxA-23651: 34,200 ± 550 14C yr BP and OxA-24818: 33,450 ± 500 14C yr BP) (Borić et al. 2012). Cryptotephra from the CI eruption was identified in varying proportions throughout Layer 207 (Lowe et al. 2012).
We included the two published samples as reliable calibrated dates and the age of the CI eruption. The UP phase estimate (Figure 3.3b) shows the published range from 41-35 kcalBP based on three additional samples.

**Table 3.3:** Layer classifications according to Borić et al. 2012.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>207/217</td>
<td>UP (Protoaurignacian?), CI cryptotephra</td>
</tr>
<tr>
<td>206/209</td>
<td>MP</td>
</tr>
</tbody>
</table>

**Baranica I:** On the bank of the Trgoviški Timok River in Serbia, Baranica cave has been investigated through test trenches in 1994 and systematic excavations in 1995, 1997, and 2004 (Mihailović et al. 2011; Dimitrijević 2011). Four lithostratigraphic layers were identified within a 2.2 m pit that did not reach bedrock. The uppermost Pleistocene Layer 2, consisting of lighter brown sediment with eboulis, contained three artifacts: a laterally retouched sidescraper, a blade, and a bladelet. These may represent Gravettian occupation, although diagnostic pieces were not found (Mihailović et al. 2011). The underlying gray silt Layer 3 was archaeologically sterile and had only rare small mammal remains, whereas the other Pleistocene layers contained abundant large mammal remains. In dark brown Layer 4b ten artifacts were found including flakes, an asymmetrical cortical blade, and an atypical carinated endscraper on a massive retouched flake. The layer was relatively undisturbed and the assemblage was classified as UP and possibly EUP. Reddish Layer 4c yielded quartz flakes and a broken asymmetrical blade. The artifacts found in Baranica are very few, but mostly finished tools made of diverse, high-quality raw materials including chalcedony, flint, and chert—a pattern that suggests transitory use of the site (Mihailović & Mihailović 2014). Two radiocarbon dates have been measured from faunal bones. A giant deer phalanx from Layer 2 produced a
radiocarbon age of $23,520 \pm 110 \text{^{14}C \ yr \ BP}$ (OxA-13827) and a cave bear molar from Layer 4 dated to $35,780 \pm 320 \text{^{14}C \ yr \ BP}$ (OxA-13828) (Dimitrijević 2011). Signs of human modification were not documented and therefore we cannot confidently link the samples to human occupation. Although the layers appeared relatively undisturbed based on field observation, with only two dates, it is unclear if materials found in the same layer were deposited within the same timespan. Therefore, we include these dates as uncertain ages for EUP and UP occupation of Baranica.

**Table 3.3:** Layer classifications according to Borić et al. 2012.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface humus layer</td>
</tr>
<tr>
<td>2</td>
<td>Sidescraper, blade, bladelet (Gravettian?)</td>
</tr>
<tr>
<td>3</td>
<td>sterile</td>
</tr>
<tr>
<td>4a</td>
<td></td>
</tr>
<tr>
<td>4b</td>
<td>EUP?</td>
</tr>
<tr>
<td>4c</td>
<td>Quartz flakes, broken blade (MP?)</td>
</tr>
</tbody>
</table>

**3.7.1.2 Macedonia**

**Golema Pesht:** Golema Pesht in Macedonia has been investigated through test excavations in 1999 and systematic excavations in 2003 and 2004 (Salamanov-Korobar 2008). These seasons uncovered UP and MP finds within 3 meters of six lithostratigraphic layers and did not reach bedrock. Artifacts classified as UP were concentrated in Layers 3 and 4, and include cores with single-platform, double-platform, and changed orientation. The dominant tools were retouched flakes and notched and denticulated pieces. Layers 5 and 6 contained MP artifacts, which resemble Denticulate Mousterian and/or Micromousterian. Levallois cores and unretouched Levallois flakes and points were present. In all layers, quartz finds and small artifacts were abundant. There was a $\sim 15 \text{ cm}$ contact zone between the MP Layer 5 and UP Layer 4, and the
bottom of Layer 4 contained mixed MP/UP elements. Within Layer 5 two charcoals from apparent hearths have been radiocarbon dated to $47,000 \pm 4800$ $^{14}$C yr BP and an infinite age of $>50,000$ $^{14}$C yr BP (no sample numbers provided; dated at AMS laboratory Physikalisches Institut der Universitat Erlangen-Nurnberg, Germany). Pretreatment procedures and preservation parameters were not reported. Lowe and colleagues reported that CI eruption cryptotephra overlies early UP levels at Golema Pesht (Lowe et al. 2012). While their chemical identification of the cryptotephra is likely accurate, no specific information has been provided about the provenience of the measured samples. It is unclear how the cryptotephra relates to the archaeological sequence.

The two radiocarbon dates have been included as uncertain calibrated dates due to lack of sample information. The dates extend beyond the calibration curve, but provide an extrapolated age for the MP of 41.7 kcalBP and older.

**Table 3.5**: Layer classifications from Salamanov-Korobar 2008.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>UP</td>
</tr>
<tr>
<td>4</td>
<td>UP</td>
</tr>
<tr>
<td>Contact zone (15 cm)</td>
<td>Mixed MP/UP</td>
</tr>
<tr>
<td>5a</td>
<td>MP</td>
</tr>
<tr>
<td>Ash from fireplaces</td>
<td></td>
</tr>
<tr>
<td>5b</td>
<td>MP</td>
</tr>
</tbody>
</table>

3.7.1.5 Romania

**Peştera cu Oase**: A modern human mandible, Oase 1, was found on the surface of the cave interior of Peştera cu Oase in southwest Romania in 2002 by spelunkers (Trinkaus et al. 2003). It was associated with faunal bones, but no artifacts. A nearly complete modern human cranium, Oase 2, was found later, but did not yield sufficient collagen for radiocarbon dating by standard pretreatment procedures (Rougier et al. 2007;
Trinkaus 2013). Ancient DNA analysis suggests that the Oase 1 individual 1) had a Neanderthal ancestor four to six generations earlier and 2) did not contribute substantially to later modern humans in Europe (Fu et al. 2015; Fu et al. 2016). Radiocarbon dates were produced on samples of Oase 1 by two laboratories (Trinkaus et al. 2003; Trinkaus 2013). At Groningen, the sample was prepared by ABA and gelatinization. The sample sent to Oxford also underwent ultrafiltration. The Oxford sample produced a low collagen yield of 0.4%, a C:N ratio of 3.3, and an infinite date of >35,200 $^{14}$C yr BP. The percent collagen is lower than the values usually accepted for dating at Oxford. The Groningen sample had a collagen yield of 4%, C:N ratio of 2.6, and absolute date of 34,290 ±970/−870 $^{14}$C yr BP. In this case, the C:N ratio is below standard accepted values, suggesting deamination of the collagen had occurred (Higham, Ramsey, et al. 2006). Thus the more rigorous pretreatment procedure (Oxford ultrafiltration) produced an infinite date from a low collagen yield and the milder pretreatment (Groningen) produced an absolute date with a C:N ratio outside the accepted range. The authors combined these dates by a weighted average of the activity ratios and propose an absolute age of 42-37 kcalBP (OxA-11711/GrA-22810: 34,950 ±990/−890 $^{14}$C yr BP) for the Oase 1 fossil, but it may be older. We include this combined date as an uncertain date.

**Peștera Muierii:** Human skeletal remains were found at Peștera Muierii, Romania in the 1950s in a surface depression and not in stratified archaeological layers (Soficaru et al. 2006). Excavations in other chambers revealed MP, UP, and mixed Holocene layers. The human remains comprise a cranium, mandible, scapula, and tibia, thought to represent one individual, Muierii 1, as well as a temporal (Muierri 2) and fibula (Muierri 3) that may represent different individuals. The Muierii 1 cranium
produced a radiocarbon date of ~34 kcalBP (OxA-15529: 29,930 ± 170 $^{14}$C yr BP) and the Muierii 2 temporal dated to 33.7-32.8 kcalBP (OxA-16252: 29,110 ± 190 $^{14}$C yr BP). These dates are included as reliable calibrated dates.

**Peștera Cioclovina:** Peștera Cioclovina, Romania was excavated in the early 1900s and a human cranium, Cioclovina 1, was discovered during phosphate mining in the 1940s (Soficaru et al. 2007). The context of the fossil is unknown and it was only associated with three undiagnostic artifacts. Mousterian and Aurignacian lithics have been found there, although the cave seems to have been predominately occupied by cave bears. A sample of the Cioclovina 1 occipital was dated to 33-32 kcalBP (OxA-15527: 28,510 ± 170 $^{14}$C yr BP). This is included as a reliable calibrated date.

**Românești-Dubrăvița I:** Românești-Dubrăvița I is an open-air site in the Banat region of western Romania. Original investigations in the 1960s and 70s excavated 450 m$^2$, revealing six lithostratigraphic layers (V-VI) (Mogosanu 1983). According to Mogosanu, a Quartzitic Mousterian layer (VI) was below rich Aurignacian layers (V-II) and a thin Gravettian layer (I). Reanalysis of the collections and new excavations were conducted in 2009-1010, which have revised the original interpretations (Sitlivy et al. 2014; Sitlivy et al. 2012). The new excavations did not find such clear boundaries between archaeological phases, as reported in publications from the original excavations. Rather, an indistinct quartzite assemblage (Layer GH4) was overlain by ~25 cm assemblage (top of Layer GH4, all of GH3) that combines elements of Proto- and Early Aurignacian traditions. Gravettian or Epigravettian artifacts were found above (Layers GH2-1). The sequence was dated by TL of flint artifacts and OSL of sediments (Schmidt et al. 2013). Flints from layers GH3-2 were TL dated by three measurement protocols.
Including only samples that exhibited proper luminescence behavior, the study found that artifacts from Proto/Early Aurignacian Layer GH3 had an average age of 40.6 ± 1.5 ka. The one artifact dated from GH2 produced an age of 15.6 ± 1.4 ka, suggesting that the assemblage is Epigravettian, rather than Gravettian. For OSL the quartz fine grain fraction was dated from sediment samples from GH3 and directly above and below the layer. The OSL date for GH3 of 40.6 ± 1.5 ka is consistent with the average TL date for this layer.

We included the TL dates for five artifacts from Layer GH3 that produced successful measurements according to the authors (Schmidt et al. 2013). The reported date of each specimen is an average of different measurement protocols applied to that specimen. The phase span for Proto/Early Aurignacian (Figure 3.3b) shows the average age of samples from Layer GH3.

**Table 3.6:** Layer classifications described by Schmidt et al. 2013 and Sitlivy et al. 2014.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>GH1</td>
<td>Epigravettian or Gravettian</td>
</tr>
<tr>
<td>GH2</td>
<td>Epigravettian or Gravettian</td>
</tr>
<tr>
<td>GH3</td>
<td>Proto/Early Aurignacian</td>
</tr>
<tr>
<td>GH4</td>
<td>Indistinct quartzite; Proto/Early Aurignacian at top</td>
</tr>
</tbody>
</table>

**3.7.1.6 Bulgaria**

**Kozarnika:** Kozarnika Cave is located in northeast Bulgaria along the Skomlia River tributary, about 30 km from the Danube River. The cave has been systematically excavated since 1996 by a French-Bulgarian team (Sirakov et al. 2010; Sirakov et al. 2007; Guadelli et al. 2005). The 8-meter sequence contained 21 lithostratigraphic layers including archaeological layers classified as Lower Paleolithic (13-11a), Middle Paleolithic (10b-9a), Upper Paleolithic (layers 5c-3a), and Holocene. Layers 6-7 are
poorly characterized, containing a mix of Levallois and blade based technologies likely due to post-depositional mixing. Within lithostratigraphic Layer 5b, archaeological Layer VII contains the Kozarnikian assemblage, characterized by blades and bladelets made by continuous reduction of the same cores (Tsanova et al. 2012; Tsanova 2008). Bladelet blanks were used to produce pointed tools by direct marginal and bilateral retouch and Dufour bladelets with alternate retouch (Teyssandier 2008). The assemblage is unique to the region and shows affinities with the Levantine Ahmarian and the Southern European Protoaurignacian, leading some archaeologists to consider these industries to be the product of related groups (Hublin 2015; Teyssandier 2008; Tsanova et al. 2012). Layers 4-3 most likely contained Gravettian assemblages. Lowe and colleagues identified cryptotephra sourced to the CI eruption “within early UP” layers, but the specific location of the cryptotephra were not provided (Lowe et al. 2012).

Radiocarbon dates were produced from charcoal, other burned plant remains, charred sediment, and bone, but little sample information is available (Tsanova 2008; Guadelli et al. 2005). We excluded dates from mixed Layers 6 and 7. Dates from other layers were included as uncertain calibrated dates due to insufficient sample and pretreatment information. The dates are remarkably consistent with the stratigraphic position of the samples, ranging from 45-13.5 kcalBP. The dates from Kozarnikian Layer VII range from 44-40 kcalBP. We did not produce a Bayesian model because the location of the CI tephra within the cultural and stratigraphic sequence was not reported.
### Table 3.7: Layer according to Guadelli et al. 2005 and Tsanova 2008.

<table>
<thead>
<tr>
<th>Lithostratigraphic layer</th>
<th>Arch. layer</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>0I</td>
<td>Gravettian (<em>Kozarnikien supérieur</em>)</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>II</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IVa</td>
<td>Gravettian (<em>Kozarnikien moyen</em>)</td>
</tr>
<tr>
<td></td>
<td>IVb</td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>5b (volcanic ash)</td>
<td>VI</td>
<td></td>
</tr>
<tr>
<td>5c</td>
<td>VII</td>
<td>Kozarnikian</td>
</tr>
<tr>
<td>6-7</td>
<td>VIII</td>
<td>MP/UP mixed</td>
</tr>
<tr>
<td>9a</td>
<td>IX</td>
<td>MP: Levallois Mousterian <em>Est balkanique</em></td>
</tr>
<tr>
<td>9b</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9c</td>
<td>XI, XII?</td>
<td></td>
</tr>
<tr>
<td>10a</td>
<td>XIII</td>
<td></td>
</tr>
<tr>
<td>10b</td>
<td>XIV</td>
<td></td>
</tr>
<tr>
<td>11a</td>
<td>XV</td>
<td>LP: core and flake non-Acheulean</td>
</tr>
<tr>
<td>11b</td>
<td>XVI</td>
<td></td>
</tr>
<tr>
<td>11c</td>
<td>XVII</td>
<td></td>
</tr>
<tr>
<td>11d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Temnata Doupka**: Systematic excavations between 1985-1995 in Temnata Doupka cave, northwest Bulgaria, revealed stratified assemblages spanning from the MP through the Epigravettian (Kozlowski et al. 1992; Tsanova 2008). The cultural sequence manifested differently in three main excavation trenches: TD-1 and TD-V inside the cave and TD-II in the talus outside of the cave. Much attention has been given to the assemblage found in TD-II Layer VI, which has been described as a transitional industry that combines MP Levallois method and UP volumetric blade method (semi-tournante) (Drobniewicz et al. 2000; Kozlowski 2004; Ginter et al. 1996). This claim has been challenged by Tsanova (Tsanova 2008), who concluded after detailed lithics analysis that
the MP and UP components of the assemblage likely combined by post-depositional mixing and should not be described as a transitional industry. However, as Tostevin points out, this combination of MP and UP elements may well characterize a transitional industry and the mixing should be demonstrated with geoarchaeological evidence (Tostevin 2013).

In the TD-I trench there is a convincing technological discontinuity between the final Mousterian Layer 6 and Layer 4, which are separated by a stalagmitic surface (Layer 5). Tsanova described the TD-I Layer 4 assemblage as volumetric, semi-tournante method without evidence for Levallois concept, and therefore classified it as Early Upper Paleolithic (Tsanova 2008). This result supports previous proposals that the Layer 4 assemblages from TD-I as well as TD-V represent an EUP industry that evolved into the Aurignacian (Drobniewicz et al. 2000; Ginter et al. 1996; Kozlowski 2004). However, numerous authors refer to these assemblages as Bachokirian or Initial Upper Paleolithic (Jöris & Street 2008; Kuhn & Zwyns 2014; d'Errico & Banks 2015). The uppermost sublayer 4A of TD-I contained bladelets that most likely intruded from an overlying Gravettian layer.

A tephra layer was observed across the site and considered to represent the CI eruption based on chemical characterization of visually identical tephra at nearby Cave 16, which was archaeologically sterile (Giaccio et al. 2008). If the visual correlations are accurate, then the CI tephra layer is found at different positions within the cultural sequence across different excavation areas of Temanta. In TD-I the tephra separates the Initial or Early UP Layer 4 from Gravettian Layer 3f with a potential occupational hiatus. In TD-V the tephra separates Aurignacian or Early Aurignacian Layer 3i from Evolved
Aurignacian Layer 3h (Fedele et al. 2008; Ginter et al. 1996). This discrepancy may be due to variable deposition/erosion across the cave.

**Table 3.8:** Dates used in this study are all from sector TD-I. The layer classifications are according to Tsanova 2008 and *Layer 4 is left undetermined.

<table>
<thead>
<tr>
<th>TD-I Layer</th>
<th>Archeological level</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>18\textsuperscript{th} century filling</td>
</tr>
<tr>
<td>2</td>
<td>2a</td>
<td>Iron Age</td>
</tr>
<tr>
<td></td>
<td>2b</td>
<td>Eneolithic</td>
</tr>
<tr>
<td>3a</td>
<td>1, 01-02</td>
<td>Epigravettian</td>
</tr>
<tr>
<td>3b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3c</td>
<td>IV, Va, Vb</td>
<td>Gravettian</td>
</tr>
<tr>
<td>3d</td>
<td>VI, VIIa, VIIb, VIII</td>
<td></td>
</tr>
<tr>
<td>3f</td>
<td>IXa, IXb, X</td>
<td></td>
</tr>
<tr>
<td>tephra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>*TD-I Layer 4 (IUP or EUP?)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Stalagmitic floor</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>MP: denticulate Mousterian</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>MP: typical Mousterian</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>MP: <em>Moustérien à débitage Levallois</em></td>
</tr>
</tbody>
</table>
Table 3.9: Correlations between excavation sectors with layer classifications according to Ginter et al. 1996, with the exception of * and **. The classification of these layers remains undetermined.

<table>
<thead>
<tr>
<th>Sector TD-I (inside)</th>
<th>Sector TD-V (inside)</th>
<th>Sector TD-II (outside)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Layer</strong></td>
<td><strong>Archaeology</strong></td>
<td><strong>Layer</strong></td>
</tr>
<tr>
<td>3a</td>
<td>Epigravettian</td>
<td>3a</td>
</tr>
<tr>
<td>3b</td>
<td>Epigravettian</td>
<td></td>
</tr>
<tr>
<td>3c</td>
<td>Gravettian</td>
<td>IVA</td>
</tr>
<tr>
<td>3d</td>
<td>Gravettian</td>
<td>IVB</td>
</tr>
<tr>
<td>3f</td>
<td>Gravettian</td>
<td></td>
</tr>
<tr>
<td>3g</td>
<td>Evolved</td>
<td>3h</td>
</tr>
<tr>
<td>3h</td>
<td>Aurignacian</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Tephra</td>
<td>V</td>
</tr>
<tr>
<td>4</td>
<td>EUP or IUP*</td>
<td>4a</td>
</tr>
<tr>
<td>4b</td>
<td>EUP or IUP*</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Transitional or mixed**</td>
<td>5pg 4/3</td>
</tr>
<tr>
<td>5pg</td>
<td>MP</td>
<td></td>
</tr>
</tbody>
</table>

We eliminated dates from layers with possible mixing (TD-II Layer VI and TD-I Layer 4A) and sector TD-V, which has not been reported in detail. We also eliminated dates produced on bones that were not prepared with ultrafiltration (Bluszcz et al. 1992; Ginter et al. 1996). The remaining radiocarbon dates were produced on charred material collected from hearths (a mixture of charcoal particles, ash, and sediment) in TD-I Layers 4B-C. These samples were only prepared with acid-base, rather than acid-base-acid pretreatment and preservation parameters were not reported. Moreover the associated archaeology has an ambiguous classification as EUP/Early Aurignacian or IUP/Bachokirian. We included these samples as uncertain dates with an undetermined industry. It is likely that there are EUP and Bachokirian phases at Temnata cave, but
based on the published data and interpretations it is not possible to assign specific layers or dated samples to these phases. We also included TL dates on flints from TD-I Layers 4B-C and the final Mousterian TD-I Layer 6. These dates were used to construct an uncertain model of three sequential phases of the TL date from MP layer 6, the $^{14}$C and TL dates from layers 4B-C, and the calendar age of the CI eruption. Two of the radiocarbon dates may extend beyond the calibration curve. By this model the MP ends by 42 kcalBP and TD-I Layer 4 has a modeled range of 46-41 kcalBP.

OxCal code:

```oxcal
Plot()
{
    Sequence()
    {
        Boundary("Start MP");
        Phase("MP")
        {
            Age("Gd-TL-254",N(67000,11000));
        };
        Boundary("End MP");
        Boundary("Start TDI-4");
        Phase("TDI-4")
        {
            Age("Gd-TL-256",N(45000,7000));
            R_Date("OxA-5169", 39100, 1800);
            R_Date("OxA-5170", 38800, 1700);
            R_Date("OxA-5171", 38200, 1500);
            Age("Gd-TL-255",N(46000,8000));
        };
        Boundary("End TDI-4");
        Boundary("Start CI");
        Phase("CI")
        {
            C_Date("CI", -37330, 110);
        };
        Boundary("End CI");
    };
    Sequence()
    {
        Boundary("=Start TDI-4");
    }
}
```
Bacho Kiro: Bacho Kiro was first investigated by Garrod (1939) and then by a Bulgarian-Polish team from 1971-1975 (Kozłowski 1982b). The latter project revealed 14 lithostratigraphic layers to a depth of almost 5 meters, with Mousterian, IUP, EUP, and Epigravettian phases. The Layer 11 assemblage was used to define the Bachokirian, a transitional industry focused on the production of elongated, convergent blades by hard hammer production likely rooted in Levallois technology (Teyssandier 2003; Tsanova & J.-G. Bordes 2003; Kozłowski 2004). However inferring technological traits of the Layer 11 assemblage has been difficult because it is mostly heavily reused, nonlocal flint tools. There is little evidence of on-site knapping (cores, refits), which could be used to reconstruct the reduction sequence.

Fragmentary human bones and teeth have been found throughout Layers 6-11. Of particular interest is a mandible fragment with a deciduous first molar from the bottom of Layer 11, which is the only human remain associated with a Bachokirian assemblage (Glen & Kaczanowski 1982). The specimen was described in the final site report, but has since been lost. The original physical anthropologists considered the human remains more Neanderthal-like than modern, but the taxonomic attribution of these specimens remains ambiguous.
Radiocarbon dates have been produced for Bacho Kiro at three points (Evin et al. 1978; Mook 1982; Hedges et al. 1994). We excluded finite dates produced on bones or teeth without ultrafiltration. We included the following: Two bones from the penultimate MP Layer 13 were published as a single radiocarbon date of >47,000 $^{14}$C yr BP. One charcoal from a hearth in Bachokirian Layer 11 produced an infinite age of >43,000 $^{14}$C yr BP. It is unclear whether the other dated charcoals were isolated pieces or collected from in situ hearths. A charcoal from Bachokirian Layer 11 dated to 45-39.5 kcalBP. Two charcoals were dated from Layers 7 and 6b, which has an undetermined industry.

**Table 3.10:** Layer classifications from Tsanova 2008.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a, 5</td>
<td>Epigravettian</td>
</tr>
<tr>
<td>4a</td>
<td><em>Aurignacoïdal</em></td>
</tr>
<tr>
<td>4b</td>
<td></td>
</tr>
<tr>
<td>4b, 6a</td>
<td></td>
</tr>
<tr>
<td>6a, 7</td>
<td>Aurignacian (<em>Aurignacien Balkanique typique</em>)</td>
</tr>
<tr>
<td>7</td>
<td>Bachokirian/Aurignacian?</td>
</tr>
<tr>
<td>7, 6b</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Bachokirian with Aurignacian elements</td>
</tr>
<tr>
<td>11</td>
<td>Bachokirian</td>
</tr>
<tr>
<td>11a</td>
<td>Bachokirian/Mousterian</td>
</tr>
<tr>
<td>12</td>
<td>MP: Mousterian</td>
</tr>
<tr>
<td>13</td>
<td>MP: Mousterian, non-Levallois</td>
</tr>
<tr>
<td>14</td>
<td>MP: typical Mousterian</td>
</tr>
</tbody>
</table>

3.7.1.7 Italy

**Castelcivita:** Major excavations in Castelcivita Cave in southern Italy occurred between 1976-1988 (Gambassini 1997). A 3.4 meter sequence of Mousterian, Uluzzian, and Protoaurignacian layers was capped by volcanic ash sourced to the CI eruption (Giaccio et al. 2008; Douka et al. 2014). An erosional contact separated the final MP from the Uluzzian layers and the latter consisted of distinct fine red sediment. A series of
burnt bones was dated by Gambassini (Gambassini 1997), but we do not consider burnt bone a suitable material for radiocarbon dating. One charcoal from the uppermost Uluzzian layer was divided and dated after ABA and ABOx-SC pretreatment methods (Wood et al. 2012). The ABOx-SC method provided an older and likely more accurate date of 41-40 kcalBP (OxA-22622: 36,120 ± 360 14C yr BP). However, given that 50-55 cm and several Protoaurignacian layers separate the sample from the overlying CI tephra deposit, it is surprising, according to the authors, that the charcoal is not more older (Douka et al. 2014). The authors also note that the layer “contained evidence of hearths,” but do not clarify if the dated charcoal piece was collected from a hearth (Douka et al. 2014:7; Wood et al. 2012:19). We have included the ABOx-SC charcoal measurement as a reliable calibrated date of 41.5-40 kcalBP and indicated the CI tephra.

**Table 3.11:** Layer classifications according to Supplementary data in Douka et al. 2014.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI tephra</td>
<td></td>
</tr>
<tr>
<td>ars</td>
<td>Protoaurignacian</td>
</tr>
<tr>
<td>gic</td>
<td></td>
</tr>
<tr>
<td>rsa'</td>
<td></td>
</tr>
<tr>
<td>rsa”</td>
<td>Uluzzian</td>
</tr>
<tr>
<td>rpi</td>
<td></td>
</tr>
<tr>
<td>pie</td>
<td></td>
</tr>
<tr>
<td>rsi'</td>
<td></td>
</tr>
<tr>
<td>rsi”</td>
<td>MP</td>
</tr>
<tr>
<td>gar</td>
<td></td>
</tr>
<tr>
<td>cgr</td>
<td></td>
</tr>
</tbody>
</table>

**Cavallo Cave:** Cavallo Cave in southeast Italy was systematically excavated from 1963-1966 and 1986-2007, in addition to salvage excavations in the late 1970s and early 1980s (Douka et al. 2014). The nearly 7 meters of archaeological deposits comprised MP (MIV- FI), Uluzzian (E-DIb), Late Epigravettian, and Neolithic layers. Directly overlying the final Uluzzian layer was a stalagmitic floor (DIa) and tephra deposit (C). It has long
been assumed that this layer results from the CI eruption based on its location in the archaeological sequence (Benazzi et al. 2011). Citing personal communication with R. Sulpizio, several publications have stated that this assignment has been confirmed by chemical characterization, although no chemical data have been published (Douka et al. 2014; Moroni et al. 2013; d'Errico & Banks 2015). Another unidentified green volcanic ash (Fα) was observed between the final Mousterian (FI) and first Uluzzian layer (EIII). Two deciduous molars, excavated in 1964 from the two lowest Uluzzian layers (EII-I and EIII), were recently reanalyzed and assigned to modern humans (Benazzi et al. 2011). If the proposed taxonomic affinity and archaeological association of these teeth are correct, the implication follows that modern humans produced the Uluzzian tradition. However, others have questioned this conclusion (Trinkaus & Zilhão 2013; Banks et al. 2013; Zilhão et al. 2015; Peresani et al. 2016).

Table 3.12: Layer classifications according to Benazzi et al. 2011.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI</td>
<td>Epigravettian (Romanellian or Epiromanellian)</td>
</tr>
<tr>
<td>BII</td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>Volcanic ash (likely CI)</td>
</tr>
<tr>
<td>CII</td>
<td></td>
</tr>
<tr>
<td>Dla</td>
<td>Stalagmitic crust</td>
</tr>
<tr>
<td>Dlb</td>
<td>Final Uluzzian</td>
</tr>
<tr>
<td>DII</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>Evolved Uluzzian</td>
</tr>
<tr>
<td>EII</td>
<td></td>
</tr>
<tr>
<td>EIII</td>
<td>Archaic Uluzzian</td>
</tr>
<tr>
<td>Fs</td>
<td></td>
</tr>
<tr>
<td>Fα</td>
<td>Green volcanic ash</td>
</tr>
<tr>
<td>FI-MIV</td>
<td>MP</td>
</tr>
</tbody>
</table>

Radiocarbon dates have been produced for samples from Uluzzian layers of Cavallo in several attempts. One charcoal dated in the 1960s provided an infinite date of >31,000 (Palma di Cesnola 1969). Ten burnt bones from the lowest Uluzzian layer (E III)
produced divergent and interstratified dates between 42-23 kcalBP (Riel-Salvatore 2007). We do not consider burnt bone to be suitable material for dating because the source of the carbon is unclear. Due to the absence of charcoal in collections and collagen in bones, Douka dated a series of eight shells from the Uluzzian layers (Benazzi et al. 2011). The dates that the authors considered reliable and consistent with the stratigraphy range from 44-39 kcalBP. Under the assumption that the overlying tephra belongs to the CI eruption, these dates appear to be accurate. It is unlikely that the Uluzzian materials, including the human molars and dated shells, infiltrated from a higher layer because the Uluzzian layers are sealed by a stalagmitic crust. However, it is unclear how much mixture occurred between the Uluzzian layers and the underlying Mousterian layers. Moreover, all of the dates accepted by the authors were from marine shell beads. The marine organisms, which already incorporate ocean reservoir carbon older than atmospheric carbon, may have died thousands of years before humans crafted their shells into beads (Sivan et al. 2006). It is also unclear if diagenetic carbonate can be completely identified and removed from shells (Busschers et al. 2014).

We included the shell dates as uncertain calibrated dates using the Marine13 curve (Reimer et al. 2013). We excluded the two dates that Douka et al. (Douka et al. 2014) considered to be outliers, as well as OxA-19242 because its aragonite/calcite ratio did not meet standard accepted values. The remaining dates were used to construct an uncertain two-phase model. Five shells were constrained to an Uluzzian phase, which had a sequential boundary with a phase defined by the calendar date of the CI eruption. This model suggests that the Uluzzian tradition was present at least from 43-39 modeled kcalBP. No samples were dated from the lowest two Uluzzian layers (EII and EIII),
where the molars were discovered. With our current understanding of site formation processes and chronology at Cavallo, we can say that human teeth were found within an Uluzzian assemblage that seems to have been deposited for a few thousand years up until the CI eruption.

OxCal Code:

Plot()
{
  Sequence()
  {
    Boundary("Start Uluzzian");
    Curve("Marine13","Marine13.14c");
    Phase("Uluzzian")
    {
      R_Date("Ox-19256", 39060, 310);
      R_Date("Ox-19258", 36000, 400);
      R_Date("Ox-20631", 36780, 310);
      R_Date("OxA-19255", 36260, 250);
      R_Date("OxA-19254", 35080, 230);
    };
    Boundary("Transition Uluzzian/CI");
    Phase("CI")
    {
      C_Date("CI", -37330, 110);
    };
    Boundary("End CI");
  };
  Sequence()
  {
    Boundary("=Start Uluzzian");
    Date("Uluzzian");
    Boundary("=Transition Uluzzian/CI");
  };
}

3.7.1.8 Greece

Theopetra Cave: Theopetra Cave in Greece has been excavated since 1987 (Kyparissi-Apostolika 1999). The 5.4 meter sequence comprised six lithostratigraphic units (I-VI) with material culture spanning from the MP through Neolithic. The UP
assemblage has few diagnostic pieces and is mixed with MP and Mesolithic material (Karkanas 2001). The upper part of the Paleolithic and the Mesolithic layers was disturbed by large, irregular trenches and horizontal tunnels. In contrast, MP layers (I-II9) exhibited a relatively well-preserved stratigraphic sequence of alternating water-lain and burnt layers.

Table 3.13: Unit classifications according to descriptions of Karkanas 2001.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>Holocene mixed</td>
</tr>
<tr>
<td>V</td>
<td>Channel infilling</td>
</tr>
<tr>
<td>IV</td>
<td>Mesolithic</td>
</tr>
<tr>
<td>III</td>
<td>Channel infilling</td>
</tr>
<tr>
<td>II12-II10</td>
<td>Sparse UP</td>
</tr>
<tr>
<td>II9-II1</td>
<td>MP</td>
</tr>
<tr>
<td>I</td>
<td></td>
</tr>
</tbody>
</table>

Over 60 radiocarbon dates have been produced from mostly charcoals by different protocols at three laboratories: the Laboratory of Archaeometry of NCSR Demokritos, Greece; the Radiocarbon Dating and Cosmogenic Isotopes Laboratory of Weizmann Institute of Science, Israel; and the Oxford Radiocarbon Accelerator Unit, UK (Karkanas et al. 1999; Facorellis et al. 2001; Facorellis et al. 2013). We did not consider dates from the disturbed UP and more recent layers. The charcoals from in situ hearths in well-stratified MP layers (I-II9) likely came from reliable contexts, but their radiocarbon dates reflect unequivocal contamination (Facorellis et al. 2013; Karkanas et al. 2015).

Tephrochronology and TL dates indicate that charcoals from the MP layers should be older than 50 ka and beyond the limits of radiocarbon dating (Valladas et al. 2007; Karkanas et al. 2015). Nine flints from layers II2 and II4 provided TL dates from 107 ± 12 to 150 ± 15 ka, and one outlier gave an age of 67 ± 11 ka (Valladas et al. 2007). Cryptotephra from the Pantellerian Y6/Green Tuff dated to 45.7 ± 0.5 ka (Scaillet et al. 2000).
2013) and the Nisyros Upper Pumice dated to >50.4 ka (Bronk Ramsey et al. 2015) were found in layers II12 and II10, respectively, which are above the intact MP layers. Cryptotephra from the P-11 Pantellerian eruption dated to 131-128 ka was identified in layer II5. From Theopetra, we did not include any radiocarbon dates, but indicated the tephra layers. The TL samples from good contexts were older than the limits of our chronology.

**Klissoura Cave:** Excavations between 1994-2006 of Klissoura Cave, southern Greece, revealed an 8-meter long sequence with cultural layers from the Mousterian through Mesolithic (Kaczanowska et al. 2010). Above ~6.5 meters of Mousterian layers was an erosional contact and a concentration of cryptotephra from an unknown eruption (Lowe et al. 2012; Kuhn et al. 2010; Douka et al. 2014). The final MP Layer VII was characterized by non-Levallois technique, primarily on discoidal and single-platform cores. The next Layer VI contained a mixture MP and UP artifacts, followed by a thin, discontinuous Uluzzian Layer V, which contained arched backed blades diagnostic of the Uluzzian. There was no technological or typological continuity between final MP (VII) and Uluzzian (V) assemblages (Kaczanowska et al. 2010). Directly above the Uluzzian layer was cryptotephra identified to the CI eruption, which decreased in concentration upwards through the overlying Aurignacian Layer IV (Lowe et al. 2012). Based on micromorophology, the depositional hiatus between these layers (Uluzzian V/Aurignacian IV) appears to have been relatively minor (Karkanas 2010).

The Aurignacian assemblage (Layers IV, IIIg-d, IIIc-a) was characterized by carinated forms, bladelets with fine retouch (Dufour type), splintered pieces, and bone points. Layer III” contained a unique flake industry with single- and double-platform core
technique, dominated by end-scrapers, notched-denticulated tools, retouched flakes, and side-scrapers. It differs from the underlying Aurignacian Layer (IIIc-a) and the overlaying backed-blade layer (III’). The authors classify it as “not yet named,” but propose it may represent the Late Uluzzian (Kaczanowska et al. 2010). Layer III’ contains a backed bladelet industry, which likely belongs to the Gravettian. The overlaying Layer 6a constitutes a ditch with a mixture of Aurignacian and Gravettian elements.

Table 3.14: Layer classifications according to Kaczanowska et al. 2010.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>3, 5, 5a</td>
<td>Mesolithic and modern</td>
</tr>
<tr>
<td>IIa, IIb, IIId</td>
<td>Epigravettian</td>
</tr>
<tr>
<td>6, 6a, 6/7</td>
<td>Aurignacian/Gravettian, “ditch”</td>
</tr>
<tr>
<td>III’</td>
<td>Backed bladelet industry (Mediterranean Gravettian?)</td>
</tr>
<tr>
<td>III”</td>
<td>Not yet named (epi-Uluzzian?)</td>
</tr>
<tr>
<td>IIIa-IIIc</td>
<td>Aurignacian (upper)</td>
</tr>
<tr>
<td>IIIId-IIIg</td>
<td>Aurignacian (middle)</td>
</tr>
<tr>
<td>IV</td>
<td>Aurignacian (lower)</td>
</tr>
<tr>
<td>CI tephra</td>
<td>Uluzzian</td>
</tr>
<tr>
<td>V</td>
<td>Uluzzian</td>
</tr>
<tr>
<td>VI</td>
<td>MP/UP mixed</td>
</tr>
<tr>
<td>Other tephra</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>MP</td>
</tr>
<tr>
<td>VIII</td>
<td>MP</td>
</tr>
</tbody>
</table>

A sequence of soil carbonates were dated (Koumouzelis et al. 2001), but this material is not a reliable reservoir of atmospheric carbon from the time of deposition of associated archaeological material. Kuhn and colleagues (Kuhn et al. 2010) reported 29 dates of mostly charcoal or charred sediment from Pleistocene layers produced at four different laboratories with different procedures. The majority of dates from Aurignacian layers ranged between 38-34 kcalBP, and the MP dates were all greater than 48,000 $^{14}$C
yr BP, or beyond the calibration curve. Dates from the Uluzzian Layer V were inconsistent with the stratigraphic sequence. There was a cluster of Uluzzian layer dates around 34 kcalBP, which are younger than the overlying CI cryptotephra. One sample (Gif-99168) from the Uluzzian layer (V) produced a date ~44 kcalBP, which overlaps with the dated samples from the mixed Layer VI.

One charcoal was divided and prepared with ABA and ABOx-SC followed by an ultra-clean vacuum line (Pigati et al. 2007) at the NSF-Arizona AMS Laboratory. The resulting ages differed significantly, and the ABOx-SC/ultra-clean vacuum treatment produced an older, presumably more-accurate age. This was the only charcoal prepared by both methods, although other samples prepared by ABA overlap with associated charcoals prepared by ABOx-SC. Based on one charcoal it is difficult to reject all the samples prepared by ABA, especially those prepared at different laboratories. Because no preservation parameters were reported and some anomalies were observed in the dates, we included the charcoal series as uncertain dates. We excluded samples from mixed layers (6a, VI) and samples from the Uluzzian Layer V that produced dates younger than the age of the overlying CI tephra. We also excluded dates older than 50,000 $^{14}\text{C}$ yr BP.

Douka dated one Cyclope and one Dentalium shell bead from Uluzzian Layer V (Douka et al. 2014). The Cyclope (OxA-19936: $27,950 \pm 160\ ^{14}\text{C}$ yr BP), which produced an anomalously young age, was rejected based on its uncertain context and low %C yield. The Dentalium (OxA-21068: $34,580 \pm 220\ ^{14}\text{C}$ yr BP) was considered reliable by the authors, although the sample had an aragonite/calcite ratio outside of generally accepted values. We have excluded these dates.
The uncertain charcoal dates were used to construct a model of six sequential phases of MP (Layer VII) before Uluzzian (Layer V) before CI before Aurignacian (Layers IV-IIIe) before an undetermined industry (Layer III”) before Gravettian (Layer III’). We applied t-type outlier analysis, in which all dates were given a 5% prior likelihood of being outliers (Bronk Ramsey 2009b). By this model the MP ends by 46 kcalBP, followed by the Uluzzian until 41 kcalBP. The Aurignacian spans from 37-33 kcalBP and the Gravettian phase spans from 29-25 kcalBP.

OxCal code:

```
Plot()
{
  Outlier_Model("General",T(5),U(0,4),"t");
  Sequence()
  {
    Boundary("Start MP");
    Phase("MP")
    {
      R_Date("AA-73820", 48990, 1770)
      {
        Outlier("General", 0.05);
      }
    }
    Boundary("End MP");
    Boundary("Start Uluzzian");
    Phase("Uluzzian")
    {
      R_Date("Gif-99168", 40100, 740)
      {
        Outlier("General", 0.05);
      }
    }
    Boundary("End Uluzzian");
    Boundary("Start CI");
    Phase("CI")
    {
      C_Date("CI", -37330, 110);
    }
    Boundary("End CI");
    Boundary("Start Aurignacian");
  }
}
```
Phase("Aurignacian")
{
  R_Date("Gd-10567", 29950, 460)
  {  
    Outlier("General", 0.05);
  };
  R_Date("Gd-10562", 32400, 600)
  {  
    Outlier("General", 0.05);
  };
  R_Date("GdA-228", 31150, 480)
  {  
    Outlier("General", 0.05);
  };
  R_Date("Gd-9688+", 22500, 1000)
  {  
    Outlier("General", 0.05);
  };
  R_Date("Gd-7892", 34700, 1600)
  {  
    Outlier("General", 0.05);
  };
  R_Date("AA-73817", 31630, 250)
  {  
    Outlier("General", 0.05);
  };
  R_Date("Gd-7893", 31400, 1000)
  {  
    Outlier("General", 0.05);
  };
  R_Date("RTT-4786", 30925, 420)
  {  
    Outlier("General", 0.05);
  };
  R_Date("RTT-4788+", 22270, 160)
  {  
    Outlier("General", 0.05);
  };
  Boundary("End Aurignacian");
  Boundary("Start unknown");
  Phase("unknown")
  {  
    R_Date("Gd-15351", 24820, 520)
    {  
      Outlier("General", 0.05);
    };
  };
}
Boundary("End unknown");
Boundary("Start Gravettian");
Phase("Gravettian")
{
  R_Date("AA-73821", 31460, 210)
  {  
    Outlier("General", 0.05);
  
  R_Date("Gd-15349", 23000, 540)
  {  
    Outlier("General", 0.05);
  
  
  Boundary("End Gravettian");
  
  Sequence()
  {
    Boundary(="Start MP");
    Date("MP");
    Boundary(="End MP");
  
  Sequence()
  {
    Boundary(="Start Uluzzian");
    Date("Uluzzian");
    Boundary(="End Uluzzian");
  
  Sequence()
  {
    Boundary(="Start Aurignacian");
    Date("Aurignacian");
    Boundary(="End Aurignacian");
  
  Sequence()
  {
    Boundary(="Start unknown");
    Date("unknown");
    Boundary(="End unknown");
  
  Sequence()
  {
    Boundary(="Start Gravettian");
    Date("Gravettian");
    Boundary(="End Gravettian");
Franchthi Cave: Excavations at Franchthi Cave between 1967-1979 reached a depth of 11.2 meters, revealing materials from the UP through Neolithic (Douka et al. 2011). Lithics in the earliest UP layers (P, Q, R) varied in abundance and character. The lowermost Layer P was thick (1.5-2 m), but the artifacts were few and non-diagnostic. The layer was tentatively classified as UP, although a couple of isolated finds near the base suggest that a MP phase occurred, which was not found as a distinct stratigraphic unit. The overlying Layer Q consisted of 5-9 cm of tephra deposits sourced to the CI eruption (Lowe et al. 2012). Lithics within the tephra layer included straight and curved bladelets and carinated cores, consistent with Early Aurignacian modes of production. Above this, Layer R appeared to contain a typical Aurignacian assemblage overlain by and somewhat mixed with Gravettian material.

Table 3.15: Layer classifications according to descriptions in Douka et al. 2011.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Archaeology</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Gravettian</td>
</tr>
<tr>
<td></td>
<td>Aurignacian</td>
</tr>
<tr>
<td>Q</td>
<td>Early Aurignacian and CI tephra</td>
</tr>
<tr>
<td>P</td>
<td>Poor, undiagnostic</td>
</tr>
</tbody>
</table>

Radiocarbon dates from Franchthi are ambiguous (Douka et al. 2011). Numerous dates should be discarded because they were made on unsuitable material including soil and calcite grains. Shell dates from trench FAS are not consistent with the samples’ positions relative to the CI eruption, which can be explained due to post-depositional mixing or the use of fossil shells. In contrast, three shells from trench H1B fit the chronology suggested by the tephra layer and lithic industries. In short, radiocarbon dates from Franchthi cave have not improved our understanding of the site’s chronology.
because the dates have been accepted or rejected based on their consistency with site’s preexisting chronology established by the CI tephra layer.

The sequence at Franchthi is important to the regional chronology because the occurrence of an Early Aurignacian industry within and immediately above CI tephra suggests the presence of modern humans through this climatic event and its aftermath. However, the available radiocarbon dates do not provide a fine enough resolution to synchronize the timing of human occupations with that of climatic events. The dated shells may be thousands of years older than the date when they were used by humans, in which case it is difficult to determine how soon before and after the CI eruption humans were present at Franchthi.

Given these caveats, we classified the three shells from H1B measured by Douka et al. (Douka et al. 2011) as uncertain and calibrated them with the Marine13 curve. We also included the CI tephra. The dates suggest that a UP population was present sometime between 40-35 kcalBP.

3.7.2 Comparing dates

The OxCal program was used to compare the order and overlap of dates using several commands. First all Neanderthal fossil and finite MP dates were compared to dates from modern human fossils and the earliest assemblages attributed to modern humans (Appendix B). Specifically the latter included EUP dates from Tabula Traiana, Baranica, Kozarnika, and Franchthi, TD-I Layer 4 dates from Temnata, Bachokirian dates from Bacho Kiro, and the Oase 1 fossil. The Order command was used to calculate the probability that the modern human-attributed date is older than the Neanderthal-attributed date for each pair. For pairs with >20% probability of an older modern human
date, the Difference command was used to calculate a probability density function for how many years different the dates may be at 95.4% confidence (Appendix B). The results are reported from the maximum to minimum number of years older the modern-human attributed date could be than the Neanderthal-attributed date. When the second value is negative, the modern-human attributed date could be that many years younger than the Neanderthal-attributed date. When zero falls within the probability range, the dates are statistically indistinguishable and could be contemporaneous. For example, the pair GifA-99662 from Kozarnika and Ua-? from Vindija have an estimated difference of 3898 to -5422, which should be read as the modern-human attributed date from Kozarnika is from 3989 years older to 5422 years younger than the Neanderthal date from Vindija at 95.4% confidence. Lastly, the Oxcal Combine command was used to estimate the range of years during which the Vindija Vi-80 Neanderthal (Ua-?) and Oase 1 modern human (OxA-11711/GrA-22810) could have been contemporaneous. This was between 42,000-38,800 kcalBP (95.4%).

3.8 Acknowledgements

We thank Eugenia Mintz and Lior Regev for their great assistance in radiocarbon sample preparation and measurement; Vesna Dimitrijevic for assistance with faunal samples; and David Pilbeam, Christian Tryon, and Daniel Lieberman for comments on the manuscript.

3.9 References


Boaretto, E., 2009. Dating materials in good archaeological contexts: the next challenge


Bronk Ramsey, C. et al., 2015. Improved age estimates for key Late Quaternary European tephra horizons in the RESET lattice. *Quaternary Science Reviews*, 118, pp.18–32.


Fu, Q. et al., 2016. The genetic history of Ice Age Europe. Nature. doi:10.1038/nature17993


Higham, T., 2011. European Middle and Upper Palaeolithic radiocarbon dates are often older than they look: problems with previous dates and some remedies. Antiquity, 85, pp.235–249.


Nigst, P.R. et al., 2014. Early modern human settlement of Europe north of the Alps


Sitlivy, V. et al., 2012. The earliest Aurignacian in Romania: new investigations at the open air site of Românești-Dumbrăvița I (Banat). *Quartär*, 59, pp.85–130.


Wood, R.E. et al., 2012. Testing the ABOx-SC method: Dating known-age charcoals


CHAPTER 4– LATE MIDDLE PALEOLITHIC OF SOUTHERN POLAND:
RADIOCARBON DATES FROM CIEMNA AND OBLAZOWA CAVES

4.1 Introduction

Between 60,000-30,000 years ago the European continent was home to numerous Neanderthal and modern human groups with distinct behaviors and material culture (Hublin 2015). Understanding the nature of interactions between these groups is predicated on an accurate reconstruction of their spatial and temporal distributions. The population history for much of Europe 60-30 ka is becoming resolved thanks to improvements in chronometric dating of human fossils and archaeological assemblages (Higham et al. 2014). However, the population history of some regions remains poorly established.

One such region is Northeast Europe, north of the Carpathian and Sudeten mountain chains in present day Poland (Figure 4.1). In a relatively small area (<900 km²) between mountains to the south and a glacier with fluctuating margins to the north, there are a number of distinct archaeological assemblages, which are attributed to MP and UP traditions (Wiśniewski et al. 2013; Bobak et al. 2013). This pattern may result from the cultural adaptability of a single group or it may reflect the presence of several groups (Kozłowski 2014). Moreover, it is unclear whether the region was occupied continuously by humans or if cold phases forced abandonment or local extinctions (Hublin & Roebroeks 2009; Skrzypek et al. 2011; Kozłowski 2000). Here we report radiocarbon dates from current excavations of Late Middle Paleolithic (MP) layers of two sites in Southern Poland: Ciemna and Oblazowa caves. The results clarify site-specific issues of
Figure 4.1: Late Pleistocene sites of Southern Poland and Moravia mentioned in the text. 1) Ciemna, 2) Obłazowa, 3) Stajnia, 4) Biśnik, 5) Nietoperzowa, 6) Piekary IIa, 7) Hallera Avenue, Wrocław, 8) Dzierżysław I, 9) Lubotyń 11, 10) Kúlna, 11) Brno-Bohunice, 12) Stránská skála, 13) Vedrovice, 14) Moravský Krumlov IV. Colors indicate the primary archaeological industry reported during Marine Isotope Stage 3 (MIS 3). Ciemna and Obłazowa Caves shown in photos. The cave entrance to Ciemna can be seen within the white box.
chronology and site formation processes as well as contribute to our understanding of the regional population history.

### 4.2 Archaeological background

Broadly, the Late MP assemblages of Poland can be divided into Mousterian industries characterized by unifacial tools, and Micoquian industries characterized by bifacial tools (Kozłowski 2014). The Mousterian seems to have emerged earlier and is found stratigraphically below numerous Micoquian assemblages (Neruda & Nerudová 2013b; Valde-Nowak et al. 2016). However in some sequences the traditions are reversed in order, interstratified, or seem to be both present in a given layer (Kozłowski 2014; Cyrek et al. 2010). The relationship between these traditions is an open question and may not be of the same nature in Poland as in other areas of Central/Eastern Europe. Among the Mousterian industries, the Taubachian is a subtype distinguished by non-Levallois reduction and small artifacts usually less than 3 cm long that includes cores, blanks, and tools (Valoch 1984; Moncel & Neruda 2000). Taubachian assemblages also have discoidal cores and an abundance of denticulate and notched tools (Cieśla & Valde-Nowak 2015). Micoquian assemblages, in addition to having bifacial technology, contain an abundance of backed bifacial knives or Keilmesser (Kozłowski 2014; Ruebens 2013). Assemblages with these characteristics in Central/Eastern Europe have been called Keilmessergruppe (KMG) (Jöris 2006). While it is widely believed that both Mousterian and Micoquian industries in Europe were produced by Neanderthals (Higham et al. 2014), the only human remains associated with Polish Late MP assemblages are three molars interpreted as Neanderthals found with Micoquian artifacts in Stajnia Cave (Urbanowski et al. 2010; Dąbrowski et al. 2013; Nowaczewska et al. 2013). However,
more Neanderthal fossils were associated with a Micoquian assemblage in Kůlna Cave (Layer 7a), Czech Republic, less than 500 km from the main concentration of Southern Polish sites (Valoch 1988).

A number of transitional industries have been reported in Poland, but the claims should viewed with caution (Bobak et al. 2013). Some assemblages were collected decades ago and/or classified based on a small number of diagnostic artifacts. The Szeletian is a transitional industry documented in Poland and elsewhere in Central/Eastern Europe, which is characterized by distinctive bifacial foliate points or leaf points, mainly MP tools (side scrapers, notches), and rarer Upper Paleolithic tools (endscrapers, burins) made by non-Levallois methods (Kaminská et al. 2011; Svoboda et al. 1996). The Szeletian is thought to have been developed from the local Micoquian by Neanderthals (Neruda & Nerudová 2013b), and more contentiously is suggested to reflect contact between Neanderthals and Upper Paleolithic-bearing modern humans (Allsworth-Jones 2004; Allsworth-Jones 1986; Valoch 2000). Recent analysis demonstrated that Moravian Micoquian and Szeletian assemblages differ significantly in blank production strategies and that similarities are due to toolkit morphologies—a pattern that weakens the argument for local development of the Micoquian into the Szeletian (Tostevin 2013).

The Jerzmanowician belongs to a technocomplex of industries known as the Lincombian-Ranisian-Jerzmanowician (LRJ), which is found across Northern Europe and mostly in Great Britain (Flas 2011; Chmielewski 1961). LRJ assemblages are characterized by distinctive leaf-points made on blade blanks by partial bifacial retouch (Jerzmanowice points) and other tools are mostly UP types. The technology focused on the production of blade blanks from cores with opposed platforms likely by soft hammer.
Most researchers believe that the LRJ developed from Late MP industries of Northern/Central Europe (Kozlowski 2007).

Lastly several sites in Poland have assemblages suggestive of the Bohunician, a transitional or Initial Upper Paleolithic (IUP) industry best documented in the Brno Basin of Moravia (Škrdla 2013; Richter et al. 2008). In Bohunician assemblages Levallois-like core reduction was used to produce elongated blanks often made into Levallois points and UP tools. The Bohunician shows strong technological similarities with the IUP or Emiran of the Near East (Tostevin 2013; Škrdla 2003; Valoch 1986). It is generally believed that the Bohuncian and IUP/Emiran were produced modern humans (Hublin 2015).

4.3 Sites and samples

4.2.1 Ciemna

Ciemna Cave (50°11’48” N, 19°49’54” E) is part of the Kraków-Częstochowa Upland, approximately 25 km from Kraków (Figure 4.1). The cave system sits 62 m above the Prądnik Stream Valley (372 m asl). The Main Chamber (Sector CK) consists of a large gallery (88 m longer, 23-10 m wide, 8 m high) that narrows and continues for approximately 60 meters (Appendix C). A smaller, eroded chamber is partially preserved to the southeast of the Main Chamber entrance. Beginning in the late 19th century, several excavations took place outside the cave roof and in the smaller chamber. These early excavations used differing methodology and nomenclature, with only partially published results. A new project began in 2007 that seeks to correlate the previously excavated areas and to excavate in the Main Chamber with modern methods (Valde-Nowak et al. 2014; Valde-Nowak et al. 2016).
The excavation trench in the Main Chamber was 12 meters wide and 6 meters deep at its largest, reaching bedrock. Twenty-four lithostratigraphic layers (Layers 1.1-19) were defined based on changes in sediment color, grain size, and limestone rubble (Table 4.1, Appendix C).

**Table 4.1:** Lithostratigraphic and archaeological layers at Cienna Cave.

<table>
<thead>
<tr>
<th>Lithostrat. layer</th>
<th>Arch. level</th>
<th>Industry</th>
<th>¹⁴C samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>I</td>
<td>Holocene</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>II</td>
<td>Mixed Holocene, UP, MP</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>III</td>
<td>Micoquian</td>
<td>RTD7386, RTD7494</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>IV</td>
<td>Micoquian?</td>
<td>RTD7825, RTD7387, RTD7353</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>V</td>
<td>Micoquian without Levallois</td>
<td>RTD7388</td>
</tr>
<tr>
<td>9</td>
<td>VI</td>
<td>Taubachian</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>VII</td>
<td>Mousterian with Levallois</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>VIII</td>
<td>Mousterian</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>IX</td>
<td>unidentified MP</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nine archaeological levels (I-IX) were identified as horizontally distributed concentrations of artifacts between relatively sterile sedimentary layers (Valde-Nowak et al. 2014). The overall sample was small (~500 artifacts) and artifacts exhibited varying degrees of postdepositional modification that resembled retouch. For these reasons the
assignments of levels to particular archaeological industries is tentative. The levels were characterized by frequency of raw materials, Levallois method, bifacial retouch, paraburin treatment, small abruptly retouched forms, and spliter technique (Valde-Nowak et al. 2016). Level I contained Holocene material and Level II had a mixed assemblage of MP, UP, and Holocene artifacts. The richest level was Level III with 150 artifacts assigned to the Micoquian tradition. Level IV had Micoquian characteristics, but yielded less than 20 artifacts. The sequence continued with Level V classified as Micoquian without Levallois, Level VI as Taubachian, Level VII as Mousterian with Levallois, and Level VIII as Mousterian. Lastly, Level IX contained an unidentified MP industry with only a few artifacts including a sidescraper with bifacial retouch.

The faunal assemblage is overwhelmingly dominated by cave bear (*Ursus spelaeus*) of all ages, suggesting the cave was used as a hibernation den. In addition to the thousands of cave bear remains, carnivore remains are on the order of tens and herbivores are more rare, represented by a few specimens of reindeer (*Rangifer tarandus*) and *Bison/Bos*. Abundant botanical remains were recovered including charcoal and unburned wood. The botanical remains appeared concentrated horizontally in archaeological levels, but were not recovered from intact hearths. The depositional history of the charcoal and unburned wood pieces is a question that the current radiocarbon dating program sought to address.

Radiocarbon dates have been previously reported for samples from old and current excavations of Ciemna Cave (Valde-Nowak et al. 2014; Valde-Nowak et al. 2016; Krajcarz et al. 2015). The dates do not show increasing age with depth, which has been interpreted as evidence of stratigraphic mixing or sample contamination. The
previous dates were produced mostly from teeth or bone collagen without the ultrafiltration step and therefore may underestimate the true age of the samples due to modern carbon contamination (Higham 2011). New samples were collected to produce dates with state-of-the-art methods. Four bones, one charcoal, and one unburned wood sample from archaeological Levels III, IV, and V were selected for radiocarbon dating. The charcoal and wood samples were identified as Scots pine (Pinus sylvestris) and birch (Betula), respectively. Of the dated bones, three were cave bear long bones and one was identified less specifically as a large mammal long bone shaft fragment.

4.3.2 Obłazowa

Obłazowa Cave (49°25’48” N, 20°9’36” E) is located on approximately 7 m above the bank of the Bialka River (670 m asl) in the Western Carpathian Mountains of Southern Poland (Valde-Nowak et al. 2003) (Figure 4.1). The cave is within a limestone klippe, a geologic feature formed when a block of rock has been moved by a thrust fault and subsequently eroded to appear as an isolated mound. Systematic excavation occurred between 1985-1995, which uncovered important UP finds including the oldest modern human remains in Poland (Trinkaus et al. 2014) and a worked mammoth tusk resembling a boomerang (Valde-Nowak et al. 1987). These excavations revealed a ~4 m sequence divided into 21 lithostratigraphic and 10 archaeological layers spanning from the MP to historical times (Table 4.2). Excavations were resumed in 2008-2009 and 2012-2015, which reached bedrock and expanded the units horizontally (Valde-Nowak & Nadachowski 2014) (Appendix C).
Layer VIII was the oldest clear UP layer and has been attributed to the Pavlovian tradition, a variant of the Gravettian best documented at the Moravian sites of Dolní Věstonice and Předmostí (Svoboda 2012). Layer VIII contained blades from conical cores, the worked mammoth tusk, and ornaments of *Conus* shell, carnivore teeth, and ivory (Valde-Nowak 2015; Valde-Nowak et al. 2003). Many of the items showed traces of iron-rich pigment and were deposited within a stone circle. Two human phalanxes were also found in this layer. It has been proposed that Layer VIII represents ritual activity due to the presence of rare artifacts and the absence of occupational debris including lithic debitage, faunal remains, and charcoal (Valde-Nowak et al. 2003). Layer XI contained a small assemblage (66 lithics) with a mixture of MP and UP tools. Leaf

### Table 4.2: Lithostratigraphic and archaeological layers from VIII and below of Obłazowa Cave.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Industry</th>
<th>(^{14})C samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIII</td>
<td>Pavlovian</td>
<td>OxA-3694, Gd-2555, OxA-4584, OxA-4585, OxA-4586, Poz-35627, Poz-35628</td>
</tr>
<tr>
<td>IX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XI</td>
<td>Szeletian</td>
<td>Poz-1135</td>
</tr>
<tr>
<td>XII</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XIII</td>
<td>Mousterian</td>
<td></td>
</tr>
<tr>
<td>XIV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XV</td>
<td>Charentian</td>
<td>RTD7396</td>
</tr>
<tr>
<td>XVI</td>
<td>Taubachian</td>
<td></td>
</tr>
<tr>
<td>XVII</td>
<td>Taubachian</td>
<td>RTD7492, RTD7400</td>
</tr>
<tr>
<td>XVIII</td>
<td>Micoquian</td>
<td>RTD7355, RTD7397</td>
</tr>
<tr>
<td>XIX</td>
<td>Taubachian</td>
<td>RTD7493, RTD7399</td>
</tr>
<tr>
<td>XX</td>
<td>Taubachian</td>
<td></td>
</tr>
<tr>
<td>XXI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
points were represented by several fragments and one complete point refitted from two
to pieces, which exhibited retouch on both sides and a small tang. Due to the presence of
leaf points and mixed MP/UP toolkit this assemblage has been classified as Szeletian.

The MP assemblages were found in Layers XIII and below. More specific
classification of the archaeological layers is uncertain, as finds from the more recent
excavations have called into question the original classifications (Valde-Nowak et al.
2003; Valde-Nowak & Nadachowski 2014). The youngest MP Layer XIII contained
small, often microlithic tools with denticulate retouch and was classified as Mousterian.
The next cultural layer XVb had an abundance of side scrapers with steep retouch and
may represent the Charentian type of Mousterian. The remaining sequence was thought
to be culturally homogenous as the observed archaeological Layers XVI, XVII, XIX, and
XXb were classified as Taubachian (Valde-Nowak 2010). In these layers there was no
evidence of Levallois method on the cores or flakes and the preferred reduction method
seems to have been discoidal. The most abundant tools are side scrapers and small backed
knives. Within these layers, a distinct assemblage was recently identified in Layer XVIII,
previously thought to be archaeologically sterile (Valde-Nowak & Nadachowski 2014;
Valde-Nowak & Cieśla 2014). Sublayer XVIIIb contained 95 artifacts from a 1.5 m²
excavated area, which are characteristic of the Micoquian. Diagnostic pieces include a
hand-axe, an asymmetric knife with a para-burin blow of the Prądnik type, and two
backed knives. The one core recovered was Levallois with a prepared striking platform.
The meaning of this apparent interstratification of a Micoquian assemblage within
homogenous Taubachian layers is an open question.
In a portion of the cave, the MP and leaf point layers were disturbed by a pit of younger age ("Layer" XXII). The fill of the pit contained sediments and artifacts from different phases in secondary deposition. A portion of the artifacts appeared to belong to the Aurignacian tradition, which was not represented in stratigraphic sequence at Obłazowa. The Aurignacian-like artifacts include two bone points, endscrapers, blades, and a possible carinated core (Valde-Nowak et al. 2003).

Radiocarbon dates for Obłazowa have been reported in several studies from material excavated from 1985-1992 (Appendix C) (Housley 2003; Valde-Nowak 2015; Lorenc 2006). Although the dates were produced at different laboratories by different procedures, the results are in good agreement. Seven samples were dated from UP Layer VIII. Among these dates, five samples, including a human phalanx, ranged between 37-31 kcalBP (from oldest start date to youngest end date at 68.2% probability). Another date from this layer had a larger uncertainty as it was produced by decay counting of several small bones combined (Gd-2555: 32,400 ± 1700 $^{14}$C BP). The one outlier from this layer was the mammoth boomerang, dated to ~22 kcalBP (OxA-3694: 18,160 ± 260 $^{14}$C BP). From the transitional Layer XI, one bird bone produced a date of 41-39 kcalBP (Poz-1135: 36,400 ± 700 $^{14}$C BP). The only previous date from MP layers was 32-28 kcalBP, produced from a bone from Layer XV/XVI (Gd-4532: 25,900 ± 1700 $^{14}$C BP). This date is probably unreliable because the bone was not prepared by the ultrafiltration method and it is younger than the Layer VIII samples, found nearly one meter higher in the sequence. Lastly, a Uranium-Thorium date of 90-63 ka for a horse bone from Layer XIX was reported, but no sample information or procedures were provided (Cieśla & Valde-Nowak 2015).
Although no reliable radiocarbon dates had been produced for MP layers, the approximate ages of layers have been inferred based on sedimentology and biostratigraphy. Layers XXI-XX were characterized by coarse, well-rounded river gravel, while Layers XIX-XII consisted of sandy loam. Madeyska (2003) interpreted the sediment change as indicative of the colder then warmer conditions that occurred from MIS 5-4 (~130-60 ka). This timing disagrees with the conclusion based on biostratigraphy that MP Layers XIX-XVII were deposited during MIS 3 (Valde-Nowak & Nadachowski 2014). Features of rodent dental morphology changed in the region between MIS 6-3 and the rodent sample from Oblazowa layers XIX-XVII was consistent with average MIS 3 forms. Moreover, differences in species composition between Layers XIX-XVII suggest that the environment changed from humid steppe-tundra to forest, a change which may have occurred during the relatively warm conditions of early MIS 3, between 60-50 ka.

In this study, radiocarbon dates were produced from one charcoal and six bone samples excavated in 2012-2013 from MP Layers XV, XVII, XVIIIb, and XIX. The charcoal was identified as Scots pine (*Pinus sylvestris*). The dated bones were mammal long bone shaft fragments. One dated bone (RTD7399) from Layer XIX had visible cut marks (Valde-Nowak & Nadachowski 2014). Few bones from MP layers showed any taphonomic features to indicate deposition by humans or carnivores. The exception was burned bone fragments from Layer XIX, but burned bone is not suitable for radiocarbon dating.
4.4 Methods

Samples were chosen for radiocarbon dating that passed selection criteria related to context and preservation. All dated samples came from known contexts and were collected during recent excavations. Samples underwent routine prescreening procedures at the DANGOOOR Research Accelerator Mass Spectrometry Laboratory (D-REAMS), Max Planck-Weizmann Center for Integrative Archaeology and Anthropology, Israel (Yizhaq et al. 2005; Rebollo et al. 2011; Boaretto et al. 2009). Bones were characterized by percent insoluble fraction after acid dissolution in 1 N HCl. To ensure that the insoluble fractions were well-preserved collagen the fractions were analyzed by Fourier Transform Infrared spectrometry (FTIR). Well-preserved samples showed FTIR spectra characteristic of collagen, with absorption peaks at 1650 cm\(^{-1}\) for amide I, 1540 cm\(^{-1}\) for amide II, 1455 cm\(^{-1}\) for proline (Appendix C). FTIR was also used to prescreen charcoal samples, which should show absorption peaks characteristic of untreated fossil charcoal (COO- at 1590 cm\(^{-1}\) and 1385 cm\(^{-1}\)) and no peaks indicating clay contamination (Rebollo et al. 2008; Ascough et al. 2011).

Bone collagen was purified for radiocarbon dating by the acid-base-acid (ABA) acid dissolution, gelatinization, and filtration procedure (Boaretto et al. 2009; Yizhaq et al. 2005). Approximately 500 mg of bone powder was dissolved in 0.5 N HCl for 1 hour until mineral was dissolved and then washed with Nanopure water until pH=7. Samples then were treated with 0.1 N NaOH for 30 minutes to remove humics and washed until pH=7. To remove atmospheric CO\(_2\) adsorbed during the base treatment, the samples received an additional treatment of 0.5 HCl for 5 minutes followed by washing until pH=3. The solutions were gelatinized at 70°C for ~24 hours in a vacuum oven and the
gelatin samples were passed through polyethylene (Eezi-filters™) and ultrafilters (Vivaspin™ 15, 30kD MWCO) cleaned according to (Brock et al. 2007). The filtrates were lyophilized for 24 hours.

Charcoal samples were prepared by ABA pretreatment (Rebollo et al. 2011; Yizhaq et al. 2005). Approximately 50 mg of charcoal pieces were treated with 1 N HCl for 30 minutes and rinsed until pH=6. This was followed by base treatment of 0.1 N NaOH for 15 minutes and washing until pH=6, then acid treatment in 1 N HCl for 1 hour in a water bath of 80ºC and washing until pH=6. Samples were dried for 24 hours at ~60ºC and reanalyzed by FTIR. ABA-treated fossil charcoal should show carboxylic acid peaks around 1715 and 1250 cm\(^{-1}\) and carboxylate peaks around 1600 and 1400 cm\(^{-1}\) (Appendix C). A fraction of the charcoal samples were also prepared by water-BA pretreatment, which followed the same procedure except Nanopure water was used in the first wash step, rather than acid. The unburned wood sample was prepared by cellulose extraction, which consisted of ABA followed by bleach pretreatment with sodium chlorite solution (Brock et al. 2010).

Pretreated botanical and bone samples were combusted to CO\(_2\) with ~200 mg CuO at 900ºC and reduced to graphite in a vacuum line. The graphite samples were measured by AMS at the D-REAMS radiocarbon laboratory. Radiocarbon dates are reported as radiocarbon years before present (\(^{14}\)C BP) and converted to calibrated years before present (calBP) by the IntCal13 curve (Reimer et al. 2013) and OxCal4.2 software (Bronk Ramsey 2009). Calibrated dates are reported at their 68.2% highest probability density function (pdf) unless otherwise noted.
4.5 Results

Three bones samples from Ciemna archaeological Levels III, IV, and V (lithostratigraphic Layers 3, 6, 8) produced finite radiocarbon dates that extend beyond the 50 kcalBP limit of the calibration curve (between 56,600 ± 5000 and 46,300 ± 1360 $^{14}$C BP) (Table 4.3). One bone from Level III produced an infinite date (RTD7494: $>39,570$ $^{14}$C BP), meaning its radiocarbon content was below the background measurement for that particular run of the AMS. The charcoal from archaeological Level IV produced a date of 46-45 kcalBP when pretreated by ABA (RTD7353-A: 42,600 ± 400 $^{14}$C BP) and a date of 44-43 kcalBP (RTD7373-B: 40200 ± 300 $^{14}$C BP) when pretreated by water-BA. Both dates are several thousand years younger than the bones from all levels. The unburned wood sample was modern, dating to 1975-1980 calAD by the Post-bomb atmospheric NH1 curve (Hua et al. 2013).

Six bones from Oblazowa MP layers produced dates older than 45 kcalBP (Table 4.3, Figure 4.2). One bone from each of the Layers XV, XVII, XVIIIb, and XIX produced finite dates between 49-45 kcalBP. These radiocarbon dates overlap in uncertainty and cannot be ordered temporally based on radiocarbon content. Two additional bones produced finite dates older than 50 kcalBP and beyond the calibration curve: one from Layer XVII (RTD7492: 52,600 ± 3300) and one from Layer XIX (RTD7399: 56,600 ± 6600), which was the sample with cutmarks. The charcoal from Layer XVIIIb produced dates of ~43 kcalBP for the ABA fraction (RTD7355-A: 39400 ± 300 $^{14}$C BP) and 41-40 kcalBP for the water-BA fraction (RTD7355-B: 36100 ± 200 $^{14}$C BP). Again, both dates are younger than all bone dates from MP layers.
Table 4.3: New dates from Ciemna and Obłazowa. Ages in italics are extrapolated beyond the calibration curve.

<table>
<thead>
<tr>
<th>Lab code</th>
<th>Layer</th>
<th>Location</th>
<th>Material</th>
<th>$^{14}$C yr BP</th>
<th>calBP (68.2%)</th>
<th>calBP (95.4%)</th>
<th>% eff.</th>
<th>% C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ciemna</strong> (x, y, z)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7386 3-III (0.5, 5.0, 378.75)</td>
<td>Bone: <em>Ursus</em> sp. humerus</td>
<td>55300 ± 5000</td>
<td>68800-50500</td>
<td>83500-49800</td>
<td>0.6</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7494 3-III (0.9, 5.4, 378.71)</td>
<td>Bone: large mammal LBSF</td>
<td>&gt;39600</td>
<td></td>
<td></td>
<td>2.7</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7825 6-IV (1.2, 0.3, 378.47)</td>
<td>Unburned Wood: <em>Betula</em></td>
<td>-2300 ± 10</td>
<td>1975-1980 calAD</td>
<td>1960-1985 calAD</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7387 6-IV (3.4, 3.9, 378.39)</td>
<td>Bone: <em>Ursus</em> sp. femur</td>
<td>46300 ± 1360</td>
<td>&gt;48500</td>
<td>&gt;47200</td>
<td>0.7</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7353 6-IV (2.4, 6.1, 378.36)</td>
<td>Charcoal: <em>Pinus sylvestris</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTD7353-A (ABA)</td>
<td></td>
<td>42600 ± 400</td>
<td>46200-45500</td>
<td>46700-45100</td>
<td>47.9</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTD7353-B (water-BA)</td>
<td>40200 ± 300</td>
<td>44200-43500</td>
<td>44500-43200</td>
<td>45.8</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTD7388 8-V (2.4, 8.1, 378.08)</td>
<td>Bone: <em>Ursus</em> sp. tibia</td>
<td>56600 ± 6400</td>
<td>77800-51300</td>
<td>93700-51100</td>
<td>0.5</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td><strong>Obłazowa</strong> Square, elevation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7396 XV C(2)b, 270</td>
<td>Bone</td>
<td>44700 ± 1100</td>
<td>49200-46900</td>
<td>&gt;46300</td>
<td>2.6</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7492 XVII B(1)a, 320-325</td>
<td>Bone</td>
<td>52600 ± 3300</td>
<td>58200-49300</td>
<td>68200-57600</td>
<td>2.3</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7400 XVII B(1)a, 325-330</td>
<td>Bone</td>
<td>43900 ± 1000</td>
<td>48300-46100</td>
<td>49600-45500</td>
<td>1.2</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7355 XVIIIb B(-3)a/c, 335</td>
<td>Charcoal: <em>Pinus sy.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTD7355-A (ABA)</td>
<td>39400 ± 300</td>
<td>43300-42800</td>
<td>43700-42600</td>
<td>29.2</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RTD7355-B (water-BA)</td>
<td>36100 ± 200</td>
<td>41000-40500</td>
<td>41300-40200</td>
<td>53.7</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7397 XVIIIb B(-2)b, 335</td>
<td>Bone</td>
<td>42600 ± 860</td>
<td>46800-45100</td>
<td>48000-44500</td>
<td>1.0</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7493 XIX B(1)b, 330-335</td>
<td>Bone</td>
<td>47600 ± 1600</td>
<td>49500-46000</td>
<td>52000-44700</td>
<td>1.7</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7399 XIX B(1)a, 335-340</td>
<td>Bone: cutmarks</td>
<td>56600 ± 6600</td>
<td>78900-51300</td>
<td>94900-51100</td>
<td>2.2</td>
<td>41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.2: Calibrated radiocarbon dates from Obłazowa Cave. Probability density functions of calibrated radiocarbon dates. New dates from this study have laboratory code RTD and belong to MP Layers XV and below. The unreliable charcoal date is shown in gray.
4.6 Discussion

4.6.1 Sample reliability

For both sites the charcoal dates are significantly younger than all of the bone dates. We assume that the bone dates are closer in age to the artifacts with which they are associated and that the charcoal dates are underestimates. In general, older dates more reliable because a small fraction (<1%) of contaminant modern carbon can alter the date of Pleistocene-age samples by thousands of years (Bronk Ramsey 2008). Moreover, extracting specific biomolecules, such as bone collagen (Higham et al. 2006) or hydroxyproline (Marom et al. 2012), is currently the best way to isolate original biogenic carbon from contaminant carbon. In dating charcoal, there is no target biomolecule; rather, amorphous carbon is dated under the assumption that the more resistant carbon, which survives pretreatment, is the ancient carbon. It is also possible that the charcoal dates from Ciemna reflect original carbon, but the samples have been moved lower in the stratigraphic sequence by post-depositional processes. This is less likely of the bone samples, which were cut from complete long bones of large mammals.

In addition to the standard ABA pretreatment, the charcoal samples were subjected to a water-BA treatment in order to detect the presence of more-recent contaminant carbon. For both samples, the water-BA fraction produced a significantly younger date than the ABA fraction (Table 4.3, Appendix C). Comparing FTIR of the fractions, the spectra after ABA and water-BA show absorptions indicative of pretreated fossilized charcoal. A peak is also visible ~1033 cm$^{-1}$, which represents the major silicate absorption in clay. The clay absorption is strong in the water-BA fraction, and reduced but not eliminated in the ABA fraction. This experiment indicates the presence of fairly
resistant contamination in the charcoal samples. The difference in measured ages suggests that the harsher ABA pretreatment removed some contaminant carbon, but it is impossible to know if all contaminant carbon was removed. Indeed the most likely contaminant would be humic substances, or organic polymers in sediment, which have can have FTIR absorption peaks indistinguishable from those of fossil charcoal (Weiner 2010).

The bone samples, on the other hand, seem to have produced reliable dates and better estimates for the ages of depositional layers. A number of preservation parameters are used to evaluate the purity of bone collagen in radiocarbon dating. The percent carbon upon combustion of collagen should be 50-30% (Brock et al. 2010), a criterion that all of the samples in this study met. Many laboratories reject samples for which <1% of the initial starting weight of bone powder survives the pretreatment procedure, as this measure often indicates that the bone contains little to no collagen (Van Klinken 1999; Brock et al. 2010). Several of the samples dated in this study would have been rejected by this criterion alone. However FTIR spectra of the insoluble fractions show peaks indicative of well-preserved collagen, and therefore these samples were dated (Boaretto et al. 2009; Yizhaq et al. 2005) (Appendix C). Although any radiocarbon measurements approaching the age limit of the method should be viewed with caution, the quality of the collagen spectra from the bones dated in this study supports the reliability of the associated dates.

At Ciemna most dates were produced from cave bear long bones. Generally cave bear bones are a poor material for dating human occupations, as we assume that humans were not in the cave at the same time as cave bears. However, in the case of Ciemna,
cave bear bones provide the best material to estimate the age of depositional layers, which are palimpsests of human and cave bear occupations. Any layer as well as the error range of a given radiocarbon date subsumes numerous occupations by different groups that may have been seasonal, annual, or longer. Cave bear bones were chosen specifically because: 1) they overwhelmingly dominate the faunal assemblage. The few herbivore specimens were small, fragmentary, and without signs of human modification, such as cutmarks. Thus the other fauna are not clearly linked with human occupations. 2) The dates from smaller specimens including unburned wood and charcoal indicate post-depositional mixing. Large complete cave bear long bones were less likely to have moved through the stratigraphic sequence.

4.6.2 Chronology of Ciemna

Because the samples approach or exceed the age limit of radiocarbon dating, the chronology of MP occupations of Ciemna Cave cannot be resolved by this method. However, several important conclusions can be drawn from the radiocarbon results. First, if the calibration curve is extrapolated beyond its 50 kcalBP limit, the finite bone samples suggest material in MP Levels III-V was deposited sometime between 90-50 ka. The relative age order of the samples, however, cannot be determined because the uncertainties of the dates overlap. It is unclear how much time distinguishes Levels III, IV, and V—just that the package was likely deposited between 90-50 ka.

Next, the wood sample from archaeological Level IV is dated to recent decades. This is well beyond the date-shift that could be explained by contaminant modern carbon, and certainly evidences post-depositional intrusions or mixing in the stratigraphic sequence. Only one wood sample was large enough to prepare for radiocarbon dating, but
it is possible that all of the unburned wood samples collected from Ciemna result from modern intrusions. Furthermore the degree of post-depositional mixing necessary to distribute modern wood throughout the sequence would suggest the movement of other materials, and especially charcoal. We therefore advise caution when inferring paleoenvironmental conditions through the sequence based on botanical remains.

4.6.3 Chronology of Oblazowa

Combining the new bone dates with previously published ones, the full sequence shows age-depth consistency and suggests ages for the final MP, transitional, and first UP layers (Figure 4.2). MP layers seem to have been deposited until 50-45 kcalBP, although no dates have been produced for the final MP Layer XIII. This age corroborates interpretations of the faunal record that MP Layers XIX-XVII reflect the relatively warm conditions of early MIS 3 (~60-50 ka) (Valde-Nowak & Nadachowski 2014). The only date from the transitional, possibly Szeletian, Layer XI was 41-39 kcalBP and the next series of dates came from approximately 1 meter higher in the sequence, where six bones from UP (Pavlovian) Layer VIII ranged between 39-31 kcalBP. It sum it seems that the MP ended before 45 kcalBP, the transitional industry was deposited sometime between 45-39 kcalBP, and the earliest UP occupants appeared sometime after 39 kcalBP.

4.6.4 Regional context

Before discussing the regional chronology (Figure 4.3), it should be emphasized that there are few reliable chronometric dates associated with recently excavated and well-characterized Late MP and transitional assemblages in Southern Poland (for reviews see Bobak et al. 2013; Kozłowski 2014; Wiśniewski et al. 2013). Some assemblages were collected and analyzed several decades ago with methods that would not meet modern
Figure 4.3: Chronometric dates from Southern Poland and Moravia for Late MP, transitional, and Early UP assemblages. a) All chronometric dates produced from layers reported to contain Late MP, transitional, or Early UP industries. Straight lines are radiocarbon dates of charcoals or bones at 68.2% probabilities. Lines with circles are OSL or TL dates of sediments at 1σ uncertainty. Lines with stars are TL dates of heated flints at 1σ uncertainty. The colors indicate the archaeological industry reported from the same layers as the dated samples. Opaque lines are samples with a direct link to human activity such as cutmarked bones or heated flint artifacts. Semi-transparent lines are samples with no direct link to human activity such as sediments or isolated charcoals. Dates are organized by site and stratigraphic layer. b) The same data, but black lines are samples with a direct link to human activity and gray lines are samples with no direct link to human activity. The shaded regions indicate archaeological industries that have been well-characterized and are associated with dates with a direct link to human activity. For comparison dates produced in this study remain color coded by the archaeological industry they are thought to represent.
standards, or have been assigned to stone tool industries based on a small number of informative artifacts. Thermoluminescence (TL) and optically stimulated luminescence (OSL) dates are shown as 1σ ranges and radiocarbon dates are shown as calibrated 68.2% probability ranges.

Of the Late MP sites with chronometric dates, Biśnik Cave has been excavated since 1992 and dated by several methods (Cyrek et al. 2014; Cyrek et al. 2010). The final MP layers (lithostratigraphic Layers 5-8) have been classified as Micoquian. There are two published radiocarbon dates of bones from Layers 5-6, but no information regarding the samples or pretreatment method (Poz-46807: 40,000 ± 1000; Poz-46809: 45,000 ± 2000). TL and OSL dates of sediments have been produced for Layer 7, which range from 78 to 58 ka. The large open-air site of Hallera Avenue, Wrocław contained two MP palimpsest horizons (Wiśniewski et al. 2013; Skrzypek et al. 2011). Sediments from the upper horizon, which may represent Micoquian traditions, were OSL dated to 61-50 ka. At Stajnia Cave, a large lithic assemblage assigned to Micoquian was associated with three human molars, which likely belonged to Neanderthals (Nowaczewska et al. 2013; Dąbrowski et al. 2013; Urbanowski et al. 2010). Chronometric dating by several methods is underway, but thus far one associated cave bear sample produced an infinite radiocarbon date of >49,000 ^14C BP.

Regarding the transitional industries, Lubotyń 11 is an open-air site excavated since 2006, which according to preliminary reports contains one of the richest Szeletian assemblages (Połtowicz-Bobak et al. 2013). Six charcoals from two combustion features produced finite dates ranging from 49-39 kcalBP (Bobak et al. 2013). Lubotyń 11 is 1.5 km south of Dzierżysław I, where both Szeletian and Bohunician assemblages have been
reported (Fajer et al. 2005; Foltyn & Kozłowski 2003). The Dzierżysław I assemblages are not well associated with the chronometric dates of sediments (Bluszcz et al. 1994), and the Bohunician classification was rejected by Škrdla (2013).

At Piekary IIa three layers (7a-7c) contained MP tools, blade and flakes produced by independent reduction processes, and Levallois elements including elongated blanks (Sitlivy et al. 2008). The assemblages from these layers possibly belong to the Bohunician technocomplex (Škrdla 2013; Richter et al. 2008), although they were initially described as MP (Sitlivy et al. 2008). The arithmetic means\(^1\) of TL dates of heated flints were 39±4 ka for Layer 7a, 39±5 ka for Layer 7b, and 55.0±6.5 ka for Layer 7c (Valladas et al. 2008). OSL measurements were deemed unreliable but indicate that sediments were exposed to light at different times, suggesting a possibly mixed assemblage (Valladas et al. 2008; Mercier et al. 2003). The overlying Layer 6 contained an assemblage with double-platform cores and endscrapers on blades, which is thought to represent UP occupations and dated to 36-34 kcalBP (OxA-7347: 31,100±1100 \(^{14}\)C BP) by one charcoal from a hearth.

Jerzmanowician or LRJ has been reported at Nietoperzowa Cave (Layers 4, 5a, 6) from Chmielewski’s early excavations and analysis (Chmielewski 1961). The assignment is primarily based on the abundance of unifacial leaf points (~60% of the assemblage) and has been challenged (Allsworth-Jones 1986) as well as maintained (Kozłowski 2000; Flas 2011). One charcoal from cultural Layer 6 was dated to 44-42 kcalBP in the 1960s (Vogel & Waterbolk 1964).

\(^1\) The authors prefer the arithmetic means to the weighted means originally reported Valladas et al. 2003.
More comparative assemblages are provided by sites southwest of the mountain chains in the Moravia region of the Czech Republic. At Kůlna Cave major excavations were conducted from 1961-1976 by Valoch, which revealed 14 lithostratigraphic layers (Valoch 1988). The lowest UP layer is considered Gravettian and then the MP sequence follows with layers classified as Micoquian (Layers 6-9), Taubachian (Layers 10-13), and Mousterian with Levallois method (Layer 14). Layer 7a yielded several Neanderthal remains, including a partial maxilla, partial parietal, and three deciduous molars.

Recently, a large series of radiocarbon dates were produced on material from the final Micoquian Layers 6-7, and the majority of samples were bones with human modifications from known stratigraphic positions prepared by ultrafiltration (Neruda & Nerudová 2013a; Neruda & Nerudová 2013b). Most samples (26/38) produced infinite dates (>48,000 \(^{14}\text{C}\) BP) and four samples produced finite dates extending beyond the calibration curve. Several samples produced more recent dates and were likely intrusive material from younger layers. OSL dates show increasing age with depth and suggest that sediments accumulated in Micoquian Layers 6-9 between 80-40 ka and Taubachian Layers 11-14 between 100-70 ka (Nejman et al. 2011).

Vedrovice V contained a well-studied Szeletian assemblage excavated by Valoch in the 1980s (Tostevin 2013; Valoch 1993). Dates for the Szeletian layer of 45-40 kcalBP were produced from samples (n=4) from charcoal concentrations that Valoch interpreted as hearths. OSL samples were taken from a test pit dug ~10 m southwest of Valoch’s trench. Sediments from the base of the layer correlated with the Szeletian assemblage dated to 102.1±7.0 ka while those from the top dated to 60.3±3.5 ka. Sediments from overlying sterile palaeosol dated to 45.1±2.5 ka. Similar dates were produced for the
Szeletian assemblage ~4 km away at the site of Moravský Krumlov IV, excavated from 2000-2004 by Neruda and Nerudová (Neruda & Nerudová 2009; Neruda & Nerudová 2010). Isolated charcoals from the Szeletian layer produced radiocarbon dates 43-41 kcalBP (Davies & Nerudová 2009). Sediments from the top of the layer OSL dated to 43.6±3.3 ka, while those from the base of the layer dated to 64.6±7.0 ka (Nejman et al. 2011).

The most intensively dated and studied Bohunician assemblages come from Stránská skála and the 2002 excavations of Brno-Bohunice² (Tostevin 2013; Richter et al. 2008; Nejman et al. 2011). Radiocarbon dates of charcoals from these sites range approximately 44-35 kcalBP, but the samples’ depositional history and association with Bohunician occupation have been questioned (Richter et al. 2008; Richter et al. 2009). Similar issues have been raised regarding OSL dates of sediments from the sites (Nejman et al. 2011). The most reliable dates for the Bohunician of Moravia were produced by TL dating of heated flint artifacts from Brno-Bohunice. The weighted mean of 11 flints samples was 48.2±1.9 ka.

In sum the regional chronology of Southern Poland and Moravia documents the occurrences of a number of archaeological industries during the Late Pleistocene (Figure 4.3). During the period from 55-40 ka there are dates associated with assemblages assigned to the Taubachian, Micoquian, Szeletian, LRJ, and Bohunician traditions. However there is substantial disagreement between dates produced from different methods and materials. Much of the noise in this data is probably due to dated materials

² Radiocarbon dates were also produced for earlier excavations at the Bohunice Red Hill sites of Kejbaly I-IV and Cihelna, several hundred meters from the Brno-Bohunice 2002 site. The Kejbaly sites were excavated by bulldozers without systematic collection methods and the Cihelna site was a quarry without artifacts.
without clear links to human activity, including sediments, isolated charcoals, or faunal bones without human modifications. Moreover, a number of the named industries are based on assemblages that were collected from old excavations and/or a small number of informative artifacts.

A more reliable chronology can be produced by considering only dated samples directly linked to human presence, which were associated with well-characterized and recently excavated assemblages (Figure 4.3b). These conditions limit the chronology to: the Bohunician between 50-46 ka based on heated flints from Bohunice; the Szeletian between 49-39 kcalBP based on charcoals from possible hearths at Vedrovice and Lubotyň 11; and the Micoquian ending by 44 kcalBP based on cutmarked bones from Kůlna. The resulting chronology is accurate, but not very informative on a human timescale due to the small number of dates and their large analytical uncertainties. With this level of resolution it is unclear whether distinct archaeological traditions occurred contemporaneously or sequentially in the region.

4.7 Conclusions

At Ciemna Cave bear long bones provided the best age estimates for the deposition of Late MP layers. Although cave bear bones are not linked to human occupations, the large samples are less susceptible to post-depositional mixing, evidenced by the botanical remains. The cave bear samples with finite dates (n=3) came from Micoquian Levels III, IV, and V, within lithostratigraphic Layers 3, 6, and 8, respectively. The dates overlap and extend beyond the calibration curve, but together suggest that the final MP levels were deposited sometime between 90-50 ka. At Oblazowa Cave new radiocarbon dates were produced for MP Layers XV-XIX. Once
again the dates overlap and age ranges cannot be determined for the particular layers. However the dates support that MP occupations occurred until 50-45 kcalBP. The MP was followed by an assemblage with leaf points sometime between 45-41 kcalBP, which may belong to the Szeletian transitional industry.

These dates can be compared to the chronology of reliable dates for archaeological industries in Southern Poland and Moravia (Figure 4.3b). Radiocarbon dates from human modified bones from Kůlna suggest Micoquian presence ended by ~45 kcalBP or earlier. The dates from Ciemna and Oblazowa also suggest a termination of MP before 45 kcalBP, although the particular tradition of the final MP occupants of Oblazowa is unclear and may be Micoquian or Taubachian. The dated charcoals from hearths at Luboťn 11 and Vedrovice suggest Szeletian presence at some point between 49-39 kcalBP, which agrees with the age range of the leaf point, possibly Szeletian, phase at Oblazowa constrained between 45-39 kcalBP.

Most scholars believe that MP Taubachian and Micoquian industries were produced by Neanderthals (Jöris & Street 2008; Valoch 1988). It has been further argued that the transitional Szeletian industry was produced by Neanderthals who had some contact with modern humans (Neruda & Nerudová 2013b; Allsworth-Jones 1986). The earliest industry attributed to modern humans in the region is the Bohunician, which is most reliably dated to 50-46 ka by TL of flint artifacts from Bohunice (Richter et al. 2008). It is therefore possible that modern human makers of the Bohunician overlapped with Neanderthal makers of the final MP or transitional industries, based on the dates produced in this study combined with the reliable dates from the greater region. However, due to the large uncertainty of TL dates and age limit of radiocarbon dating,
the question of Neanderthal-modern human overlap in this region remains unresolved. The current record demonstrates diverse artifact assemblages in Southern Poland during MIS 3. Future research may clarify whether this pattern results from sequential or simultaneous occupations by biologically or culturally distinct human groups.

4.8 Acknowledgements

We thank Eugenia Mintz and Lior Regev for assistance in radiocarbon sample preparation and measurement; M. Moskal-Del Hoyo for paleobotanical identifications of Ciemna material; Valentina Caracuta for paleobotanical identifications of Oblazowa material; Damian Stefański for access to Ciemna material; and Magda Cieśla for access to Oblazowa material. Analytical work was funded by National Science Foundation (NSF) Doctoral Dissertation Improvement Grant #1334615, Fulbright Student Scholarship from the US-Israel Educational Foundation, and NSF Graduate Research Fellowship Program Award DGE-1144152. AMS dates were supported by the Exilarch’s Foundation, the DANGOOR Research Accelerator Mass Spectrometry Laboratory (D-REAMS), and the Max Planck-Weizmann Center for Integrative Archaeology and Anthropology.

4.9 References


Boaretto, E. et al., 2009. Radiocarbon dating of charcoal and bone collagen associated


Cyrek, K. et al., 2010. Palaeolithic of Bišník Cave (Southern Poland) within the environmental background. *Quaternary International*, 220(1-2), pp.5–30.


Higham, T., 2011. European Middle and Upper Palaeolithic radiocarbon dates are often...


Krajcarz, M. et al., 2015. New radiocarbon dating of animal bones from Ciemna Cave- a
Micoquian site in Poland. In Hugo Obermaier-Gesellschaft für Erforschung des Eiszeitalters und der Steinzeit e.V. Heidenheim, p. 43.


Skrzypek, G., Wiśniewski, A. & Grierson, P.F., 2011. How cold was it for Neanderthals moving to Central Europe during warm phases of the last glaciation? *Quaternary Science Reviews*, 30(5-6), pp.481–487.


Trinkaus, E. et al., 2014. The Obłazowa 1 early modern human pollical phalanx and Late Pleistocene distal thumb proportions. *HOMO-Journal of Comparative Human*


Valde-Nowak, P. et al., 2016. Late Middle Palaeolithic occupations in Ciemna Cave, South Poland. *Journal of Field Archaeology*.


CHAPTER 5– CONCLUSION

5.1 Reliable radiocarbon dates

A main conclusion of this dissertation is that the reliability of a radiocarbon date depends on the question, “what event is the date meant to represent?” (Boaretto 2015). The event in question for this project is the presence of particular human types or archaeological industries as proxies for human types. The most obvious materials to date then are human fossils. There are few dated, taxonomically unambiguous human fossils from 50-30 ka. We can try to discover more fossils through excavations or by identifying overlooked specimens in collections. In this project I also dated six modern human fossils from the Natural History Museum in Belgrade and National Museum in Kraljevo, Serbia. There was “tenuous contextual evidence” to suggest a Pleistocene age for these specimens (Roksandic et al. 2014:7), but all of the fossils produced radiocarbon dates of less than 8000 calBP (Figure 5.1). It was possible that the young ages were due to contaminant carbon from glue or consolidant. The FTIR spectra showed peaks indicative of well-preserved collagen, but glues have been historically produced from animal collagen. In order to test for the presence of non-human animal collagen, samples were sent for Zooarchaeology by Mass Spectrometry (ZooMS) at the University of York BioArCh laboratory. The peptide markers were consistent with those expected for hominins, and not mammals used for collagen-based glues (Welker, pers. comm.). The Holocene-dates likely represent the true ages of these individuals.

Short of fossils, most dates in this study were associated with archaeological assemblages. A radiocarbon sampling program was developed for each site, which integrated fieldwork and laboratory analyses (Figure 5.2). The sampling strategy was customized for each site depending on the site conditions, research questions, and
**Figure 5.1:** Calibrated radiocarbon dates of human fossils from Serbian museum collections. Specimens had archival documentation to suggest Pleistocene age, but the dates are all younger than 8,000 calBP.
Figure 5.2: Generalized radiocarbon sampling program customized for each site. Taking into consideration the research questions, site conditions, and excavation methods, samples were chosen from all dateable material based on context, taxonomic affinity, taphonomic features, and preservation. Those that survived pretreatment were measured, and those that produced finite dates were calibrated. If enough dates and contextual information were available, the dates were used to build a Bayesian model. Calibrated or modeled dates determined the site chronology.
excavation methods. The objective was to determine the timing of human presence and archaeological assemblages. The radiocarbon samples most closely linked with human presence, however, were not always the samples best-associated with artifacts. For most sites, the ideal samples did not exist, and the sampling programs were designed to produce the most informative and accurate chronologies with the available material.

The program followed a number of selection criteria to choose samples for radiocarbon dating. The first criterion considered was context, which was evaluated by in-field sample collection, FTIR of sediments, and micromorphological analysis (Boaretto 2009; Toffolo et al. 2012). One prioritized context was in situ hearths, which were demonstrated by identification of wood ash and heated clay (Berna et al. 2007; Regev et al. 2010). The next criteria were taxonomy and taphonomy. Bone and charcoal samples were identified as specifically as possible by zooarchaeologists and paleobotanists. Features were identified to clarify the taphonomic history of samples, such as cutmarks linking a bone to human butchery or gnawing marks linking a bone to carnivore activity. The preservation of samples was evaluated by a number of parameters (Yizhaq et al. 2005; Boaretto et al. 2009; Rebollo et al. 2011). Bones were primarily characterized by % insoluble fraction, % C upon combustion, and FTIR of collagen throughout pretreatment. Charcoals were characterized by % C upon combustion and FTIR throughout pretreatment.

Bones that passed these selection criteria were prepared by acid-base-acid, gelatinization, and ultrafiltration (Boaretto et al. 2009; Brock et al. 2010). Charcoals were prepared by acid-base-acid pretreatment (Boaretto et al. 2009; Rebollo et al. 2011). A subset of samples was graphitized in an ultraclean vacuum line dedicated to material
older than 30,000 $^{14}$C yr BP. The background carbon in the ultraclean line is lower than the normal line, which allowed finite dates to be produced for several specimens that produced infinite dates when graphitized in the normal line.

An integrative dating program was best achieved at Manot Cave, where there has been a fully equipped in-field laboratory for most excavation seasons (Weiner 2010). Manot Cave comprises a steep talus. At the top of the slope are occupational surfaces with \textit{in situ} hearths, but low artifact yields for some archaeological phases. Near the base of the talus there is a rich stratified sequence of artifacts, which are in secondary position. An objective at Manot was to correlate the \textit{in situ} features from the top of the cave to the rich secondary deposits near the base of the cave. In this way we combined data from two complementary contexts to produce the chronology. No bones from Manot yielded collagen and dates were produced from charcoals. The charcoals from hearths were used to evaluate the isolated charcoals in secondary position. All dated specimens were identified as \textit{Amygdalus} sp. wood charcoal based on morphological features. The FTIR spectra of samples were consistent with fossil charcoal. However humic substances, the most likely contaminants, would have similar peaks. We cannot be sure that the charcoal samples were free of contaminant carbon, but the dates are consistent with \textit{or older} than dates for similar assemblages in the region. Contamination overwhelmingly makes radiocarbon dates younger; hence the charcoal dates from Manot are probably closer to the true age of the associated industries than younger dates from other sites.

At the Serbian sites, the dating program differed. Pešturina, Hadži Prodanova, and Smolučka are shallow palimpsest deposits with low artifact yields and evident stratigraphic mixing. No charcoals were available, but bones yielded well-preserved
collagen. Priority was given to bones with signs of human modifications, which would at
the very least produce occurrence dates for humans. The dates clustered into those older
than 39 kcalBP and those younger those between 34-28 kcalBP. The artifacts recovered
from the sites likely belong to the MP and Gravettian traditions. It is a reasonable
hypothesis that the human modified bones dated to >39 kcalBP were left by MP people,
while those 34-28 kcalBP were left by Gravettian people.

In Poland, at Ciemna the vast majority of bones were cave bear. The few
herbivore bones were fragmentary with no signs of human modification. There were no
combustion features in the Late MP layers, but abundant isolated charcoals and unburned
wood were dispersed throughout archaeological levels. Young dates for botanical
remains indicated stratigraphic mixing of small materials. Therefore the most suitable
materials for radiocarbon dating at Ciemna were complete cave bear long bones, which
are less likely to have moved between layers. The dates provide an estimate for the age of
depositional layers, but do not directly date human presence. At Obłazowa this is also the
case, with the exception of one cutmarked bone, which produced a finite date beyond the
calibration curve. Considering that most bones from MP layers at Ciemna and Obłazowa
produced dates beyond the calibration curve with large uncertainties, the chronology of
the Late MP at these sites probably cannot be more finely resolved by radiocarbon dating.

5.2 Major conclusions of case studies

Chapter 2 focused on the dating of Manot Cave, which is proving to be an
important site for modern human fossils and Early Upper Paleolithic archaeological
material. The study produced a chronology of over 50 radiocarbon dates, which shows
that the Levantine Aurignacian occurred at least between 37,000-35,000 calBP and the
Early Ahmarian was likely present by 46,000 calBP. Compared to other sites in the region, the Manot chronology comprises the most dates produced from state-of-the-art methods and collected from well-defined contexts of active excavations. The dates greatly reduce uncertainty over the timing of the Levantine Aurignacian, and do not refute the hypothesis that the Levantine Aurignacian descends from the European Aurignacian. These industries could represent a migration of people from Europe to the Levant. Regarding the Early Ahmarian, the dates from Manot agree with early appearance dates reported from Kebara and disagree with late appearance dates reported for Ksar Akil and Üçağızlı. The disagreement is probably due to the fact that most dates from Ksar Akil and Üçağızlı were produced from shells, while dates from Manot and Kebara were produced from charcoals. I argue that the charcoal dates from Manot and Kebara are closer to the true age of the industries. The difference between early and late appearance dates is significant because only the early dates from Manot and Kebara allow for the possibility that Ahmarian people in the Levant led to Protoaurignacian people in Europe.

In Chapter 3, I produced chronologies for three cave sites in Serbia (Pešturina, Hadži Prodanova, and Smolučka) and reviewed published dates from nineteen other sites in the Balkans and adjacent areas. Most sites in the Balkans are shallow palimpsest deposits with low artifact yields. Producing a reliable chronology for this region requires careful evaluation of dates and their contexts. In our paper, dates were classified as rejected, uncertain, or reliable based on their ability to answer, “when were particular archaeological industries or human types present?” The newly produced dates from Pešturina, Hadži Prodanova, and Smolučka (n=25) constitute nearly half of the reliable
Figure 5.3: Published and newly produced radiocarbon dates reviewed for Balkans regional chronology. New dates were produced in this study from three sites in Serbia. Published dates came from nineteen other sites. Dates were classified as rejected, uncertain, or reliable.
dates and one quarter of the uncertain dates for the greater region (Figure 5.3). The results show that a number of distinct archaeological industries occurred between 45-39 kcalBP, until the time of the Campanian Ignimbrite eruption. Only Early Upper Paleolithic industries (Proto/Early Aurignacian, Kozarnikian) continue through this period until ~35 kcalBP when the Gravettian appears across the region. If industries are assumed to represent human groups, Neanderthals and moderns overlap for several thousand years. During the period of overlap Neanderthals are restricted to the western/central mountains and modern humans are along the Danube Corridor and Mediterranean Coast.

Chapter 4 presented dates from Ciemna and Obłazowa, caves with Late MP and transitional assemblages in Southern Poland. At Ciemna bones produced finite dates beyond the calibration curve, which suggest final MP layers were deposited sometime between 90-50 ka. At Obłazowa the MP seems to have ended between 50-45 kcalBP, followed by a transitional industry which may be Szeletian between 45-39 kcalBP, and an UP industry after 39 kcalBP. There are few recently excavated and well-described assemblages in the region, but sites south of the mountains in Moravia, Czech Republic provide comparative sequences. During MIS-3, the areas of Southern Poland and Moravia clearly contained a number of distinct industries—some of which were probably produced by Neanderthals, while others were probably produced by modern humans. The small number of reliable dates as well as the large uncertainty of dates near the radiocarbon limit make it impossible to distinguish with the present data whether the industries were contemporaneous or sequential.
5.3 Biogeographic approach applied to each region

I proposed several models that relate the biogeography (as spatial distribution over time) of Neanderthals and modern humans to different types of interactions between the groups. The interaction models included no overlap, rapid replacement, and prolonged coexistence. Within the prolonged coexistence scenario, the interactions could have been characterized by integration, displacement, or avoidance.

Interaction Models

- **No overlap** - Neanderthals absent from region before moderns arrive
- **Rapid replacement** – overlap between groups for fewer than 1000 years
- **Prolonged coexistence** – overlap between groups for greater than 1000 years
  - **Integration** – Neanderthals and moderns in same territory
  - **Displacement** – Neanderthals territory changes after moderns arrive
  - **Avoidance** – Moderns enter unoccupied territory, Neanderthal territory remains constant

5.3.1 Northeast Europe

The biogeographic approach is difficult to implement in Northeast Europe because the potential contact period is near the limit of radiocarbon dating (Figure 5.4). Other methods of dating including TL and OSL are in disagreement and have such large uncertainties that they cannot distinguish between no overlap, rapid replacement, or prolonged coexistence. It is possible that modern human makers of the Bohunician overlapped with Neanderthals producing Micoquian and/or Szeletian traditions between 50-46 ka. The diversity of industries reported between 60-30 ka merits further
Figure 5.4: Regional chronology of Northeast Europe (Southern Poland and Moravia) compared to model of prolonged coexistence. Because most dates are beyond the limit of radiocarbon or associated with large uncertainties, the current data cannot distinguish between models. It is possible that Bohunician-producing modern humans (pink) overlapped with Neanderthals producing Micoquian (dark blue) and/or Szeletian (light blue) traditions.
investigation. The Carpathian and Sudeten mountain ranges may have provided a traversable boundary between human groups. The habitability of Southern Poland for humans during cold phases has been questioned (Kozłowski 2000), although the mountains may have provided a cryptic refugium for temperate species (Stewart & Lister 2001).

5.3.2 The Levant

As a biogeographic corridor linking Eurasia and Africa, the Levant was a likely hybrid zone during phases when Neanderthals and moderns expanded from their home ranges (Stewart & Stringer 2012). The fossil and archaeological records indicate the presence of Neanderthals and modern humans with distinct cultural traditions at different times (Shea 2010). Approximately 130-75 ka the Levant was occupied by anatomically modern humans associated with MP traditions, based on the finds at Skhul and Qafzeh (Grun et al. 2005; Schwarcz et al. 1988). Neanderthals with MP traditions were present approximately 75-50 ka (Shea 2010) and modern humans with IUP and EUP traditions appeared sometime around 50 ka (Hershkovitz et al. 2015; Bosch et al. 2015). The earlier Skhul/Qafzeh individuals may represent a failed dispersal of modern humans, who were in contact with Neanderthals. However this potential overlap is well beyond the limits of radiocarbon dating and so I focus on the later group of modern humans, associated with IUP and EUP traditions. A period of admixture likely occurred between 60-50 ka based on the length of introgressed Neanderthal DNA in Ust’Ishim (Fu et al. 2014). This timing does not determine where admixture occurred, but Southwest Asia is a likely hypothesis, given that Neanderthal and modern human fossils in the Levant are dated approximately to this interval.
Figure 5.5: Regional chronology of archaeological industries in the Levant compared to interaction models. The dates from Manot and Kebara are considered reliable, while those from Ksar Akil and Üçağızlı are argued to be too recent. The IUP, the earliest industry attributed to MIS-3 modern humans, has not been found at Manot and Kebara. Thus we do not have a range for the industry that may be able to distinguish between the interaction models. Calcite crust on the Manot 1 fossil was U-Th dated to 60-49.2 ka, indicated by the red arrow.
The current regional chronology of archaeological industries does not resolve the question of Neanderthal-modern human overlap during MIS-3 in the Levant (Figure 5.5). In Chapter 3 I argued that shell dates from Ksar Akil and Üçağızlı are probably underestimates, and charcoal dates from Kebara and Manot are closer to the true age of archaeological industries. At Kebara the MP, assumed to have been made by Neanderthals, has a modeled end date of 49-48 kcalBP. EUP layers from Kebara and Manot begin by ~46 kcalBP, but there are no stratified IUP layers at these sites so far, and it is the IUP (as defined by (Kuhn & Zwyns 2014)) which is thought to represent the earliest modern humans in this period. The modern human calvaria (Manot 1) from Manot has a calcite crust U-Th dated to 54.7 ± 5.5 ka, which offers a minimum age for the fossil (Hershkovitz et al. 2015). It is therefore possible that Manot 1 belongs to the earlier Skhul/Qafzeh population of modern humans. However based on the rapid formation of geogenic calcite in Manot Cave, the little sediment between the fossilized bone and calcite crust, and the calvaria’s affinity to later UP modern humans in Europe, it has been argued that Manot 1 is close in age to ~55 ka and belongs to a lineage of modern humans that dispersed from the Near East to Europe.

The Manot 1 fossil suggests that the first appearance date for MIS-3 modern humans is just beyond the limits of radiocarbon dating. In this case, we will not be able to determine the length and nature of overlap based on radiocarbon dated archaeological assemblages. Moreover, the well-dated and described IUP and EUP assemblages are from caves in temperate woodlands of the Mediterranean coast. The culture history of the region cannot be understood without including open-air sites from the arid zone of the Sinai, Negev, and Jordanian deserts.
5.3.3 The Balkans

The interaction models are most applicable to the situation in the Balkans. The regional chronology of the Balkans fits the model expectations of prolonged coexistence (Figure 5.6). Dates attributed to modern humans overlap in uncertainty with dates attributed to Neanderthals for a span of ~5000 years. These date ranges are probability density functions of point measurements after calibration, which means the calendar age could be anytime within that span at 95.4% probability. Are these dates convincing evidence for prolonged coexistence between Neanderthals and moderns in the Balkans?

I performed pairwise comparisons to test the likelihood that modern human-attributed dates are older than Neanderthal-attributed dates (Appendix A). For pairs with greater than 20% probability of the modern human date being older, I also estimated the difference in age between the pairs. Fifty pairs produced a difference range that included zero, and therefore the dates could be the same age. For the remaining 26 pairs, the modern human attributed date was unambiguously older. Figure 5.7 shows the estimated differences in age between pairs. Several dates attributed to modern humans had >50% probability of being older than Neanderthal-attributed dates.

However, the uncertainty term of chronometric dates only reflects analytical error. It does not reflect the likelihood that the sample was associated with an archaeological assemblage and that the archaeological assemblage represents a human population. This uncertainty is more significant, but cannot be quantified or defined as significant in a statistical sense. Modifying previous methodologies (Pettitt et al. 2003; Waterbolk 1971), I represent uncertainty due to sample-selection by classifying dates as reliable, uncertain, or rejected. Because of this qualitative component of the uncertainty, I am averse to
Figure 5.6: Regional chronology of fossils and archaeological industries for the Balkans fits the model expectations for prolonged coexistence. MP assemblages attributed to Neanderthals (blue) overlap for ~5000 years with assemblages attributed to modern humans.
Figure 5.7: Estimated differences in age between overlapping modern human and Neanderthal attributed dates. Horizontal bars show estimated age differences at 95.4% for pairs of Neanderthal-attributed dates and modern human-attributed dates. Black bars represent pairs with two reliable dates. Gray bars represent pairs with one reliable and one uncertain date. Light gray bars represent pairs with two uncertain dates. Values to the left of zero indicate the number of years older the modern human date may be and values to the right of zero indicate the number of years younger the modern human date may be, compared to the Neanderthal-attributed date.
creating summed probability density functions or a region-wide Bayesian model. The resulting probability would obscure the fact that the case for overlap truly depends on how strong the links are between dated carbon and human presence. Moreover, although measured dates are point estimates, they are also samples from a population of material produced during human occupation. A given site may only have six measured dates, but I assume humans were present at that site for longer than those six moments in time. The number of dates from a site is more influenced by research history and budget constraints than intensity and duration of past human occupations (Williams 2012).

A few reliable and numerous uncertain dates are consistent with Neanderthal and modern human overlap for several thousand years—a model of prolonged coexistence. Placing the dates on a map, it appears that Neanderthals were in the central/western mountains, and modern humans entered unoccupied territory along the Danube Corridor and Mediterranean Coast (Figure 5.8). This pattern fits the expectations of the avoidance model. However, the sites along the Danube Corridor also have MP layers attributed to Neanderthals that underlie the earliest layers attributed to modern humans. Unfortunately there are no reliable, finite radiocarbon dates from these layers, and these dates are necessary to determine if human distributions in the Balkans fit the expectations for avoidance or replacement. It is unclear if Neanderthals abandoned the northern rivers before modern humans appeared, or whether modern humans forced Neanderthals into the mountains. In either case, during the period of overlap the distribution of sites is consistent with a parapatric relationship between allotaxa.
Figure 5.8: Biogeography of Neanderthals and moderns compared to models of displacement and avoidance. On the maps in the top row circles indicate uncertain and reliable radiocarbon dates of fossils or archaeological industries assumed to represent Neanderthals or moderns.
5.4 Conclusion

This work reconstructed the biogeography of Neanderthals and modern humans in order to better understand the nature of interactions between the groups in the Levant, Balkans, and Northeast Europe. Biogeography here is defined in the simplest sense as the spatial distributions of taxa over time. Ultimately my research program aims to reconstruct biogeography by a broader definition—the groups’ relations to other organisms and resources over time (Lomolino et al. 2010). In short, this dissertation reconstructed geographic space; future work should reconstruct ecological space.

Several models were proposed that link site distribution through time and space to types of interactions. The interaction models were no overlap, rapid replacement, and prolonged coexistence, the latter being subdivided into integration, displacement, and avoidance. I reconstructed biogeography by evaluating published chronometric dates and producing new radiocarbon dates for the few human fossils and many archaeological assemblages assumed to represent one group or the other.

This approach was most successful for the context of the Balkans between 50,000-30,000 calBP. Although I cannot presently distinguish between avoidance and displacement scenarios, there is a strong case that Neanderthals and moderns overlapped in the Balkans for several thousand years in distinct geographic zones. The most striking pattern that emerges from this regional chronology is that between 45-39 kcalBP there were a number of distinct industries, which plausibly were produced by distinct cultural groups within each taxon. If our assumptions are correct about the makers of these industries, then Neanderthal and some modern human groups disappeared shortly after 39
kcalBP, the age of the CI eruption. In contrast, modern humans with EUP traditions survived through this period.

There is convincing evidence from genetics that Neanderthals had a low population size at this time. I assume that modern humans dispersing to Europe were also small in numbers. EUP modern humans may have possessed cultural adaptations that allowed them to outcompete other groups with small population sizes during a period of harsh environmental conditions caused by the CI eruption and H4 event. The answer to, “why did some moderns humans survive while Neanderthals went extinct,” may be a confluence of demographic history, environmental conditions, and cultural adaptations. EUP modern humans were in the right place, at the right time, with the right behavioral repertoire.

5.5 References


Fu, Q. et al., 2014. Genome sequence of a 45,000-year-old modern human from western


Appendix A Figure 1: Top view (left) and profile view (right) of Manot Cave with excavation Areas A-L indicated.
Appendix A Figure 2: Excavation Area E. Clockwise from top left: a) Top plan of Area E showing combustion features Loci 500, 501, and 502 from which charcoals were taken for radiocarbon dating. b) View of Area E facing southwest. c) Top view of Locus 500. d) Image of rhombus-shaped ash pseudomorphs found in Locus 500 using a petrographic microscope with cross polarized light.
Appendix A Figure 3: Section of Area C Squares J66, J65, J64 showing location of radiocarbon samples and micromorphology blocks. The laboratory code of radiocarbon dates are listed within their excavation basket, plotted by provenience and color-coded by stratigraphic unit. Dates with * are sediment samples that were collected with associated charcoal. Micromorphology blocks are shown in gray with thin sections (75x50 mm) and micrographs under plane polarized light. The thin sections show homogeneous composition and microstructure throughout the section. The micrographs show characteristic fabric and inclusions including phosphatic nodules (1) and microcharcoal (2).
Appendix A Figure 4: a) Levantine Aurignacian artifacts including bone awl (1), antler projectile points (2-4), incised decorated bone (5), carinated and nosed endscrapers (6-8). b) Early Ahmarian artifacts including bidirectional blade core (1), single platform pyramidal blade core (2), and el-Wad points (3-8). Drawn by M. Smelansky.
Appendix A Figure 5: Fourier Transform Infrared (FTIR) spectra of sediment exposed to different temperatures in experimental heating study. Above 500°C the kaolinite OH absorption at 3695 cm\(^{-1}\) disappears. At 800°C the shoulder at 3620 cm\(^{-1}\) disappears and the major Si-O silicate absorption begins to shift from 1035 cm\(^{-1}\) to higher wavenumbers (>1070 cm\(^{-1}\)). The spectra have been stacked vertically for display and therefore the y-axis represents relative absorption from the baseline of each spectrum and not an absolute value from the axis baseline.
Appendix A Figure 6: Characterization of *Amygdalus* sp. charcoal by SEM (a-d) and FTIR (e). a) Transverse section showing the distinct pattern of the growth rings. b) Enlarged picture of a portion of wood tissue represented in picture (a). Vessels in radial groups in the early wood and solitary in the late wood. Rays 1 to 5 seriates (features 1 and 3). Parenchyma very sparse, mostly apotracheal and occasionaly paratracheal (feature 2). c) Tangential section showing the distribution of rays, vessels and fibers. d) Enlarged picture of wood tissue in (c) showing a 5-seriate, 15 cells long ray (feature 4), vessel with spiral thickenings (feature 5), and thick-walled fibers (feature 6). e) FTIR spectra of charcoal sample RTD7197 before (below) and after (above) ABA pretreatment. The “before” spectrum shows carboxylate absorptions at 1577 and 1385 cm⁻¹, which are characteristic of fossil charcoal, as well as a silicate absorption at 1032 cm⁻¹ indicative of clay. The “after” spectrum shows the pattern characteristic of ABA treated charcoal.
Appendix A Figure 7: Calibrated radiocarbon dates from Area E plotted by absolute elevation and shown against Area E section. Charcoals came from combustion features (Loci 500, 501, 502) with the exception of RTD7245, which came from 10 cm above Locus 502 in the Unit 1 colluvium. Highest probability density functions (pdfs) shown and calculated with OxCal2.4 software (Bronk Ramsey 2009a) and the IntCal13 calibration curve (Reimer et al. 2013).
Appendix A Figure 8: Calibrated radiocarbon dates from Area C plotted by absolute elevation. Dates from the J squares (J66, J65, J64) are shown against the stepped section, which contained a well-preserved archaeological sequence. Dates from adjacent square I65 came from a more mixed context next to the cave wall, but are broadly consistent with those from the J squares. Highest probability density functions (pdfs) shown and calculated with OxCal2.4 software (Bronk Ramsey 2009a) and the IntCal13 calibration curve (Reimer et al. 2013).
Appendix A Figure 9: Dates constrained by Bayesian models with outlier analysis. Model 1 comprises three sequential cultural phases (Ahmarian>Aurignacian>post-Aurignacian) of samples from the most secure contexts. Model 2 includes an expanded data set of samples assumed to belong to these phases based on their age and stratigraphic position. Posterior/prior outlier likelihoods are shown in brackets after laboratory codes. Light gray pdfs are calibrated dates and dark gray pdfs are posterior dates after modeling.
**Appendix A Table 1:** Radiocarbon samples and dates for Manot Cave. All samples were *Amygdalus* sp. charcoal, except for those noted as sediment. Sediment and charcoal samples collected together have the same field ID. Samples with RTD before the laboratory code were prepared and measured by AMS at the D-REAMS, Max Planck-Weizmann Center for Integrative Archaeology and Anthropology. Samples with RTK were prepared to graphite in the D-REAMS laboratory and measured at the NSF-AMS radiocarbon laboratory, Tucson, Arizona. Percent efficiency (% Eff) is the percent by dry weight that survived pretreatment. Percent carbon (% C) was measured upon combustion.

The treatments are acid-base-acid (ABA), water-base-acid (WBA), or acid (A, for sediments only). Samples graphitized on the ultraclean vacuum are noted as “uc line” after treatment. Gray text indicates replicate samples that were either included as a combined date or rejected because of preservation parameters. Calibrations use IntCal13 (Reimer et al. 2013) and OxCal 4.2 (Bronk Ramsey 2009a).
Appendix A Table 1 (continued)

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
</table>

**AREA E**

*Combustion feature locus 501 (221.56-221.46)*

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7244</td>
<td>MAN13-358</td>
<td>SY92</td>
<td>221.46-221.42</td>
<td>2-I</td>
<td>29090 ± 150</td>
<td>33550-33120</td>
<td>-23.1</td>
<td>36</td>
<td>59</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7243</td>
<td>MAN13-357</td>
<td>SY92c</td>
<td>221.41-221.36</td>
<td>2-I</td>
<td>29030 ± 150</td>
<td>33490-33050</td>
<td>-24.4</td>
<td>32</td>
<td>46</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7242</td>
<td>MAN13-356</td>
<td>SY92</td>
<td>221.41-221.38</td>
<td>2-I</td>
<td>29460 ± 150</td>
<td>33830-33540</td>
<td>12</td>
<td>43</td>
<td></td>
<td>ABA</td>
</tr>
</tbody>
</table>

*Combustion feature locus 500 (221.04-220.95)*

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7088A</td>
<td>MAN13-340</td>
<td>B92</td>
<td>221.02</td>
<td>2-I</td>
<td>29230 ± 200</td>
<td>33710-33240</td>
<td>48</td>
<td>74</td>
<td></td>
<td>WBA</td>
</tr>
<tr>
<td>RTD7088B</td>
<td>MAN13-341</td>
<td>A92</td>
<td>220.99</td>
<td>2-I</td>
<td>29720 ± 150</td>
<td>33990-33730</td>
<td>-23.3</td>
<td>40</td>
<td>78</td>
<td>WBA</td>
</tr>
</tbody>
</table>

**Unit 1 colluvium**

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7245</td>
<td>MAN13-359</td>
<td>SY89d</td>
<td>220.37-220.19</td>
<td>1</td>
<td>30390 ± 170</td>
<td>34570-34200</td>
<td>-26.3</td>
<td>29</td>
<td>43</td>
<td>ABA</td>
</tr>
</tbody>
</table>

*Combustion feature locus 502 (220.07-220.03)*

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7246</td>
<td>MAN13-360</td>
<td>SY89</td>
<td>220.18</td>
<td>2-IV</td>
<td>32690 ± 200</td>
<td>36860-36310</td>
<td>-25.1</td>
<td>30</td>
<td>64</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7247</td>
<td>MAN13-363</td>
<td>SY89</td>
<td>220.08-220.02</td>
<td>2-IV</td>
<td>32270 ± 190</td>
<td>36380-35960</td>
<td>-25</td>
<td>36</td>
<td>68</td>
<td>ABA</td>
</tr>
</tbody>
</table>

**AREA C**

*J squares sequence*

<table>
<thead>
<tr>
<th>Laboratory ID</th>
<th>Field ID</th>
<th>Square</th>
<th>Elevation</th>
<th>Unit- Layer</th>
<th>¹⁴C BP</th>
<th>calBP (68%)</th>
<th>δ¹³C</th>
<th>% Eff</th>
<th>%C</th>
<th>treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTK6308</td>
<td>Manot10-13</td>
<td>J65a</td>
<td>206.14</td>
<td>4</td>
<td>30400 ± 400</td>
<td>34720-34050</td>
<td>-24.8</td>
<td>24</td>
<td>68</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6306</td>
<td>Manot10-10</td>
<td>J65b</td>
<td>206.03</td>
<td>4</td>
<td>30900 ± 420</td>
<td>35210-34380</td>
<td>-25.2</td>
<td>60</td>
<td>64</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6307</td>
<td>Manot10-11</td>
<td>J65b</td>
<td>206.00</td>
<td>4</td>
<td>32700 ± 530</td>
<td>37610-36140</td>
<td>-26.6</td>
<td>61</td>
<td>66</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6303</td>
<td>Manot10-7</td>
<td>J65b</td>
<td>206.00</td>
<td>4</td>
<td>31900 ± 500</td>
<td>36280-35220</td>
<td>-25.1</td>
<td>56</td>
<td>61</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6304</td>
<td>Manot10-8</td>
<td>J65b</td>
<td>205.95</td>
<td>4</td>
<td>32100 ± 500</td>
<td>36620-35440</td>
<td>-24.1</td>
<td>59</td>
<td>65</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6624</td>
<td>B3533</td>
<td>J65d</td>
<td>205.95-205.94</td>
<td>4</td>
<td>33300 ± 500</td>
<td>38260-36860</td>
<td>-24.9</td>
<td>10</td>
<td>61</td>
<td>ABA</td>
</tr>
<tr>
<td>RTK6305</td>
<td>Manot10-9</td>
<td>J65b</td>
<td>205.93</td>
<td>4</td>
<td>32100 ± 500</td>
<td>36620-35440</td>
<td>-24.5</td>
<td>43</td>
<td>69</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7195</td>
<td>MAN13-355</td>
<td>J66cd</td>
<td>205.7-205.6</td>
<td>5</td>
<td>36880-36410</td>
<td>-25.1</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7195.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33130 ± 210</td>
<td>37710-36840</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7195.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32380 ± 200</td>
<td>36490-36050</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Code</td>
<td>MAN Code</td>
<td>Date Range</td>
<td>PH</td>
<td>Temperature</td>
<td>PH</td>
<td>Water Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>----------</td>
<td>------------</td>
<td>----</td>
<td>-------------</td>
<td>----</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7194-combine</td>
<td>MAN13-353</td>
<td>J66cd</td>
<td>205.6-205.52</td>
<td>5</td>
<td>36430-36120</td>
<td>-25.9</td>
<td>44</td>
<td>ABA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7194.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7194.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7816</td>
<td>C119/12</td>
<td>J65cd</td>
<td>205.56</td>
<td>5</td>
<td>33210 ± 160</td>
<td>37780-37000</td>
<td>32</td>
<td>ABA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7784-combine (failed)</td>
<td>C137/12</td>
<td>J65a</td>
<td>205.54</td>
<td>5</td>
<td>37560-36880</td>
<td>52</td>
<td>73</td>
<td>ABA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7784.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7784.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7783</td>
<td>C129/12</td>
<td>J65cd</td>
<td>205.5</td>
<td>5</td>
<td>36990 ± 290</td>
<td>38600-37810</td>
<td>71</td>
<td>ABA-uc line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7783A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7783B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7785-combine</td>
<td>C174/12</td>
<td>J65c</td>
<td>205.42</td>
<td>6</td>
<td>32410 ± 260</td>
<td>36610-36010</td>
<td>90</td>
<td>ABA-uc line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7785.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7785.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7786-combine</td>
<td>C188/12</td>
<td>J65b</td>
<td>205.38</td>
<td>6</td>
<td>28940 ± 180</td>
<td>33420-32910</td>
<td>82</td>
<td>ABA-uc line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7786.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7786.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7086</td>
<td>MAN13-331B.1</td>
<td>J66/65</td>
<td>205.31-205.16</td>
<td>6</td>
<td>38880 ± 310</td>
<td>43000-42550</td>
<td>37</td>
<td>71</td>
<td>WBA</td>
<td></td>
</tr>
<tr>
<td>RTD7087</td>
<td>MAN13-331B.2</td>
<td>J66/65</td>
<td>205.31-205.16</td>
<td>6</td>
<td>41790 ± 380</td>
<td>45530-44840</td>
<td>-23.2</td>
<td>62</td>
<td>45</td>
<td>WBA</td>
</tr>
<tr>
<td>RTD7116</td>
<td>MAN13-347</td>
<td>J65ab</td>
<td>205.25-205.14</td>
<td>6</td>
<td>48700 ± 700</td>
<td>49440-48030</td>
<td>-28.3</td>
<td>26</td>
<td>70</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7128B</td>
<td>MAN13-347 sediment</td>
<td>J65ab</td>
<td>205.25-205.14</td>
<td>6</td>
<td>28560 ± 150</td>
<td>32920-32310</td>
<td>64</td>
<td>0.6</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>RTD7118</td>
<td>MAN13-315</td>
<td>J66/65</td>
<td>205.06</td>
<td>6</td>
<td>40280 ± 320</td>
<td>44210-43520</td>
<td>-25.2</td>
<td>17</td>
<td>54</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7119</td>
<td>MAN13-350</td>
<td>J65</td>
<td>205.04-204.90</td>
<td>6</td>
<td>42310 ± 380</td>
<td>45940-45250</td>
<td>-23.8</td>
<td>21</td>
<td>69</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7130B</td>
<td>MAN13-350 sediment</td>
<td>J65</td>
<td>205.04-204.90</td>
<td>6</td>
<td>30860 ± 180</td>
<td>35030-34670</td>
<td>53</td>
<td>0.6</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>RTD7117</td>
<td>MAN13-349</td>
<td>J65</td>
<td>205.03-204.91</td>
<td>6</td>
<td>41610 ± 540</td>
<td>45510-44570</td>
<td>-24.8</td>
<td>37</td>
<td>67</td>
<td>ABA</td>
</tr>
</tbody>
</table>
### Appendix A Table 1 (continued)

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Identification</th>
<th>Horizon</th>
<th>Date (2pp)</th>
<th>Age (2pp)</th>
<th>Comparation</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7129B</td>
<td>MAN13-349</td>
<td>J65</td>
<td>205.03-204.91</td>
<td>31270 ± 190</td>
<td>35360-34910</td>
<td>76</td>
</tr>
<tr>
<td>RTD7197-</td>
<td>MAN13-351</td>
<td>J64ab</td>
<td>205.02-204.90</td>
<td>41930-41560</td>
<td>-23.4</td>
<td>19</td>
</tr>
<tr>
<td>combine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7197.1</td>
<td>MAN13-351</td>
<td>J64ab</td>
<td></td>
<td>37330 ± 300</td>
<td>42040-41580</td>
<td>86</td>
</tr>
<tr>
<td>RTD7197.2</td>
<td>MAN13-351</td>
<td>J64ab</td>
<td></td>
<td>37120 ± 300</td>
<td>41910-41430</td>
<td>ABA</td>
</tr>
<tr>
<td>RTD7115</td>
<td>MAN13-346</td>
<td>J65</td>
<td>204.80-204.70</td>
<td>42210 ± 390</td>
<td>45870-45160</td>
<td>-25.6</td>
</tr>
<tr>
<td>RTD7127B</td>
<td>MAN13-346</td>
<td>J65</td>
<td>204.80-204.70</td>
<td>25080 ± 110</td>
<td>29280-28940</td>
<td>86</td>
</tr>
<tr>
<td>RTD7196</td>
<td>MAN13-348</td>
<td>J65cd</td>
<td>204.70-204.60</td>
<td>41100 ± 450</td>
<td>45050-44200</td>
<td>-24.3</td>
</tr>
</tbody>
</table>

**I square sequence**

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Identification</th>
<th>Horizon</th>
<th>Date (2pp)</th>
<th>Age (2pp)</th>
<th>Comparation</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTK6849</td>
<td>MAN11-108</td>
<td>I65</td>
<td>206.29</td>
<td>21550 ± 160</td>
<td>25970-25710</td>
<td>A</td>
</tr>
<tr>
<td>RTK6848</td>
<td>MAN11-107</td>
<td>I65</td>
<td>206.00</td>
<td>24430 ± 210</td>
<td>28700-28240</td>
<td>A</td>
</tr>
<tr>
<td>RTK6625</td>
<td>B3534</td>
<td>I65</td>
<td>205.96-205.91</td>
<td>30100 ± 340</td>
<td>34430-33860</td>
<td>-24.3</td>
</tr>
<tr>
<td>RTK6627</td>
<td>B3525</td>
<td>I65</td>
<td>205.95-205.90</td>
<td>27900 ± 260</td>
<td>31950-31310</td>
<td>-24.7</td>
</tr>
<tr>
<td>RTK6626.1</td>
<td>B3535</td>
<td>I65</td>
<td>205.90-205.86</td>
<td>32400 ± 460</td>
<td>36990-35770</td>
<td>-25.9</td>
</tr>
<tr>
<td>RTK6623</td>
<td>B3541</td>
<td>I65</td>
<td>205.87-205.85</td>
<td>33700 ± 530</td>
<td>38730-37280</td>
<td>-25.0</td>
</tr>
<tr>
<td>RTK6628</td>
<td>B3538</td>
<td>I65</td>
<td>205.85</td>
<td>32600 ± 460</td>
<td>37270-35970</td>
<td>-24.6</td>
</tr>
</tbody>
</table>

**M square between flowstones**

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Identification</th>
<th>Horizon</th>
<th>Date (2pp)</th>
<th>Age (2pp)</th>
<th>Comparation</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTK6704</td>
<td>C 047/12</td>
<td>M65a</td>
<td>206.23</td>
<td>23600 ± 200</td>
<td>27870-27570</td>
<td>-24.9</td>
</tr>
<tr>
<td>RTK6705</td>
<td>C 062/12</td>
<td>M65a</td>
<td>206.14</td>
<td>23200 ± 190</td>
<td>27630-27330</td>
<td>-23.7</td>
</tr>
<tr>
<td>RTK6706</td>
<td>C 067/12</td>
<td>M65a</td>
<td>206.10</td>
<td>25900 ± 280</td>
<td>31170-30840</td>
<td>-23.0</td>
</tr>
<tr>
<td>RTK6708</td>
<td>C 077/12</td>
<td>M65a</td>
<td>206.05</td>
<td>24000 ± 210</td>
<td>28350-27890</td>
<td>-23.5</td>
</tr>
</tbody>
</table>
Appendix A Table 2: Outputs of six runs of Model 2 showing the posterior outlier likelihood for sample RTD7116 and cultural phases ranges estimated by the OxCal Date function. The model does not produce consistent results for the start of the Ahmarian and outlier probability of RTD7116.

<table>
<thead>
<tr>
<th>Run</th>
<th>RTD7116 outlier %</th>
<th>Ahmarian</th>
<th>Aurignacian</th>
<th>Post-Aurignacian</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52</td>
<td>46122-41489</td>
<td>37227-35303</td>
<td>33770-33354</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>46579-41626</td>
<td>37214-35389</td>
<td>33765-33372</td>
</tr>
<tr>
<td>3</td>
<td>83</td>
<td>45551-42048</td>
<td>37229-35497</td>
<td>33761-33378</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>45873-41624</td>
<td>37220-35363</td>
<td>33767-33366</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>49356-41903</td>
<td>37191-35300</td>
<td>33755-33378</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>48391-41795</td>
<td>37173-35269</td>
<td>33758-33372</td>
</tr>
</tbody>
</table>
Appendix B

Appendix B Figure 1: Profile and top plan for Pešturina. Photo of N10-N11 south section taken by DM with layer boundaries indicated. Top plan of excavated areas as of 2013. Radiocarbon samples indicated with laboratory ID, calibrated date (kcalBP 95.4%), and color-coded by layer.
Appendix B Figure 2: Profile and top plan for Hadži Prodanova. Profile sketch of E19-F19 north section, indicated by blue line on the top plan. Radiocarbon samples, labeled with laboratory ID and calibrated date (kcalBP 95.4%), are listed by elevation (top to bottom) within a given excavation square.
Appendix B Figure 3: Profile and top plan for Smolučka. Images modified from (Dimitrijević 1991). Profile sketch of D-G 11/12 section, indicated by a blue line on the top plan. Radiocarbon samples, listed by laboratory ID, all produced infinite dates or finite dates beyond the calibration curve.
Appendix B Figure 4: Examples of bone taphonomy and collagen preservation of dated samples. a) Samples RTD7231B from Pešturina and RTD7275 from Hadži Prodanova both show percussion marks (indicated by arrows) as evidence of human modification. b) Fourier transform infrared (FTIR) spectra of the samples’ insoluble fractions show absorption peaks characteristic of collagen at 1650 cm⁻¹, 1535 cm⁻¹, and 1450 cm⁻¹, although sample RTD7231B is better preserved with sharp, distinct peaks. Neither spectrum shows peaks indicative of contamination.
Appendix B Figure 5: Time series maps of archaeological industries. Points represent individual radiocarbon dates. The size of the point is proportional to the likelihood of the date. Points are color coded as industry unclear-gray, UP (Gravettian)-green, EUP (Proto/Early/Aurignacian, Kozarnikian)-yellow, Bachokirian-pink, Uluzzian-purple, and MP-blue. The undetermined industries are not assumed to be related to one another. No human fossils are represented.
### Appendix B Table 1: Sample information and measurements for $^{14}$C dates from Pešturina, Smolućka, and Hadži Prodanova.

<table>
<thead>
<tr>
<th>Laboratory code</th>
<th>Layer</th>
<th>Square</th>
<th>Identification</th>
<th>Taphonomic notes</th>
<th>$^{14}$C yr BP</th>
<th>calBP (95.4%)</th>
<th>% eff.</th>
<th>%C</th>
<th>class</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pešturina</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7148</td>
<td>2-4</td>
<td>L9b</td>
<td>medium ungulate radius/ulna</td>
<td>cutmarks</td>
<td>13440 ± 60</td>
<td>16380-15960</td>
<td>1</td>
<td></td>
<td>reliable</td>
</tr>
<tr>
<td>RTK6446</td>
<td>2-4</td>
<td>M9b</td>
<td>large ungulate LBSF</td>
<td>percussion</td>
<td>26120 ± 620</td>
<td>31270-28990</td>
<td>1.4</td>
<td>43</td>
<td>reliable</td>
</tr>
<tr>
<td>RTK6445</td>
<td>2-9</td>
<td>N11c</td>
<td>large ungulate femur shaft</td>
<td></td>
<td>&gt;37800</td>
<td>2.4</td>
<td>38</td>
<td>uncertain- no human mod.</td>
<td></td>
</tr>
<tr>
<td>RTD7231B</td>
<td>3-12</td>
<td>M7b</td>
<td>large mammal LBSF</td>
<td>impact</td>
<td>28680 ± 180</td>
<td>33400-32069</td>
<td>0.7</td>
<td>36</td>
<td>reliable</td>
</tr>
<tr>
<td>RTK6449</td>
<td>3-15</td>
<td>O11b</td>
<td>large mammal LBSF</td>
<td>gnawing</td>
<td>40200 ± 3600</td>
<td>&gt;40660</td>
<td>1.8</td>
<td>43</td>
<td>uncertain- no human mod.</td>
</tr>
<tr>
<td>RTK6447</td>
<td>3/4-10</td>
<td>M10a</td>
<td>large ungulate LBSF</td>
<td>trampling</td>
<td>&gt;41100</td>
<td>1.2</td>
<td>41</td>
<td>uncertain- no human mod.</td>
<td></td>
</tr>
<tr>
<td>RTK6450</td>
<td>3/4-21</td>
<td>N10b</td>
<td>medium/large ungulate LBSF</td>
<td></td>
<td>36200 ± 2200</td>
<td>46330-36340</td>
<td>1.4</td>
<td>40</td>
<td>uncertain- no human mod.</td>
</tr>
<tr>
<td>RTD7149</td>
<td>4-22</td>
<td>N9b</td>
<td>large ungulate LBSF</td>
<td>cutmarks</td>
<td>40500 ± 590</td>
<td>45170-43080</td>
<td>1</td>
<td>33</td>
<td>reliable</td>
</tr>
<tr>
<td><strong>Smolućka</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OxA-1251</td>
<td>3</td>
<td></td>
<td>charcoal</td>
<td>&gt;38000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>uncertain- no human mod.</td>
</tr>
<tr>
<td>RTD7228B</td>
<td>4</td>
<td>E11</td>
<td>ibex/chamois humerus</td>
<td></td>
<td>54900 ± 3800</td>
<td>&gt;49700</td>
<td>2.2</td>
<td>35</td>
<td>&quot;</td>
</tr>
<tr>
<td>RTD7229B</td>
<td>4</td>
<td>E11</td>
<td>ibex tibia</td>
<td></td>
<td>60200 ± 6000</td>
<td>&gt;54700</td>
<td>2</td>
<td>45</td>
<td>&quot;</td>
</tr>
<tr>
<td>RTD7224</td>
<td>5</td>
<td>D12</td>
<td>ibex/chamois tibia</td>
<td></td>
<td>&gt;39170</td>
<td>6.9</td>
<td>39</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>RTD7225</td>
<td>5</td>
<td>D11</td>
<td>ibex/chamois humerus</td>
<td></td>
<td>&gt;39170</td>
<td>1.5</td>
<td>51</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>RTD7226B</td>
<td>5</td>
<td>D11</td>
<td>red deer first phalanx</td>
<td></td>
<td>53900 ± 2300</td>
<td>&gt;50000</td>
<td>2.6</td>
<td>30</td>
<td>&quot;</td>
</tr>
<tr>
<td>RTD7227</td>
<td>5</td>
<td>D11</td>
<td>ibex metacarpal</td>
<td></td>
<td>&gt;39170</td>
<td>3.7</td>
<td>50</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td><strong>Hadži Prodanova</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTD7274</td>
<td>2-1</td>
<td>D11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>25170 ± 130</td>
<td>29560-28860</td>
<td>1.1</td>
<td>42</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7480</td>
<td>2-6</td>
<td>C11</td>
<td>medium mammal metapodial</td>
<td>impact</td>
<td>18730 ± 80</td>
<td>22840-22400</td>
<td>0.8</td>
<td>43</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7271</td>
<td>2-12</td>
<td>C11, D11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>25070 ± 130</td>
<td>29470-28780</td>
<td>3.2</td>
<td>40</td>
<td>reliable</td>
</tr>
</tbody>
</table>
# Appendix B Table 1 (continued)

<table>
<thead>
<tr>
<th>RTD7277</th>
<th>3-8</th>
<th>D9</th>
<th>ibex scapula</th>
<th></th>
<th>31510 ± 190</th>
<th>35870-34930</th>
<th>0.9</th>
<th>38</th>
<th>uncertain-no human mod.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTD7276</td>
<td>4-3</td>
<td>D11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>35500 ± 280</td>
<td>40820-39430</td>
<td>4.5</td>
<td>40</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7481</td>
<td>4-23</td>
<td>C11</td>
<td>chamois radius</td>
<td>cutmarks</td>
<td>24030 ± 120</td>
<td>28400-27780</td>
<td>1</td>
<td>48</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7273</td>
<td>4-26</td>
<td>C11</td>
<td>large bovid sessamoid</td>
<td></td>
<td>33580 ± 280</td>
<td>38640-36970</td>
<td>4.7</td>
<td></td>
<td>uncertain-no human mod.</td>
</tr>
<tr>
<td>RTD7275</td>
<td>5-9</td>
<td>E11</td>
<td>medium mammal LBSF</td>
<td>impact</td>
<td>29490 ± 160</td>
<td>34010-33370</td>
<td>4.6</td>
<td>43</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7482</td>
<td>5-9</td>
<td>C11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>47690 ± 1650</td>
<td>52220-44810</td>
<td>2.7</td>
<td>48</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7478</td>
<td>5-11</td>
<td>C11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>&gt;39570</td>
<td></td>
<td>2.1</td>
<td>49</td>
<td>reliable</td>
</tr>
<tr>
<td>RTD7270</td>
<td>5-28</td>
<td>D11, C11</td>
<td>medium mammal LBSF</td>
<td>cutmarks</td>
<td>39520 ± 540</td>
<td>44310-42510</td>
<td>0.7</td>
<td>50</td>
<td>reliable</td>
</tr>
</tbody>
</table>
**Appendix B Table 2**: Probabilities that modern human-attributed dates are older than Neanderthal-attributed dates. The earliest dates attributed to modern humans form the columns and dates attributed to Neanderthals form the rows. Pairwise comparisons performed with the Oxcal Order command.

<table>
<thead>
<tr>
<th></th>
<th>Tabula Traiana</th>
<th>Baranic</th>
<th>Oase</th>
<th>Kozarnika</th>
<th>Temnata</th>
<th>Bacho Kiro</th>
<th>Franchthi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vindija</strong></td>
<td>OxA-V-2291-18</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Ua-?</strong></td>
<td>OxA-2089-06</td>
<td>0.01</td>
<td>0.00</td>
<td>0.08</td>
<td>0.05</td>
<td>0.52</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Mujina Pečina</strong></td>
<td>GrA-9635</td>
<td>0.94</td>
<td>0.80</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>OxA-8150</strong></td>
<td>GrA-9639</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>GrA-9636</strong></td>
<td>GrA-9634</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.10</td>
<td>0.11</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>GrA-9633</strong></td>
<td>GrA-9632</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Crvena Stijena</strong></td>
<td>GrN-6083</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Šalitrena</strong></td>
<td>Beta-237 686</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.91</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Beta-237 690</strong></td>
<td>RTD7270</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>RTD7482</strong></td>
<td>RTD7276</td>
<td>0.03</td>
<td>0.00</td>
<td>0.73</td>
<td>0.32</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>RTD7149</strong></td>
<td>RTD7149</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Golema</strong></td>
<td>GP1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Klissoura</strong></td>
<td>AA-73820</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Appendix B Table 3: Estimated differences in age between overlapping modern human and Neanderthal attributed dates. Neanderthal-attributed dates form the columns and modern human-attributed dates form the rows. Age differences calculated with Oxcal Difference command for pairs in which the modern human date has >20% probability of being older than the Neanderthal date. Within cells the top line shows the probability that the modern human date is older. The bottom line shows the estimated range for how much older the modern human date could be at 95% confidence. When the second value is negative, the modern human date may be that many years younger than the Neanderthal date. For example for the comparison between Mujina Pećina date GrA-9633 and Temnata date OxA-5169, the Mujina Pećina date has a 0.55 probability of being older, and is between 6099 years older to 3927 years younger than the Temnata date.
## Appendix B Table 3 (continued)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Date IDs</th>
<th>Vindija</th>
<th>Mujina Pećina</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date IDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabula Traiana</td>
<td>OxA-23651</td>
<td>0.94</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4351 to -444</td>
<td>1915 to -1962</td>
</tr>
<tr>
<td></td>
<td>OxA-24818</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3296 to -1375</td>
<td></td>
</tr>
<tr>
<td>Baranica</td>
<td>OxA-13828</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5733 to 1644</td>
<td>3276 to 246</td>
</tr>
<tr>
<td>Oase</td>
<td>OxA-11711/GrA-22810</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5740 to 18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GifA-99662</td>
<td>1.00</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8200 to 4427</td>
<td>3346 to -1592</td>
</tr>
<tr>
<td></td>
<td>GifLSM-10994</td>
<td>0.93</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7823 to 4047</td>
<td>3346 to -1592</td>
</tr>
<tr>
<td></td>
<td>GifA-101050</td>
<td>0.24</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7113 to 2654</td>
<td>4668 to 1196</td>
</tr>
<tr>
<td></td>
<td>GifA-99706</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6265 to 1885</td>
<td>3805 to 443</td>
</tr>
<tr>
<td>Kozarnika</td>
<td>OxA-5169</td>
<td>0.90</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12500 to 2806</td>
<td>5383 to 2660</td>
</tr>
<tr>
<td></td>
<td>GifA-5170</td>
<td>1.00</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11371 to 2701</td>
<td>4501 to -1106</td>
</tr>
<tr>
<td></td>
<td>GifA-5171</td>
<td>1.00</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9676 to 2555</td>
<td>4488 to -5925</td>
</tr>
<tr>
<td>Temnata</td>
<td>OxA-5169</td>
<td>1.00</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12500 to 2806</td>
<td>4813 to -3929</td>
</tr>
<tr>
<td></td>
<td>OxA-5170</td>
<td>0.54</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6321 to -12395</td>
<td>4813 to -3929</td>
</tr>
<tr>
<td></td>
<td>OxA-5171</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9676 to 2555</td>
<td></td>
</tr>
<tr>
<td>Bacho Kiro</td>
<td>OxA-3183</td>
<td>0.35</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8977 to 2104</td>
<td>2261 to -4520</td>
</tr>
<tr>
<td>Franchthi</td>
<td>OxA-20616</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5022 to 1026</td>
<td>2569 to -366</td>
</tr>
</tbody>
</table>
## Appendix B Table 3 (continued)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Crvena Stijena</th>
<th>Šalitrena</th>
<th>Hadži Prodanova</th>
<th>Pešturina</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date IDs</strong></td>
<td>GrN-6083</td>
<td>Beta-237 686</td>
<td>Beta-237 690</td>
<td>RTD7270</td>
</tr>
<tr>
<td>Tabula Traiana</td>
<td>OxA-23651</td>
<td>Beta-237 690</td>
<td>Beta-237 690</td>
<td>RTD7270</td>
</tr>
<tr>
<td></td>
<td>OxA-24818</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baranica</td>
<td>OxA-13828</td>
<td></td>
<td></td>
<td>0.73</td>
</tr>
<tr>
<td>Oase</td>
<td>OxA-11711/GrA-22810</td>
<td></td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>Kozarnika</td>
<td>GifA-99662</td>
<td>0.91</td>
<td>1925 to -430</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>GifLSM-10994</td>
<td>0.77</td>
<td>1548 to -810</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>GifA-101050</td>
<td>0.20</td>
<td>915 to -2290</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>GifA-99706</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temnata</td>
<td>OxA-5169</td>
<td>0.32</td>
<td>4453 to -4659</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>OxA-5170</td>
<td>0.26</td>
<td>3426 to -4789</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>OxA-5171</td>
<td>0.60</td>
<td>3707 to -2556</td>
<td>0.66</td>
</tr>
<tr>
<td>Bacho Kiro</td>
<td>OxA-3183</td>
<td>0.45</td>
<td>3008 to -3010</td>
<td>0.50</td>
</tr>
<tr>
<td>Franchthi</td>
<td>OxA-20616</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C Figure 1: Main Chamber top plan and section of Ciemna Cave. Photogrammetry section shows lithic artifacts as blue circles, charcoals as yellow circles, and samples taken for radiocarbon dating as red diamonds. Measured radiocarbon samples indicated with laboratory ID. Archaeological levels listed in Roman numerals and lithostratigraphic layers listed in Arabic numerals.
Appendix C Figure 2: Top plan and sections of Oblazowa Cave. Archaeological layers are indicated by Roman numerals. Section A from earlier excavations and section B from more recent excavations. Samples dated in this study were collected during the more recent excavations.
Appendix C Figure 3: Fourier transform infrared (FTIR) spectra of dated bone collagen samples. Spectra shown for samples with <1% insoluble fraction and RTD7399, which was both the oldest finite date produced and the sample with cutmarks. Absorption peaks are consistent with modern collagen, shown at the bottom.
Appendix C Figure 4: Charcoal samples prepared by acid-base-acid and water-base-acid pretreatments. One charcoal from Ciemna and one charcoal from Oblazowa were divided and prepared by acid-base-acid (ABA) and water-base-acid (water-BA) pretreatments. a) Calibrated radiocarbon dates of ABA (top, dark gray) and water-BA (bottom, light gray) pretreated fractions. The gray bar represents the ages of bones from the same layers. For both charcoals the ABA fraction produced an older date. b) FTIR spectra of Oblazowa charcoal RTD7355 pretreated by ABA (top, black) and water-BA (middle, purple) compared to humic substances after ABA (bottom, blue). Pretreated charcoal has carboxylic acid absorptions around 1715 and 1250 cm⁻¹ as well as carboxylate absorptions around 1600, and 1400 cm⁻¹. The major silicate absorption in clay is ~1033 cm⁻¹, which is present in the water-BA fraction and reduced but not eliminated in the ABA fraction. Humic substances after ABA can have peaks similar to those of pretreated charcoal. It is unclear whether contaminant substances have been removed from the ABA pretreated charcoals.
**Appendix C Table 1**: Previous chronometric dates from Obłazowa Cave Layers VIII and below.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Laboratory ID</th>
<th>Material</th>
<th>Square</th>
<th>$^{14}$C yrs BP</th>
<th>calBP (68.2%)</th>
<th>source</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIII</td>
<td>OxA-4584</td>
<td>Worked red deer antler</td>
<td>C1</td>
<td>32400 ± 650</td>
<td>37,300-35,600</td>
<td>Housley 2003</td>
<td>4.5% eff.; gelatinization AMS, excavated 1985-1992, dated 1994</td>
</tr>
<tr>
<td>VIII</td>
<td>OxA-4585</td>
<td>Bone tool</td>
<td>C1</td>
<td>30600 ± 550</td>
<td>35,000-34,100</td>
<td>Housley 2003</td>
<td>2.5% eff.; gelatinization AMS, excavated 1985-1992, dated 1994</td>
</tr>
<tr>
<td>VIII</td>
<td>Gd-2555</td>
<td>Several small bones</td>
<td></td>
<td>32400 ± 1700</td>
<td>38,700-34,800</td>
<td>Housley 2003</td>
<td>Decay counting, excavated 1985-1992</td>
</tr>
<tr>
<td>VIII</td>
<td>Poz-35627</td>
<td>Reindeer bone</td>
<td></td>
<td>31200 ± 500</td>
<td>35,600-34,700</td>
<td>Valde-Nowak 2015</td>
<td>Excavated 1985; dated 2010</td>
</tr>
<tr>
<td>VIII</td>
<td>Poz-35628</td>
<td>Reindeer bone</td>
<td></td>
<td>27500 ± 300</td>
<td>31,500-31,100</td>
<td>Valde-Nowak 2015</td>
<td>Excavated 1985</td>
</tr>
<tr>
<td>XV/ XVI</td>
<td>Gd-4532</td>
<td>Bone</td>
<td></td>
<td>25900 ± 1700</td>
<td></td>
<td>Housley 2003</td>
<td>Decay counting, excavated 1985-1992</td>
</tr>
<tr>
<td>XIX</td>
<td>U/Th</td>
<td>Horse bone</td>
<td></td>
<td></td>
<td>90-63 ka</td>
<td>Cieśla and Valde-Nowak 2015</td>
<td></td>
</tr>
</tbody>
</table>