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# Technological Responses of Neanderthals to Macroclimatic Variations (240,000–40,000 BP)

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**Keywords**

Neanderthals, lithic industry, Paleolithic, climate change, carrying capacity.

**Cover Page Footnote**

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# *Technological Responses of Neanderthals to Macroclimatic Variations (240,000–40,000 BP)*

JEAN-PIERRE BOCQUET-APPEL[1] AND ALAIN TUFFREAU[2]

*Abstract* Using a database of 499 archaeological assemblages from 332 sites in Europe, we statistically test a model of the economic reactivity of the hunter-gatherer production system to climatic variations. This model predicts an increase in the diversity of lithic tools during harsh cold periods, in order to maintain carrying capacity, and a reduction during favorable climatic periods. Diversity was measured from the variations in flint tool distributions in traditional Bordes typological categories, using Shannon's derived diversity index (*D*). Reactivity was measured in 190 archaeological assemblages from 103 sites of the Middle Paleolithic in Europe (mainly France). The Neanderthals show technological inertia in the development and use of lithic tools for 200,000 years, despite the four cool to cold macroclimatic periods they experienced.

Several investigators have been struck by the relative continuity of Neanderthal behavior despite the many climatic changes they experienced (Gamble 1999; Mellars 1996; Roebroeks and Gamble 1999). In particular, this stability resulted in the long duration of the Middle Paleolithic, about 200,000 to 250,000 years ago, with the same debitage methods being used and tools that only began to diversify during the last glacial period, most notably with Micoquian tools. This situation contrasts with the behavior of anatomically modern humans who, during the Upper Paleolithic, developed many different cultures with diversified tools. Although the two metapopulations have approximately the same average cerebral volume, the difference observed in their lithic industries has been attributed to a higher rate of innovations among anatomically modern humans than among Neanderthals. This raises questions about the cognitive efficiency of the two metapopulations, to the detriment of the Neanderthals [Wynn and Coolidge 2004; contra see D'Errico et al. (1998) and Finlayson (2004)]. To take the matter further, the speed of technological reactivity of the two metapopulations needs to be measured on the basis of their lithic industries and in terms of their response

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to the highly contrasting environmental conditions in which they lived. This is what we explore in this article with regard to the Neanderthals.

During macroenvironmental variations, did Neanderthals remain technically passive, mainly migrating back and forth periodically (Roebroeks and Tuffreau 1999; Soriano 2005; Tuffreau 2006) between their hunting and gathering areas along a latitudinal geographic axis? If Neanderthal reactivity is observable in their tools, expressing economic aspects, does this simply reflect an underlying technological improvement in lithic industries resulting from the biological evolution of the human lineage? Or, on the contrary, do the tools reflect a Neanderthal response to constraints that were independent of the underlying improvement? If so, in which direction was the response? In this article, we obtain an estimate of Neanderthal economic reactivity from the distributions observed among groups of tools in lithic assemblages. This reactivity is examined in parallel with macroclimatic variations during the Middle Paleolithic (i.e., from isotopic stages 8 to 3) on the one hand and the chronological linearity covering 250,000 years, which is taken to represent underlying improvement, on the other.

## Materials and Methods

**A Model for Technological Response.** The putative impact of environmental constraints on lithic industries is as follows. Periodic environmental variations over several millennia, that is, on a macroscale, affect the edible biomass density, inducing variations in the carrying capacity of the hunter-gatherer production system of the Neanderthals. If this variation tends toward a reduction in the carrying capacity, it will cause the local population density to decrease, through an increase in mortality and a decrease in fertility and/or migration. If the environmental effect occurs on a supraregional scale, thus closing off the migration option that would make it possible to cover food needs elsewhere, then merely maintaining the system's carrying capacity would force the population to innovate or, more accurately, would raise the probability of shifting to innovations (Wood 1998).

Innovation does not necessarily mean invention of new tools; it can also mean an increase or reduction in the use of existing or previously existing tools, even in a relatively remote past. These innovations become necessary to extend the food spectrum to new animal and plant species or to move the cursor on the existing spectrum, that is, to vary the distribution of hunted and collected items, for example, a shift from hunting mainly large ungulates (reindeers, horses) to capturing small animals (hares, or tortoises in the Mediterranean northern basin) (Stiner et al. 2008). When food constraints increase, an effect on stone tools is to be expected in order to maintain the level of food production, resulting in a change in the distribution of the various tool types or in the introduction of innovations that produce greater tool diversity. Conversely, when food constraints diminish, a less varied range of tools is to be expected. In other words, a relative increase in

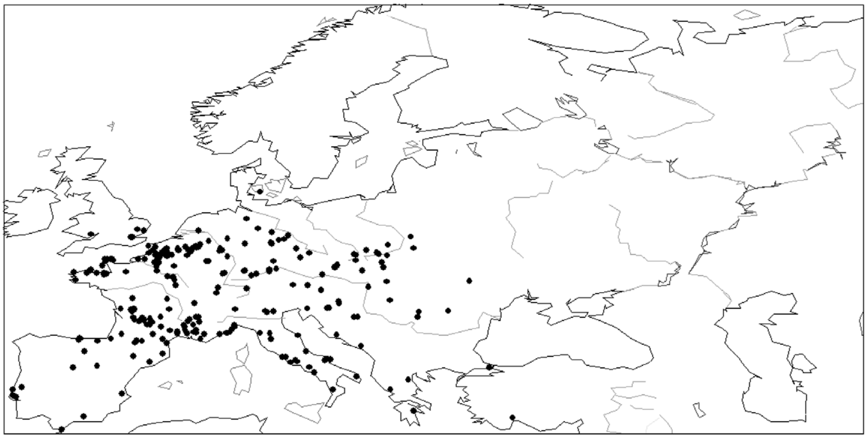

**Figure 1.** Geographic locations of the 332 archaeological sites where the 499 archaeological layers were found.

lithic cultural variance can be expected during unfavorable environmental periods and a relative reduction can be expected during favorable periods.

A proxy measurement of variation in carrying capacity during a period of worsening or improving climatic conditions could be the negative or positive difference in benthic oxygen-18 between the last climatic minimum or optimum and a given date (period). It is expected that the larger the difference, in negative terms, the higher the probability of innovation, although no proposal for a joint statistical distribution family for the two event categories can be readily put forward.

**Data and Techniques.** The data are represented by the distributions of lithic industries obtained from an exhaustive search of the literature concerning 499 archaeological layers from 332 sites in Europe, located at the geographic coordinates shown in Figure 1; each layer is called a record in the remainder of this article.

The data were subdivided into two groups. The first, called the large data set, contains 455 lithic assemblages from 314 archaeological sites. The large data set is intended to measure the variation in the density of the number of Middle Paleolithic lithic assemblages by chronology. The second group, called the reduced data set, contains 190 lithic assemblages from 103 archaeological sites with distributions of apparently complete lithic industries. These are mainly located in France, with some in Italy, eastern and central Europe, and Israel (Figure 2).

The reduced data set is intended to measure variation in the diversity of lithic tools. Each record represents the number of artifacts in the essential groups according to the Bordes method, using so-called reduced counting (Bordes 1950, 1984), that is, without technical items such as pseudo-Levallois points and knives

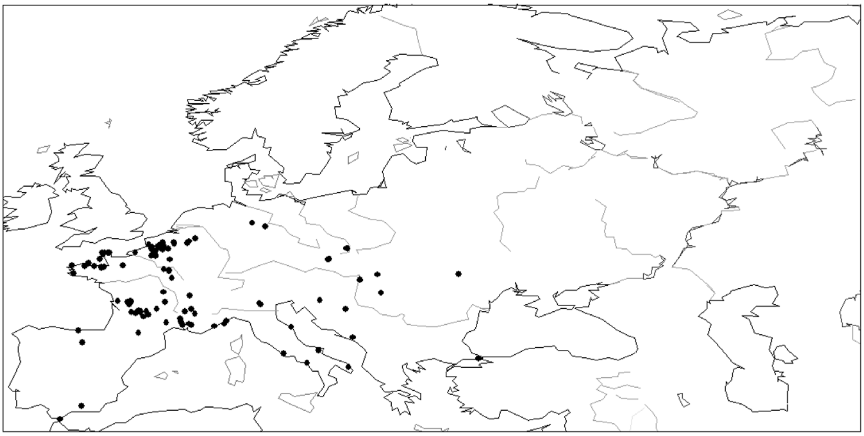

**Figure 2.** Geographic locations of the 103 archaeological sites where the 190 archaeological layers that provided the sample distributions of lithic tools were found.

with a natural back. These artifacts are classified in the following flint tool categories: scrapers (reduced IR), tools of the Upper Paleolithic type (group III), encoches (nos. 42 and 54 in Bordes's typological list), denticulates (group IV), bifaces, foliates, choppers and chopping tools, and cleavers.

The bifaces have been divided into two categories: bifaces of the Acheulean type and those of Micoquian morphology or that occur more frequently during the Middle Paleolithic [flat triangular Mousterian bifaces of the Acheulean tradition (MAT) and bifaces on flakes]. Because items in the second category are not always easy to recognize explicitly in the literature, the bifaces from the lithic industries that are present from isotopic stage 5 were classified, in doubtful cases, with the Micoquian types and MAT bifaces.

A further category was added, corresponding to the numerical difference between the calculated values of flint tool categories (our data) and the total number of tools cited in the literature. This category corresponds to various tools not taken into account in the mentioned indexes. The noninformed values of tool categories in distributions where some items have been informed were given a value of 0. In the literature, besides quantitative information, values are frequently expressed as qualitative appreciations, such as "low," "very few," "rare," and "frequent." To avoid the loss of associated quantitative information, we replaced the adjectives expressing scarcity or abundance with the values 5% and 20% of the tool total (either indicated or calculated, respectively). In all, the lithic data are distributed into 10 typological categories. The reduced data set is given in the Appendix.

The chronological data, expressed in terms of isotopic stages, were obtained from the literature, from transposing the ancient glacial periods into terms of their corresponding isotopic stages, and/or from a team member's personal knowledge of the sites (A. Tuffreau). In all, the data represent 64,823 tools distributed into 13 isotopic stages or substages (3, 4, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 6, 7, 7.1, 7.3, 8). Note that there are isotopic stages for which no additional substage can be obtained or estimated from the original publication. In that case, the average date of the stage has been taken.

The tool distribution in an archaeological layer can be regarded as a closed information system of mutually exclusive items, with a multinomial statistical distribution. The tool distribution can be considered a random sample of the distribution (observed localities) of a large archaeological layer on a regional or subcontinental scale, which records traces of the metapopulation's activity. The Shannon index ($H$) was used to quantify the lithic cultural diversity of an archaeological layer. With $p_i = n_i/n$, the Shannon index is written as

$$H = -\sum_{i=1}^{s} p_i \ln p_i, \tag{1}$$

where the $n_i$ are the observed numbers of the $i$th tools ($i = 1, \dots, s$), $n$ is the total number of tools, and the $p_i$ are their frequency, with $\sum p_i = 1$. By convention, if $n_i = 0$, then $p_i \ln p_i = 0$. This index expresses the total diversity of a set of items as a sum of frequencies weighted by (the natural logarithm of) their respective abundance. When the diversity of the items increases (i.e., tends toward a uniform distribution), the value of the index increases, and conversely, when the diversity decreases, the distribution tends to be unimodal. Many publications discuss the Shannon diversity index, which will not be discussed here (see, e.g., Krebs 1989; Lecointre and Le Guyader 2001; Magurran 1998). To measure the difference between the index values in terms of the proportion of diversity, it is better to take the value $D = \exp(H)$ (Jost 2006).

To express the climatic impact, we used the values corresponding to the isotopic stages (and substages) of the benthic Foraminifera curve, estimated from 57 curves on a worldwide scale, but with a higher frequency from the Atlantic (Lisiecki and Raymo 2005, Figure 4, p. 6). This curve, besides its broad sampling and its weighting in favor of the Atlantic, provides continuous values throughout the chronological period, which is not the case with other curves that are more centered on Europe.

To test the model of Neanderthal cultural reactivity, we used two routine statistical techniques. The first is a simple linear regression of the lithic diversity index $D$ of the sample of the archaeological layers on the explanatory variables $y = a + bx' + e$, where $y$ is the index of lithic diversity $D$, $a$ is a constant, $b$ is the vector of the regression coefficients, $x'$ is the vector of the transposed data, with $x_1$ being the chronology that expresses underlying technological progress and $x_2$ being the benthic value that expresses the effect of climate as a continuous variable and not simply as stage and substage, and $e$ is an unexplained residual. This test is intended to measure the lithic cultural reactivity of the series of archaeological layers and benthic values on a continuous basis.

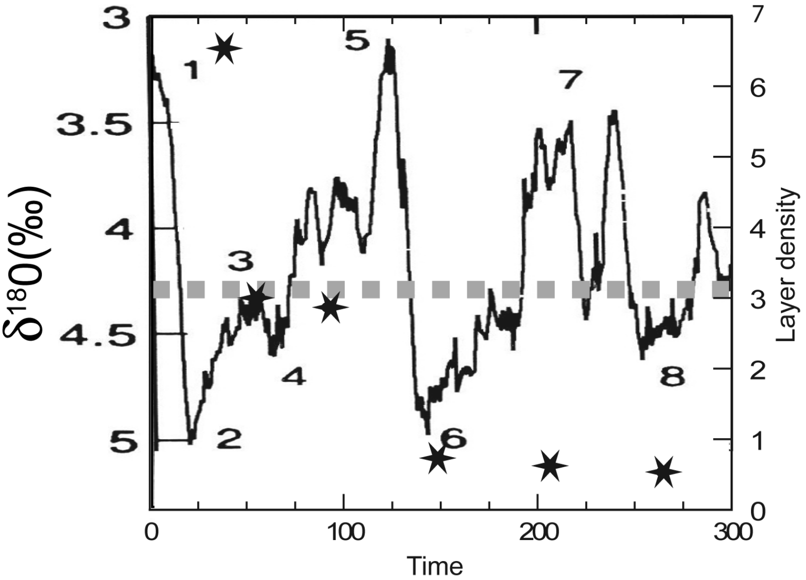

**Figure 3.** Variation in the density of the archaeological assemblages (stars, right-hand scale), superimposed on temperature variations represented by benthic foraminifer records of $\delta^{18}O$ (continuous line, left-hand scale). Hatched gray line: boundary of the cool isotopic stage 3.

## Results

**Variation in the Density of Middle Paleolithic Archaeological Assemblages over Time.** Figure 3 shows the variation in the density of the archaeological assemblages across isotopic stages 8 to 3 (stars) superimposed on temperature variations, represented by benthic foraminifer records of $\delta^{18}O$ (continuous line). To compare these two variations, their units of measurement (ordinate values) were forced onto the same vertical axis. The distribution of the density of the archaeological assemblage shows, as one would expect, a steady reduction over time. Although the degree of information definition is temporally broad, about 40,000 years, two noncontradictory interpretations of this distribution of the assemblage density per unit of time are possible.

The first interpretation is taphonomic: Preserved archaeological information becomes degraded over time. But the degradation function and its intensity are unknown (linear? asymptotic?). The observed assemblage density is the residue of this degradation. As an example, Figure 4 shows the observed density along with three simulated corrected densities, using the assumption that out of the number of observed sites, a linear degradation of information has occurred in 0.5, 1, and 2 sites per millennium, which must be added. The second interpretation of the assemblage density is demographic, using the assumption that the density is roughly

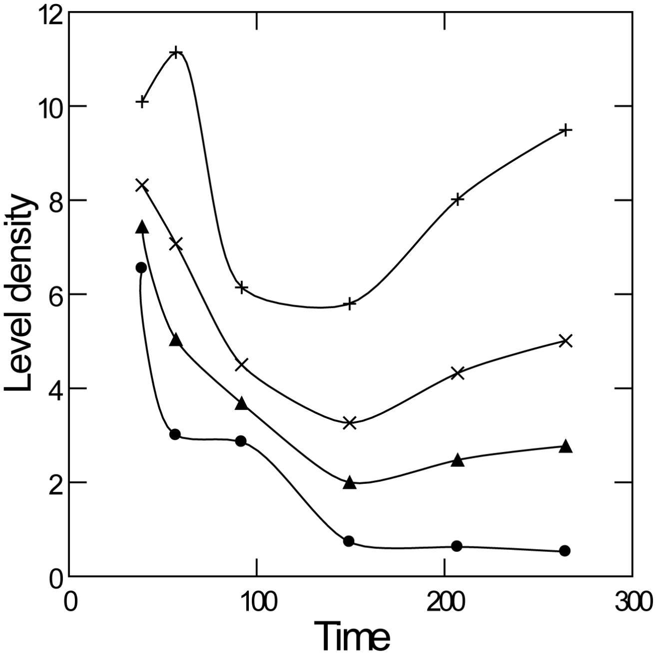

**Figure 4.** Observed density (circles) and three simulated corrected densities under the assumption that other sites must be added to the number of observed sites, representing a linear degradation of information of 0.5 site (triangles), 1 site (crosses), and 2 sites (pluses) per millennium.

proportional to that of the metapopulation (see Bocquet-Appel and Demars 2000; Bocquet-Appel et al. 2005; Gamble 1983; van Andel et al. 2003). Figure 3 shows demographic density remaining roughly stationary from isotopic glacial stage 8 (275,000 years) to stage 6 (150,000 years), after which the demographics of the metapopulation expanded rapidly up to isotopic stage 5.3 (100,000 years), stabilizing until the middle of isotopic stage 3 (50,000–55,000 years), when they took off once more, coming to an abrupt end toward 30,000 years, which coincided with the arrival of anatomically modern humans. But whatever the density distribution, whether observed or corrected using various hypotheses for the linear degradation of information (see Figure 4), we do not see the expected covariation between climate change (the proxy for secondary biomass) and demographic change (see Figure 3)—such as that observed by van Andel et al. (2003) with the number of Mousterian sites between 70,000 and 25,000 years—except, partly, for the correction of the highest density (simulated density 2 in Figure 4). But, in Figure 4, if temperature and density coincide roughly in the 250,000–150,000-year segment, then they no longer coincide afterward. If the climatic variation validates the demographic model of interpretation of the density of archaeological assemblages by their expected covariation, then, even if a possible linear degradation of

**Table 1.** Parameter Estimates of the Linear Model Expressing the Index of Lithic Cultural Diversity (Shannon's D) by Chronological Technological Progress (Chronology) and the Impact of Climatic Variation (Benthic)

| *Effect* | *Coefficient* | *Standard Error* | *Standard Coefficient* | *t* | *P* |
|---|---|---|---|---|---|
| Constant | 2.675 | 0.636 | 0.000 | 4.209 | 0.000 |
| Chronology | 0.004 | 0.001 | 0.269 | 3.798 | 0.000 |
| Benthic | 0.147 | 0.148 | 0.070 | 0.992 | 0.322 |

$R^2 = 0.073$, $P = 0.001$.

information is taken into account, the demographic interpretation of the density of Mousterian sites is rejected.

**Variation in the Diversity of Lithic Tools.** Before giving the test results, we must first state that we did not detect any effect of climatic conditions on the geographically sampled data. Correlations between the geographic coordinates of the sites (layers) and their estimated benthic values, although they tend toward the intuitively expected direction, are nil (benthic, with latitude $\cong 0.141$, $P = 0.32$; with longitude $= 0.012$, $P = 1.0$). The result of the regression of the lithic diversity index $D$ on chronology and climate is given in Table 1, which shows a highly significant chronology effect and a nil climatic effect.

Figure 5 shows the distribution of the diversity index $D$ by chronology. The average tendency is obtained through a local loess fit ($\alpha = 0.30$). This average tendency can be subdivided into two segments. The first, lasting from 260,000 to 150,000 years, shows a drop in the diversity index $D$ from 4.2 to 3.5. This reduction of the diversity index is probably the expression of the reduction in the number of Acheulean bifaces during stages 8 to 6 and of their replacement by Micoquian shapes. MAT bifaces appear later, mainly in stage 5. The second segment, lasting from 150,000 to 40,000 years, shows an absence of average change despite the presence of MAT bifaces.

We interpret Figure 5 as representing technological inertia among Neanderthals for both lithic tools and derived perishable products during the four cool to cold macroclimatic periods they experienced. The Neanderthal panoply of lithic tools was very much all-purpose, capable of adapting to all Neanderthal situations of food gathering, whether direct or indirect, from their natural environment. At the current stage of observations, it is difficult to make the link with the classic debate on the meaning of the Mousterian variability of lithic industries (cf. Binford and Binford 1966; Bordes and Sonneville-Bordes 1970; Dibble and Rolland 1992; Mellars 1969). It can be observed, however, that this variability, which is mainly ascribable to geographic conditions (access to raw materials) and cultural factors (development of stylistic traditions and specific debitage techniques), does not seem to be directly linked to demographic factors and carrying capacity.

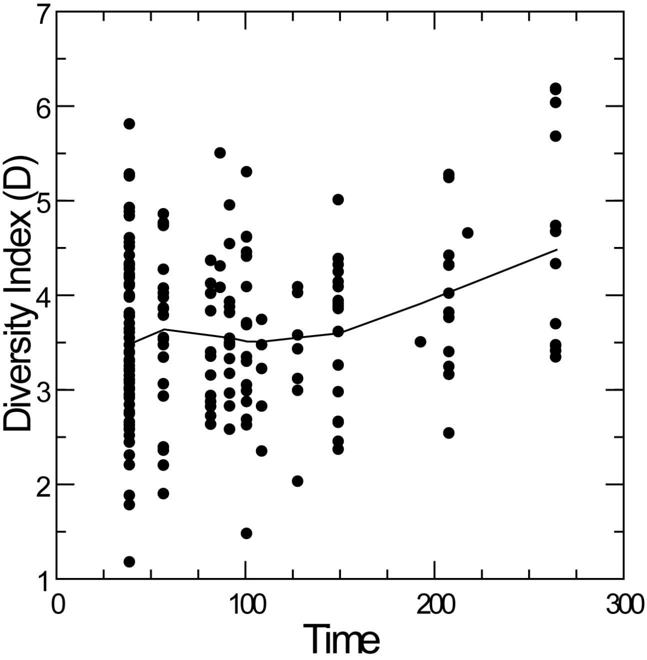

**Figure 5.** Distribution of the diversity index $D$ according to the chronology of 190 lithic assemblages from 103 sites. The average trend is obtained with a local loess fit ($\alpha = 0.30$).

## Discussion and Concluding Remarks

Some difficulties were encountered with the collection of qualitative and quantitative data on the distribution of the tools in the lithic assemblages, as a result of changes in study methods in the last 20 years and the limitations of the Bordes method, which does not take the diversity of debitage methods in Middle Paleolithic assemblages into account. Developments in technology analyses have brought considerable progress by allowing a dynamic view of lithic material (Inizan et al. 1999; Tixier et al. 1980). However, an undesired consequence has been a considerable increase in the number of publications that do not always take the lithic industries fully into consideration and offer quantitative data that are only partial or scattered in different papers. In addition, where debitage methods are concerned, the Bordes counts focus on the Levallois method, so that the diversity observable in the Middle Paleolithic assemblages is not apparent. It is impossible to identify laminar debitage, recognized since the 1980s (Révillion and Tuffreau 1994), and the now better-known discoid method (Boëda 1993). With the development of the technological approaches and the use of the concept of reducing sequence (*chaîne opératoire*), we now have detailed publications that give us more data about the behavior of the Neanderthals, especially for the socioeconomic aspects in relation to environmental constraints, since the procurement of the raw material until it is discarded. It is unfortunately impossible to take account of these data in a Bordian count.

It would have been interesting to measure the technological reactivity of early European modern humans to the climate and to compare it with that of Neanderthals. But besides the impossibility of expressing this lithic typological variability with the same set of items common to both metapopulations, it should also be borne in mind that one of the major technological innovations of early European modern humans was the use of raw animal materials (bone and ivory), which were used by groups of Neanderthals only when their metapopulation was close to extinction.

The recent analytical approaches to Middle Paleolithic technology with the use of the reducing sequence concept and detailed functional studies provide more information for a better knowledge of Neanderthal behavior. Nevertheless, these new approaches are of little use for the purpose of this paper, which was the technological responses of the Neanderthals to macroclimatic variations. In many recent publications, we can see a lack of standardization in the presentation of the results contrary to the Bordian method, whose limits are, however, clear. It would be useful to find a way to quantify all the aspects of the new Middle Paleolithic data so that we could progress to a better understanding of the economic reactivity of the Neanderthals to climatic variations. Doubtless, the need for multiregional studies will probably have repercussions on the presentation of studies in Middle Paleolithic industries.

With the current representation of the data, at least two noncontradictory hypotheses can be put forward to explain the apparent technological inertia of Neanderthal stone tools: The first calls on cognition, the second on demography.

As the metapopulation of *Homo erectus*, after *Homo antecessor*, evolved toward the Neanderthal and became isolated in Europe from the remainder of the *H. erectus* territory for some 500,000 years, its average cerebral volume was nevertheless similar to or even larger than that of anatomically modern humans at the time of contact. Although brain size was about 1,100–1,400 cm$^3$ at Atapuerca SH (Sima de les Huesos) (crania 4 and 5; Arsuaga 2009), it had enlarged to 1,200–1,900 cm$^3$ in the last Neanderthals, as against only 1,350 cm$^3$ on average in anatomically modern humans (Stanyon et al. 1993). To produce a similar increase in the cerebral volume of the two reproductively isolated metapopulations over the same duration, we must consider a selective mechanism favoring intelligence, also similar. But the contradiction is that the large Neanderthal brain does not seem to have reacted cognitively in the same efficient direction as that of anatomically modern humans of the Upper Paleolithic. Alternatively, the so-called transitional cultures must be regarded as a demonstration of the cognitive capabilities and potential of the Neanderthals to bring themselves rapidly up to the mark (Hublin et al. 1996).

It should be remembered that the production of innovations does not depend solely on the biological cognitive capacities of a population. For the same cognitive capacity, using the simple assumption that innovations are produced at a low frequency in any population, the most demographically numerous population in absolute terms will produce the greatest number of innovations (Kuznets 1973; Simon 1977). Therefore, along with the assumption of cognitive efficiency, we can also put forward the assumption of a Neanderthal metapopulation that might have been trapped in a hunter-gatherer production system that determined a low carrying capacity, about a few thousand individuals, and maintained the Neanderthal metapopulation in a state of demographic equilibrium but restrained its potential technical creativity precisely because of the smallness of its number: a Malthusian trap. The technical and social characteristics of the Neanderthal production system might have been strong residential mobility, following animal herds; direct and dangerous contact with prey animals by killing with lances, rather than by delivering death from a distance using projectiles (spears) (Gamble 1999), with the aid of beaters; and no division of labor by sex (or by age?) (Kuhn and Stiner 2006) between hunting and gathering, as observed ethnographically (i.e., with both males and females working as hunters and beaters). The example of Australian hunter-gatherer demography at the time of Western contact, with 900,000–1 million individuals (Lourandos 1997: 38) being invaded across a continent of approximately 7,600,000 km$^2$, and the advantages, on the side of the Western invaders, of technological production from tens of millions of individuals, gives an idea of the impact of numbers on technological development.

In this study we have attempted to model and quantify the Neanderthal response to macroenvironmental variations using the traditional Bordes lithic attributes over a coefficient of lithic diversity. Work still remains to be done to distinguish between the causes of the Neanderthals' disappearance that can be attributed to their cognition and those that can be assigned to the consequences of their demography.

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**Appendix.** Distribution of 190 Lithic Assemblages from 103 Middle Paleolithic Archaeological Sites Divided into 10 Bordes Typological Categories, Representing the Reduced Data Set

| *Site* | *Level* | *Culture* | *Maximum Isotopic Stage* | *Minimum Isotopic Stage* | *$\delta^{18}O$ Max.* | *$\delta^{18}O$ Min.* |
|---|---|---|---|---|---|---|
| Salzgitter-Lebenstedt | B1 | Micoquian | 3 | 3 | 4.29 | 4.29 |
| Sclayn | IA | Charente Mousterian | 3 | 3 | 4.29 | 4.29 |
| Carigüela | 1, unit 7b | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Cueva Morin | 17 sup. | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
| Gorham Cave | G | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
| Arcy-sur-Cure Cave | F | Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | E | Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | H | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | G | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | XII | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
| Baume de Gigny | XX | Mousterian racloirs | 3 | 3 | 4.29 | 4.29 |
| Baume des Peyrards | 9–5 | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Bois-du-Rocher | Ser. I | Mousterian, Acheulean | 3 | 3 | 4.29 | 4.29 |
|  | Ser. II | Mousterian, Acheulean | 3 | 3 | 4.29 | 4.29 |
| Caminade-Est | M2 | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Combe-Capelle bas | I-1B | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | I-1C1 | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | I-1D | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | I-1E | Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | II-4A | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | II-4C | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | III-1B | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | II-3A | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | I-2A | Mousterian racloirs | 3 | 3 | 4.29 | 4.29 |
| Corbehem | Terrassement | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Esquicho-Grapaou | Br2 | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| Ferrassie (large shelter) | M2e | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
|  | M2c | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Ferrassie (small shelter) | Mousterian | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Goaréva | 2 | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Hermies. le Tio Marché | Section 12 | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Ioton | Ag | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Jiboui | 3 | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Kervouster | 2 | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
|  | 3 | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
|  | 4a | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
|  | 4c | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
|  | 5 | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
| La Quina | 3 | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| La Rochette | 7 | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
| Le Moustier | G | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
| Maras | 3 | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Marillac | 10 | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| Mauran | II | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Pech de l’Azé IV | J3a | Asinipodien | 3 | 3 | 4.29 | 4.29 |
|  | F4 | Mousterian, Acheulean A | 3 | 3 | 4.29 | 4.29 |

| *Average Age (ky BP)* | *Calculated Flint Tool Total* | *Stated Flint Tool Total* | *Residual Flint Tools* | *Number of Scrapers* | *Number of Upper Paleolithic Tools* | *Number of Encoches* | *Number of Denticulates* | *Number of Acheulean Bifaces* | *Number of Micoquian MTA Bifaces* | *Number of Foliates* | *Number of Choppers and Chopping Tools* | *Diversity Index* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 407 | 320 | 128 | 142 | 11 | 36 | 3 | 0 | 87 | 0 | 0 | 4.09 |
| 39 | 27 | 26 | 26 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1.17 |
| 39 | 248 | 248 | 49 | 156 | 13 | 12 | 18 | 0 | 0 | 0 | 0 | 3.01 |
| 39 | 373 | 373 | 48 | 90 | 73 | 56 | 106 | 0 | 0 | 0 | 0 | 5.27 |
| 39 | 31 | 31 | 4 | 13 | 3 | 0 | 11 | 0 | 0 | 0 | 0 | 3.39 |
| 39 | 77 | 76 | 1 | 39 | 4 | 16 | 16 | 0 | 1 | 0 | 0 | 3.54 |
| 39 | 54 | 54 | 1 | 31 | 1 | 9 | 12 | 0 | 0 | 0 | 0 | 3.00 |
| 39 | 77 | 77 | 2 | 6 | 13 | 27 | 29 | 0 | 0 | 0 | 0 | 3.78 |
| 39 | 86 | 86 | 4 | 11 | 1 | 29 | 41 | 0 | 0 | 0 | 0 | 3.25 |
| 39 | 492 | 492 | 7 | 101 | 68 | 30 | 286 | 0 | 0 | 0 | 0 | 3.14 |
| 39 | 118 | 118 | 8 | 93 | 10 | 4 | 3 | 0 | 0 | 0 | 0 | 2.20 |
| 39 | 315 | 201 | 16 | 115 | 11 | 28 | 31 | 0 | 0 | 0 | 0 | 3.47 |
| 39 | 201 | 110 | 12 | 55 | 10 | 22 | 11 | 0 | 91 | 0 | 0 | 4.19 |
| 39 | 371 | 191 | 42 | 77 | 11 | 28 | 33 | 0 | 180 | 0 | 0 | 4.21 |
| 39 | 76 | 76 | 0 | 55 | 8 | 7 | 6 | 0 | 0 | 0 | 0 | 2.44 |
| 39 | 171 | 171 | 0 | 59 | 14 | 15 | 85 | 0 | 0 | 0 | 0 | 3.10 |
| 39 | 124 | 124 | 4 | 44 | 4 | 12 | 60 | 0 | 0 | 0 | 0 | 3.21 |
| 39 | 235 | 235 | 2 | 84 | 14 | 13 | 122 | 0 | 0 | 0 | 0 | 2.94 |
| 39 | 179 | 179 | 42 | 80 | 8 | 23 | 26 | 0 | 0 | 0 | 0 | 3.99 |
| 39 | 67 | 67 | 0 | 29 | 3 | 18 | 31 | 0 | 0 | 0 | 0 | 3.29 |
| 39 | 104 | 104 | 0 | 36 | 9 | 33 | 48 | 0 | 0 | 0 | 0 | 3.54 |
| 39 | 52 | 52 | 0 | 17 | 8 | 11 | 20 | 0 | 0 | 0 | 0 | 3.77 |
| 39 | 31 | 31 | 21 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 1.88 |
| 39 | 159 | 159 | 23 | 63 | 9 | 41 | 23 | 0 | 0 | 0 | 0 | 4.21 |
| 39 | 95 | 95 | 9 | 37 | 9 | 24 | 16 | 0 | 0 | 0 | 0 | 4.31 |
| 39 | 118 | 118 | 16 | 79 | 1 | 8 | 14 | 0 | 0 | 0 | 0 | 2.76 |
| 39 | 335 | 335 | 0 | 213 | 24 | 35 | 72 | 0 | 0 | 0 | 0 | 2.84 |
| 39 | 69 | 69 | 0 | 46 | 1 | 12 | 14 | 0 | 0 | 0 | 0 | 2.62 |
| 39 | 193 | 193 | 4 | 137 | 15 | 9 | 28 | 0 | 0 | 0 | 0 | 2.57 |
| 39 | 158 | 158 | 12 | 48 | 23 | 47 | 28 | 0 | 0 | 0 | 0 | 4.51 |
| 39 | 218 | 218 | 0 | 8 | 45 | 102 | 63 | 0 | 0 | 0 | 0 | 3.19 |
| 39 | 200 | 200 | 31 | 140 | 8 | 9 | 12 | 0 | 0 | 0 | 0 | 2.65 |
| 39 | 134 | 134 | 15 | 75 | 12 | 14 | 18 | 0 | 0 | 0 | 0 | 3.64 |
| 39 | 155 | 154 | 11 | 35 | 42 | 53 | 13 | 0 | 1 | 0 | 0 | 4.41 |
| 39 | 140 | 135 | 0 | 39 | 36 | 48 | 22 | 0 | 5 | 0 | 0 | 4.27 |
| 39 | 58 | 57 | 0 | 20 | 9 | 18 | 26 | 0 | 1 | 0 | 0 | 3.97 |
| 39 | 96 | 89 | 0 | 17 | 29 | 0 | 43 | 0 | 7 | 0 | 0 | 3.38 |
| 39 | 113 | 108 | 0 | 22 | 22 | 0 | 64 | 0 | 5 | 0 | 0 | 3.00 |
| 39 | 505 | 505 | 0 | 397 | 15 | 53 | 78 | 0 | 0 | 0 | 0 | 2.30 |
| 39 | 305 | 305 | 0 | 258 | 38 | 28 | 40 | 0 | 0 | 0 | 0 | 2.51 |
| 39 | 1217 | 831 | 25 | 201 | 85 | 200 | 320 | 0 | 386 | 0 | 0 | 4.83 |
| 39 | 58 | 58 | 8 | 31 | 11 | 8 | 0 | 0 | 0 | 0 | 0 | 3.31 |
| 39 | 133 | 133 | 0 | 70 | 5 | 25 | 37 | 0 | 0 | 0 | 0 | 3.09 |
| 39 | 135 | 110 | 16 | 18 | 3 | 24 | 49 | 0 | 0 | 0 | 25 | 4.92 |
| 39 | 144 | 144 | 20 | 30 | 26 | 40 | 28 | 0 | 0 | 0 | 0 | 4.88 |
| 39 | 683 | 674 | 49 | 235 | 62 | 153 | 175 | 0 | 9 | 0 | 0 | 4.55 |

**Appendix.** (*continued*)

| *Site* | *Level* | *Culture* | *Maximum Isotopic Stage* | *Minimum Isotopic Stage* | *$\delta^{18}O$ Max.* | *$\delta^{18}O$ Min.* |
|---|---|---|---|---|---|---|
| | Z | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| | I2 | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| | X | Mousterian racloirs | 3 | 3 | 4.29 | 4.29 |
| | J2 | Mousterian racloirs | 3 | 3 | 4.29 | 4.29 |
| | F2 | Mousterian, Acheulean B | 3 | 3 | 4.29 | 4.29 |
| Prélétang | I | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Saint-Césaire | Egpf | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
| Combe-Grenal | 11 | Denticulate Mousterian | 3 | 3 | 4.29 | 4.29 |
| Erd | e | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| Szeleta | 2 | Szelet ancien | 3 | 3 | 4.29 | 4.29 |
| | 3 | Szelet récent | 3 | 3 | 4.29 | 4.29 |
| Amud | B2 | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Rosh Ein Mor | Unique | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Fumane | A9 | Mousterian racloirs | 3 | 3 | 4.29 | 4.29 |
| Guattari | 2 | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| | 1 | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| Mezzena | III | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| | II | Ferrassie Mousterian | 3 | 3 | 4.29 | 4.29 |
| Romanelli | G | Quina Mousterian | 3 | 3 | 4.29 | 4.29 |
| Dzierzyslaw (site I) | Unit 4 | Bohunic | 3 | 3 | 4.29 | 4.29 |
| Ripiceni Izvor | VI | Mousterian | 3 | 3 | 4.29 | 4.29 |
| Brno-Bohunice | Briqueterie | Bohunic | 3 | 3 | 4.29 | 4.29 |
| Külna | 6a | Micoquian | 3 | 3 | 4.29 | 4.29 |
| Omal | 13 | Ferrassie Mousterian | 4 | 4 | 4.55 | 4.55 |
| Beauvais | 2 | Mousterian | 4 | 4 | 4.55 | 4.55 |
| Brugas | 4 | Quina Mousterian | 4 | 4 | 4.55 | 4.55 |
| Combe-Grenal | 35 | Ferrassie Mousterian | 4 | 4 | 4.55 | 4.55 |
| | 22 | Quina Mousterian | 4 | 4 | 4.55 | 4.55 |
| Fitz-James | Section 1 | Mousterian | 4 | 4 | 4.55 | 4.55 |
| Hamel | 10 | Mousterian, Acheulean B | 4 | 4 | 4.55 | 4.55 |
| Haute-Roche | 3 | Mousterian | 4 | 4 | 4.55 | 4.55 |
| Lailly Beauregard | I | Mousterian, Acheulean A | 4 | 3 | 4.55 | 4.29 |
| Mirefleurs | 6 and 4 | Quina Mousterian | 4 | 3 | 4.55 | 4.29 |
| Pech de l'Azé I | 4 | Mousterian, Acheulean A | 4 | 4.3 | 4.55 | 4.30 |
| Riencourt-lès-Bapaume | B1 | Micoquian | 4 | 4 | 4.55 | 4.55 |
| | C (partial) | Ferrassie Mousterian | 4 | 4 | 4.55 | 4.55 |
| | B2 | Mousterian | 4 | 4 | 4.55 | 4.55 |
| Saint-Brice-sous-Rânes | Parcel 6-T1 | Micoquian | 4 | 3 | 4.55 | 4.29 |
| VaufreyCave XVI | C | Mousterian, Acheulean A | 4 | 4 | 4.55 | 4.55 |
| Tor Faraj | A | ? | 4 | 4 | 4.55 | 4.55 |
| Guattari | 5 | Quina Mousterian | 4 | 4 | 4.55 | 4.55 |
| | 4 | Quina Mousterian | 4 | 4 | 4.55 | 4.55 |
| Ripiceni Izvor | IV | Micoquian | 4 | 4 | 4.55 | 4.55 |
| Külna | 7a | Micoquian | 4 | 4 | 4.55 | 4.55 |
| Bérigoule | I (partial) | Ferrassie Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Bettencourt-Saint-Ouen | N2b | Laminar Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Etoutteville | 4a | Laminar Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Gouy-Saint-André | Unit 4 | Laminar Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |

| *Average Age (ky BP)* | *Calculated Flint Tool Total* | *Stated Flint Tool Total* | *Residual Flint Tools* | *Number of Scrapers* | *Number of Upper Paleolithic Tools* | *Number of Encoches* | *Number of Denticulates* | *Number of Acheulean Bifaces* | *Number of Micoquian MTA Bifaces* | *Number of Foliates* | *Number of Choppers and Chopping Tools* | *Diversity Index* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 191 | 191 | 11 | 124 | 24 | 17 | 15 | 0 | 0 | 0 | 0 | 3.07 |
| 39 | 920 | 920 | 77 | 664 | 53 | 73 | 53 | 0 | 0 | 0 | 0 | 2.65 |
| 39 | 867 | 867 | 70 | 474 | 87 | 116 | 120 | 0 | 0 | 0 | 0 | 3.69 |
| 39 | 161 | 181 | 13 | 123 | 18 | 12 | 15 | 0 | 0 | 0 | 0 | 2.91 |
| 39 | 167 | 160 | 4 | 19 | 22 | 50 | 65 | 0 | 7 | 0 | 0 | 4.33 |
| 39 | 39 | 39 | 6 | 18 | 7 | 3 | 5 | 0 | 0 | 0 | 0 | 4.11 |
| 39 | 290 | 290 | 0 | 12 | 21 | 78 | 179 | 0 | 0 | 0 | 0 | 2.65 |
| 39 | 65 | 65 | 0 | 3 | 2 | 35 | 25 | 0 | 0 | 0 | 0 | 2.59 |
| 39 | 808 | 808 | 193 | 512 | 66 | 23 | 14 | 0 | 0 | 0 | 0 | 2.74 |
| 39 | 369 | 256 | 98 | 28 | 33 | 45 | 52 | 0 | 113 | 0 | 0 | 5.25 |
| 39 | 88 | 23 | 23 | 0 | 0 | 0 | 0 | 0 | 65 | 0 | 0 | 1.78 |
| 39 | 72 | 72 | 22 | 16 | 31 | 1 | 2 | 0 | 0 | 0 | 0 | 3.38 |
| 39 | 3723 | 3723 | 1458 | 219 | 930 | 752 | 364 | 0 | 0 | 0 | 0 | 4.18 |
| 39 | 86 | 86 | 6 | 47 | 6 | 12 | 15 | 0 | 0 | 0 | 0 | 3.60 |
| 39 | 258 | 158 | 38 | 91 | 9 | 8 | 12 | 0 | 0 | 0 | 100 | 3.99 |
| 39 | 69 | 69 | 16 | 45 | 1 | 3 | 4 | 0 | 0 | 0 | 5 | 3.19 |
| 39 | 1344 | 1344 | 88 | 935 | 64 | 76 | 181 | 0 | 0 | 0 | 0 | 2.74 |
| 39 | 454 | 454 | 28 | 300 | 20 | 42 | 64 | 0 | 0 | 0 | 0 | 2.94 |
| 39 | 162 | 162 | 35 | 83 | 8 | 15 | 21 | 0 | 1 | 0 | 0 | 3.81 |
| 39 | 66 | 66 | 23 | 9 | 13 | 14 | 7 | 0 | 0 | 0 | 0 | 4.60 |
| 39 | 36 | 36 | 6 | 9 | 1 | 13 | 7 | 0 | 0 | 0 | 0 | 4.18 |
| 39 | 348 | 324 | 83 | 55 | 87 | 38 | 61 | 0 | 14 | 10 | 0 | 5.80 |
| 39 | 311 | 296 | 52 | 131 | 39 | 41 | 33 | 0 | 15 | 0 | 0 | 4.83 |
| 57 | 333 | 324 | 7 | 263 | 30 | 0 | 24 | 0 | 7 | 0 | 2 | 2.19 |
| 57 | 0 | 92 | 7 | 25 | 43 | 8 | 9 | 0 | 1 | 0 | 0 | 4.02 |
| 57 | 248 | 248 | 21 | 162 | 18 | 17 | 30 | 0 | 0 | 0 | 0 | 3.06 |
| 57 | 719 | 716 | 29 | 612 | 22 | 32 | 21 | 0 | 0 | 0 | 3 | 1.89 |
| 57 | 716 | 716 | 0 | 633 | 56 | 61 | 111 | 0 | 0 | 0 | 0 | 2.35 |
| 57 | 51 | 51 | 0 | 12 | 0 | 21 | 18 | 0 | 0 | 0 | 0 | 2.93 |
| 57 | 288 | 272 | 45 | 125 | 39 | 28 | 35 | 0 | 15 | 0 | 1 | 4.85 |
| 57 | 102 | 102 | 1 | 36 | 9 | 42 | 14 | 0 | 0 | 0 | 0 | 3.54 |
| 57 | 270 | 253 | 91 | 110 | 33 | 0 | 19 | 0 | 17 | 0 | 0 | 3.86 |
| 57 | 378 | 378 | 132 | 225 | 6 | 0 | 15 | 0 | 0 | 0 | 0 | 2.39 |
| 57 | 2222 | 2081 | 495 | 788 | 73 | 233 | 492 | 0 | 141 | 0 | 0 | 4.76 |
| 57 | 942 | 950 | 169 | 453 | 29 | 160 | 139 | 0 | 0 | 0 | 0 | 3.85 |
| 57 | 386 | 386 | 21 | 166 | 30 | 99 | 70 | 0 | 0 | 0 | 0 | 3.97 |
| 57 | 277 | 277 | 11 | 97 | 9 | 43 | 117 | 0 | 0 | 0 | 0 | 3.53 |
| 57 | 43 | 20 | 3 | 12 | 3 | 2 | 0 | 0 | 23 | 0 | 0 | 3.34 |
| 57 | 130 | 111 | 0 | 42 | 19 | 30 | 20 | 0 | 19 | 0 | 0 | 4.73 |
| 57 | 90 | 90 | 44 | 4 | 28 | 8 | 6 | 6 | 0 | 0 | 0 | 4.07 |
| 57 | 125 | 125 | 21 | 83 | 2 | 12 | 7 | 0 | 0 | 0 | 50 | 3.78 |
| 57 | 247 | 247 | 39 | 175 | 12 | 9 | 12 | 0 | 0 | 0 | 50 | 3.47 |
| 57 | 1621 | 1364 | 297 | 842 | 56 | 74 | 95 | 0 | 200 | 57 | 0 | 4.27 |
| 57 | 1120 | 1049 | 121 | 495 | 174 | 165 | 94 | 0 | 71 | 0 | 0 | 4.74 |
| 82 | 313 | 313 | 7 | 214 | 13 | 41 | 38 | 0 | 0 | 0 | 0 | 2.72 |
| 82 | 67 | 67 | 0 | 35 | 13 | 8 | 11 | 0 | 0 | 0 | 0 | 3.35 |
| 82 | 37 | 37 | 0 | 28 | 0 | 9 | 11 | 0 | 0 | 0 | 0 | 2.63 |
| 82 | 9 | 9 | 0 | 3 | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 3.83 |

**Appendix.** (*continued*)

| *Site* | *Level* | *Culture* | *Maximum Isotopic Stage* | *Minimum Isotopic Stage* | *$\delta^{18}O$ Max.* | *$\delta^{18}O$ Min.* |
|---|---|---|---|---|---|---|
| La Roche-Tonnerre | | Ferrassie Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| La Trinité | Series south | Ferrassie Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| | Series north | Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Les Canalettes | 2 | Mousterian racloirs | 5.1 | 5.1 | 3.82 | 3.82 |
| Pech de l'Azé II | 4B | Denticulate Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Saint-Just-en-Chaussée | Superior | Mousterian, Acheulean A | 5.1 | 5.1 | 3.82 | 3.82 |
| Spagnoli (cavity B) | Rp | Quina Mousterian | 5.1 | 5.1 | 3.82 | 3.82 |
| Crvena Stijena (Rou Shelter) | XXIII to XII | Mousterian racloirs | 5.1 | 5.1 | 3.82 | 3.82 |
| Lailly Beauregard | B, layer 3 | Mousterian, Acheulean | 5.2 | 5.1 | 4.17 | 3.82 |
| Molinons/Le Grand Chante | A, layer 4 | Mousterian, Acheulean | 5.2 | 5.1 | 4.17 | 3.82 |
| Villeneuve l'Archevèque | B, layer 3 | Mousterian | 5.2 | 5.1 | 4.17 | 3.82 |
| Zobiste | B, layer 2 | Ferrassie Mousterian | 5 | 5 | 3.70 | 3.70 |
| Krapina | 7–8 | Mousterian | 5 | 5 | 3.70 | 3.70 |
| Busigny | Unique | Mousterian | 5 | 5 | 3.70 | 3.70 |
| Grainfollet | Series I | Micoquian | 5 | 5 | 3.70 | 3.70 |
| | Series II | Micoquian | 5 | 5 | 3.70 | 3.70 |
| Karreg-ar-Yellan | 7 (rock base) | Denticulate Mousterian | 5 | 5 | 3.70 | 3.70 |
| | 7 (shore) | Ferrassie Mousterian | 5 | 5 | 3.70 | 3.70 |
| La Borde | IIIb | Denticulate Mousterian | 5 | 5 | 3.70 | 3.70 |
| Meillers | 1/Bt | Denticulate Mousterian | 5 | 5 | 3.70 | 3.70 |
| Barma Grande | 4 | Mousterian racloirs | 5 | 5 | 3.70 | 3.70 |
| | 3 | Mousterian racloirs | 5 | 5 | 3.70 | 3.70 |
| Spagnoli (cavity B) | Ar-Ne | Quina Mousterian | 5 | 5 | 3.70 | 3.70 |
| Zwolen | L | Micoquian | 5 | 5 | 3.70 | 3.70 |
| Königsaue | A | Micoquian | 5.3 | 5.3 | 3.75 | 3.75 |
| | C | Micoquian | 5.3 | 5.3 | 3.75 | 3.75 |
| | B | Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Visoko Brdo | | Ferrassie Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Bourgeois-Delaunay | 9 | Ferrassie Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Les Fieux | K | Mousterian | 5.3 | 5.1 | 3.75 | 3.82 |
| Briqueterie Debus | Unique | Mousterian, Acheulean A | 5.3 | 5.1 | 3.75 | 3.82 |
| Mont-Dol | 10 | Ferrassie Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Riencourt-lès-Bapaume | II | Ferrassie Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| | CA | Ferrassie laminar Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Sains-en-Amienois | Series A | Denticulate Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Saint-Just-en-Chaussée | Atelier Kelley | Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Seclin | Unit 7 | Laminar Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Vinneuf/Les Hauts Massou | 1, layer 2 | Micoquian | 5.3 | 5.3 | 3.75 | 3.75 |
| Maastricht-Belvédère | J | Mousterian racloirs | 5.3 | 5.3 | 3.75 | 3.75 |
| Ripiceni Izvor | III | Ferrassie Mousterian | 5.3 | 5.3 | 3.75 | 3.75 |
| Külna | 11 | Taubac | 5.3 | 5.3 | 3.75 | 3.75 |
| Bourgeois-Delaunay | 10 | Ferrassie Mousterian | 5.4 | 5.4 | 4.11 | 4.11 |
| Siouville | | Denticulate Mousterian | 5.4 | 5.4 | 4.11 | 4.11 |
| Subalyuk | 11 | Quina Mousterian | 5.4 | 5.4 | 4.11 | 4.11 |
| Colonia Montani | Surface | Mousterian racloirs | 5.4 | 5.4 | 4.11 | 4.11 |
| Ponte de Crispiero | 26 | Mousterian racloirs | 5.4 | 5.4 | 4.11 | 4.11 |
| Sclayn | 5 | Mousterian | 5.5 | 5.3 | 3.09 | 3.75 |
| Gouberville | Unique | Denticulate Mousterian | 5.5 | 5.3 | 3.09 | 3.75 |

| *Average Age (ky BP)* | *Calculated Flint Tool Total* | *Stated Flint Tool Total* | *Residual Flint Tools* | *Number of Scrapers* | *Number of Upper Paleolithic Tools* | *Number of Encoches* | *Number of Denticulates* | *Number of Acheulean Bifaces* | *Number of Micoquian MTA Bifaces* | *Number of Foliates* | *Number of Choppers and Chopping Tools* | *Diversity Index* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 82 | 70 | 68 | 1 | 45 | 8 | 5 | 9 | 0 | 2 | 0 | 0 | 3.15 |
| 82 | 150 | 146 | 5 | 92 | 13 | 23 | 13 | 0 | 4 | 0 | 0 | 3.39 |
| 82 | 92 | 87 | 43 | 0 | 16 | 20 | 8 | 0 | 4 | 0 | 1 | 4.01 |
| 82 | 370 | 370 | 0 | 239 | 13 | 63 | 98 | 0 | 0 | 0 | 0 | 2.87 |
| 82 | 1199 | 1196 | 265 | 173 | 82 | 194 | 482 | 0 | 3 | 0 | 0 | 4.36 |
| 82 | 146 | 83 | 14 | 46 | 7 | 8 | 8 | 0 | 63 | 0 | 0 | 4.12 |
| 82 | 152 | 152 | 16 | 102 | 7 | 12 | 15 | 0 | 0 | 0 | 0 | 2.93 |
| 82 | 339 | 338 | 113 | 192 | 8 | 15 | 10 | 0 | 1 | 0 | 0 | 2.82 |
| 87 | 133 | 131 | 18 | 63 | 13 | 15 | 22 | 0 | 2 | 0 | 0 | 4.30 |
| 87 | 120 | 111 | 17 | 47 | 16 | 12 | 19 | 0 | 9 | 0 | 3 | 5.50 |
| 87 | 121 | 121 | 42 | 43 | 7 | 12 | 17 | 0 | 0 | 0 | 0 | 4.07 |
| 92 | 92 | 92 | 19 | 44 | 11 | 5 | 13 | 0 | 0 | 0 | 0 | 3.92 |
| 92 | 231 | 231 | 0 | 159 | 12 | 20 | 46 | 0 | 0 | 0 | 0 | 2.57 |
| 92 | 585 | 582 | 130 | 262 | 60 | 0 | 130 | 0 | 0 | 0 | 0 | 3.54 |
| 92 | 477 | 449 | 14 | 156 | 88 | 71 | 120 | 0 | 28 | 0 | 2 | 4.95 |
| 92 | 424 | 418 | 0 | 229 | 40 | 64 | 131 | 0 | 6 | 0 | 0 | 3.47 |
| 92 | 305 | 305 | 0 | 60 | 44 | 62 | 158 | 0 | 0 | 0 | 0 | 3.49 |
| 92 | 116 | 114 | 14 | 72 | 4 | 9 | 15 | 0 | 2 | 0 | 0 | 3.32 |
| 92 | 223 | 213 | 26 | 44 | 6 | 51 | 86 | 0 | 0 | 0 | 10 | 4.54 |
| 92 | 66 | 66 | 6 | 13 | 3 | 4 | 40 | 0 | 0 | 0 | 0 | 3.16 |
| 92 | 953 | 953 | 132 | 648 | 34 | 65 | 74 | 0 | 0 | 0 | 0 | 2.82 |
| 92 | 220 | 220 | 11 | 137 | 4 | 25 | 43 | 0 | 0 | 0 | 0 | 2.96 |
| 92 | 339 | 339 | 39 | 179 | 33 | 35 | 53 | 0 | 0 | 0 | 0 | 3.81 |
| 92 | 68 | 68 | 26 | 34 | 4 | 3 | 1 | 0 | 14 | 0 | 0 | 3.87 |
| 101 | 115 | 91 | 47 | 31 | 7 | 3 | 3 | 0 | 24 | 0 | 0 | 4.08 |
| 101 | 23 | 20 | 20 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1.47 |
| 101 | 115 | 114 | 75 | 21 | 6 | 6 | 6 | 0 | 1 | 0 | 0 | 2.98 |
| 101 | 38 | 38 | 9 | 25 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 2.62 |
| 101 | 501 | 501 | 0 | 263 | 55 | 64 | 136 | 0 | 0 | 0 | 0 | 3.29 |
| 101 | 82 | 81 | 25 | 12 | 2 | 19 | 23 | 0 | 1 | 0 | 0 | 4.41 |
| 101 | 109 | 72 | 20 | 32 | 11 | 3 | 6 | 0 | 37 | 0 | 0 | 4.61 |
| 101 | 436 | 436 | 7 | 274 | 45 | 36 | 74 | 0 | 0 | 0 | 1 | 3.04 |
| 101 | 356 | 356 | 92 | 145 | 0 | 70 | 49 | 0 | 0 | 0 | 0 | 3.70 |
| 101 | 123 | 123 | 26 | 46 | 24 | 10 | 17 | 0 | 0 | 0 | 0 | 4.45 |
| 101 | 35 | 31 | 0 | 2 | 12 | 3 | 18 | 0 | 0 | 0 | 4 | 3.68 |
| 101 | 170 | 170 | 42 | 50 | 34 | 32 | 12 | 0 | 0 | 0 | 0 | 4.61 |
| 101 | 27 | 27 | 16 | 8 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 2.68 |
| 101 | 178 | 151 | 61 | 33 | 19 | 12 | 26 | 0 | 27 | 0 | 0 | 5.30 |
| 101 | 79 | 79 | 2 | 40 | 3 | 3 | 31 | 0 | 0 | 0 | 0 | 2.87 |
| 101 | 226 | 226 | 47 | 129 | 9 | 25 | 16 | 0 | 0 | 0 | 0 | 3.34 |
| 101 | 530 | 525 | 67 | 233 | 57 | 103 | 65 | 0 | 0 | 5 | 0 | 4.40 |
| 109 | 122 | 122 | 5 | 60 | 15 | 13 | 29 | 0 | 0 | 0 | 0 | 3.74 |
| 109 | 11 | 11 | 2 | 5 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 2.82 |
| 109 | 203 | 203 | 20 | 154 | 14 | 12 | 3 | 0 | 0 | 0 | 0 | 2.34 |
| 109 | 215 | 215 | 65 | 115 | 9 | 12 | 14 | 0 | 0 | 0 | 0 | 3.22 |
| 109 | 312 | 312 | 84 | 162 | 19 | 32 | 15 | 0 | 0 | 0 | 0 | 3.47 |
| 128 | 163 | 163 | 10 | 65 | 34 | 0 | 54 | 0 | 0 | 0 | 0 | 3.42 |
| 128 | 176 | 176 | 32 | 23 | 9 | 34 | 78 | 0 | 0 | 0 | 0 | 4.08 |

**Appendix.** (*continued*)

| *Site* | *Level* | *Culture* | *Maximum Isotopic Stage* | *Minimum Isotopic Stage* | $\delta^{18}O$ *Max.* | $\delta^{18}O$ *Min.* |
|---|---|---|---|---|---|---|
| Querqueville | Unique | Micoquian | 5.5 | 5.1 | 3.09 | 3.82 |
| Saint-Germain-des-Vaux | D2A | Denticulate Mousterian | 5.5 | 5.5 | 3.09 | 3.09 |
| Tréissény | | Mousterian, Acheulean | 5.5 | 5.5 | 3.09 | 3.09 |
| Subalyuk | 3 | Mousterian racloirs | 5.5 | 5.5 | 3.09 | 3.09 |
| Tata | | Quina Mousterian | 5.5 | 5.5 | 3.09 | 3.09 |
| Abri Suard (La Chaise) | 51 | Ferrassie Mousterian | 6 | 6 | 4.98 | 4.98 |
| Bapaume. les Osiers | Series B | Upper Acheulean | 6 | 6 | 4.98 | 4.98 |
| Barbas I | C′3 base | Acheulean | 6 | 6 | 4.98 | 4.98 |
| Beaumetz-les-Loges | Glossy series | Mousterian | 6 | 6 | 4.98 | 4.98 |
| Combe-Grenal | 59 | Middle Acheuleam | 6 | 6 | 4.98 | 4.98 |
| Mont-de-l’Evangile | LBN | Upper Acheulean | 6 | 6 | 4.98 | 4.98 |
| Le Lazaret | UA25 | Upper Acheulean | 6 | 6 | 4.98 | 4.98 |
| Longavesnes | Unique | Acheulean | 6 | 6 | 4.98 | 4.98 |
| Piégu | G | Ferrassie Mousterian | 6 | 6 | 4.98 | 4.98 |
| Port Pignot | III | Upper Acheulean | 6 | 6 | 4.98 | 4.98 |
| Vaufrey | VIII | Mousterian racloirs | 6 | 6 | 4.98 | 4.98 |
| El Colombo | 11.10.8.6.5 | Mousterian | 6 | 6 | 4.98 | 4.98 |
| Pietraszyn 49 | | Eastern Micoquian | 6 | 6 | 4.98 | 4.98 |
| Ripiceni Izvor | I | Mousterian | 6 | 6 | 4.98 | 4.98 |
| | II | Mousterian | 6 | 6 | 4.98 | 4.98 |
| Cotte-de-St-Brelade | A | Upper Acheulean | 6 | 6 | 4.98 | 4.98 |
| Külna | 14 | Epi-Acheulean | 6 | 6 | 4.98 | 4.98 |
| Cotte-de-St-Brelade | E | Mousterian racloirs | 7.1 | 7.1 | 3.54 | 3.54 |
| Rissori | Ivb | Ferrassie Mousterian | 7 | 7 | 3.70 | 3.70 |
| Bapaume. les Osiers | Series A | Upper Acheulean | 7 | 7 | 3.70 | 3.70 |
| Biache-Saint-Vaast | IIA | Ferrassie Mousterian | 7 | 7 | 3.70 | 3.70 |
| | II base | Ferrassie Mousterian | 7 | 7 | 3.70 | 3.70 |
| Champvoisy | | Ferrassie Mousterian | 7 | 7 | 3.70 | 3.70 |
| Port Pignot | II | Acheulean | 7 | 7 | 3.70 | 3.70 |
| Salouel | All | Denticulate Mousterian | 7 | 7 | 3.70 | 3.70 |
| Vimy | 17 | Upper Acheulean | 7 | 7 | 3.70 | 3.70 |
| Cave of Poggio | 9-3 | Mousterian | 7 | 7 | 3.70 | 3.70 |
| | 2 | | 7 | 7 | 3.70 | 3.70 |
| Cotte-de-St-Brelade | C | Upper Acheulean | 7 | 7 | 3.70 | 3.70 |
| Yarimburgaz Cave | lower layers W–X | Tayac | 7 | 7 | 3.70 | 3.70 |
| Cotte-de-St-Brelade | H | Denticulate Mousterian | 7.3 | 7.3 | 3.54 | 3.54 |
| Mesvin IV | Channels I and II | Mousterian, Acheulean | 8 | 8 | 4.41 | 4.41 |
| Atapuerca | TD, unit IV | Mousterian | 8 | 8 | 4.41 | 4.41 |
| Mont-de-l’Evangile | CLG | Acheulean | 8 | 8 | 4.41 | 4.41 |
| Vallée du Muid | G | Upper Acheulean | 8 | 8 | 4.41 | 4.41 |
| | H | Upper Acheulean | 8 | 8 | 4.41 | 4.41 |
| Les Bosses | Unique | Acheulean | 8 | 8 | 4.41 | 4.41 |
| Orgnac 3 | 4b | Acheulean | 8 | 8 | 4.41 | 4.41 |
| | 4a | Acheulean | 8 | 8 | 4.41 | 4.41 |
| | 3, base | Acheulean | 8 | 8 | 4.41 | 4.41 |
| | 2 | Acheulean | 8 | 8 | 4.41 | 4.41 |
| Saint-Acheul | Bultel-Tellier quarry | Upper Acheulean | 8 | 8 | 4.41 | 4.41 |
| Torre Pagliaccetto | Unit m, layer 8 | Acheulean | 8 | 8 | 4.41 | 4.41 |

| *Average Age (ky BP)* | *Calculated Flint Tool Total* | *Stated Flint Tool Total* | *Residual Flint Tools* | *Number of Scrapers* | *Number of Upper Paleolithic Tools* | *Number of Encoches* | *Number of Denticulates* | *Number of Acheulean Bifaces* | *Number of Micoquian MTA Bifaces* | *Number of Foliates* | *Number of Choppers and Chopping Tools* | *Diversity Index* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128 | 159 | 155 | 8 | 28 | 19 | 18 | 82 | 0 | 4 | 0 | 0 | 4.02 |
| 128 | 160 | 160 | 4 | 32 | 18 | 7 | 99 | 0 | 0 | 0 | 0 | 2.99 |
| 128 | 90 | 64 | 0 | 51 | 8 | 0 | 5 | 0 | 24 | 0 | 2 | 3.11 |
| 128 | 105 | 105 | 10 | 88 | 2 | 3 | 2 | 0 | 2 | 0 | 0 | 2.02 |
| 128 | 2318 | 2318 | 644 | 1196 | 231 | 102 | 145 | 0 | 5 | 0 | 10 | 3.57 |
| 149.5 | 321 | 321 | 3 | 214 | 25 | 15 | 64 | 0 | 0 | 0 | 0 | 2.66 |
| 149.5 | 201 | 193 | 6 | 105 | 27 | 18 | 37 | 8 | 0 | 0 | 0 | 3.93 |
| 149.5 | 1463 | 1296 | 293 | 197 | 71 | 558 | 177 | 167 | 0 | 0 | 0 | 5.00 |
| 149.5 | 105 | 105 | 18 | 45 | 17 | 10 | 15 | 0 | 0 | 0 | 0 | 4.32 |
| 149.5 | 692 | 676 | 87 | 354 | 43 | 78 | 114 | 16 | 0 | 0 | 0 | 4.08 |
| 149.5 | 11 | 4 | 0 | 3 | 1 | 0 | 0 | 7 | 0 | 0 | 0 | 2.36 |
| 149.5 | 99 | 74 | 9 | 44 | 8 | 9 | 4 | 25 | 0 | 0 | 0 | 4.38 |
| 149.5 | 303 | 112 | 16 | 42 | 3 | 21 | 30 | 191 | 0 | 0 | 0 | 3.25 |
| 149.5 | 36 | 36 | 2 | 18 | 7 | 3 | 6 | 0 | 1 | 0 | 0 | 4.14 |
| 149.5 | 80 | 72 | 0 | 14 | 16 | 2 | 40 | 5 | 0 | 0 | 3 | 3.90 |
| 149.5 | 105 | 105 | 0 | 59 | 3 | 3 | 40 | 0 | 0 | 0 | 0 | 2.45 |
| 149.5 | 121 | 121 | 17 | 78 | 3 | 8 | 15 | 0 | 0 | 0 | 0 | 2.97 |
| 149.5 | 42 | 22 | 0 | 12 | 10 | 0 | 0 | 0 | 3 | 0 | 0 | 2.65 |
| 149.5 | 271 | 271 | 79 | 129 | 9 | 23 | 31 | 0 | 0 | 0 | 0 | 3.61 |
| 149.5 | 164 | 164 | 60 | 57 | 6 | 11 | 30 | 0 | 0 | 0 | 0 | 3.85 |
| 149.5 | 0 | 2516 | 280 | 1453 | 285 | 220 | 278 | 70 | 0 | 0 | 0 | 3.88 |
| 149.5 | 35 | 34 | 10 | 15 | 4 | 3 | 2 | 1 | 0 | 0 | 0 | 4.24 |
| 193 | 0 | 398 | 28 | 222 | 25 | 45 | 78 | 0 | 0 | 0 | 0 | 3.50 |
| 208 | 37 | 37 | 14 | 10 | 6 | 3 | 4 | 0 | 0 | 0 | 0 | 4.31 |
| 208 | 76 | 75 | 5 | 34 | 9 | 13 | 14 | 1 | 0 | 0 | 0 | 4.32 |
| 208 | 290 | 290 | 63 | 146 | 29 | 15 | 37 | 0 | 0 | 0 | 0 | 3.76 |
| 208 | 62 | 62 | 11 | 37 | 2 | 7 | 5 | 0 | 0 | 0 | 0 | 3.24 |
| 208 | 318 | 318 | 27 | 234 | 11 | 20 | 26 | 0 | 0 | 0 | 0 | 2.53 |
| 208 | 42 | 36 | 2 | 5 | 6 | 5 | 18 | 2 | 0 | 0 | 4 | 5.27 |
| 208 | 73 | 73 | 7 | 2 | 9 | 14 | 41 | 0 | 0 | 0 | 0 | 3.39 |
| 208 | 400 | 229 | 4 | 109 | 26 | 18 | 72 | 171 | 0 | 0 | 0 | 4.01 |
| 208 | 4300 | 4300 | 954 | 1419 | 194 | 830 | 903 | 0 | 0 | 0 | 0 | 4.41 |
| 208 | 550 | 550 | 99 | 275 | 45 | 34 | 97 | 0 | 0 | 0 | 0 | 3.81 |
| 208 | 0 | 646 | 54 | 426 | 44 | 42 | 80 | 7 | 0 | 0 | 0 | 3.15 |
| 208 | 0 | 538 | 128 | 121 | 45 | 50 | 194 | 0 | 0 | 0 | 64 | 5.24 |
| 218 | 0 | 160 | 36 | 22 | 15 | 47 | 40 | 0 | 0 | 0 | 0 | 4.65 |
| 264.5 | 154 | 136 | 38 | 46 | 30 | 0 | 22 | 0 | 18 | 0 | 0 | 4.73 |
| 264.5 | 49 | 49 | 4 | 5 | 10 | 11 | 19 | 0 | 0 | 0 | 0 | 4.33 |
| 264.5 | 369 | 258 | 45 | 59 | 41 | 35 | 78 | 97 | 0 | 0 | 14 | 6.18 |
| 264.5 | 768 | 725 | 35 | 136 | 84 | 314 | 156 | 43 | 0 | 0 | 0 | 4.67 |
| 264.5 | 1261 | 972 | 21 | 100 | 15 | 709 | 127 | 282 | 0 | 0 | 7 | 3.46 |
| 264.5 | 215 | 165 | 39 | 28 | 7 | 41 | 50 | 14 | 0 | 0 | 36 | 6.17 |
| 264.5 | 262 | 254 | 27 | 160 | 22 | 10 | 35 | 8 | 0 | 0 | 0 | 3.47 |
| 264.5 | 295 | 285 | 27 | 185 | 29 | 12 | 32 | 10 | 0 | 0 | 0 | 3.41 |
| 264.5 | 388 | 371 | 38 | 230 | 33 | 22 | 48 | 17 | 0 | 0 | 0 | 3.69 |
| 264.5 | 465 | 460 | 181 | 212 | 14 | 24 | 29 | 5 | 0 | 0 | 0 | 3.34 |
| 264.5 | 66 | 55 | 8 | 17 | 13 | 6 | 11 | 15 | 0 | 0 | 0 | 5.67 |
| 264.5 | 101 | 98 | 23 | 37 | 9 | 11 | 18 | 51 | 0 | 0 | 24 | 6.03 |