On the age of Border Cave 5 human mandible

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Abstract

An enamel fragment from the Border Cave 5 specimen was analysed with non-destructive ESR combined with laser ablation ICP-MS for uranium profiling. We obtained an age of 74 ± 5 ka which fits exactly into the chronological framework that has been previously established for Border Cave by a variety of dating techniques. The result lays at rest the view that BC5 could be of Iron Age, as was implied by (Journal of Human Evolution, 31 (1996) 499) based on nitrogen contents and infra-red splitting factors.
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Location of BC5

The archaeological site of Border Cave, Kwazulu-Natal, South Africa, has yielded a number of modern hominid remains, labelled BC1 to BC8. A short summary of the human remains was recently given by Grün and Beaumont (2001). BC5 is a fairly complete lower jaw (Fig. 1) which was recovered by C. Powell in 1974 from the northwest edge of square T20, while she and one of us (PB) were collecting sediment samples, at the request of K.W. Butzer, from the south face of Excavation 3A (Fig. 2). It came from the Layer 3 WA (the site shows a succession of white and brown sands which have been termed "white ashes" (WA) and "brown soils" (BS), numbered

from top to bottom), about 0.25 m below its intact surface, and immediately adjacent to a previously mapped and photographed depression (Fig. 3). The base of this depression is cut by up to 0.15 m into the upper part of the underlying 4BS. The excavation of square T20 about six months later, and of T21, U20 and U21 by G. Miller in 1987, permitted the full extent of this 1.8 m wide sub-circular feature to be traced, but, no further human remains were found in it.

The 3WA in that vicinity, including the infill of the depression, was predominantly composed of an unstratified orange ash, and it was consequently impossible to certainly identify the rim of a larger pit of which the shallow depression is best considered to represent the base. However, it can be inferred that this pit was not made when the 3WA had just commenced formation, because if it had, a
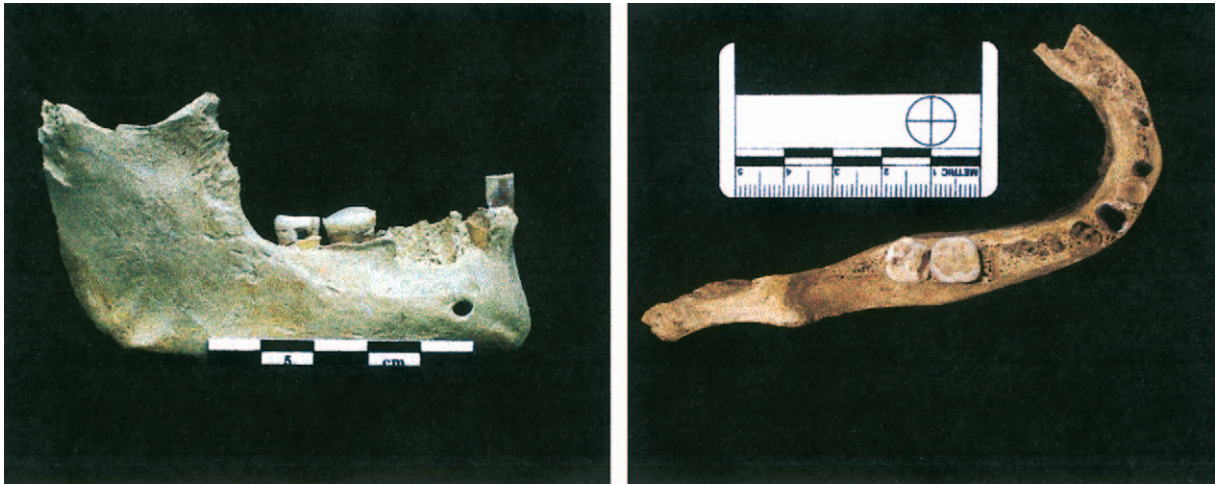
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Fig. 1. Lateral and occlusal views of the BC5 mandible (Photos by Jason Heaton with assistance of Colin Menter).
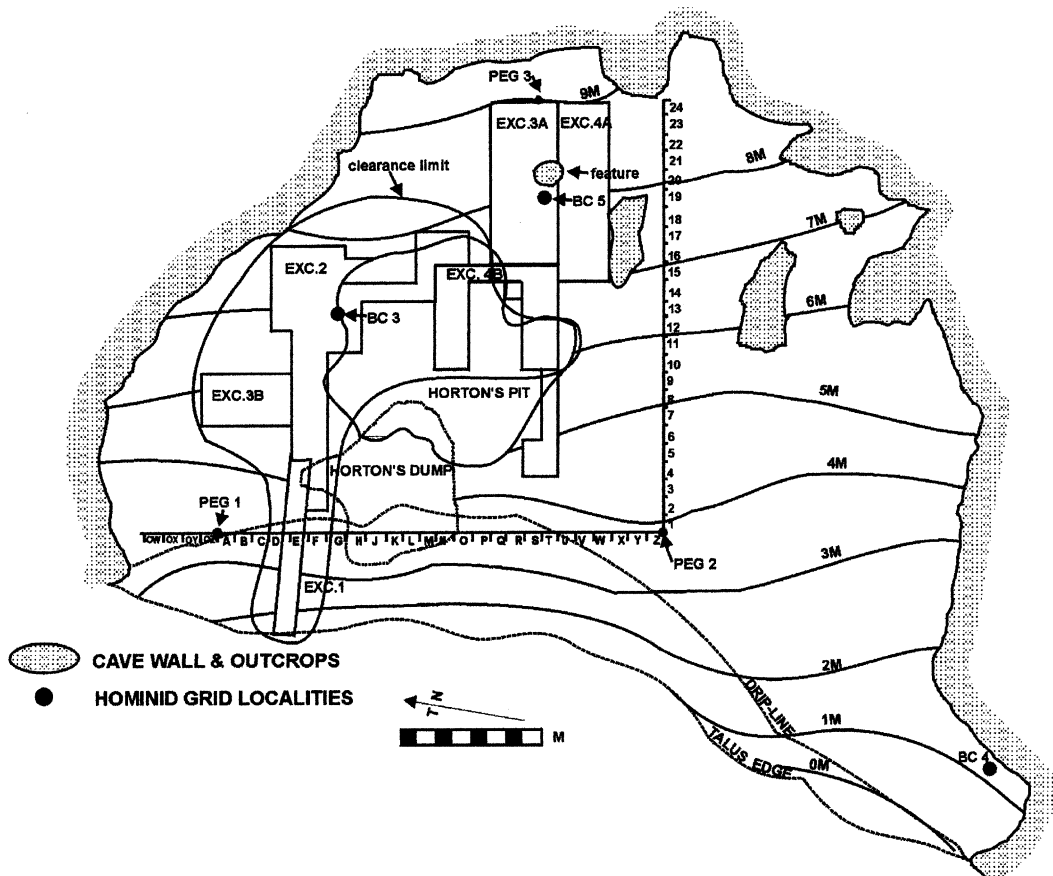

Fig. 2. A plan of Border Cave showing the extent of the clearance in 1987, the location of Excavations 1 to 4, and the grid localities of hominids BC3 to BC5.
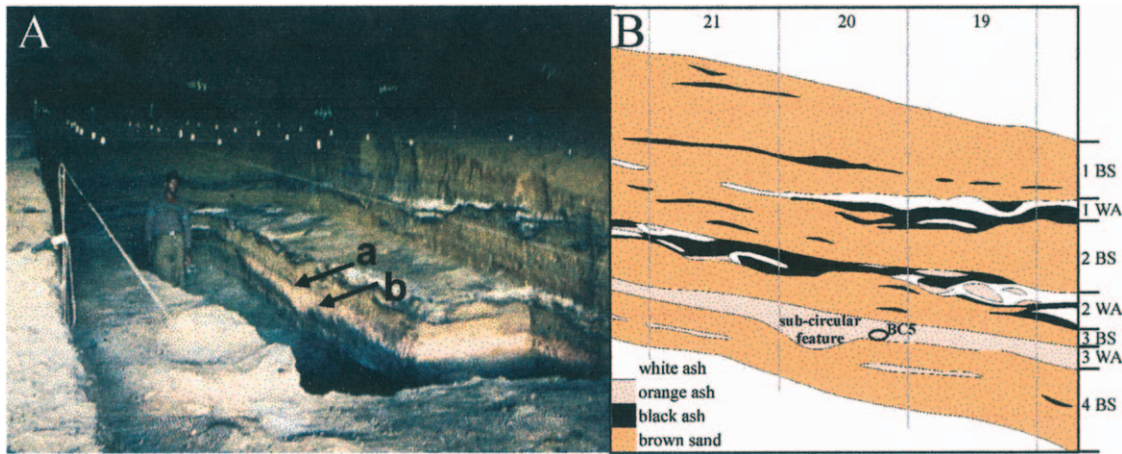
Fig. 3A. A photograph taken in February 1971 of the completed Excavation 3A (rear) showing (a) the intact surface of the feature in square T20, and (b) the point where BC5 was found in 1974.

3B: North face of squares (in yards) T19 to T21 in Excavation 3A. Subsequent fieldwork showed that the circular feature reached its maximum depth about 80 cm to the South.

high proportion of grey-brown sand derived from where it cut into the underlying 4BS would have markedly deepened the colour of the depression infill. This was not so, which would rather suggest that the pit was dug when the 3WA was close to its maximum thickness, in which case sporadic ill-defined lens of darker sediment at that level, including one obliquely above the jawbone, suggest that it was wider than the depression to an extent that it perhaps incorporated BC5.

Previous dating studies

Border Cave has been the subject of several dating studies, employing radiocarbon on charcoal (see Beaumont et al., 1978; Beaumont, 1980; Bird et al., 2003), ESR on faunal teeth (Grün et al., 1990; Grün and Beaumont, 2001), amino acid racemisation of ostrich eggshells (see Beaumont et al., 1992; Miller et al., 1999) and thermo-luminescence on burnt flint (J. Huxtable and H. Valladas, pers. comm. to PB). Comparison of the dating results reveals slightly younger mean ESR dates (in the range of 5 to 10%) than those of the other dating techniques. This has been attributed to a small fading component (see Grün and Ward, 2002). There are unfortunately no amino acid and

TL results available on layers 3WA and 4BS. If BC5 was contemporaneous with the faunal teeth found in 3WA its age would be about 64 ± 2 ka (average ESR age of layer 3WA) and younger than 77 ± 2 ka (average ESR age of Layer 4BS; see Fig. 9, below).

Infrared splitting factors and nitrogen assays

Sillen and Morris (1996) have published and provided one of us (PB) with splitting factor (SF) and nitrogen (N) assays on BC1 through to BC7 and on faunal cortical fragments from the Excavations 3A and 4A sequence that were submitted to Sillen between 1990 and 1993. The interpretation by Sillen and Morris (1996) of the Border Cave data (Fig. 4) was based on Elands Bay Cave (EBC) results where SF increases with depth to a limit at about 20 ka BP (Sillen and Parkington, 1996). However, no comparable trend is evident at Border Cave, except for increases from about 2.9 to 3.7 in the 1BS.UP (Iron Age) spits and from about 3.4 to 5.3 in the basal 6BS (arrows in Fig. 4). Sillen and Morris (1996) concluded that "*until the differences* [of SF factors] *between BC3 and BC5 on the one hand, and the MSA fauna on the other can be explained, these*
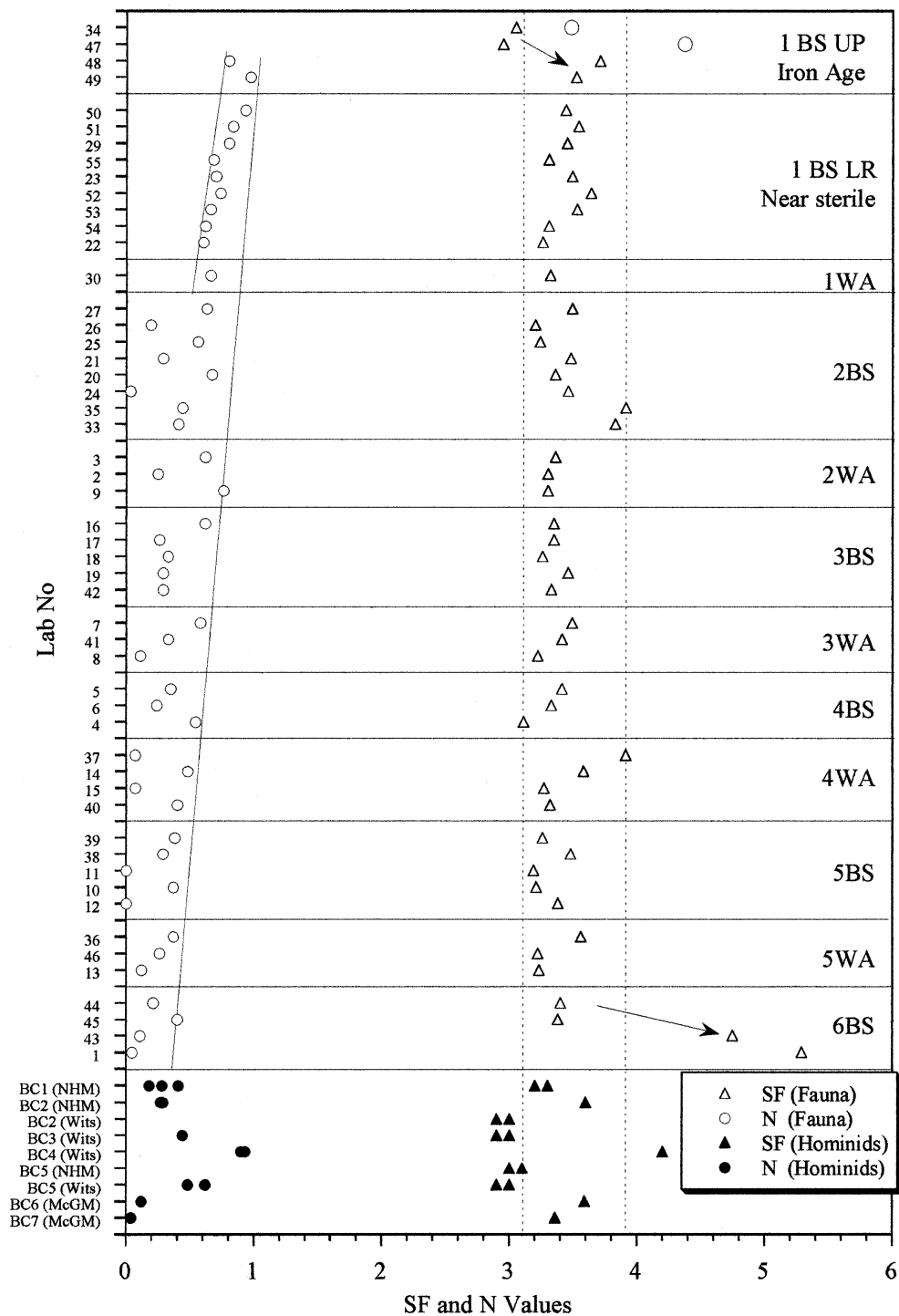
hominids cannot be connected to the MSA period with confidence".

The following questions arise from the study of Sillen and Morris (1996):

- Are BC3 and BC5 significantly younger than the layers in which they were found?
- Is the measurement of lower SF factors in hominid material proof of their claimed Holocene provenance?

Stratigraphic considerations

A full account in Beaumont (1978: his Appendix 4) listed the mean depth of the thickness of each stratum in Excavation 3A square by square, including those of the nine undisturbed major units that were found to overlie the 3WA in square T20. Samples of bone and charcoal from 1WA in T20 and T21 were U-series dated to about 35 ka and with ^{14}C to 39.5 and 38 ka BP. Despite those data, Klein (1983, 1989) and Parkington (1990) have claimed that BC5 "may have" come from a post-MSA grave, supposedly indicated by marked preservational differences between the human and animal bones from the 3WA. It is evident that any purported, $\geqslant 1.0$ m deep burial shaft from the Iron Age or Early LSA strata down to the 3WA in square T20 (Fig. 3B) would have led at least to some artefact mixing within it and homogenization of temporal patterns shown by surrounding, intact sediments. To determine if any such effects could be detected, all pertinent samples in square T20 were re-examined and comparative figures for three nearby squares were compiled, using listings in Appendices 18, 27 and 35 of Beaumont (1978). The results of seven tests are as follows:

There is no evidence in T20, or in any other Excavation 3A square for:

1) the vertical displacement of artefact types typical of the Howieson's Poort, MSA3, Early LSA or Iron Age that a pit dug and refilled from the Iron Age or Early LSA levels would have caused;
2) the distortion of a distinctive pattern shown by the proportion of opaline-based artefacts in the lithic assemblages, which declines from about 60% in 3WA to about 1% in 2BS.LR.C, before increasing again to about 80% in the Early LSA levels (Fig. 5A);
3) the distortion of a distinctive pattern shown by the number of stone artefacts per stratum and square, in which low values in the IBS.LR.A and 2BS.UP are separated by a stratum with a value about 25 times higher in the Early LSA levels (Fig. 5B);
4) the distortion of a distinctive pattern shown by the mass of macrofaunal fragments per stratum and square, in which low values in the IBS.LR.A and 2BS.UP are separated by a value about 25 times higher in the Early LSA levels (Fig. 5C);
5) the distortion of a distinctive pattern shown by the mass of charcoal nodules per stratum and square, in which lows in the IBS.LR.A and 2BS.UP are separated by a layer with a value about 22 times higher in the Early LSA levels (Fig. 5D).

Furthermore, it was found that:

6) during the 1987 fieldwork the precise orientation and dip of all artefacts larger than 25 mm long were measured by L.C. Todd and G. Miller, who found a total concordance with stratigraphy throughout Excavation 4A (Fig. 2), including those levels above the 3WA in squares T21, U20 and U21;
7) samples of bone and charcoal from the 1WA in squares T20 and T21 were dated by U-series

Fig. 4. (previous page) SF and N values for faunal and hominid samples from Border Cave (data supplied by Sillen to PB). All samples fall, without trend, into a band of SF values between 3.1 and 3.9 (vertical dotted lines), except for sub-recent samples 34 and 47 (which are slightly lower) and the lowermost samples 43 and 1 (which have significantly higher values). The low SF values of BC3 and BC5 have been used to correlate these hominid remains with the sub-recent faunal specimens (34 and 47). The N assays, after the depletion of an initial collagen reservoir (still present in 34 and 47), show a broad trend from about 0.8% in IBS.LR.A to about 0.4% in 6BS.LR (dotted line) that can perhaps be used for coarse temporal correlation. Abbreviations for human samples: NHM: sample stored in the Natural History Museum, London; Wits: Witwatersrand University; McGM: McGregor Museum.
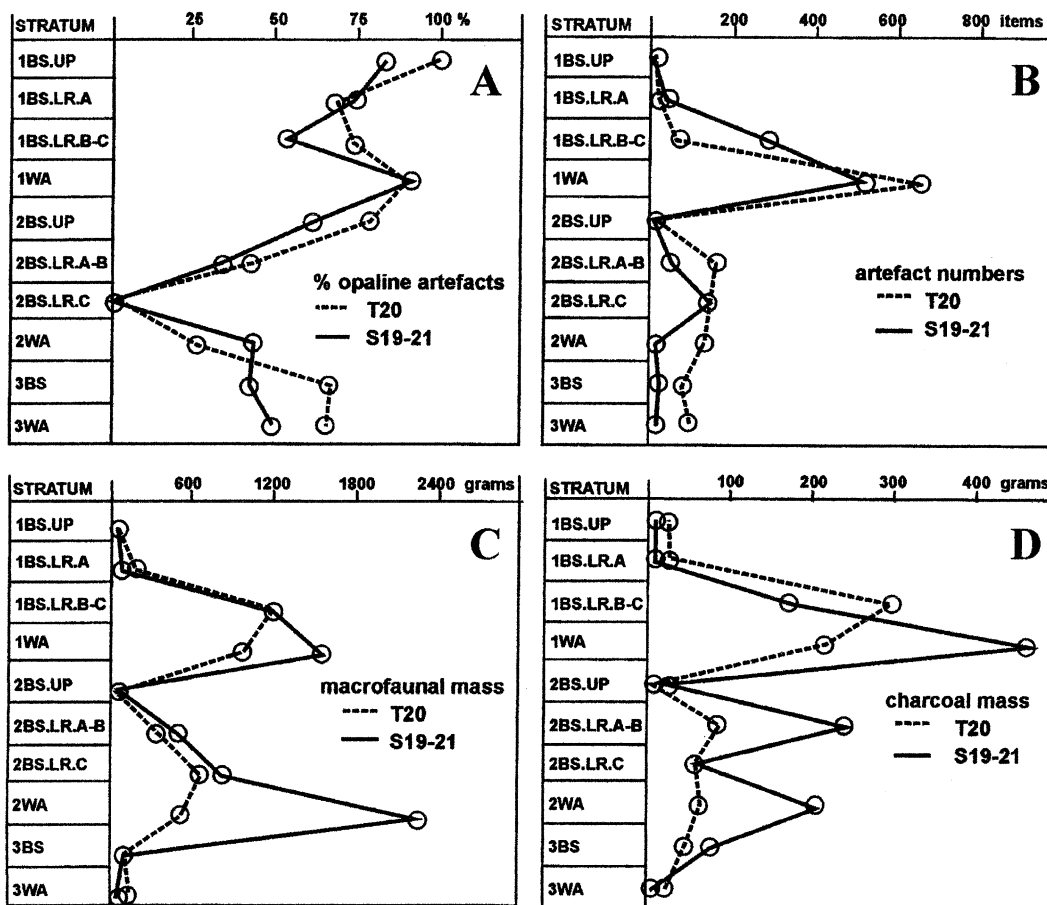
Fig. 5. Temporal shifts between the IBS.UP and 3WA levels in square T20 relative to squares S19–21 in (A) the percentage of opaline artefacts, (B) artefact numbers, (C) macrofaunal mass, and (D) charcoal mass.

and ^{14}C dated to about 35 and 38 ka BP respectively, which is consistent with the other ^{14}C readings for that level (Beaumont et al., 1992), but not, in the former case, with a pit-derived age, which would have reflected the contribution of bones from below 2BS.UP (Fig. 5C).

In view of this absence of any stratigraphic support for the post-MSA derivation of BC5 it was considered useful to extend an unpublished 1974 comparison of the preservational quality of the mandible relative to the associated fauna from the 3WA in square T20. Sets of uncharred bone from each level in that square were isolated and compared. Bone surface preservation was found uniformly good between 1BS.UP and 3WA, and consequently there is no difference in this respect between any set and BC5. This conclusion is complemented by a consideration of the mechanism that has been evoked to explain the supposedly poor preservation of the animal bones, namely postdepositional leaching (Klein, 1977, 1983, 1989). This is a process dependent on moisture, for which there is no evidence in the hyper-arid interior strata, as shown by exceptional floral preservation (Fig. 6) and teeth that are all virtually uranium-free (Grün et al., 1990).
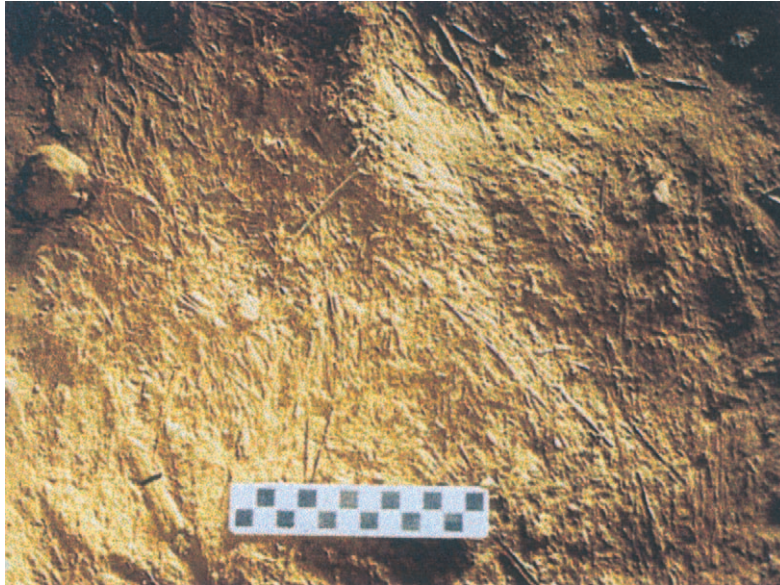
Fig. 6. Intact lenses of floral debris, such as this 1WA occurrence, cover extensive areas in levels down to the 2WA in Excavations 3 and 4, including square T20.

Dating analysis of BC5

However, all arguments above are circumstantial and conclusive proof for the age of BC5 can come only from the direct dating of this specimen (see also Grün and Beaumont, 2001). In 2002, we obtained permission to sample a small tooth fragment of BC5 for ESR dating. Using a small screwdriver, a 4.6 mg fragment (Figs. 7A,B) was detached from the loose, partial crown of the mandibular right third molar by Dr. R.J. Clarke. The crown can be fitted back on to the stump of that tooth which is still in the alveolar part of the mandible. The tooth is moderately worn with only a small island of dentine exposure, in contrast with the more heavily attrited second molar of the same side, which is in position in the jaw. The degree of wear of the second and third molars is compatible with this jaw having belonged to an adult individual. The average thickness of the fragment was $600 \pm 100 \, \mu m$.

First, we used laser ablation ICP-MS on the mirror surface of the remaining tooth to obtain ^{238}U- and ^{232}Th-profiles of the enamel and dentine (Fig. 7C; for details of this technique, see Eggins et al., 2003). These concentration profiles are shown in Fig. 7D. The uranium concentration in the enamel, 1 to 10 ppb, is close to modern values, whereas the uranium concentration in the dentine, 220 ± 20 ppb (all analytical and age uncertainties in this paper are given with a 1-σ confidence level), is slightly elevated and very uniformly distributed. The Th-concentrations are within the background range (~ 1 ppb), except very close to the surface of the enamel where the ^{232}Th concentration rises to about 30 ppb. The total Th-dose rate is significantly less than 1 $\mu Gy/a$.

Some dentine adhering to the fragment was removed and the enamel fragment was mounted in a Bruker ER 218PG1 programmable goniometer and measured at each dose step at 10° angle intervals for 440° (the spectra past 360° were used to check for short-term fading effects). ESR measurements were carried out on a Bruker ECS 106 spectrometer with a 15 kG magnet and a rectangular 4102 ST cavity. The samples were recorded with the measurement parameters routinely applied in the ANU laboratory: accumulation of between 500 (natural sample) and 400 scans (for the higher dosed samples) with
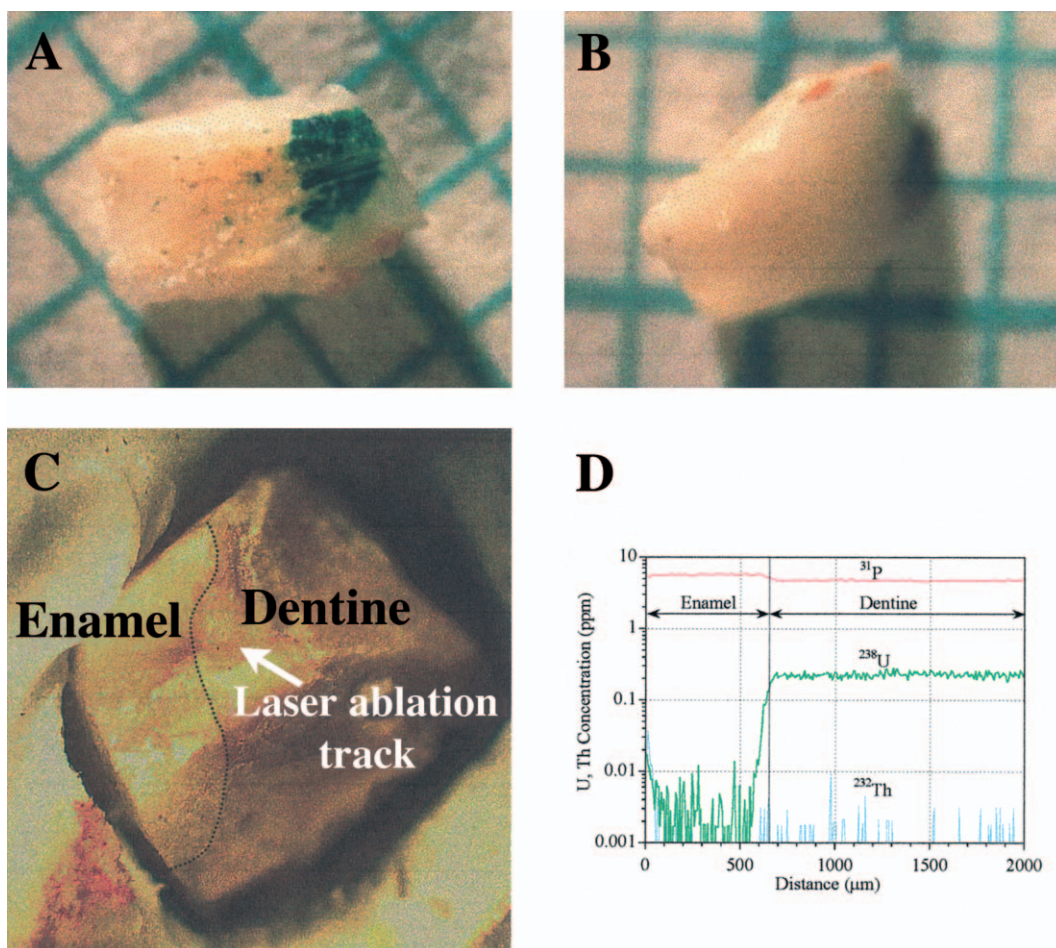
Fig. 7A,B. Photographs of the enamel fragment used for dating analysis, the underlying metric paper has 1mm squares. The green dot is used for orientation of the sample in the sample holder.

7C: Laser ablation track on the mirror surface of the remaining tooth. The ablation track is 120 μm wide.

7D: Laser ablation ICP-MS profiles for ^{238}U and ^{232}Th (the ^{31}P track is used for normalisation). The uranium in dentine is slightly above modern values and is homogeneously distributed (220 ± 20 ppb). The uranium in enamel drops to modern values (5 ± 5 ppb). The Th concentrations are close to detection limit within both enamel and dentine (<5 ppb).

1.015 Gpp modulation amplitude, 10.24 ms conversion factor, 20.48 ms time constant, 2048 bit spectrum resolution (resulting in a total sweep time of 20.972 s), 120 G sweep width and 2 mW microwave power. The enamel piece was successively irradiated with the following cumulative doses: 0, 13.4, 25.0, 45.5, 68.0, 111, 158, 248 and 392 Gy. Note that the total, uninterrupted measuring time was more than 43 days. ESR intensity values were obtained by natural spectrum fitting (see Grün, 2002), dose values were obtained by applying a single saturating function with linear conversion, and errors were estimated by Monte Carlo simulation (for more details see Grün and Brumby, 1994). Fig. 8 shows the angular dose measurements, which yielded an average value of 150 ± 5 Gy.

Moisture content measurements on Border Cave sediment samples show negligible moisture contents. Varying water concentrations in the sediment could introduce significant uncertainties in the age calculations (see e.g. Aitken, 1985). This
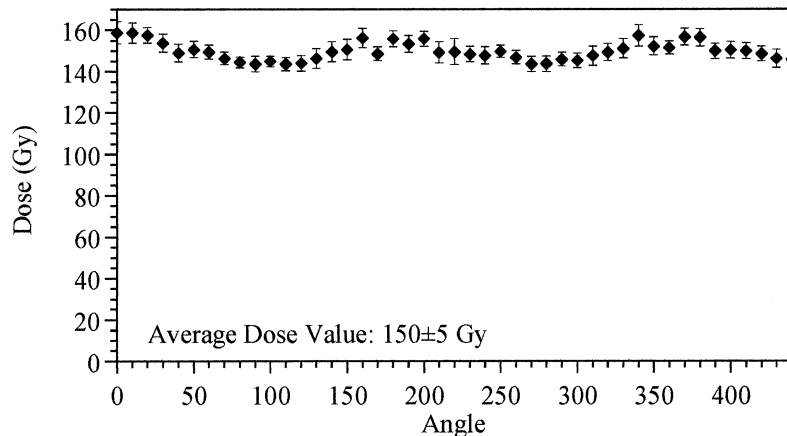
Fig. 8. Dose values at different angles. Natural spectrum fitting (see Grün 2002) yields an average dose value of 150 ± 5 Gy (mean and standard deviation of repeated measurements).

would particularly apply in Border Cave where the dose rates of the teeth are virtually completely derived from the sediment. Based on the analysis of micromammalian remains, Avery (1992) found that the rainfall during stage 4 was approximately the same as today and decreased during stage 3. Thus, there are no climatic indications that the moisture contents of the sediments in Border Cave could have been significantly higher in the past. This is corroborated by the extremely good floral preservation (Fig. 6) as well as lack of any uranium enrichment in any of the teeth from layer 4BS upwards (see Table 1 in Grün and Beaumont, 2001).

The cosmic dose rate is difficult to assess as the thickness of the cave roof is not precisely known. A roof thickness of 10 ± 5 m ($\rho \approx 2.6$ g/cm^3) results in a cosmic ray contribution of 48 ± 19 µGy/a (Prescott and Hutton, 1988, 1994).

In 1999, Helene Valladas and her collaborators measured 13 gamma dose rates using TL dosimeters. Unfortunately, no measurements were carried out on layer 3WA. Excluding measurement D7 on 4WA, which showed a 50% discrepancy, the TL gamma dose rates (Helene Valladas, pers. comm., 9 September 1999) differ from those derived from Fig. 3 in Grün and Beaumont (2001) on average by about 7.6%. However, there is no detectable bias in the data sets as the averages of the TL and gamma spectrometric measurements

agree within less than 1%. Most of the differences between the measurement sets can be attributed to intra-layer dose rate variations, which are particularly pronounced in layer 4WA, where most of the TL measurements were carried out. We are thus confident that our gamma spectrometric measurements are appropriate for the calculation of ESR and TL ages.

About 200 g of a sediment sample from the base of Layer 3WA in square T20 was homogenised and analysed by neutron activation and the following concentrations were obtained: 2.05 ± 0.50 ppm U, 10.8 ± 0.2 ppm Th and $2.87 \pm 0.1\%$ K (these values agree well with other sediment samples from 3 WA; see table 1 in Grün and Beaumont, 2001). The results were used for the calculation of the external beta dose rate. The gamma dose rate derived from this sediment sample, 1447 ± 63 µGy/a, is somewhat higher than the dose rate interpolated from the previous detailed gamma ray survey, 1350 ± 27 µGy/a (see Fig. 3 in Grün and Beaumont, 2001). We therefore decided to use the average of these two measurements, 1400 ± 100 µGy/a. Using dose rate values of Adamiec and Aitken (1998), an alpha efficiency of 0.13 ± 0.02 (Grün and Katzenberger-Apel, 1994), and Monte Carlo beta attenuation factors of Marsh (1999), the following dose rate values were obtained: enamel alpha and beta dose rate: 1 ± 1 µGy/a; beta dose rate (sediment): 573 ± 66 µGy/a; beta dose
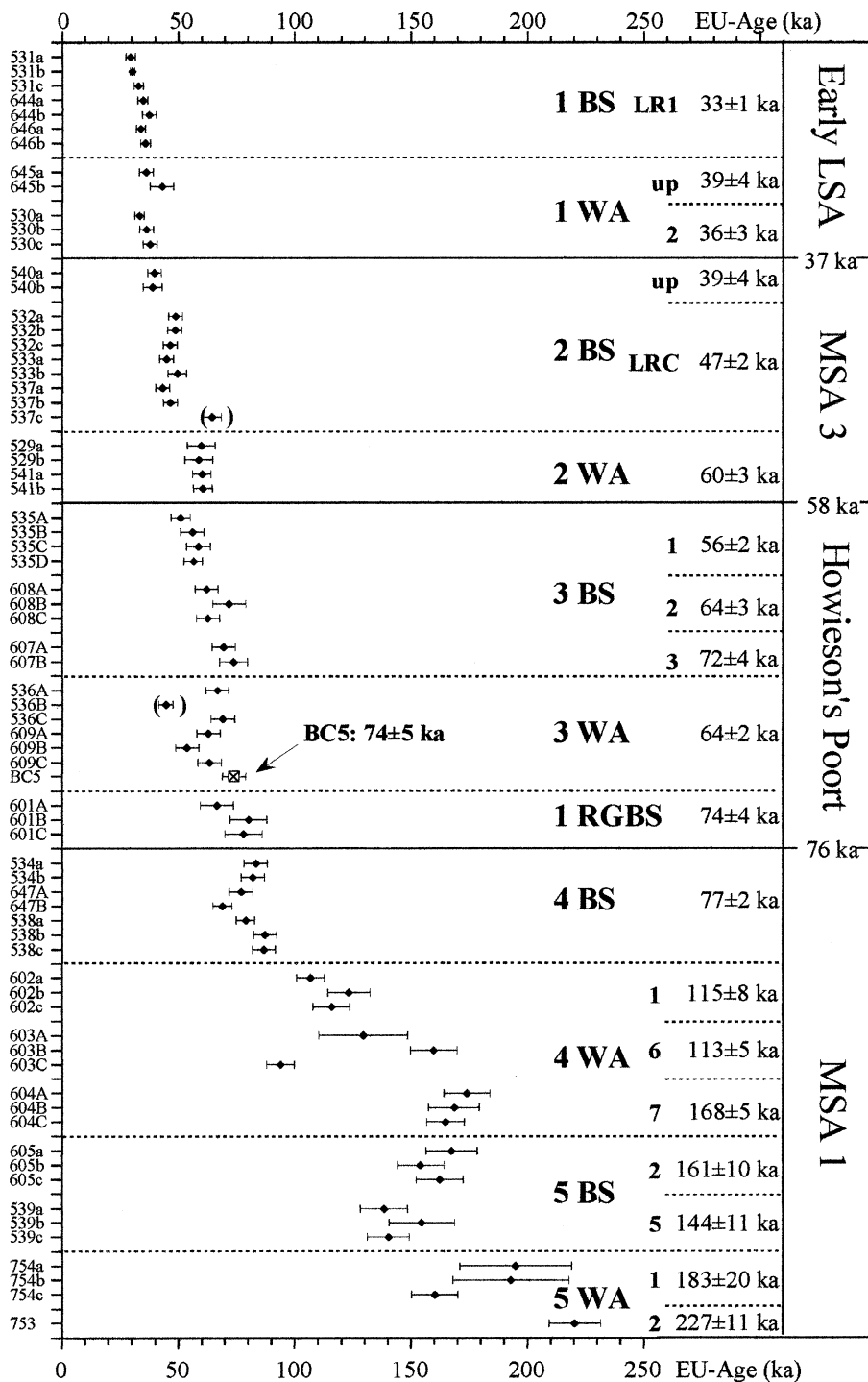
rate (dentine) $4 \pm 0 \mu Gy/a$, resulting in a total dose rate of $2026 \pm 121 \mu Gy/a$ and an age of 74 ± 5 ka. Because of the low U-concentrations in enamel and dentine, resulting in very small dose rate contributions from the tooth itself (<0.3%), the age estimate is not sensitive to the mode of U-uptake.

Discussion

Note that the cosmic dose rate was neglected in the previous ESR data set. All previous ages were re-calculated with a cosmic ray contribution of $48 \pm 19 \mu Gy/a$ and plotted into Fig. 9. The individual age estimates decreased by between 2 and 4%. In order to avoid bias by correlated errors (e.g. each sub-sample of a tooth has the same error in the external gamma dose rate value, which cannot be minimised by analysing more sub-samples of the same tooth), an average age and average error was calculated for each separate tooth sample before the average age of a layer and its error was derived from weighted means of the different tooth samples of the respective layer. As a consequence, the error in the average age of layer 4WA1 (three sub-samples of one tooth) is larger than the error in the average age of 4WA6 (three separate enamel fragments) although the results of 4WA6 show a much larger scatter in the individual results. Nevertheless, the age results are within the 1-σ error range of the previously published values (Grün and Beaumont, 2001).

When the age BC5 result (74 ± 5 ka) is compared to those of the faunal material (Fig. 9) it is obvious that BC5 fits exactly into the ESR age sequence of the faunal material. It may be argued that some of the assumptions made for the ESR age estimation, e.g. the constancy of the negligible moisture contents in the sediment, are inappropriate. Whilst this may affect the resulting age calculations of BC5 to a small if not negligible extent,

the same processes would also systematically bias the age calculations of the faunal elements. As a result, the age relationship between BC5 and the faunal material would remain the same.

The ESR results obtained on BC5 suggests that the mandible was probably incorporated into the sedimentary sequence at the beginning of the deposition of 3WA, rather than later when 3 WA had reached it maximum thickness. BC5 was clearly not inserted into 3WA from any higher level, and is certainly not of Holocene age.

Revisiting the SF/N assays on the samples from Border Cave, we can make the following observations (see Fig. 10): the hominid samples BC 3 to BC5 do not fit into the data cluster provided by the faunal material. This is due to the fact that the hominid SF factors lie outside the relatively narrow range (3.1 to 3.9) of the faunal material. When only the nitrogen values are considered, we find that the provenanced human specimens BC4 (1 BS UP), BC5 (3WA) and BC3 (4BS) are in the correct order and are compatible with the N concentrations of the corresponding faunal material. The scatter in the N concentration results on faunal material as well as in the repeated analyses of the human bones (e.g. BC1), however, does not allow the assignment of a human specimen to a particular layer. For example, faunal samples with N results in the same range as BC1 and BC2 can be found in all layers below 1 WA.

An explanation for the differing faunal and human SF factors could be attributable to the proposition that at least some of the human remains were intentionally buried. The ESR dates (Grün and Beaumont, 2001) show that the 1BS.LR.B-4WA.B strata accumulated very slowly. As a result, it would take on average about 600 years to cover a 20 mm thick bone. Some indication of the degree to which crystallinity values have changed over such a period is provided by radiocarbon readings for superficial stratum

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Fig. 9. (previous page) The age of BC5 in context with the revised ESR chronology for Border Cave. Lowercase letters following the sample number denote sub-samples of a single tooth, capital letters separate enamel fragments. The two bracketed results were not used for the calculation of the average ages of the units. Note that the ESR ages of the faunal remains differ slightly from those of Grün and Beaumont (2001) because of incorporation of a cosmic dose rate of $48 \pm 19 \mu Gy/a$ as well as the elimination of bias from correlated errors between sub-samples of a single tooth.
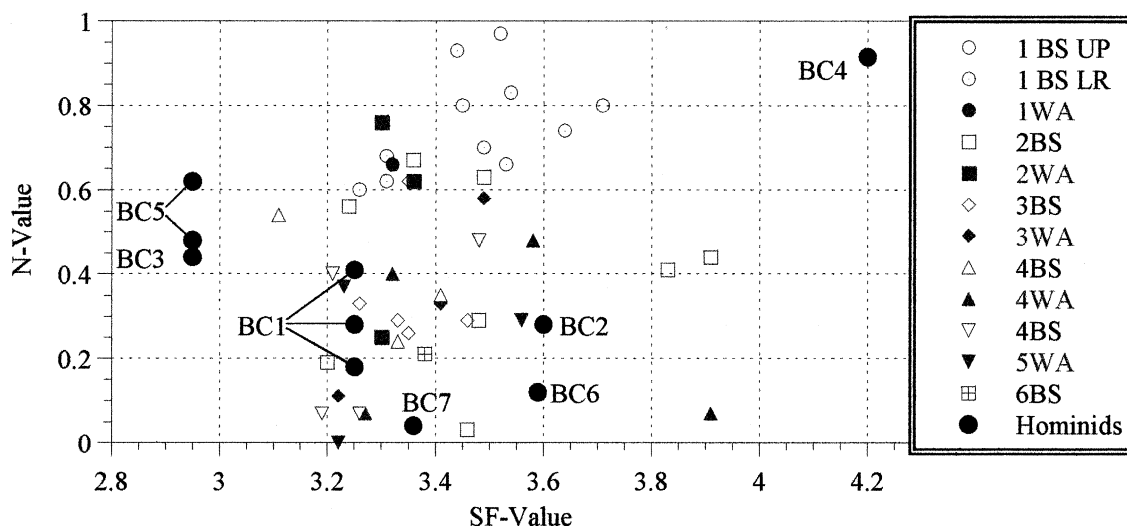
Fig. 10. The plot of SF values versus N assays show that BC3 to BC5 fall outside the range that is defined by the faunal material. This may be due to the proposition that this human material was intentionally buried.

1BS.UP. Spits 1 and 3 of that level have midpoint ages (Beaumont, 1980) and SF readings that differ by about 300 years and 0.7, respectively. This suggests a mean SF increase of 0.2 per century. From that estimate it may be inferred that the SF shifts were, in general, entirely induced in surface bones by occasional mist and cloud influxes (Beaumont, 1973, 1978). Once covered by typically fine-grained and hydrophobic sediments (Beaumont, 1978), the demonstrable lack of moisture in these sediments (see above) precluded any further SF increase (Hedges and Millard, 1995).

Conclusions

Our dating result demonstrates conclusively that BC5 was buried at the beginning of the deposition of layer 3 WA. Our best age estimate is 74 ± 5 ka. We conclude from our dating result on BC5 and the comparison with measurements of SF and N assays that the latter are not particularly well suited to derive age estimates for the fossil hominids at Border Cave. The ages of the other specimens are also best obtained by chronometric studies. At present ESR cannot provide any further age constraints for the Border Cave hominids.

The only other specimen with teeth, BC3, has partly vanished and the enamel of the few remaining teeth is very thin. It may, however, be possible to date enigmatic fossils BC1 and BC2 by U-series dating (see Pike, 2000; Pike et al., 2002). On the other hand, non-destructive ESR dating may help to establish the ages of other important fossils whose age is debatable, e.g. the mandible of Banyoles (see Julià and Bischoff, 1991).

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