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# RADIOCARBON DATING OF A VERY OLD AFRICAN BAOBAB FROM SAVÉ VALLEY, ZIMBABWE

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**ABSTRACT.** The article reports the radiocarbon investigation results of the Humani Bedford baobab, an old African baobab from Savé Valley, Zimbabwe. Two wood samples were collected from the large inner cavity. Several segments were extracted from these samples and analysed by AMS (accelerator mass spectrometry) radiocarbon dating. We found that the age values of segments increase with the distance into the wood. This major anomaly is characteristic to multi-stemmed baobabs with a closed ring-shaped structure and a false cavity inside. The investigation of the Humani Bedford baobab evinced that the baobab consists of three fused stems. The fourth stem of the ring is missing. The oldest dated segment was found to have a radiocarbon date of 1655 ± 14 BP, which corresponds to a calibrated age of 1575 ± 30 yr. The dating results show that the stems which build the ring stopped growing toward the false cavity more than 600 yr ago. By considering the position of the oldest segment in the investigated stem, we concluded that the Humani Bedford baobab is around 1800 yr old. According to our dating results, the Humani Bedford baobab becomes the oldest living African baobab.

***Keywords:*** *AMS radiocarbon dating, Adansonia digitata, tropical trees, dendrochronology, age determination.*

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## INTRODUCTION

The genus *Adansonia* belonging to the Bombacoideae, a subfamily of Malvaceae, consists of nine species. Two species originate from mainland Africa, six are endemic to Madagascar and one can be found in northern Australia [1-4]. The African baobab (*Adansonia digitata* L.), which has a natural distribution in mainland Africa, especially in savanna areas, is the biggest and best-known of the *Adansonia* species [4-8].

In 2005, we started an in-depth research aimed to elucidate several controversial or poorly understood aspects concerning the architecture, growth and age of the African baobab. The research is based on our new approach which enables to investigate and date also standing live specimens. This approach consists of AMS radiocarbon dating of tiny wood samples collected especially from inner cavities, but also from deep incisions/entrances in the stems, fractured/broken stems and from the outer part/ exterior of large baobabs [9-14].

The radiocarbon investigation has revealed very interesting features of the African baobab. Due to the special ability of baobabs to produce stems periodically during their life cycle, over time they develop architectures of increasing complexity. The obtained results have demonstrated that all large baobabs are multi-stemmed. We identified the so-called open and closed ring-shaped structures, which are the most important architectures that enable African baobabs to reach old ages and large sizes. We documented the presence of false cavities, which are large natural empty spaces between fused stems disposed in a closed ring-shaped structure. The oldest dated *A. digitata* individuals were found to have ages up to 2500 years. According to these values, the African baobab becomes the angiosperm with the longest life span [14-16].

One should mention that the identification of very complex architectures and the accurate dating of large and old baobabs are not enabled by traditional dendrochronological methods, which are based on tree-ring investigation [16-19]. Old baobabs have often large cavities, especially in the central area of their trunk/stems. In normal cavities generated by wood removal, the pith/centre of the stem is located inside the cavity. For wood samples collected from normal cavities, ages decrease continuously from the cavity walls toward the outer part of the stem. Our research of large and old baobab specimens identified a major anomaly in the age sequence of samples dated by radiocarbon. In such cases, ages of samples collected from their inner cavities increase from the cavity walls up to a certain distance into the wood, after which they decrease toward the outer part. The only reasonable explanation for this finding is that such cavities are in fact only natural empty spaces, which were never filled with wood, between several fused stems disposed in a closed ring-shaped structure. We named them false cavities [15, 18].

The closed ring-shaped structures are formed progressively and close over time, as they consist of fused stems which typically are of different ages. The stems grow faster along the outer circumference and each develops a kind of crescent shape, which is necessary for fusing. As already mentioned, false cavities are natural empty spaces between the fused stems that build the closed ring. The first noticeable difference between false and normal cavities is the presence or absence of the bark inside the cavity. While normal cavities become larger over time due to continuous decay, false cavities tend to become smaller due to stem growth [15, 18].

Recently, we documented a new anomaly in the radiocarbon dating results of samples collected from large and/or old baobabs. In several cases, we found that the outermost rings (for samples collected from the outer part) or the innermost rings (for samples collected from false cavities), which were adjacent to the bark, were found to be old, with ages of several hundreds of years, instead of being very young. We named this unexpected phenomenon growth stop. For multi-stemmed baobabs, the growth stop may occur for one, for several or for all stems. We found that the growth stop may be induced by old age, stress, the need to preserve a stable internal architecture and the collapse of stems that survived this event. The baobabs and their stems affected by growth stop may survive for several centuries, continuing to produce leaves, flowers and fruits [19].

Dated growth rings of several studied African baobab specimens, which may act as a proxy climate archive, were used for past climate reconstruction in southern Africa [20-22].

We extended our research on the architecture, growth and age of the *Adansonia* genus by starting to investigate, using the same approach, large individuals of the most representative three Malagasy species, namely the fony baobab (*Adansonia rubrostipa* Jum. & H. Perrier), the za baobab (*Adansonia za* Baill.) and the Grandidier's baobab or Reniala (*Adansonia grandidieri* Baill.) [18, 23, 24]. We found that their characteristic features are similar to those of the African baobab.

The Savé Valley Conservancy is a large wildlife area (3442 km$^2$), located in the semi-arid South East Lowveld of Zimbabwe at an altitude of 480–620 m, with deciduous woodland savanna, low and variable rainfall and poor-quality soils. The Conservancy comprises multiple properties held by private ranchers, local councils, government and a local community [25]. Savé Valley hosts thousands of African baobabs, out of which 4 specimens, located all to the north of Turgwe river (in the Matendere, Chishakwe, Mokore and Humani ranches), have very large dimensions (circumference over 23 m) and are well over 1000 years old.

Here we disclose the AMS radiocarbon dating results of the oldest tree of Zimbabwe, i.e., the Humani Bedford old baobab.

## RESULTS AND DISCUSSION

*The Humani Bedford old baobab and its area.* The Humani Bedford old baobab is located in the Bedford Block that was incorporated in 1992 in the Humani ranch (formerly known as Gumani), which is part of the Savé Valley Conservancy, Chiredzi district, Zimbabwe. Somewhat surprisingly, the old baobab was discovered only in 2011 by Roger and Anne Whittall. Its GPS coordinates are 20º24.474' S, 032º14.135' E and the altitude is 432 m. The mean annual rainfall in the area is 457 mm.

The Humani Bedford baobab has a maximum height of 18.2 m, the circumference at breast height (cbh; at 1.30 m above ground level) is 23.65 m and the overall wood volume (trunk and branches, including the cavity) is around 240 $m^3$ (**Figures 1 and 2**).

Its big trunk has a closed ring-shaped structure, which consists now of three fused stems that close partially a false cavity with the walls completely covered by bark. A fourth stem is missing; it toppled likely more than one century ago, thus opening the false cavity toward the west. We estimate that prior to the collapse of the fourth stem, the baobab had a circumference close to 26-27 m and a total wood volume of around 300 $m^3$.

The false cavity has a quasi-ellipsodial shape with the axes of 2.59 x 2.70 m at ground level and of 2.54 x 2.98 m at the height of 1.50 m. The maximum height of the cavity was of 6.10 m, but now the roof is completely missing due to the multiple transformations suffered by the tree over time. The opening toward the cavity has a width of 0.70 m at ground level, 1.77 m at 1.30 m and 2.55 m at 2.00 m above the ground. A crocodile bark tree (*Diospyros quiloensis*) grows inside the false cavity (**Figure 3**).

The baobab has very large gnarled and twisted branches, with diametres up to 2.2 m; this is usually an indicative of old age. Several branches are broken or missing. The canopy consists of three distinct units of different heights; its horizontal dimensions are 27.2 x 24.7 m.

**Figure 1.** General view of the Humani Bedford baobab taken from the west, at the end of the rainy season. In the middle of the trunk one can observe the false cavity which is now opened.

**Figure 2.** Another general view of the Humani Bedford baobab taken from the north-east.

**Figure 3.** The false cavity with the crocodile bark tree that grows inside. The cavity has an ellipsoidal shape and its walls are covered by bark.

*Wood samples.* Several wood samples were extracted from the walls of the inner cavity. Even if the penetration of the borer in the wood was almost complete, the samples were short, revealing that the trunk is mainly hollow. However, two samples (labelled 1 and 2) were considered to be sufficiently long, i.e., 0.195 and 0.250 m, for investigation. The heights of the sampling points were 1.86 and 1.45 m. The two sampling positions are shown in **Figures 4 and 5**. A number of five small pieces/segments, each of the length of 0.001 m (marked as a, b, c), were extracted from determined positions of the two samples. We also extracted a very short sample from the outer part of the same stem (labelled 11), which consisted mainly of the outermost rings. The sampling height was 1.98 m.

*AMS results and calibrated ages*. Radiocarbon dates of the six segments extracted from the three samples are listed in Table 1. Radiocarbon dates and errors were rounded to the nearest year. The radiocarbon dates are expressed in $^{14}C$ yr BP (radiocarbon years before present, i.e., before the reference year AD 1950).


**Figure 4.** Detail of the western flank, also showing the false cavity and the sampling points (marked by 1 and 2). One should remark the very large branches of the Humani Bedford baobab.

Calibrated (cal) ages, expressed in calendar years, are also shown in Table 1. The 1-σ probability distribution was selected to derive calibrated age ranges. For three sample segments, the 1-σ distribution is consistent with only one range of calendar years, while for the other three segments the 1-σ distribution corresponds to two ranges of calendar years. For these segments, the confidence interval of one range is considerably greater than that of the other; therefore, it was selected as the cal AD range of the segment for the purpose of this discussion. For obtaining single calendar age values of sample segments, we derived a mean calendar age of each segment from the selected range (marked in bold). Calendar ages of segments represent the difference between AD 2016 and the mean value of the selected range, with the corresponding error. Calendar ages and errors were rounded to the nearest 5 yr.

**Table 1.** AMS Radiocarbon dating results and calibrated calendar ages of samples/segments collected from the Humani Bedford baobab.

| Sample (Segment) code | Depth[1] [height[2]] ($10^{-2}$ m) | Radiocarbon date [error] ($^{14}$C yr BP) | Cal AD range 1-σ [confidence interval] | Sample age [error] (cal yr) |
|---|---|---|---|---|
| 1a | 0.5 [186] | 585 [± 20] | **1398-1417 [68.2%]** | 610 [± 10] |
| 1b | 19.5 [186] | 1375 [± 20] | **658-682 [50.2%]** 746-757 [18.0%] | 1345 [± 10] |
| 2a | 0.5 [145] | 601 [± 18] | **1392-1414 [68.2%]** | 615 [± 10] |
| 2b | 15.0 [145] | 1230 [± 20] | 778-810 [26.2%] **843-888 [42.0%]** | 1150 [± 20] |
| 2c | 25.0 [145] | 1655 [± 14] | **410-469 [68.2%]** | 1575 [± 30] |
| 11 | 0.5 [198] | 303 [± 22] | 1520-1536 [11.5%] **1626-1657 [56.7%]** | 375 [± 15] |

[1] Depth in the wood from the sampling point.
[2] Height above ground level.

*Dating results of samples (segments).* The most interesting investigated sample was the longest one, i.e., sample 2, out of which we dated three segments. Two segments, 2b and 2c, were found to have radiocarbon dates greater than 1000 BP. The oldest dated segment 2c originates from a distance of 0.25 m into the wood from the sampling point, which corresponds to the deepest part/end of sample 2. Its radiocarbon date of 1655 ± 14 BP corresponds to a calibrated age of 1575 ± 30 calendar yr. The second oldest segment 2b, which originates from a depth of 0.15 m into the wood, was found to have a radiocarbon date of 1230 ± 20 BP and a calibrated age of 1150 ± 20 yr. The segment 2a corresponds to the innermost rings of the cavity, which were adjacent to the bark that covers the cavity walls. Its radiocarbon date of 601 ± 18 BP corresponds to a calibrated age of 615 ± 10 yr.

We also dated two segments extracted from sample 1. The deepest segment 1b, that originates from a distance of 0.195 m into the wood, had a radiocarbon date of 1375 ± 20 BP. This value corresponds to a calibrated age of 1405 ± 20 yr. The segment 1a, which corresponds to the innermost cavity rings, had a radiocarbon date of 585 ± 20 BP and a calibrated age of 610 ± 10 yr.

The sample/segment 11, which consists of the outermost rings of the same stem, had a radiocarbon date of 303 ± 22 BP and a calendar age of 375 ± 15 yr.

**Figure 5.** Collecting sample 2 from the eastern wall of the cavity.

*Architecture of Humani Bedford baobab*. The age values of segments extracted from the two samples collected from the cavity walls of the Humani-Bedford baobab increase with the depth into the wood, as revealed by Table 1. This demonstrates that the Humani-Bedford baobab possesses a closed ring-shaped structure with an accessible false cavity inside.

According to our research on baobabs, the number of fused stems that build the closed ring varies between three and eight. In principle, the number of stems can be determined from the analysis of radiocarbon dates of many samples collected from different areas of the tree, combined with a careful visual inspection of the false cavity, the trunk and the canopy for identifying stems and possible fusion lines [15,16]. In the case of the Humani Bedford baobab, due to the hollow parts inside its trunk and to the elephant damage which has affected constantly the stems over time, the samples were short and their number was insufficient for an accurate determination of the number of stems which build the closed ring. However, after the visual inspection of the baobab and the analysis of photos taken from all directions, we have established that the Humani Bedford baobab consists of three perfectly fused stems, while a fourth stem which toppled some time ago is missing. The false cavity, which has now a large opening on the western flank, was completely closed prior to the collapse of the fourth stem of the ring.

*Age of Humani Bedford baobab.* The two dated samples 1 and 2 were extracted from the eastern wall of the false cavity, more precisely from the same stem, which divides into the largest branches. For baobabs with a closed ring-shaped structure, such as the Humani Bedford baobab, the age sequence of samples collected from false cavities exhibits a continuous increase from the cavity walls up to a certain distance into the wood, which corresponds to a point/area of maximum age.

One can state without doubts that the age of the stem with the biggest branches of the Humani Bedford baobab is greater than the age of the oldest dated segment 2c, i.e., 1575 ± 30 yr. This segment corresponds to the deepest end of sample 2, which was continuous and had a length of 0.25 m. In this area, the width of the cavity wall, i.e., the distance from the sampling point 2 to the outer part of the tree is 1.20 m.

The point/area of maximum age, which is the oldest part of a stem, is typically hollow for very old baobabs, as a result of decay; the missing wood corresponds to the first years of life of the respective stem. On the other hand, for baobabs with closed ring-shaped structures, the stems which build the ring grow always faster toward the outer part than in the direction of the false cavity. Consequently, the point of maximum age is always located closer to the cavity than to the outer part.

In the case of the Humani Bedford baobab, the question to be answered is: at what distance is the point of maximum age positioned from sampling point 2 and from the outer part, respectively? For answering this question, we need also to know whether and when the investigated stem stopped growing.

The segment 2a, that consists of the innermost rings of the false cavity, had a calibrated age of 615 ± 10 yr. Meanwhile, the sample/segment 11, which corresponds to the outermost rings of the same stem, was found to be 375 ± 15 yr old. The age of segment 2a shows that the investigated stem of the Humani-Bedford baobab has stopped growing toward the false cavity around 615 yr ago. Our research on baobabs with closed ring-shaped structure has evinced that all stems, which build the ring, stopped growing toward the cavity almost simultaneously, when the false cavity reached a stable internal architecture. This growth stop is necessary for preventing the collapse of the cavity and of the entire ring. The radiocarbon investigation of the Humani-Bedford baobab shows that its stems stopped growing toward the false cavity around AD 1400.

Our previous research has also shown that, after their growth stop toward the cavity, the same stems continue growing toward the outer part, at least for a period of time [15]. The age of sample/segment 11 demonstrates that the investigated stem has continued its growth toward the outer part for almost 250 yr, until AD 1640.

According to the dating results disclosed here, we consider that the point of maximum age in the sampling direction 2 is located at 0.35 – 0.40 m from the cavity walls (sampling point 2) and 0.85 – 0.80 m from the outer part of the stem. Thus, the distance between the oldest dated segment 2c, which originates from a distance of 0.25 m from the cavity walls, and the point of maximum age of the stem, which corresponds to missing wood, was of 0.10 – 0.15 m. By considering both the sample ages and the growth stop, this distance may correspond to 250 – 350 yr of growth. Therefore, we estimate that the investigated stem of the Humani-Bedford baobab has an age of 1800 ± 100 yr and started growing around AD 200.

Over the past decade we investigated and dated almost all very large and potentially old African baobabs around the world. We dated four baobab specimens with sample ages greater than the oldest dated sample of the Humani Bedford baobab. However, all four baobabs toppled or at least their oldest stems died. Therefore, the Humani Bedford baobab is now very likely the oldest living African baobab.

## CONCLUSIONS

Our research discloses the AMS radiocarbon investigation results of the Humani Bedford baobab, a very old African baobab from Savé Valley, Zimbabwe. The main aim of the research was to determine the age and the architecture of this baobab. Two wood samples were collected from the walls of the large inner cavity. The age values of the segments extracted from these samples increase with the distance into the wood. This anomalous age sequence is specific to multi-stemmed baobabs having a closed ring-shaped structure with a false cavity inside. Such structures, that enable baobabs to reach large sizes and old ages, consists of several fused stems disposed around a natural empty space which corresponds to the false cavity. The investigation of the Humani Bedford baobab shows that in present it consists of three fused stems, while a fourth stem is missing.

Three segments were found to have radiocarbon dates greated than 1000 BP. The oldest segment had a radiocarbon date of 1655 ± 14 BP, which corresponds to a calibrated age of 1575 ± 30 yr. Dating results also show that the stems stopped growing toward the false cavity over 600 yr ago, while the investigated stem has continued growing toward the outer part for almost 250 yr. By considering the original position of the oldest dated segment in the investigated stem, we estimate that the Humani Bedford baobab is 1800 yr old and has started growing around 200 BP.

## EXPERIMENTAL SECTION

*Sample collection.* The wood samples were collected with a Haglöf CH 600 increment borer (80 cm long, 0.54 cm inner diametre). A number of five tiny pieces/segments of the length of 0.1 cm were extracted from predetermined positions along the wood samples. The segments were processed and investigated by AMS radiocarbon dating.

*Sample preparation*. The standard acid-base-acid pretreatment method was used for removing soluble and mobile organic components [26]. The pretreated samples were combusted to $CO_2$ by using the closed tube combustion method [27]. Then, $CO_2$ was reduced to graphite on iron catalyst, under hydrogen atmosphere [28]. Finally, the resulting graphite samples were analysed by AMS.

*AMS measurements.* AMS radiocarbon measurements were performed at the NOSAMS Facility of the Woods Hole Oceanographic Institution (Woods Hole, MA, U.S.A.) by using the Pelletron ® Tandem 500 kV AMS system. The obtained fraction modern values, corrected for isotope fractionation with the normalized $\delta^{13}C$ value of -25 $^{0}/_{00}$, were ultimately converted to a radiocarbon date.

*Calibration*. Radiocarbon dates were calibrated and converted into calendar ages with the OxCal v4.2 for Windows [29], by using the SHCal13 atmospheric data set [30].

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