Z

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Paleolithic archaeologists have been recording the three-dimensional coordinates of excavated artifacts for several decades. These data, however, have been put to limited use. Z, or absolute elevation, in particular, is seldom used in analysis despite the fact that it speaks most directly to one of the more important areas of research we have—namely, behavioral change through time. This article addresses this deficiency in two ways. First, it examines the way in which we record elevations. The point is made that the elevations returned by high-resolution recording systems like total stations provide behavioral and site formation data that traditional recording systems are probably incapable of capturing. Second, elevation data from two Middle Paleolithic sites are used to examine changes in behavioral factors that structure the archaeological record and that apparently take place independent of changes in factors which structure the geological record. © 2005 Wiley Periodicals, Inc.

INTRODUCTION

Context is everything when it comes to the interpretation of an archaeological find, and today all archaeologists pay critical attention to documenting the positions of their finds. Although the level of precision of provenience recording varies considerably, most prehistoric archaeologists utilize some sort of technique for fixing three-dimensional (X, Y, and Z) coordinates to at least most of their recovered artifacts. This is often called point proveniencing. Usually, these coordinates are taken in addition to other stratigraphic or contextual information (such as feature, level, layer, etc), and it is most often these latter units, rather than XYZ coordinates, that are relied on when creating, analyzing, and interpreting the artifact assemblages. X and Y, which refer to the horizontal position, can and are used to map and analyze the spatial distribution of artifacts and other remains. There are virtually no analyses, however, based solely on elevation (Z) data (Koetje, 1991), with the one exception being the production of cross-sectional plots, typically used to show the vertical distribution of artifacts within stratigraphically defined units. Given this situation, it is almost worth asking the fundamental question of whether we really need to

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record elevations. But before asking that question, perhaps some effort should be made to see what Z can offer us. As a step in that direction, we ask two related questions in this paper: (1) How good do elevation measurements need to be in order to be useful, and (2) can elevation data provide insights into behaviorally meaningful patterning independent of stratigraphic assignments? What we will show first is that elevation data have not been as useful in the past as they might have been simply because it has not always been recorded well enough; and second, change through time can be beneficially studied with units created on the basis of elevation data and natural stratigraphy.

A little more background and detail should be given for these two questions. The first concerns the precision of provenience information required for certain kinds of interpretations. To a large extent, our measurement of X, Y, and Z follows standard practices in French Paleolithic archaeology, in place since roughly the 1960s, to record three-dimensional coordinates of excavated finds. While we have used a total station to record proveniences since 1986 (Dibble, 1987; Dibble and McPherron, 1988), there is still a lot of variability among French Paleolithic archaeologists in terms of how they point-provenience artifacts. No matter what technique is used, however, recording three-dimensional proveniences takes time and effort, which means that it increases the costs of excavation and decreases the amount of material that can be excavated per field season. Increasing the precision of the measurements is even more expensive, and so balancing the level of precision against these costs is a real issue. What we will show is that increased precision does yield important benefits, in spite of the cost.

The second question has to do with the interpretive potential of elevation data relative to stratigraphic context alone. Like most other Paleolithic archaeologists, we have mostly relied on geologically defined strata to delineate our assemblages. Strata are defined based on criteria such as sediment color, texture, composition, compaction, and lateral facies changes; all of the artifactual material recovered from each stratum is lumped together and considered a somewhat contemporaneous unit—in other words, an assemblage. Thus, geological criteria provide the contextual units for defining archaeological assemblages. In the Lower and Middle Paleolithic, these contextual units are rarely, if ever, direct reflections of past behavior. More direct behavioral units, or features such as burial or storage pits, are seldom encountered. Stratigraphic units can indirectly reflect behavior, though the tools for inferring these behaviors are still being developed (e.g., Goldberg, 1980; Butzer, 1982; Courty et al., 1989; Matthews, 1995; Macphail and Goldberg, 2000; Courty, 2001; Meignen et al., 2001). For instance, the onset of human occupation in a cave can drive away bat populations, which, in turn, affects the geochemistry in ways that affect the composition of the deposits and, ultimately, the stratigraphic aspect of the entire site (Shahack-Gross et al., 2004). Clearly, geologically defined units provide important paleoclimatic and taphonomic information. However, there is no *a priori* reason to think that geologically defined units map accurately onto behaviorally meaningful units, since it is much more likely that the factors controlling the geological record vary independently of human behavior. We will show below that using elevation data independently of geological units provides important information that could otherwise be missed. In one case, changes in behavior are not accompanied by a noticeable change in the stratigraphic record, and, in the other example, behavioral changes and stratigraphic changes are independent of one another throughout the sequence.

PRECISION IN RECORDING Z: HOW GOOD IS GOOD ENOUGH?

There are three criteria used to assess measurements: reliability, accuracy, and precision. Reliability refers to the degree of interobserver error, that is, the amount of variability in the results when the same measurement is taken repeatedly. A reliable measure is one that gives the greatest degree of replicability. Accuracy is the relationship between the measured result and the "true" measure. Inaccuracy is a result of bias in the measurement—it is, on average, understating or overstating the true measure. Precision refers simply to the size of the intervals that can be recorded. So, in the case of provenience information, do we measure to the nearest centimeter, millimeter, or at an even higher precision? Reliability, accuracy, and precision all work together to affect the final result of piece proveniencing.

As noted earlier, there are many ways of recording Z in the field. Hand methods include the use of a level and stadia rod,[1] a water level,[2] and the use of horizontal strings arranged in a triangle at a fixed elevation.[3] A total station records elevation as part of its normal X, Y, and Z calculations based on horizontal and vertical angles and the slope distance from the instrument to a prism held on the point to be recorded. All of these methods, assuming proper setup and care in recording, are equally accurate. Reliability, however, can become an issue in most of them, mainly due to how the excavator holds the meter stick, or in the case of the total station, the prism rod—if not held vertically, the resulting measurement will be in error. In terms of recording Z, they also vary in precision. Undoubtedly the most precise is the total station, which records measurements to the nearest 1 mm, while most hand methods are usually used to record to the nearest centimeter.

To our knowledge, there have been no studies designed to compare these methods directly. The best way to do this, of course, would be to measure the same set of objects by the different methods, though it would be important to replicate field conditions that might underlie varying degrees of care taken by individual excavators. However, we do have two sets of data that show differences obtained by the use of the total station and other hand methods.

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[1] In this case, the level is set up at a known elevation in the global site grid system. To record the elevation of an object, the excavator places a stadia rod on the object and a reading of the relative height is taken through the level.

[2] A water level is constructed by filling a large container to a fixed level. The elevation of the water level in the container is recorded with a level and stadia rod. A long tube from the bottom of the container is attached to a meter stick. The meter stick is held vertically on an object and, as the water in the tube flows to the level in the container, the elevation can then be read off of the meter stick.

[3] In this method, three posts are pounded into the ground arranged in an open, roughly equilateral triangle. A level string is wrapped around them at a fixed elevation, which is recorded with a level and stadia rod. To record an elevation, the excavator places one end of a meter stick vertically on the object and in such a way that the measure is between their eye and the triangle string. Then, by lining up the two strings (thereby avoiding any parallax problem), the elevation of the object relative to the strings is read from the meter stick.

The first example is from the site of Pech IV, a collapsed, Middle Paleolithic cave site in Southwest France, which was most extensively excavated under Bordes' direction from 1970 to 1977 (Bordes, 1975). Bordes was a pioneer in many areas of archaeological method, many of which are still in use today. His techniques are well known to us since (a) one of us (HLD) worked with Bordes at Pech IV for two seasons and (b) we have Bordes' field manual that was used to instruct new students on the excavation methods.

Using the horizontal string method, Bordes piece provenienced all stone artifacts above a minimum size, as well as teeth and bones (if they were not shaft fragments); other artifacts were simply bagged by square, level, and by 5–10-cm spits. As part of our new excavation at the site, one of our first tasks was to create a Geographic Information System (GIS)-based spatial database of provenienced artifacts, which meant entering in the X, Y, and Z coordinates from the handwritten field notebooks.

From 2000 to 2003 we reexcavated a portion of the site to address, among other issues, potential biases in Bordes' collection resulting from his excavation methods (McPherron and Dibble, 2000; McPherron et al., 2001). We used a Topcon GTS-3B total station to record spatial data (McPherron and Dibble, 2002). This instrument records angles with a 5-second precision, and in our experience, has an accuracy of 1 mm or less when recording a fixed prism over the short distances typical of piece-proveniencing artifacts (as opposed to topographic survey). Additional sources of error include the initial installation of the instrument each day, the installation of new station locations, and the way in which the prism is held over the object being recorded. New station locations typically have a random error of 5 mm or less in the combined X, Y, and Z coordinates, and this error is typically introduced only a few times each season (as the total station has to be moved to accommodate changing excavation strategies). Station initialization errors typically vary day to day by 1 mm or less. This error level is achieved by using a reference prism attached to the wall of the site. The error associated with how the prism is held is more difficult to quantify. In our experience, however, we estimate that it is less than 5 mm in the combined X, Y, and Z.[4]

Our excavations, along the western section of the site, continued exactly where Bordes' ended. This gave us an opportunity to compare the results of two very different methods of recording artifact locations in immediately adjacent areas. We found that the higher precision and reliability of the total station mapping reveals patterns that were obscured by the use of the string method for recording elevations. Figure 1 shows the two adjacent sets of squares at Pech IV. On the left, artifacts from three of Bordes' squares (D12, E12, F12) are projected in section view (Y-Z). On the

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[4] Other types of more catastrophic errors are also possible with a total station. Using a spatial database (GIS) in real time (daily) makes it easy to spot and correct these kinds of errors. The most common error, which effects only the elevation, involves the use of prisms of different heights to record objects. To make a correct elevation calculation, the computer attached to the total station needs to know the height of the prism used to record the object. When prisms of different heights are used on an excavation, the total station operator can substitute the wrong prism in the calculation. To catch this mistake, it is important to use prisms of widely varying heights and to backplot sections daily. When this is done, incorrectly recorded points appear floating above or below the rest of the artifacts recorded that day, and the mistake can be easily corrected.

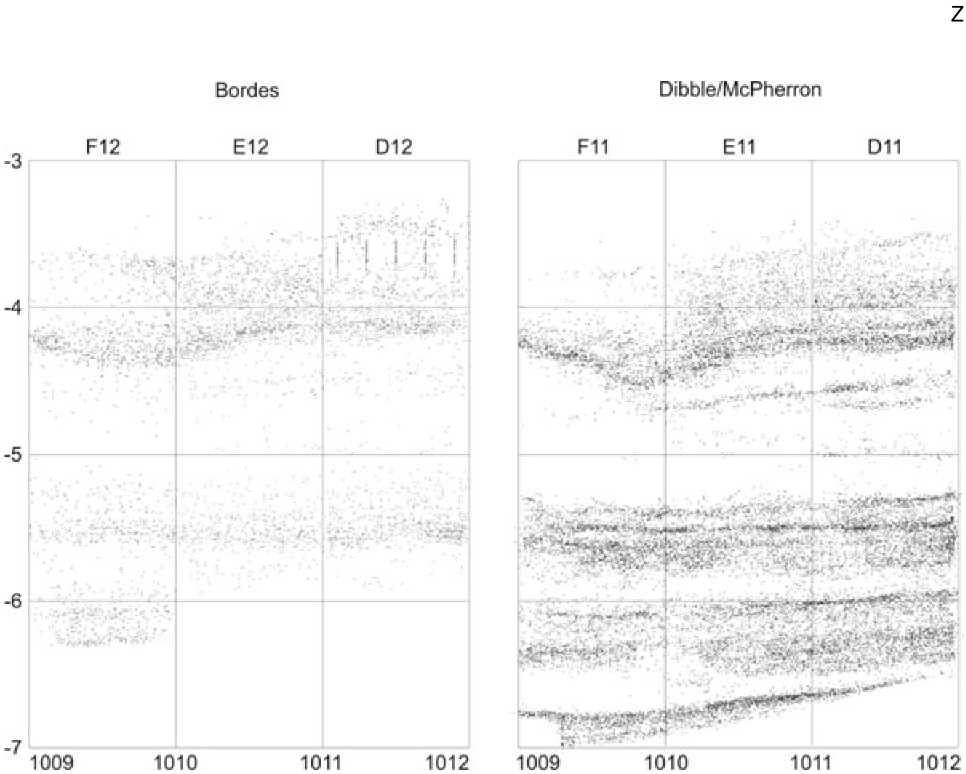

Figure 1. Three squares from Bordes' excavation of Pech IV (left) and three adjacent squares from Dibble/McPherron excavation of Pech IV (right). Note the presence of distinct lenses in the plot to the right that are difficult to identify on the left (the vertical lines in the left figure are a result of an excavator's error in recording proveniences).

right, artifacts from three adjacent squares (D11, E11, F11) excavated by us are also shown in section (Y-Z). Every effort has been made to standardize this comparison so that, aside from the 1-m offset in which artifacts are being mapped, the only difference between the two is in how the piece proveniences were recorded. On the right, in the section from our excavation, several lenses are clearly visible. These lenses fall within a much larger stratigraphic unit and were not isolated during excavation. In Bordes' excavations, these lenses cannot be identified.

It is extremely unlikely that these lenses simply terminated before they reached Bordes' excavated squares. There are some lateral geologic changes in the Pech IV stratigraphic units, but they occur at a much larger scale and are related to the changing morphology of the site as the cave collapsed and retreated through time. Behaviorally we know of no explanation that would account for a lateral change in the vertical distribution of artifacts such as we see here. Thus, the most likely explanation is that we are looking at the error inherent in Bordes' triangle string method of recording artifact elevations.

In effect, the error in Bordes' method appears to be on the scale of several centimeters and results in a general smearing of vertical patterning. There are many implications of this finding. First, it is a rather sobering cautionary tale for the reanalysis of older collections. In this part of southwest France, there are currently several projects very similar to our own in which sites and collections are being restored to modern curation and analytical standards (including the employ of GIS) with the extant documentation from the previous excavation usually in combination with some limited sampling or excavation of the site. In our case, the site was excavated a mere 30 years ago by one of the leading figures in the field who had decades of field experience and was considered by many to be the father of modern Paleolithic archaeology and many of the excavators are practicing prehistorians and anthropological archaeologists today. Yet, it is clear from this example that we are missing significant amounts of microstratigraphic information that has a high potential for yielding behaviorally interesting results. This is particularly disappointing since Bordes excavated large horizontal exposures that are prohibitively expensive to replicate today. We would very much like to follow these lenses over a larger area in order to enlarge the sample of artifacts associated with each and thereby aid in the interpretation. Currently, we only have a 1-m-wide sampling of these lenses, which will make their interpretation very difficult.

A second example comparing two methods deals with artifact orientations, which have been shown to be extremely useful for interpreting site-formation processes (e.g., Shipman, 1981; Butzer, 1982:101–104; Kroll and Isaac, 1984; Schick, 1986, 1992; Francis, 1992; Petraglia, 1993; Bertran and Texier, 1995b; Kluskens, 1995; Bertran et al., 1997; Dibble et al., 1997; Roberts et al., 1997; Sahnouni and de Heinzelin, 1998; Byers, 2002; Lenoble and Bertran, 2004). Artifact orientations, for instance, provide one way of detecting stream flow because objects moved by a stream are typically oriented either parallel and/or perpendicular to the direction of stream flow or slope (Isaac, 1967; Kelling and Williams, 1967; Blatt et al., 1980; Schick, 1986; Kluskens, 1995). In addition, the dip or plunge of artifacts deposited on a surface will normally follow the topography of that surface, while the dips of artifacts disturbed by trampling, bioturbation, etc., should vary from this surface and appear more randomly oriented. Water flow also tends to lower, or imbricate, the upstream end of artifacts as the current displaces fine sediments from their upstream end and deposits them behind the downstream end (Sengupta, 1966; Briggs, 1977; Schick, 1986; Kluskens, 1995).

One way to record artifact orientations is by measuring two three-dimensional coordinates at the endpoints of elongated artifacts (McPherron, 2005). For this method to successfully record potentially subtle artifact dips, it is important that the Z coordinates be measured both accurately and precisely, since the difference in elevation of two ends of an artifact may not be very great. The change in elevation on a slope of 10°, for instance, is less than 1 cm over the length of a typical 5-cm artifact. An error of 5 mm at each end would dramatically change the calculation of its dip or plunge.

We have one dataset set from an earlier excavation in which proveniences were recorded mostly with the total station, but for various reasons there was a short period where measurements had to be taken by hand in some parts of the site.

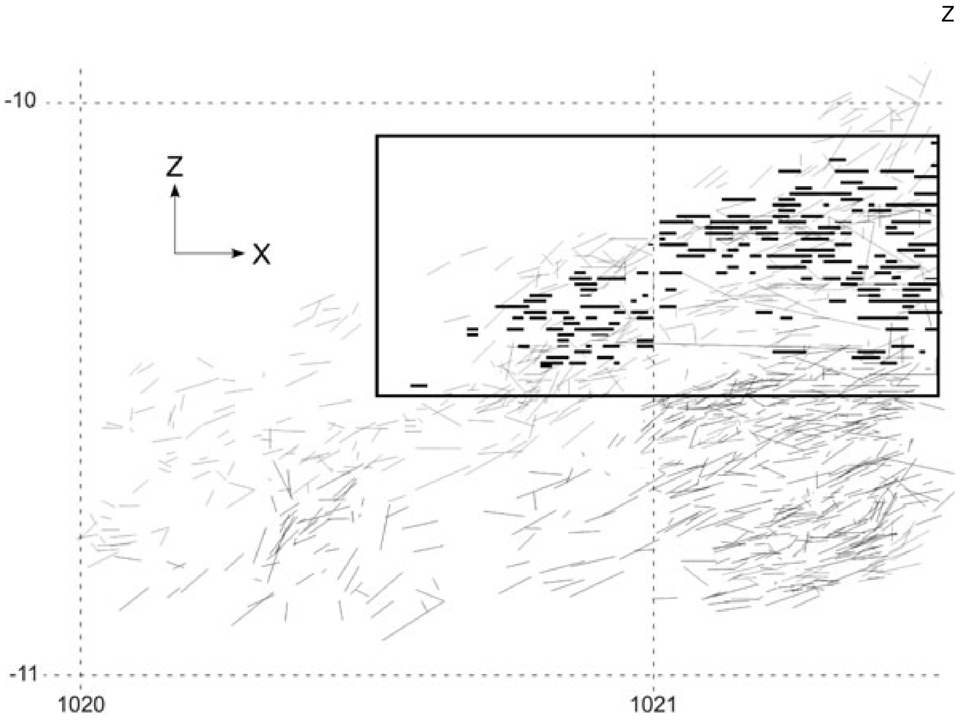

Figure 2. A section view of artifacts from a Paleolithic site. The artifacts lying horizontal (shown here in bold with the box) were hand-recorded. The remaining artifacts were recorded with a total station.

Horizontal strings with line-levels were used to record the elevations. Not wanting to lose data on orientations, two measurements on elongated artifacts were still recorded by hand. Figure 2 shows clearly the effect that this had on the slopes of the artifacts. The area within the box includes most of the artifacts whose provenience was measured by hand, and it is clear that the slopes of the hand-recorded artifacts do not follow the patterns generally observable in the surrounding artifacts whose provenience was recorded with the total station.

These two examples show that recording elevation data by hand may not provide the resolution necessary for certain kinds of analyses. We have heard arguments expressed by some that, in effect, since prehistoric hominins did not deposit their artifacts with millimeter precision, why should archaeologists be so concerned with it during excavation? The answer is that low-resolution proveniencing is probably adequate for mapping the distribution of artifacts on a surface or on a cross-section, or in cases where geological/pedological conditions do not provide optimal contexts. But for some studies, such as those dealing with artifact orientations, the lack of reliability and precision of hand proveniencing does not generate data of sufficient quality for analysis. Furthermore, as the first example shows, recording elevations by hand can obscure stratigraphic patterning that is both behaviorally and taphonomically meaningful.

Stratigraphic Analysis Independent of Geology

There is no question that stratigraphic context is an important element of archaeological interpretation. Beyond the role of geological analyses of individual levels, which provide information on both paleoclimate and site-formation processes, the role of stratigraphy as a tool for relative dating is so fundamental that it hardly bears repeating. However, the other side of the dating coin is that materials derived from a single geological level are assumed to have some degree of contemporaneity. Of course, this contemporaneity is on the scale of geological time, and so one level may represent tens, hundreds, or even thousands of years. Nonetheless, we tend to aggregate all of the material from one level into an assemblage—be it artifactual, faunal, or whatever—and treat it as if it represents a single entity (Stern, 1993; 1994).

It has long been known that using elevations within a geological level can be helpful, especially if the level is particularly thick. In these situations, many archaeologists define arbitrary levels, or spits, based on elevation (usually taking care not to cross-cut observable boundaries in the natural stratigraphy). While useful for examining chronological change within a natural stratigraphic unit, most often such arbitrary levels, defined at the time of excavation, remain as fixed entities. Using Z coordinate data, however, allows one to regroup artifacts in any number of different arbitrary segments after the excavation, and thus increases the analytical capabilities considerably. We will present two examples here of how using such groupings helps address certain problems. In the first case, again drawn from Pech IV, the problem is understanding the structure and significance of changes though time in stone tool frequencies during the late Mousterian. In the second case, coming from Combe-Capelle Bas, the problem is one of understanding the site-formation processes and their effects on the integrity, and, therefore, the behavioral significance of the archaeological assemblages.

Temporal Trends in the Mousterian of Acheulian Tradition at Pech de l'Azé IV

At the top of the cultural deposits at Pech IV, Bordes (1975) defined what he called Layer F on the basis of geological criteria he then subdivided it into four arbitrarily defined levels from bottom to top: F4, F3, F2, and F1. He did this presumably because F is a fairly thick layer (approximately 1 m), and in order to detect any changes in the stone tool industries within it, smaller subdivisions were required. This strategy worked well in this instance, and what this example will show is that piece provenience data can be used to gain an even finer appreciation for changes in behavior that occur while the depositional processes remain constant.

Overall, the stone tools from Layer F are representative of the Mousterian of Acheulian Tradition (MTA), an industry that frequently occurs at or near the top of Middle Paleolithic sequences (Mellars, 1996). MTA industries are characterized by the presence of bifaces, relatively few scrapers, relatively high percentages of notched tools and Upper Paleolithic tool types, and in particular, a relatively high frequency of backed knives (Bordes and de Sonneville-Bordes, 1970). For Bordes, this latter point is important because it shows the beginnings of a trend that links the final

Mousterian with the subsequent Upper Paleolithic (especially the Châtelperronian) and, therefore, suggests continuity between the two periods.

Within the MTA, Bordes recognized two variants: Type A and B. These differ on several typological grounds. In contrast to MTA-A, MTA-B generally has fewer handaxes, more notched tools, more Upper Paleolithic types, and more backed knives. Several sites in southwest France show that MTA-B follows MTA-A, and there are no sites that show a reversed trend from MTA-B to A. Pech IV is one of the sites with such an A to B sequence; at the top of the sequence in Layer F. From the base to the top, Level F4 is MTA-A, Level F3 is transitional between MTA-A and B, and Levels F2 and F1 are both MTA-B.

Had Bordes excavated Layer F as a single unit following the geology, he would not have been able to demonstrate the time trends within it. In fact, in a critique of the apparent contemporaneity of the MTA-A of Pech I and the MTA-B of Le Moustier (Level H), Bordes (1981:78) notes that had the 1-m thick level at Le Moustier been excavated in finer subdivisions, then it might be shown that the lower part was MTA-A and only the very top (and, presumably, no longer contemporaneous with Pech I) was MTA-B. For Bordes, this was an important point because he viewed these industries not as contemporaneous, functional variants, but as successive stages showing a progressive development towards the Châtelperronian and Upper Paleolithic. Thus, how these layers were excavated and defined at Le Moustier and Pech de l'Azé IV has significant implications for the definition and interpretation of their stone tool industries.

Clearly, Bordes was aware of the effect that these smaller, arbitrary divisions could have on the typological character of the industries of Layer F. The question remains, however, to what extent are the industrial distinctions seen within Layer F a function of how Bordes defined the levels? And what, exactly, is the nature of the transition, i.e., is it gradual or abrupt? To investigate these questions, a three-dimensional GIS program was used to slice through the Layer F spatial dataset created from Bordes' notebooks. The slices ranged in elevation from –4.4 to –3.4 m below datum. This range covers all of Layer F and overlaps only slightly with Layer G at its base (there are no Paleolithic deposits over Layer F). The deposition in this portion of the site appears to have been fairly horizontal, with the exception of a slight depression that is clear in the section (see Figure 1). As a result, while the slices ignore geological distinctions within this portion of the sequence, they minimize the mixture of chronologically distinct materials.

Several of the typological indices that figure in the definition of MTA Types A and B are plotted against elevation, as defined by the slices (Figure 3). Bifaces are not included because there are too few (N = 19) to make meaningful comparisons, and Levallois is included simply to assess how this important index varies as well. Each slice represents the material from 5 cm of deposit. This interval was selected as the smallest that would allow a sufficient sample size in each unit to calculate the various typological and technological indices and, based on the results from the Pech IV example discussed above, finer slices would likely exceed the accuracy of the data themselves. As it is, given the inaccuracies in Bordes' elevations, these slices constructed on the basis of elevation data will likely be somewhat "fuzzy." Nevertheless,

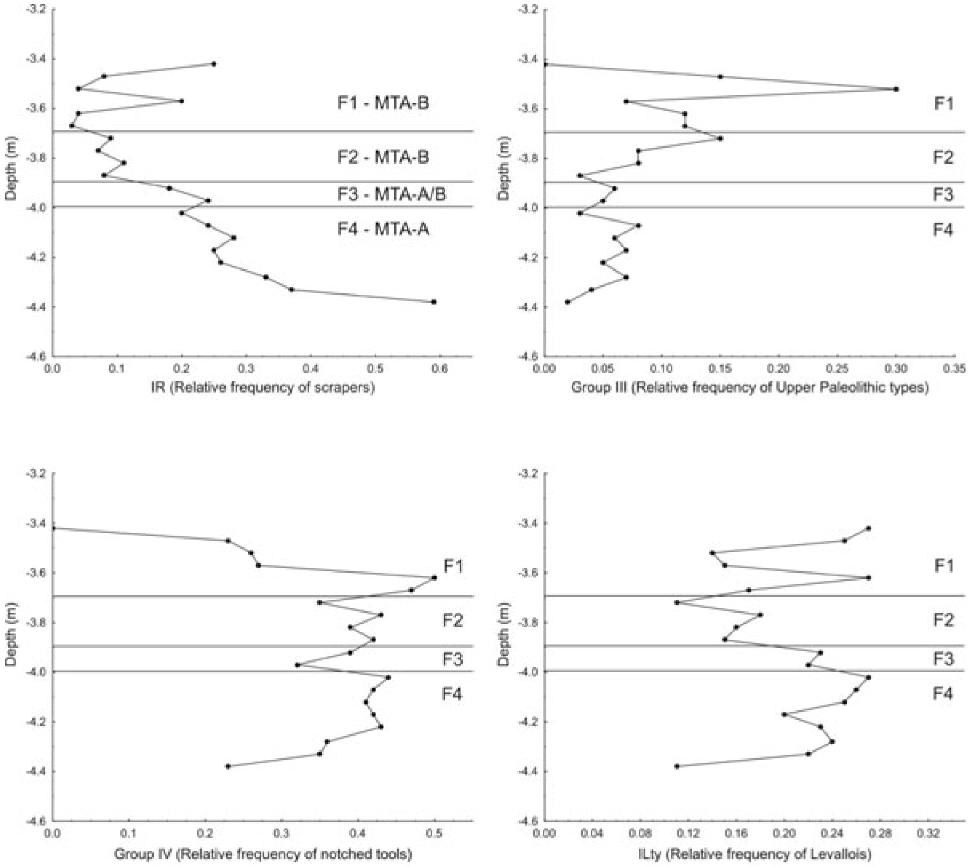

Figure 3. Variation in four typological and technological indices in Layer F deposits from Pech IV. Each data point represents a 5-cm slice of deposit. The horizontal lines represent stratigraphic divisions defined by Bordes. For the definition of how the indices are calculated, see Debénath and Dibble (1993).

patterning is apparent, and as one would expect, the patterns generally follow Bordes' definitions of these industries, including the switch from MTA Type A to B.

First, the percentage of scrapers (IR) shows a steady and rapid decline from a high of nearly 60% at the base of the sequence to below 5% near the top. This trend cross-cuts Bordes' arbitrarily defined units and shows continuity in this behavioral pattern, though it is also clear from this graph that Level F3 samples an intermediate point in this trend, which would lead Bordes to a transitional A to B attribution. To the contrary, the last 20 cm of the sequence show a fairly variable scraper ratio. The percentage of Upper Paleolithic types (primarily backed knives) shows almost the opposite pattern. While the percentage of scrapers is falling, the percentage of Upper Paleolithic types remains roughly constant at low levels, and then gradually climbs and peaks quickly near the very top of the sequence. It is well demonstrated that scrapers and notched tools account for most of the variability in the Middle Paleolithic and that they are inversely correlated (Dibble, 1988). This is generally the case here, though the Upper Paleolithic types, normally not a large component of Middle Paleolithic assemblages, complicate the picture somewhat.

What is interesting here, however, is that notched tools (notches and denticulates) are supposed to increase in frequency with the change from Type A to B. Instead, we see a fairly constant percentage from the middle of Level F4 (MTA-A) to the lower part of Level F1 (MTA-B) followed by a rapid decrease. Additionally, notched tools do not peak at the same time as Upper Paleolithic tools but slightly before. Given the error in the original elevation data, this has to be taken as a preliminary finding, but it would appear that despite Bordes' assertion that MTA-B shows an increase in denticulates and Upper Paleolithic types, at least in this case it seems to be a question of how the samples were constructed. When looked at with slices, these two ratios appear to be more independent of one another. The last ratio plotted is the percentage of Levallois types. This ratio does not figure in the definition of MTA, and there are MTA industries with abundant Levallois and others with little. In this case, it can be seen that: (1) Levallois varies from 10% and 30%, (2) only vaguely correlates with Bordes' level distinctions, and (3) does not show a trend through time.

It is clear from this figure that Bordes was correct to subdivide Layer F into smaller units. Had he analyzed Layer F as a whole, he likely would have classified the industry as MTA-A and missed the spike in Upper Paleolithic types near the top of the sequence. It is also clear that Bordes could have gone further. There are time trends within Bordes' levels, particularly with regard to the decreasing relative frequencies of scrapers. In other words, Bordes' levels average behavior patterns that actually show constant change through time. Why behavior changed during this interval is unclear. To the extent that geological units represent unchanging depositional processes and to the extent that these, in turn, represent unchanging local environmental conditions, we cannot view these behavioral changes as a response to environmental changes. We await additional analyses from our excavations to help interpret this pattern. In the meantime, it would be interesting to conduct similar piece-provenience–based analyses at other MTA sites to gain a fuller appreciation of variability in this pattern.

Site Formation and the Integrity of the Lithic Assemblages at Combe-Capelle Bas

Combe-Capelle Bas, a Middle Paleolithic site in southwest France, was most recently excavated from 1987 to 1990. The results of these excavations were published in 1995 (Dibble and Lenoir, 1995) and more recently, TL-derived OIS 3 dates were published for one portion (Sector I) of the site (Valladas et al., 2003). Today, Combe-Capelle Bas is an open-air site located at the base of a deposit that slopes upwards from the valley floor to the overlying plateau at approximately 25°. Given this context, it is likely that there has been movement of the sediments and archaeological materials, though the degree to which things have moved at Combe-Capelle Bas became a point of contention in the final publication and elsewhere (Bertran and Texier, 1995a, 1995b).

Based on their geological analysis of the deposits, Bertran and Texier (1995a) argue that most of the sediments and their archaeological industries are derived from deposits originally situated upslope somewhere between the site itself and the base of the plateau at the top. The primary transport mechanism, in this case, was high-velocity debris flows (Bertran and Texier, 1995a:190). In the lower portion of Combe-Capelle Bas, Sector I, they observed an intermixing of debris flows and alluvial deposits from the ancestral Couze River. In sum, they (1995a:191) argue that "the geology . . . shows clearly that the archaeological industries are not in primary position but rather have been strongly reworked; because of this, interpretations based on them should be viewed with caution."

To the contrary, Dibble (1995) argues that while a certain degree of movement is likely given the slope, there are a number of lines of evidence suggesting that movement was limited and not of sufficient intensity to alter the basic integrity of the archaeological assemblages. One line of evidence is the nature of the stone tool industries. While typologically they are all quite similar, technologically the industries from different sectors within the site are quite different, and there are technological changes through time within each sector. Dibble argues that on closer examination the industries show a high level of internal consistency that would not be expected if they resulted from the transport and redeposition of an archaeological deposit upslope from the current site location as Bertran and Texier suggest.

The two opposing interpretations of the site-formation processes can be reconciled if one considers a separate and independent origin for the sediments and the archaeological materials (Dibble, 1995:257). Bertran and Texier (1995a:190) acknowledge this alternative stating that "it is possible that there were occupation levels on the [debris] cone itself, which were buried and little reworked." However, for unstated reasons, they assume that the high-velocity debris flows that formed this cone would have brought archaeological industries, while providing no evidence for the previous existence of a site upslope (a necessary condition in their model). Thus, they (1995:190) conclude that "unfortunately, it seems difficult to distinguish [the *in situ* occupation levels] from the industries brought by the debris flow."

The independence of the behavioral activities leading to the formation of the stone tool assemblages and the geological processes leading to their sedimentary context can be tested using the same GIS methods as were used in the previous Pech IV example. The artifacts from the Combe-Capelle Bas excavations were piece-provenienced using the same total station methods outlined here and elsewhere (Dibble et al., 1995), and the resulting dataset on which the following analysis is based has been published on CD (Dibble and McPherron, 1996) and on the Internet (www.oldstoneage.com).

The Combe-Capelle Bas excavations are divided into three sectors located at varying distances upslope. In this example, the artifacts from the base, Sector I, will be analyzed for two reasons. First, these deposits are particularly interesting in the context of this article because Bertran and Texier argue that two separate geological processes formed them: debris flow and fluvial action. Second, artifacts from these deposits have now been dated and thus provide yet another line of evidence to aid in the interpretation of the site's formation.

Slicing this deposit into arbitrary levels is complicated by the fact that the archaeological levels are sloped. While the point of this analysis is to analyze the artifacts independent of their original level designations, in forming new analytical units, it is also important not to mix artifacts from different natural strata, whose boundaries span significantly different elevations. To solve this problem, the first step in the analysis was to use the GIS to rotate the artifacts 25° in the YZ plane. The Y-axis is parallel to the approximately 25° slope of the deposits at Combe-Capelle Bas. Thus, rotation in the YZ plane removes the effect of the slope in the Z. Next, the dataset was divided into 12 units of 28-cm thickness (originally, it was excavated in nine stratigraphically defined units—Levels I-4 through I-1B). Level I-1A, at the top of the deposit, was excluded from analysis because it was impacted by more recent disturbances.

The number of units used in this analysis was arrived at through iteration. The largest number of units was sought without dropping the unit sample size for the stone tool analysis below $N = 10$. The upper units are quite rich, but the surface area excavated near the base of Sector I produced small samples which, when divided into yet smaller analytical units, quickly resulted in insufficient sample sizes. Even so, with 12 units, some technological indices could not be computed for some of the basal units.

The results of this analysis are presented in Figure 4 and summarized in Figure 5a. In this example, the indices plotted are based on the same ones Dibble (1995) uses to argue for the internal coherence and stratigraphic integrity of the assemblages. They were selected as independent measures of technology and are computed as follows. The percentage cortex is based on complete flakes and complete tools only. Cortex was originally published as interval data. The midpoint of each interval is used to calculate averages. The percentage of shatter is calculated as the ratio of the number of fragments defined as shatter to the total of all worked lithics (including shatter). The blank-to-core ratio is calculated as the number of flakes and tools with preserved platforms relative to all complete cores. The flake surface ratio is calculated only on all complete flakes with valid length and width measurements. The flake surface is the product of the length and width. The platform surface area is calculated on all pieces with complete platforms and valid platform width and thickness measurements (width and thickness > 2 mm). The surface area is the product of these two numbers. Core length is the measured length of complete cores only (see Dibble et al. [1995] for more information on how these observations and measurements were made).

While typologically the stone tool industries of Combe-Capelle Bas are fairly homogenous, as can be seen from the figures, these technological indices show a great deal of variability and directional change through time. Particularly important in this regard is Figure 5a, where the indices have been standardized to a consistent scale (0–1) so that they can be plotted together. With the exception of shatter, the indices all co-vary. They show a set of internally consistent assemblages that change through time. The reason for this is that they are all tracking one aspect of behavior, namely, the intensity of core reduction. In the base of the deposit, reduction intensity is low. Fewer flakes are being removed from each core. As a result, the core size is larger and the percentage of cortex on the flakes is higher. The flakes are also larger on aver-

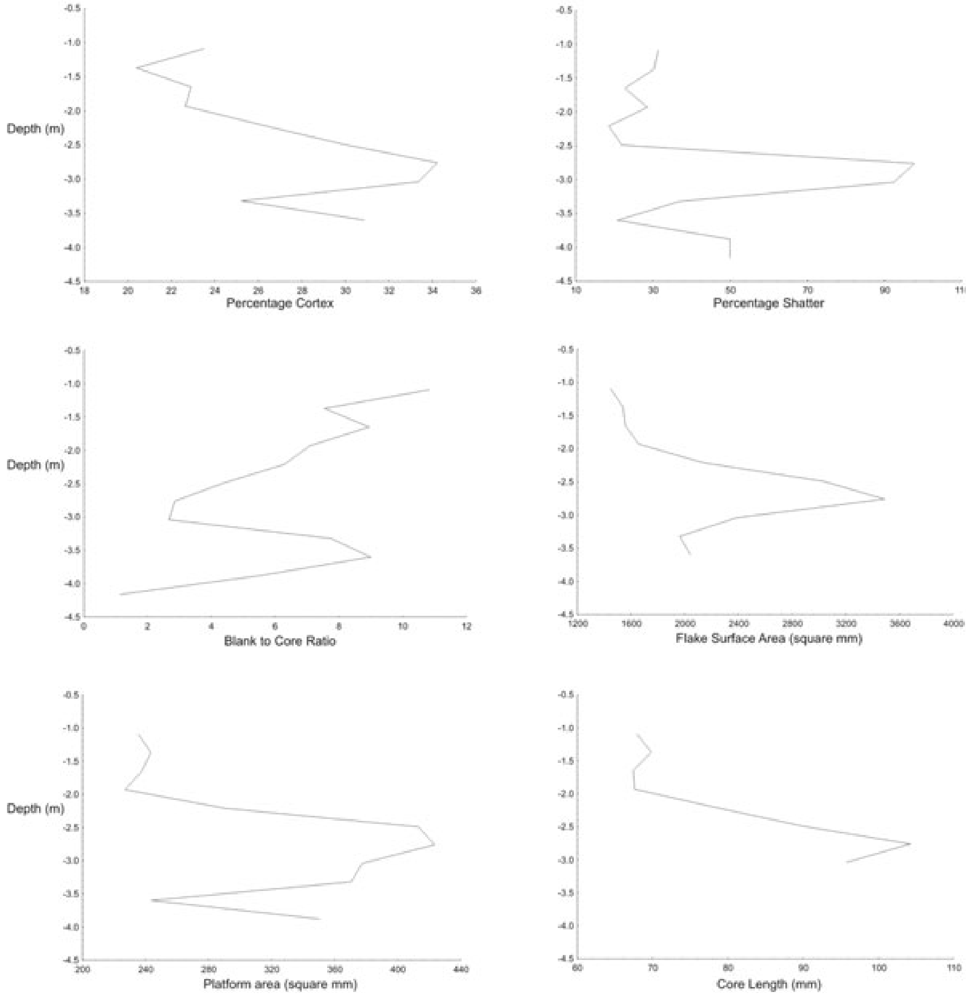

Figure 4. Variation in several stone tool indices (described in the text) through time in the Sector I deposits at Combe-Capelle Bas.

age and have larger platforms (given a consistent technology, platform size is typically correlated with flake size, and thus these two indices are not as potentially independent of one another as are the others). Through time, the intensity of lithic reduction increases, more flakes are removed from the core, the cores become smaller, average flake size decreases, platforms become smaller, and the percentage of cortex on the flakes decreases.

The one index that does not track well with the others is shatter. The shatter measured here is larger than 2.5 cm (the cutoff used for stone tool analysis at

Z

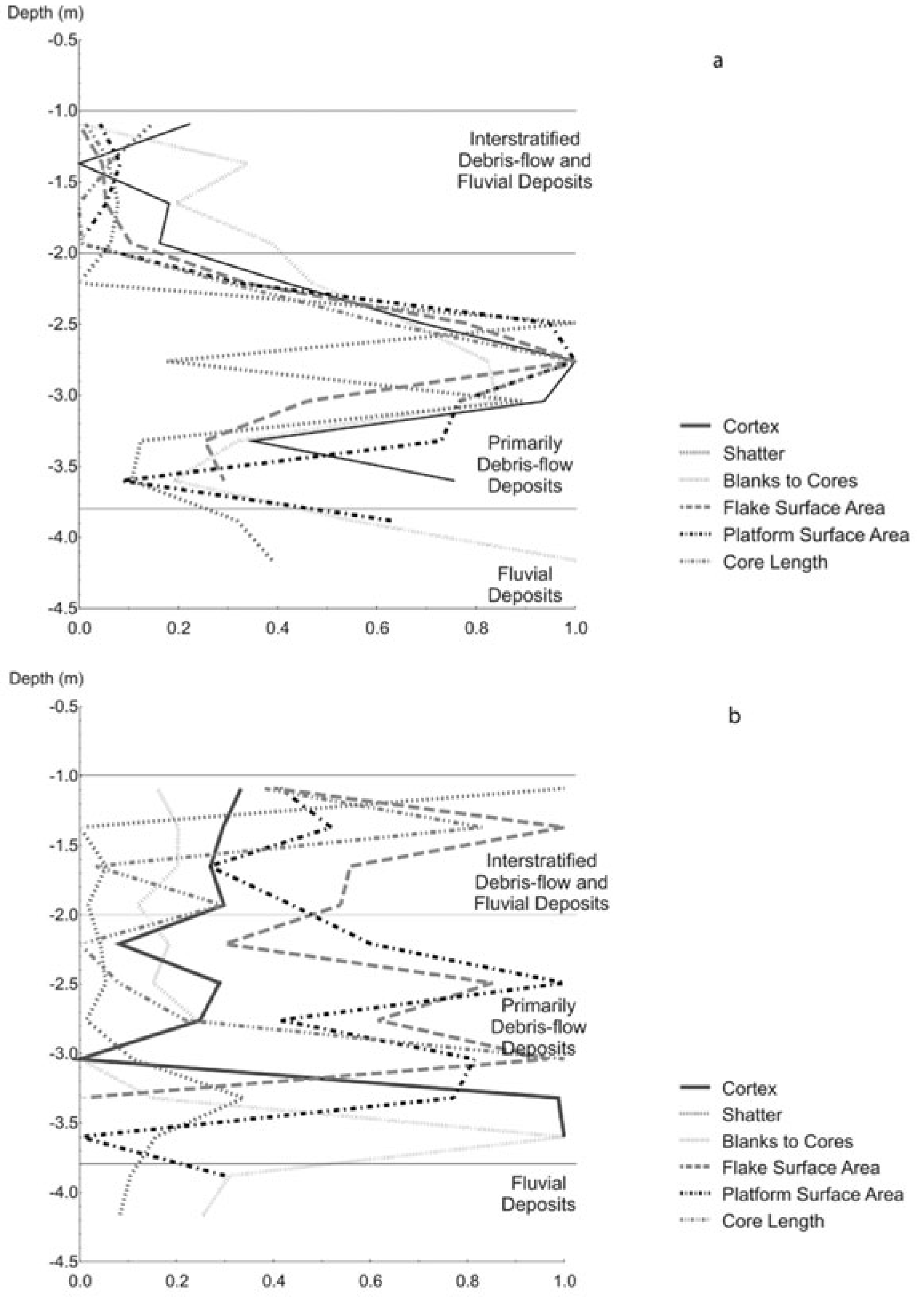

Figure 5. On the top, (a) the indices from Figure 4 have been normalized to the same scale and plotted together to illustrate synchronized changes. Note that the core-to-flake ratio has been inverted to make the patterning in the trends easier to read. On the bottom, (b) the same normalized indices are plotted from a hypothetical, randomly derived set of assemblages based on the total Sector I assemblage.

Combe-Capelle Bas) and not the very small type of debris, recovered in the screens, that results from stone tool reduction. The problem with this larger material is that it can be difficult to identify. Broken flakes, particularly medial flakes, can be difficult to distinguish from shatter. This is significant because medial flakes can result from post-depositional processes, such as trampling. Thus, while the relative proportion of shatter might be expected to increase with the intensity of lithic reduction, there are other factors that can alter this pattern.

Such co-variation in several indices measuring lithic reduction intensity is not what would be expected if the assemblages were created by unrelated factors. This can be illustrated through simulation. In Figure 5b, the association in the GIS between the spatial coordinates for each object and the object's typological and technological characteristics has been randomized. In effect, this is an attempt to simulate what would happen if an assemblage with the exact same typological and technological characteristics as the Combe-Capelle Bas assemblage had once existed upslope from the present-day site and had been randomly eroded, reworked, and redeposited by high-velocity debris flows in exactly the same spatial configuration seen during excavations. The result is clear in that the indices do not co-vary. In other words, it is possible to have an assemblage in which the indices that Dibble selected do not follow the patterns he observed and which have been replicated here. What this strongly suggests is that these indices are tracking behavior and not geology.

In this regard, it is interesting to compare the top of the sequence ($Z > -2$ m) with the middle portion ($-3.8 < Z < -2$). Bertran and Texier (1995a:186) describe the upper portion as interstratified debris-flow and fluvial deposits. If they are correct in suggesting that the industries were brought in with the deposits, then one would expect a highly variable industry, given the two very different sources. In fact, the upper portion shows a consistent industry representing a higher degree of core reduction. The middle portion of the deposit is attributed entirely to debris flow with some fluvial reworking of material at the base (Bertran and Texier, 1995a:186). Core reduction first decreases and then starts to increase towards the top of the middle deposits, where it peaks in the top portion of the sequence. The changes within this portion of the sequence do not correlate with changes in deposition, and the trend towards higher core-reduction intensity begins prior to the first fluvial deposits in the top portion of the sequence. That said, it is entirely possible that increasing core reduction was a response to changing environmental conditions that are reflected only a bit later in the changing depositional environments at the top of the sequence.

Recent TL dates from this sequence also support the assemblage integrity and continuity seen in this analysis (Valladas et al., 2003). Flints from both fluvial and debris-flow contexts gave consistent dates of approximately 55 kyr. Consistent dates would seem highly unlikely if flints from two different sources were heated prior to their redeposition at Combe-Capelle Bas. On the other hand, if they were deposited at Combe-Capelle Bas prior to heating, this would imply that the assemblages are a mix of derived and *in situ* elements, but the core reduction indices just presented show internally coherent assemblages and not mixed ones.

CONCLUSIONS

To return to the questions we posed at the beginning of this paper, it does seem that elevation data provide important information that can be used in a variety of ways. Therefore, it is important that they be recorded both accurately and precisely.

The examples we presented demonstrate that the accuracy and precision with which proveniences are recorded impact the kinds of analyses that can be done. In the Pech IV MTA example, Bordes' elevations, recorded with the triangle string method, showed some interesting patterning. It is also clear, however, that some significant information was missed. In our own excavations of the MTA, we identified a level at the base of the MTA that is defined, in part, by a much denser occupation that is clearly visible in cross-section plots of the total station-derived data. In addition, by recording two points on elongated artifacts, we have also been able to use provenience information to calculate orientations and assess site-formation processes (McPherron, 2005). While we do not have comparable datasets produced by all other methods of recording proveniences, it is clear that they should be analyzed to determine whether or not they yield data of sufficient accuracy and precision for these kinds of studies.

Some examples show that there is a certain degree of independence between geological units and behavior. This is not always the case, of course. In cases where anthropogenic deposits can be recognized and analyzed (e.g., combustion features at sites like Klasies River Mouth [Deacon et al., 1986]; Kebara [Meignen et al., 2001]; Üçağızlı [Goldberg, 2003], and Pech de l'Azé IV—interim reports), behavioral signals can correspond closely with lithological units, as defined on the basis of geological criteria. In Lower and Middle Paleolithic archaeology, however, the link between geology and behavior is most often assumed and seldom tested. It is difficult to know whether archaeologists doing Lower and Middle Paleolithic research equate behavioral changes with stratigraphic changes or, more precisely, whether they acknowledge the possibility that behavioral change can occur independent of stratigraphic changes because, until recently, geologically defined stratigraphic units were the only units we had to work with. For this reason, it seems likely that the two have become fused. A good example is nearly any discussion of mixed or contaminated assemblages. It is assumed, for instance, that the transition from one industry to another will be accompanied by a change in the character of the sediment that will be clear enough to define a separate layer for each. If tools from industry/technocomplex B are found in the underlying technocomplex A or vice versa, it is assumed that either post-depositional processes moved the particular artifacts or that the excavator missed some sort of stratigraphic complication (such as a pit) that could account for the apparent mixing of two different entities. Rarely (if ever) is the possibility considered that the behaviors generating these stone tools changed without impacting the geological criteria used to define their stratigraphic context. In other words, perhaps the switch from A to B anticipated a stratigraphic change. The example of the MTA from Pech IV presented here clearly shows that behavior can change without impacting the geology, and the Combe-Capelle Bas example demonstrates that that geology can change without impacting the behavior. Clearly, in some cases, changes in behavior can be correlated with changes in the stratigraphy, but our point is that, by using elevation data, we can now test this association. In other words, using elevations allows us to treat stratigraphic level as an independent variable that may or may not correlate with changes in the artifactual assemblage.

The history of archaeology has seen a continuous development in the level of accuracy and precision of field recording, and there is often an assumption that better data lead to better results. But better recording is expensive, both in time and equipment. We want to be sure, therefore, that the result is worth the investment. While Z is a standard variable recorded, not much has been done to see whether it is worth the investment or whether different techniques of recording make a difference for later interpretations. It would seem that both of those questions should be answered affirmatively.

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