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Age, Growth and Death of a National Icon: The Historic Chapman Baobab of Botswana

Adrian Patrut [1,*], Stephan Woodborne [2,3], Roxana T. Patrut [1,4], Grant Hall [3], Laszlo Rakosy [4], Christiaan Winterbach [5] and Karl F. von Reden [6]

1 Faculty of Chemistry and Chemical Engineering, Babeş-Bolyai University, 11 Arany Janos, RO-400028 Cluj-Napoca, Romania; roxanapatrut@yahoo.com
2 iThemba LABS, Private Bag 11, WITS 2050, South Africa; swoodborne@tlabs.ac.za
3 Mammal Research Institute, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa; grant.hall@up.ac.za
4 Faculty of Biology and Geology, Babeş-Bolyai University, 44 Republicii, RO-400015 Cluj-Napoca, Romania; laszlo.rakosy@ubbcluj.ro
5 Tau Consultants(Pty) Ltd., P/Bag 83, Maun, Botswana; tauconsultants@gmail.com
6 NOSAMS Facility, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA; kvonreden@gmail.com
* Correspondence: apatrut@gmail.com

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Abstract: The year 2016 witnessed the fall of a symbol of the botanical world: the historic Chapman baobab of Botswana. This article presents the results of our investigation of the standing and fallen tree. The Chapman baobab had an open ring-shaped structure composed of six partially fused stems. Several wood samples collected from the stems prior and after their collapse were analysed by using radiocarbon dating. The radiocarbon date of the oldest sample was 1381 ± 22 BP, which corresponds to a calibrated age of 1345 (+10, −15) calendar years. The dating results show that the six stems of the Chapman baobab belonged to three different generations, which were 1350–1400, 800–1000 and 500–600 years old. The growth rate variation of the largest and oldest stem is presented and correlated with the climate evolution in the area over the past 1000 years. The factors that determined the sudden fall and death of the Chapman baobab are also presented and discussed.

Keywords: *Adansonia digitata* L.; tropical trees; age determination; AMS radiocarbon dating; growth rate; multiple stems

1. Introduction

According to recent research, populations of large old trees are rapidly declining in many parts of the world. This fact has serious implications on ecosystem integrity and biodiversity. The decline of large old trees is associated especially with the increasing frequency of severe droughts in many regions of the world as a result of climate change [1,2].

One of the most affected species is certainly the African baobab (*Adansonia digitata* L.). The African baobab is the best known and most widespread of the eight or nine *Adansonia* species [3,4]. The very large size of several specimens, which have massive swollen trunks, suggests this tree lives to an old age. According to our in-depth research on the African baobab, the oldest dated individuals have ages greater than 2000 year [5–8].

Large and old-looking baobabs are living natural monuments. Some of them are historic trees. Historic baobabs witnessed past events, were discovered and/or visited and described by early explorers or had special destinations in the past. Notable examples are Dorslandboom, Ombalantu, Okahao

(Namibia), Chapman, Green, Baines group, Kasane prison tree (Botswana), Big tree at Victoria Falls (Zimbabwe), Leydsdorp (South Africa) and Gouye Ndiouly (Senegal).

The most famous of them, the Chapman baobab (Figures 1 and 2), was located on the Missionary Road in the salt pans of Central Botswana and was declared a National Monument. On January 7, 2016, the Chapman baobab fell unexpectedly. The sight of the six large stems of Chapman lying on the ground in three different directions with roots exposed is likely the most dramatic in the history of monumental trees (Figures 3 and 4).

Figure 1. Main view of the Chapman baobab taken from the west (June 2015). The six stems are numbered (1–6). The cavity entrance is also shown (see arrow).

Figure 2. Another general view of the standing Chapman baobab taken from the east, with stem numbering.

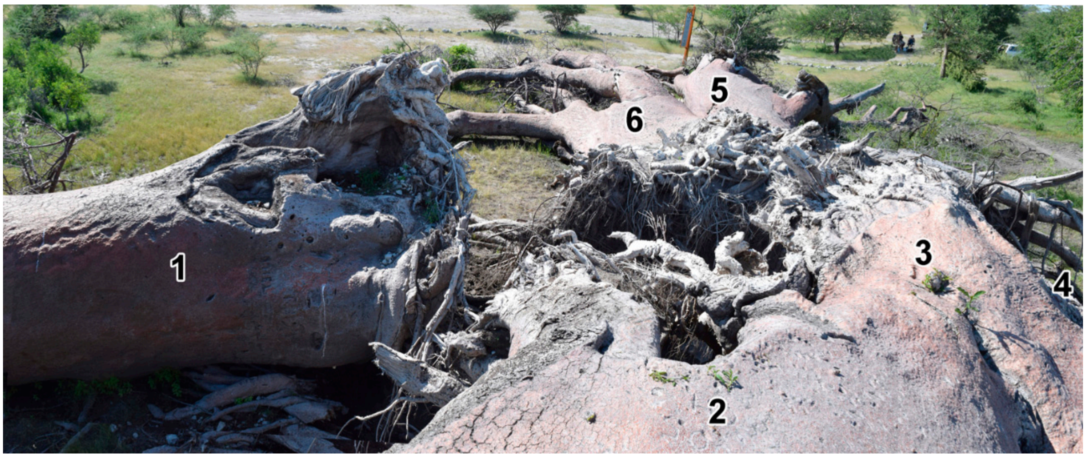

Figure 3. Dramatic photograph of the fallen Chapman baobab taken from stem 2, with stem numbering. The tree lies on the ground with unbroken stems and branches.

Figure 4. View of the fallen baobab taken from the ground level, with stem numbering.

Here, we report our research on the age, growth and death of the Chapman baobab, based on our field investigation and radiocarbon dating results.

2. Materials and Methods

2.1. The Chapman Baobab and Its Area

The Chapman baobab was located close to Ntwetwe Pan of the large Makgadikgadi Pans of Central Botswana, in an area with a mean annual rainfall of around 450 mm. The GPS coordinates are 20°29.404′ S, 025°14.971′ E and the altitude is 905 m.

The baobab was named after the South African explorer and hunter James Chapman, who visited the tree on July 10, 1852 [9,10]. Recent research indicates that the tree had been previously visited in 1849 by David Livingstone, the Scottish missionary and explorer [11].

This mighty baobab, known locally as Xaugam (in Tsoa/Tshwa, "lion's tail"), functioned as a navigation beacon for travellers who crossed the salt pans. Many of them camped under the tree and carved inscriptions on stems. The cavity in its trunk served as a local post office for explorers and travellers going north, hoping that other travellers returning south would take the mail and post it when arriving home [10].

The maximum height of the Chapman baobab was 22.6 m, the circumference at breast height (cbh) 25.90 m and the overall wood volume 275 m^3. It had an open ring-shaped structure consisting of six partially fused stems of different dimensions. The fusion of stems in the inner part of the ring was almost complete up to a height of 2.0–2.2 m, thus forming a corridor from west to east. The canopy dimensions were 42.25 × 37.85 m. A network of buttressed roots, up to 65 m long, surrounded the baobab. The nearest significant tree in this flat area, the Green baobab, can be found 11 km to the northwest.

2.2. Investigation of Chapman Baobab

2.2.1. Sample Collection

Several wood samples were collected from the standing and fallen stems, using long Haglöf increment borers (0.80–1.50 m long, 0.010–0.012 m inner diameter) (Figure 5). A number of tiny pieces/segments, of the length of 10^{-3} m, were extracted from predetermined positions/distances along each sample.

Figure 5. Collecting very long samples from the collapsed stem 3.

2.2.2. Sample Preparation

The α-cellulose pretreatment method was used for removing soluble and mobile organic components [12]. The resulting samples were combusted to CO_2, which was next reduced to graphite on an iron catalyst [13,14]. The graphite samples were analysed by accelerator mass spectrometry (AMS).

2.2.3. AMS Measurements

AMS radiocarbon measurements were performed at the NOSAMS Facility of the Woods Hole Oceanographic Institution by using the Pelletron®Tandem 500 kV AMS system [15,16]. The obtained fraction modern values were ultimately converted to a radiocarbon date. Radiocarbon dates and errors were rounded to the nearest year.

2.2.4. Calibration

Radiocarbon dates were calibrated and converted into calendar ages with OxCal v4.3 for Windows [17], by using the SHCal13 atmospheric dataset [18].

2.2.5. Water Content

The water content of stems was determined by dehydration of wood segments (depth of 0.30–0.40 m) for 72 h at 120 °C.

3. Results and Discussion

3.1. Radiocarbon Dates and Calibrated Ages

Radiocarbon dates and calibrated ages of 11 sample segments are listed in Table 1. The 1σ probability distribution (68.2%) was selected to derive calibrated age ranges. For two segments, the 1σ distribution is consistent with one range of calendar years. For nine segments, the 1σ distribution corresponds to two or three ranges. For seven of them, the confidence interval of one range is considerably greater than that of the other(s); therefore, it was selected as the cal AD range of the sample (marked in bold) for the purpose of this discussion. Nonetheless, in two cases (CH-3′c and CH-3′d), the range with the lower confidence interval was selected, as it is consistent with the age sequence along the corresponding sample. For obtaining single age values, each corresponding to an assigned year, we derived a mean value for the 11 selected ranges, which divided divides the range into two equal areas. The assigned years for the 11 sample segments are also presented in Table 1.

Table 1. Radiocarbon dating results and calibrated ages of sample segments collected from the Chapman baobab.

Sample/Segment Code (Stem)	Depth * (Height) (m)	Radiocarbon Date (Error) (^{14}C Year BP)	Cal AD Range 1σ (Confidence Interval)	Assigned Year (Error) (cal AD)	Sample/Segment Age (Error) (cal AD)	Accession #
CH-1x (1)	0.75 (1.47)	618 (±18)	1326–1341 (28.9%) **1390–1404 (39.3%)**	1397 (±7)	620 (±5)	OS-125224
CH-2x (2)	0.70 (1.60)	353 (±25)	**1508–1584 (61.4%)** 1620–1628 (6.8%)	1551 (+33, −43)	465 (+35, −45)	OS-109251
CH-3x (3)	1.90 (1.20)	1381 (±22)	**654–681 (63.0%)** 749–752 (5.2%)	669 (+12, −15)	1345 (+10, −15)	OS-95069
CH-4x (4)	0.78 (1.38)	340 (±24)	**1510–1576 (56.0%)** 1622–1636 (12.2%)	1546 (+30, −36)	470 (+30, −35)	OS-95070
CH-6x (6)	1.25 (2.57)	745 (±18)	**1278–1300 (68.2%)**	1288 (+12, −10)	730 (±10)	OS-126138
CH-3′a (3)	0.25 (2.80)	211 (±22)	1670–1678 (8.9%) **1732–1785 (53.0%)** 1794–1800 (6.3%)	1758 (+17, −16)	260 (±15)	OS-126074
CH-3′b (3)	0.35 (2.80)	342 (±22)	**1510–1576 (57.6%)** 1622–1634 (10.6%)	1546 (+30, −36)	470 (+30, −35)	OS-125229
CH-3′c (3)	0.45 (2.80)	630 (±16)	1324–1342 (45.4%) **1390–1398 (22.8%)**	1394 (±4)	620 (±5)	OS-127129
CH-3′d (3)	0.65 (2.80)	687 (±21)	**1300–1320 (26.5%)** 1350–1386 (41.7%)	1311 (+9, −11)	705 (±10)	OS-126075
CH-3′e (3)	0.85 (2.80)	841 (±22)	**1222–1266 (68.2%)**	1243 (+23, −21)	775 (+25, −20)	OS-126076
CH-3′f (3)	1.06 (2.80)	985 (±18)	1044–1054 (7.5%) 1060–1068 (6.1%) **1078–1147 (54.5%)**	1110 (+37, −32)	905 (+35, −30)	OS-125231

* Depth in wood from the sampling point.

This approach for selecting calibrated age ranges and single values for sample ages was used in previous articles on AMS radiocarbon dating of large and old angiosperm trees, especially of baobabs [5–8,19–22].

3.2. Sample Ages

Sample ages, expressed in calendar years, represent the difference between AD 2016 (when all stems died) and the assigned year. Sample ages and errors were rounded to the nearest 5 years. Sample ages and tree/stem ages are shown in Table 1.

3.3. Tree/Stem Ages

The first five items in Table 1 correspond to the deepest segment (marked x) extracted from samples collected with borers from the exterior of five stems (1, 2, 3, 4 and 6). The only exception is the oldest dated segment, CH-3x, which was extracted from the cavity in stem 3, very close to the presumptive pith. Its radiocarbon date was 1381 ± 22 BP; the assigned year AD 669 (+12, −15) corresponds to a calibrated age of 1345 year. The ages of stems were calculated by extrapolating the oldest sample ages to the calculated positions of their piths. Stems 5 and 6 are twin stems and have the same age.

The six stems of Chapman baobab belonged to three generations that were 1350–1400 (stem 3), 800–1000 (stems 1, 5 and 6) and 500–600 (stems 2 and 4) years old. The dimensions and calculated stem ages are displayed in Table 2.

Table 2. Dimensions and ages of Chapman baobab's stems.

Stem	Height (m)	Circumference */Radius * (m)	Age (Year)
1	21.4	9.25/1.47	800–1000
2	14.5 (broken)	6.20/0.99	500–600
3	19.0	12.39/1.97	1350–1400
4	22.2	5.64/0.90	500–600
5	19.7	9.64/1.53	800–1000
6	22.6	9.23/1.47	800–1000

* At 1.30 m above ground level.

The open ring-shaped structure consists typically of 5–8 stems that are fused at the base, are pointed sideways and describe at ground level a circle or an ellipse. Research on such baobabs indicates that the ring is completed in the first 50–200 year of growth [7]. Over time, stems may collapse and die, while new stems may emerge periodically from roots or from other fallen or broken stems. Such multistemmed and multigeneration baobabs are going through successive cycles of death and rebirth from their remains. The collapse and death of one or even several stems usually does not affect the other stems. In the case of Chapman, five stems (1, 2, 4, 5 and 6) were too young to have belonged to the original ring. Therefore, they replaced older stems in the ring, which fell and died many centuries ago. The investigation of Chapman baobab also revealed a gap in the ring, between stems 1 and 6, which was likely produced by the death of an earlier stem.

3.4. Growth

The last six items in Table 1 (labelled a–f) correspond to segments extracted from determined positions of sample CH-3′. The dating results and assigned years offer information on growth rates of the biggest stem (stem 3) for almost 1000 years and can be correlated with climate evolution in southern Africa [23–25]. Thus, ages of segments CH-3′f and CH-3′e show that stem 3 had grown 0.21 m in radius (from 1.06 to 0.85 m, measured from the bark) in 133 years (between 1110 and 1243; growth rate 0.158×10^{-2} m year^{-1}). According to the ages of segments CH-3′e, CH-3′d and CH-3′c, stem 3 had grown almost twice as fast (i.e., 0.20 m; from 0.85 to 0.65 m) in 68 years (1243–1311; 0.294 × 10^{-2} m $year^{-1}$) and another 0.20 m (from 0.65 to 0.45 m) in 83 years (1311–1394; 0.241 × 10^{-2} m $year^{-1}$). These growth rates and periods may be associated with the Medieval Warm Period in southern Africa (from around 900 to 1300–1400), which was warmer and wetter than the present climate [26]. Around 1400–1500, the growth rate of stem 3 decreased considerably. Based on the ages of segments CH-3′c and CH-3′b, stem 3 had grown only 0.10 m (from 0.45 to 0.35 m) in 152 years (1394–1546; 0.066 × 10^{-2} m $year^{-1}$). In this period, the climate shifted from wetter to drier conditions and the Little Ice Age, which was cold and dry, had begun in southern Africa (from ca. 1400–1500 to 1800) [26]. The slowing of growth continued with the cooling of the climate, culminating with the Maunder minimum (1690–1740 in southern Africa [25,27]). Thus, the ages of segments CH-3′b and CH-3′a indicate that stem 3 grew the next 0.10 m (from 0.35 to 0.25 m) in 212 years (1546–1758; 0.047 × 10^{-2} m $year^{-1}$). Eventually, stem 3 grew the last 0.25 m in 258 years, until its demise (1758–2016; 0.096 × 10^{-2} m $year^{-1}$).

As stem 3 was almost cylindrical, one could also include in the discussion segment CH-3x, which originated from a lower height. By considering the ages of segments CH-3x and CH-3′f, stem 3 had grown its first 0.84 m (from 1.90 to 1.06 m) in 441 years (669–1110; 0.190 × 10^{-2} m $year^{-1}$).

The growth rate variation of stem 3 is shown in Table 3.

Table 3. The growth rate variation of stem 3 during its life cycle.

Age Range (AD)	Increase in Radius * (m)	Growth Rate * (10^{-2} m $Year^{-1}$)
669–1110	0.84	0.190
1110–1243	0.21	0.158
1243–1311	0.20	0.294
1311–1394	0.20	0.241
1394–1546	0.10	0.066
1546–1758	0.10	0.047
1758–2016	0.25	0.096

* At 2.80 m above ground level.

This rough attempt to correlate calculated growth rates (deduced from mean values of calculated sample/segment ages and assigned years, by neglecting the errors) with the climate evolution in the area must be considered only informative. A most accurate correlation will be possible after finishing the stable isotope analysis in progress of a larger number of previously dated wood segments.

3.5. Fall and Death

On January 7, 2016, at 7 a.m., the six stems of Chapman baobab toppled almost simultaneously, with a sound of thunder and in a cloud of dust. The order in which the stems fell was 1, 4 and 2 fused with 3, and over it, and 5 fused with 6. The fact that all six stems of a giant baobab fell suddenly is exceptional. This was due to the unfortunate combination of several factors:

(i) The critical size of the postbox cavity. The cavity started sometime in the past (possibly in the 17th century), as a fire scar in stem 2, very close to the junction with stem 1. Over time, this scar extended progressively in three stems (2, 3 and 1) due to decay, producing a very large cavity with parts of burned and rotten wood inside (Figure 6). We measured a length of 5.15 m at ground level across the three stems. The cavity shape was very irregular and the height varied between 0.7 and 3.2 m. The critical point was the junction area of stems 1 and 2, where only an inner column of partially rotten wood remained, having a height of 3.0 m and a diameter of 0.50 m. We estimated that the progress of decay could cut the tree in this area, thus favouring the collapse of stem 1, which had a greater lean.

Figure 6. View of the large inner cavity, which consisted mainly of rotten and burned wood.

(ii) The low water content of stems associated with severe drought. Baobab wood usually has a high water content, up to 79% [28,29]. Big baobabs stay erect/upright mainly due to the weight of the stems (gravitational effect). When this weight drops to a critical level (due to water loss, especially during periods of drought), the stability is affected and stems might topple [7,29]. In June 2015, we determined a low water content of stems 3 and 6 of Chapman (i.e., 49.5% and 52.1%). Usually, in the area, some rain falls in September, more rain follows in October and heavy rain falls in November–January. In the 2015–2016 rainy season, the first rains started in February. This fact was unprecedented over the past 100 years. In October and November, the Chapman baobab produced flowers and flushed leaves as usual. This effort weakened the tree and, in absence of rain, its water content dropped to critical values. In 2016, we measured the water content of the fallen stems 3 and 6 at only 39.8% and 43.1%. The extreme drought over the past years in southern Africa was mainly determined by the intensification of El Niño, which warms the waters in the equatorial Pacific. El Niño caused devastating drought in Botswana and other areas of southern Africa in 2015–2016.

(iii) The lean of stems. All stems had variable leans, between 10° and 25°. They fell in the direction of their lean. The analysis of different photographs revealed that the lean of stems increased by around 5° over the past 50 years. We consider that the lean of stems in different directions contributed to the breaking of the high corridor between them and determined their almost simultaneous collapse.

(iv) The age of the tree. In the period 2005–2017, we investigated and dated practically all known very large and potentially old African baobab specimens from northern and southern continental Africa, African islands and outside Africa throughout the tropics. According to the radiocarbon age of the oldest sample and the calculated age of the tree, the Chapman baobab ranks 11th in the top oldest African baobabs. Since 2005, 9 of the 13 oldest and 5 of the 6 largest African baobabs, including the Chapman, have died or at least their largest and/or oldest parts/stems have collapsed and died [8]. All of these trees are or were located in southern Arica. We suspect that the demise of the oldest and

largest baobabs in a very short period may be associated with significant modifications of climate conditions, which affect especially southern Africa [8,30].

4. Conclusions

Our research reports the results of the AMS radiocarbon investigation of the famous historic Chapman baobab from the salt pans of Botswana. The stems of this iconic baobab toppled practically simultaneously in January 2016. The research was performed in order to ascertain the architecture, age and growth rate of the Chapman baobab, as well as the factors which determined its untimely demise.

The Chapman baobab had an open ring-shaped structure, which consisted of six fused stems of different dimensions. Several wood samples were collected from the stems of the tree before and after their collapse. The radiocarbon date of the oldest sample was found to be 1381 ± 22 BP, which corresponds to a calibrated age of 1345 (+10, −15) calendar years. According to the dating results, the six stems of the Chapman baobab belonged to three different generations, which were 1350–1400, 800–1000 and 500–600 years old.

The growth rate variation of the biggest and oldest stem was discussed in correlation with the climate evolution in the area. Our research indicates that the fall and death of the Chapman baobab was caused by a combination of several factors: the critical size of the postbox cavity, the low water content of stems associated with extreme drought, the lean of the stems and the age of the tree.

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