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Diagenesis of bone from Border Cave: implications for the age of the Border Cave hominids

Hominids from the site of Border Cave purportedly provide direct evidence for the early emergence of anatomically modern humans (AMH) in Southern Africa. ESR dating of Border Cave faunal enamel has confirmed the antiquity of the sediments, although questions persist regarding the provenience of the hominid specimens. Here we establish that, at Border Cave as elsewhere, bone mineral crystallinity, measured as the infrared (IR) splitting factor (SF), distinguishes between contemporary and recent bones on the one hand, from Middle Stone Age (MSA) bones on the other. Two hominid postcranial bones recovered in 1987 from a slumped profile, having essentially no provenience, are shown to have crystallinity indices consistent with the MSA fauna, while two of the purportedly ancient AMH specimens (BC3 and BC5) have values consistent with recent fauna. We conclude that BC3 and BC5 may be considerably younger than the sediments from which they were recovered.

Introduction

The Middle Stone Age (MSA) sequence at Border Cave (KwaZulu/Natal, South Africa) has been purported to contain very early examples of anatomically modern Homo sapiens (amHs), supporting the idea that anatomically and behaviorally modern people appeared first in Africa (Beaumont et al., 1978; Rightmire, 1979). A number of specimens are central to this argument including BC3, the well-preserved skeleton of an infant recovered in 1941 from a burial associated with MSA layers (Cooke et al., 1945), and BC5, an anatomically modern mandible also associated with the MSA excavated in 1974 (Beaumont et al., 1978; Beaumont, 1980; de Villiers, 1976). The bearing of these and other Border Cave hominids on the timing and location of the emergence of amHs depends upon the demonstration that they are of the same age as the sediments from which they were derived. Some investigators have argued that BC3 and BC5 are somewhat better preserved than faunal remains from the MSA layers of Border Cave, suggesting that the human specimens might be derived from more recent intrusive burials (Klein, 1989; Parkington, 1990). Unfortunately attempts to directly date the BC5 mandible using AMS 14C dating have been unsuccessful because of insufficient collagen (Stringer, pers. comm.).

In order to address whether these and other Border Cave hominids are likely to be contemporaneous with the sediments from which they were obtained, we characterized diagenetic changes in Border Cave faunal and hominid bones using both bone mineral crystallinity and nitrogen concentration. “Crystallinity” is a general term that is a function of crystallite size, structural defects, and strain (LeGeros, 1991). Bone mineral is poorly crystalline, and various studies using both X-ray diffraction (XRD) and infrared (IR) spectroscopy have shown that archaeological and fossil bones have increased crystallinity when compared with fresh bone (Weiner & Bar-Yosef, 1990; Bartsiokas & Middleton, 1992; Sillen & Parkington, 1996). The rate of increase appears to be highly dependent upon temperature, hydrology, and other local conditions such that, as a rule, the relationship between crystallinity and time is unsatisfactory for meaningful relative dating (Person et al., 1995). Moreover, the increase appears to be finite and limited; crystallinity measurements on Holocene and Late
Pleistocene fauna from Eland’s Bay Cave (South Africa) have been shown to increase from a baseline of 2.8 (± 0.1) in fresh bone to values in the region of 3.2–3.6 by 17 ka ago, with little subsequent increase thereafter (Figure 1) (Sillen & Parkington, 1996).

When IR splitting factor (SF) measurements are regressed against age, they increase in these Holocene specimens with an $r^2$ of 0.72. While this relationship is not robust enough for dating, it is clearly appropriate for the modest application of determining whether specimens are likely to be derived from relatively recent sediments (<5 ka ago) or relatively ancient ones (>ca. 30 ka ago). This can be seen by examining Figure 1; although there is considerable variability in SF measurements throughout the Holocene sequence, the rapid increase in SF during the first 17 ka of interment makes it possible to distinguish between bones from the top of the sequence, and those from the bottom.

In order to use crystallinity measurements for the purpose of establishing the antiquity of bones, it is necessary to assume that crystal growth is irreversible in fossils. While this has never been proven empirically, it is a reasonable working assumption both on biological and physiochemical grounds. Another assumption is that variation in the crystallinity of fresh specimens due to species or age of individual is insignificant when compared with diagenetic alteration.

One serious constraint is that microenvironmental conditions in caves will affect crystallinity; cave environments have been shown to be quite variable with regard to the diagenesis of bone (Weiner et al., 1993). Therefore, spatial controls are an essential aspect of relative dating studies based on diagenesis. Comparison of a faunal series with individual hominid specimens becomes less tenable with increasing distance; conversely such comparison is best applied where the faunal series and hominids are spatially consonant.
In this study, we examined a series of faunal bones obtained during excavations in the southeast (interior) area of the cave, derived from excavations by Peter Beaumont in the early 1970s (Figure 2). As can be seen from the figure, they are directly comparable with BC5, which was obtained from the base of the Third White Ash (3WA) level in the same excavations.

Other hominid specimens examined in this study are the unprovenienced, fragmentary humerus and ulna recovered in 1987 by sieving sediments which had slumped with time into the eastern (upslope) portion of Horton’s Pit (Figure 2). These specimens have no official designation, but are generally referred as “the BC humerus” and “the BC ulna”. Although there is no provenience, from Figure 2 it can be seen that the eastern portion of Horton’s Pit is next closest in space to the faunal series. Somewhat more distant are BC 1, BC 2, and BC 3, which were obtained in the 1940–1941 excavations by R. Dart and H. B. S. Cooke (Figure 2). These specimens were also obtained from the interior of the cave, but approximately 15 m to the northwest. The faunal series is not comparable with BC 4, an Iron Age (IA) skeleton having a $^{14}$C date of AD1460, which was obtained from the extreme southwestern corner of the cave, near the drip line.

Border Cave chronostatigraphy, deduced from $^{14}$C and electron spin resonance (ESR) studies, is characterized by a short IA occupation (IBS Upper, ca. 100–600 years ago) which followed a culturally sterile period (having occasional faunal inclusions) within the same stratigraphic unit ranging from ca. 0.5–2.0 ka ago. Below the IBS Upper, Early Later Stone
Age (ELSA) and MSA occupations span the period ca. 30–130 ka ago (Beaumont, 1989; Grun et al., 1990; Grun & Stringer, 1991; Beaumont et al., 1992).

Methods

Faunal specimens were obtained from the collections housed at the McGregor Museum (Kimberly) from the Beaumont excavations. Human specimens were obtained from various sources: (1) specimens of BC 1 and BC2 initially studied by Kenneth Oakley were obtained from the Natural History Museum, London (NHM), (2) an additional specimen of BC2 was sampled directly from the mandible housed at the Department of Anatomy, University of Witwatersrand (Wits), (3) BC3, BC4 and BC5 were similarly sampled from the Wits collection, and (4) an additional fresh sample of BC5 was taken from bone submitted in the 1970s to the NHM for radiocarbon analysis. All samples were freshly obtained from hominid and faunal specimens, with the exception of the NHM BC1 and NHM BC2 samples; these had been previously ground into powder sometime in early 1970s.

Samples were first prepared as a powder using a Spex Model 6700 freezer mill. Crystallinity was measured using the IR SF based on the splitting of the phosphate anti-symmetric bending mode into two peaks in the region of 440–605/cm. Bone powders were prepared as KBr pellets containing 0·5% sample by weight (1·5 mg sample/300 mg KBr) and examined using a Shimadzu model 460 IR spectrometer. The method of calculation was that most recently employed for other specimens of archaeological interest (Weiner & Bar-Yosef, 1990; Weiner et al., 1993; Sillen & Parkington, 1996). A baseline is drawn from approximately 495–750/cm. The heights of the double mode (in the region of 603/cm and 565/cm) are summed, then divided by the height of the trough between them. The reproducibility of SF measurements in our laboratory is & 0·15.

Nitrogen was determined using a Carlo-Erba model NA1500 nitrogen analyzer. Atropine and cyclophanone-2, 4-dinitrophenylhydrazone were used for standards; reproducibility was 0·01%.

Results and discussion

SF measurements clearly distinguish IA faunal bones at the surface layers of the cave from all of the older specimens (Figure 3). Figure 3 shows that all faunal bones have SF values greater than 3·1 with the exception of fresh bone and specimens derived from the IA sediments (1BS UP L1). These recent specimens have SF values of under 3·1.

Specimens from the 1BS UP L1 have elevated nitrogen in the region of 4%, while the rest of the faunal series have values below 1% (Figure 4). Specimens from 1BS UP L3-B6 on average have elevated nitrogen when compared with specimens from lower levels, although there is considerable overlap in individual values.

The SF and nitrogen results on the hominid specimens sampled in this study are presented in Table 1. With regard to nitrogen, hominids provided values which were in general agreement with previously published values. BC4 stands out for having relatively elevated nitrogen, and this is consistent with its IA origin. Even so, the value of 0·90% nitrogen is rather low when compared with IA fauna from the Beaumont excavations (ca. 4·0%), illustrating the incomparability of this specimen with the faunal series. The humerus and ulna have depleted nitrogen; in fact the value of 0·04% obtained for the humerus is among the lowest seen in
the entire BC sequence. All of the other hominid specimens have values ranging from approximately 0·30–0·60% nitrogen, with the exception of BC1 (0·18% in this study). Nitrogen values below 1% have been used to suggest an ancient date for BC3 and BC5 (Beaumont, 1980). In this study, while a general decrease in mean nitrogen with time was seen (Figure 4), fauna from the culturally sterile levels of 1BS have nitrogen values ranging from 0·60–0·97%, while MSA fauna ranges widely between 0·80% and no measurable nitrogen. Therefore, the value of 0·62% nitrogen obtained from BC5 (Table 1) is as consistent with faunal specimens from the culturally sterile 1BS UP as it is with ones from the ELSA or MSA. Fauna from the 3WA consistently have depleted nitrogen (X=0·34%; S.D.=0·24) when compared with BC5.

Regarding crystallinity, all samples provided results which were internally consistent, however different samples from the same hominid specimen in one instance provided conflicting results. The NHM BC2 powder provided an “old” signal of 3·6, while the...
freshly-sampled Wits BC2 specimen provided a “young” signal of 3·0. We have no explanation for this discrepancy although the possibilities include (1) the NHM specimens were heated when they were ground into a powder, and (2) increased surface area and exposure to atmospheric moisture during the past 20 years has caused a recent maturation in crystallinity in the powdered specimens. Such bone powder preparations may have a limited “shelf life.” Because we have no clear explanation for the difference, we are uncertain of the BC2 results. Taken at face value, the elevated crystallinity seen in the NHM BC1 specimen would appear to be consistent with an MSA origin. However, given the possible “shelf-life” phenomenon seen in the BC2 specimens, we have similar cause to doubt the signal obtained from the NHM BC1 powder. Because it has not been possible to obtain a fresh specimen of BC1, the application of crystallinity measurements to BC1 and BC2 remains unresolved.

Five other hominin specimens from Border Cave supplied consistent and reproducible results (Table 1). The infant BC3 skeleton provided a “young” crystallinity signal which seems inconsistent with faunal bones in the MSA layers from the Beaumont excavations. BC5 also
provided a “young” signal in both the Wits and NHM whole samples. The value obtained from this hominid, 3·0, is markedly lower than that of faunal specimens from the 3WA (X=3·4; S.D.=0·12), with which it is associated. BC4, the IA burial, provided a reproducible highly-crystalline signal. Finally, the two unnumbered postcranial bones had developed crystallinity consistent with the bulk of the MSA faunal sequence.

We do not suggest that the techniques reported here can date the hominid specimens in any chronometric or relative sense. Nevertheless the results have a number of implications. First, they show that crystallinity is not necessarily related to the loss of nitrogen: the IA specimen BC4 has relatively high nitrogen (0·9%) but elevated crystallinity. This is in contrast to observations Eland’s Bay Cave, where an excellent inverse correlation between nitrogen and crystallinity was observed in a sequence of Holocene specimens (Sillen & Parkington, 1996). Together with differences in nitrogen and SF between BC4 and the IA fauna, the observations further demonstrate that bones from cave mouths have different diagenetic patterns to bones from cave interiors, and that spatial controls are an essential prerequisite for relative dating in caves.

Second, the humeral and ulnar fragments, which have the same macroscopic state of preservation as the MSA fauna (being highly fragmented), also have the same crystallinity and very low nitrogen, and are thus, likely to be derived from the same broad period of time. Clearly, they are relevant to the history of early human occupation of the site.

Third, the BC3 infant burial, with good macroscopic preservation and poor crystallinity, may be intrusive. This is of particular importance because the formal burial of the BC3 infant with associated grave goods is the sole evidence for such practices in MSA times. If it is indeed intrusive, the BC3 infant would be associated with the Holocene and would be archaeologically consistent with other sites in the region.

Finally, the well-preserved BC5 mandible also has both poor crystallinity and elevated nitrogen when compared with faunal bones from the 3WA, suggesting that it was intrusive. Because this specimen gave reproducible SF values, and because it is spatially associated with the faunal remains, we are most confident of this result.

Until the differences between BC 3 and BC5 on the one hand, and the MSA fauna on the other can be explained, these hominids cannot be connected to the MSA period with

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NHM, National History Museum. Wits Anatomy, Department of Anatomy, University of Witwatersrand.
confidence. The bearing of these specimens on the early emergence of modern humans in the region is equivocal.

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