Palynological evidence for abrupt climatic cooling in equatorial Africa at about 43,000–40,000 cal BP

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ARTICLE INFO

Article history:
Received 9 September 2017
Received in revised form 20 November 2017
Accepted 23 December 2017
Available online 09 January 2018

Keywords:
Quaternary
Tectonic activity

ABSTRACT

The same basal sequence of two pollen zones is found in three previously published pollen diagrams for widely separated sites situated along highlands adjacent to the Albertine Rift in equatorial Africa. Here evidence is presented that is supportive of the hypothesis that the transition between the zones was contemporaneous at all sites and dates to about 43,000–40,000 cal BP. Environmental interpretation of the sequence indicates that there was a major fall in temperature, depressed temperature thereafter persisting until the transition to the postglacial at 14,000–11,500 cal BP. The climate also became drier. Well-dated sediments of this age are rare in equatorial Africa, so comparisons are scarce. However, there is some evidence from the Eastern Arc Mountains, Tanzania, of a similar climatic event at about the same time. Farther afield, there is good evidence for abrupt climatic deterioration at ~40,000 cal BP in western Eurasia, where there was accompanying cultural change. Sedimentary basins along the Albertine Rift-margin highlands are especially well suited for palynologically-based investigations of past temperatures. Their relatively well-defined catchment areas result in reduced inputs of pollen derived from vegetation growing under different climatic conditions.

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1. Introduction

Attention is directed at a major change in vegetation from moister lower montane forest or Syzygium swamp forest (Forest Zone 1) to vegetation with abundant Cliffortia nitidula (Cliffortia Zone) apparent in previously published pollen diagrams from three widely separated sites in Uganda, Rwanda and Burundi (Hamilton, 1982; Bonnefille and Riollet, 1988; Taylor, 1990). Cliffortia nitidula R.E. and T.C.E. Fries, the only East African species of the genus, is a shrub typical of the Ericaceous Belt. A major change in climate has previously been inferred for each site separately, but what has not been recognised earlier is that the dating evidence is consistent with the hypothesis that the climatic events recognised for each site were contemporaneous (dating to sometime between ca. 43,000 and 40,000 cal BP). A major climatic event is indicated, possibly having major environmental impacts over an extensive area.

Very few sediment sequences containing well preserved pollen of this age are known from eastern Africa, hence the ability to identify contemporaneous climatic changes in neighbouring sites is rare. The topographic contexts of the sites are particularly appropriate for identifying temperature changes from pollen diagrams, because all are in valleys situated within a belt of highlands stretching along the eastern margin of the Albertine Rift, the total altitudinal ranges of their catchments or immediate neighbourhoods being relatively limited. This contrasts with some lowland lakes or sites of sediment accumulation on taller mountains, into which considerable quantities of pollen can be transported from vegetation growing under environments markedly different from those that prevail near the sample sites. This complicates assessments of past temperatures.

The three sites, all peat-forming systems associated with the Albertine Rift in central Africa, are Muchoya Swamp (2260 m), Kamiranzovu Swamp (1950 m) and Kashiru Swamp (2014 m) in Uganda, Rwanda and Burundi respectively and separated from one another by distances of 120–240 km (Fig. 1). Swamp vegetation at Muchoya is dominated by the sedge Pycreus nigricans (Steud.) C.B. Clarke with scattered bushes of Erica kingaensis Engl. (Morrison, 1968; Taylor, 1990), Kamiranzovu is extensively covered by Cyperus latifolius Poir., with a central zone of Syzygium cordatum Krauss bordered by Erica kingaensis (Deuse, 1966; Bouxin, 1974), and Kashiru supported a Xyris/Sphagnum community prior to its destruction by peat mining in 1986 (Bonnefille and Riollet, 1988). All sites lie within the lower part of the Montane Forest Belt (Hamilton, 1982). Forest still persists around Muchoya and Kamiranzovu (Echuya and Nyungwe Forests), but has been removed at Kashiru to make way for agriculture.
2. Sediment sampling and profiles

Sediments were examined at four places at Muchoya Swamp (cores MC1–4) and one each at Kamiranzovu and Kashiru. Sediment sampling was by a Hiller borer at Kamiranzovu and Muchoya and a Russian borer at Kashiru, except at depth at Muchoya where a 20 cm auger was substituted. Sediment sampling and subsequent pollen analysis at Kashiru were by Bonnefille and Riollet (1988) and at the other two sites by one or both of ourselves. In principle, a Russian borer should allow the extraction of sediments less likely to be contaminated with foreign carbon than with the other devices, but it cannot penetrate stiff sediments, for which a Hiller borer is more suitable, or, if very stiff, an auger. Core MC2 at Muchoya, which, at 20.54 m, is one of the longest hand-drilled through Quaternary sediments in Africa, contains very stiff sediment at depth. Great care was taken at Muchoya and Kamiranzovu to avoid contamination of the samples collected for pollen analysis or radiocarbon dating, an ambition generally achieved judging by the conformability of nearly all the radiocarbon dates despite the great ages of some.

The stratigraphy of the sediments in the lower parts of cores MC2 and MC4 at Muchoya and at Kamiranzovu and Kashiru is shown on Fig. 2, together with pollen zones and calibrated radiocarbon dates (given as 95.4% probability ranges; see caption to Table 2 for details of calibration). Identification of the sediment types is as described in the field, augmented by the results of palynological and other laboratory investigations.

Kamiranzovu differs from the other sites in that there is a layer of grey sticky clay (marked L3 on Fig. 2) above a stratum of organic clay dating to the Cliffortia Zone. Its appearance is similar to that of a clay layer below the Cliffortia Zone (L2) and to another (L1) below the mud that is suspected to be a fossil soil. The pollen spectra of L3, L2 and the uppermost part of L1 are similar, indicating the presence of Syzygium swamp forest. It is postulated that the anomalous presence of a second forest zone (Forest Zone 2) contained within L3, is due to re-deposition of material at the locality of the coring site eroded out of exposures of L1 and/or L2 exposed elsewhere on the mire. L2 might also be redeposited material.

3. Dating

Twenty radiocarbon dates older than 29,000 cal BP are available for the four cores. They are arranged on Table 2 to allow visual estimates of the ages of the transitions between Forest Zone 1 and the Cliffortia Zone, being placed in order of depth within each core and grouped according to pollen zone. This is one approach to modelling the radiocarbon data to reveal the possible ages of boundaries between the pollen zones. We are cautious about applying modelling using interpolation to determine the ages of zonal boundaries especially in the lower parts of these
cores, given that cross-comparison of the diagrams and dates shows that rates of sediment accumulation have been very variable and hiatuses have likely occurred. These sediment profiles are similar in these respects to many others that have been studied under mires in eastern Africa (Thompson and Hamilton, 1983; Hamilton and Taylor, 1986).

Taking standard deviations into account and noting the four points below, we assess that 18 of the 20 dates are supportive of the hypothesis that the transition between Forest Zone 1 and the Cliffortia Zone was coeval at all sites and occurred at ca. 43,000–40,000 cal BP. Refinement will require further research. The degree of support for this hypothesis is considered remarkable given the great age (towards the limit of radiocarbon dating), uncertainties in dating due to the extensive depth ranges of some of the sediment samples taken for radiocarbon dating and lack of dates for critical horizons (that is, those known with certainty to be just above or below the boundary between Forest Zone 1 and the Cliffortia Zone).

The following were taken into account in reaching this dating conclusion:

1. There is one date that is certainly contradictory to the hypothesis of contemporaneity of the Forest Zone 1/Cliffortia Zone boundary, that of 49,350–43,110 cal BP (Pta-4195) from Muchoya. This date was given special weight in the original interpretation of the pollen diagrams for this site, leading to the conclusion that both Forest Zone 1 and the Cliffortia Zone were older (Taylor, 1990). We offer no explanation for this anomaly.

2. Some of the samples near the base of the cores may contain old carbon from fossil soils. Modern forest soils can give radiocarbon ages dating back to many thousands of years BP (Passenda et al., 2001). Although well above the limit of radiocarbon dating, this may be true of sample SRR-1617, given that it includes some sediment collection (De Vleeschouwer et al., 2010/11). This was suggested in the original publication describing this core (Taylor, 1982). The boundary between the Cliffortia and Poaceae Zones for Kashiru is drawn on the profile considering the level at which Platycaulos (Restio) pollen becomes abundant, thought to be about 36,000 cal BP (Bonnefille et al., 1992).

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4. There is some uncertainty about the depths at which the basal two samples for radiocarbon dating were collected at Kashiru (UQ-763, UQ-1456), because contradictory figures are given in the original publication describing the core (Bonnefille and Riollet, 1988). We take those depths repeated in a subsequent article as correct (Bonnefille et al., 1992). The boundaries between the Cliffortia Zone and higher and lower pollen zones are less well defined at Kashiru, compared with Muchoya and Kamiranzovu, likely related in part to a long hiatus in sediment accumulation (see caption to Fig. 2).
4. Palynology and inferred palaeo-environments

Pollen diagrams for the three sites have been published elsewhere (Hamilton, 1982; Bonneille and Rolilet, 1988; Taylor, 1990). They extend further back in time than any others so far available for the rift-shoulder highlands (Morrison, 1968; Morrison and Hamilton, 1974; Taylor, 1990; Jolly and Bonneille, 1991; Bonneille et al., 1992; Jolly et al., 1994; Bonneille et al., 1995; Jolly et al., 1997; Marchant et al., 1997). These diagrams, when considered together, show that there was a major climatic transition at about 14,000–11,500 cal BP from a long phase that was relatively cold and often dry to one, still continuing, that is warm and generally comparatively wet. The two phases correlate with the latter part of the last glacial period and the postglacial. The first phase extends back to the beginning of the Cliftonia Zone at Muchoya and Kashiru and to the end of Forest Zone 2 at Kamiranzovu (ca. 43–40 ka cal BP).

The latter part of the last glacial period was marked by abundant grasses at all three sites, a scarcity of trees (except sometimes for Hagenia abyssinica (Bruce) J.F. Gmel. – a species characteristic of Upper Montane Forest) and the frequent occurrence of shrubs typical of drier types of Ericaceous Belt vegetation (above the Montane Forest Belt – Anthospermum (presumed Anthospermum usambarensis K. Schum), Artemisia afr. Jacq. ex Willd.. Cliftonia nitidula (Engl.) R.E. & T.C.E. Fr. and Stoebel kilimandscharica O. Hoffm. Moist Lower Montane Forest replaced these higher altitude vegetation types at about 11,500 cal BP, thereafter persisting until the clearance of much of it for agriculture (Morrison and Hamilton, 1974; Hamilton et al., 1986; Taylor, 1990; Hamilton et al., 2016).

The basal two pollen zones, both present in the pollen diagram for core MC4 at Muchoya, as well as the pollen diagrams for Kamiranzovu and Kashiru, are a lowermost pollen zone containing abundant arboreal pollen (Forest Zone 1) and an upper zone with abundant pollen of Cliftonia (Cliftonia Zone). Sedimentation at the site of Core MC2 at Muchoya appears to have commenced later. The lowermost pollen zone present in each core is contained within sediment that rests directly on bedrock or consists of material suspected to be fossil soil. Sediment dating to the Cliftonia Zone is more organic than that of sediments beneath it, being peat at Muchoya and Kashiru.

Several pollen types recorded in Forest Zone 1 at Muchoya and/or Kashiru indicate the presence of Moist Lower Montane Forest on surrounding slopes (Bonneille and Rolilet, 1988; Taylor, 1990). They include Alchornea, Ficalhoa, Macaranga, Olea and Podocarpus. The climate at Muchoya has been estimated to have been similar to the present (Taylor, 1990), but intermediate between that of the last glacial maximum and the postglacial period at Kashiru (Bonneille and Rolilet, 1988). Much of the arboreal pollen in Forest Zone 1 at Kamiranzovu is Myrtaceae, the pollen spectra being similar to those of surface samples collected from within modern Syzygium cordatum swamp forest (Hamilton, 1972). Kamiranzovu is the highest altitude site in the rift-shoulder highlands at which Syzygium has been recorded growing on mires today (Table 1), which suggests that temperatures during Forest Zone 1 times were at least as warm as they are now.

An exceptional find at Kamiranzovu was of a male cone of Podocarpus/Acrocarpus recovered from sediment 5 cm below the top of a layer thought to be a fossil soil (Fig. 2). The plant must have been growing locally. The cone has been identified as probably Acrocarpus (Podocarpus) usambarensis (Pilg.) C.N. Page (Bridson, pers. comm.), a species known from seasonal swamp forest at ~1160 m altitude near Sango Bay on the north-west shore of Lake Victoria (Katende et al., 1995; Lwanga, 1996) and which also grows in drier types of montane forest. Acrocarpus usambarensis is not certainly recorded from Kamiranzovu or surrounding Nyungwe Forest today. One of us (AH) has seen a species of Podocarpus or Acrocarpus growing in the marginal zone where Kamiranzovu Swamp abuts onto forest on dry land, but did not ascertain its precise identification at the time. This may have been Podocarpus latifolius (Thunb.) R. Br. ex Mirb., since this has been reported from this marginal zone (Killmann and Fischer, 2005). Elsewhere in Nyungwe Forest, P. latifolius is found on upper hillslopes, similar to its pattern of distribution in Bwindi-Impenetrable Forest in Uganda (Hamilton, 1969), further north along the rift-shoulder highlands. It is also found in low altitude swamp forest at Sango Bay, accompanying A. usambarensis.

Cliftonia is a genus of 132 species, strongly concentrated in the Cape Floristic Region where 124 species occur, 109 being endemic (Whitehouse and Fellingham, 2007). The only species found in East Africa is Cliftonia nitidula (Graham, 1960). A published photograph of a fossil grain of Cliftonia from Kamiranzovu is a close match for C. nitidula. (Hamilton, 1982). Cliftonia nitidula is a light-demanding shrub, sometimes thicket-forming or riparian, typical of drier types of lower Ericaceous Belt vegetation or glades in bamboo forest (Graham, 1960; Coetzee, 1967; Beentje, 1994; Wooller et al., 2003). The distribution of its pollen in surface samples and Quarternary sediments collected from different altitudes on Mt. Kenya (Coetzee, 1967; Wooller et al., 2003) is supportive of the view that its pollen is a good marker for the presence of the lower Ericaceous Belt.

Cliftonia is absent today from the Albertine Rift-margin highlands in Uganda, but does grow at the exceptionally low altitude of 2340 m at Kuwansenkokko Swamp in Rwanda (like Kamiranzovu, in Nyungwe Forest), where it is found at the interface between Pycreus nigricans on the swamp and tussock grassland on surrounding slopes (Hamilton, 1982). This low altitude occurrence is clearly related to temperature inversion in the small virtually enclosed valley in which the swamp lies and is taken as further evidence that it can be used as an indicator of temperature conditions similar to those found today in the lower part of the Ericaceous Belt. Hillslopes at 2300–2400 m around Kuwansenkokko display an inverted sequence of vegetation zones, with montane forest with Ocotea, Podocarpus, Syzygium and abundant Macaranga kilimandscharica Pax above, Hagenia and then tree heather below, and finally tussock grassland on the valley floor (Hamilton, 1982; Killmann and Fischer, 2005). Cliftonia at Kuwansenkokko does not occur on the swamp itself, which is consistent with records from elsewhere in eastern Africa showing that it is not a true swamp species. It is likely to have been growing on mineral-rich soils (rather than inorganic peat) during Cliftonia Zone times at Muchoya, Kamiranzovu and Kashiru, a habitat then on offer at all judging by the sediment profiles.

Past temperatures are calculated from pollen diagrams in East Africa mainly based on the altitudinal movements of plants. A standard procedure treats plant taxa identified in pollen diagrams as potentially

<table>
<thead>
<tr>
<th>Locality</th>
<th>Altitude (m)</th>
<th>Syzygium cordatum</th>
<th>Erica kingoensis</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahakagyezi Swamp, Uganda</td>
<td>1830</td>
<td>+</td>
<td>–</td>
<td>(Hamilton, 1969)</td>
</tr>
<tr>
<td>Kamiranzovu Swamp, Rwanda</td>
<td>1950</td>
<td>+</td>
<td>+</td>
<td>(Deuse, 1966, Bouxin, 1974)</td>
</tr>
<tr>
<td>Butongo Swamp, Uganda</td>
<td>2025</td>
<td>–</td>
<td>+</td>
<td>(Morrison and Hamilton, 1974)</td>
</tr>
<tr>
<td>Muchoya Swamp, Uganda</td>
<td>2256</td>
<td>+</td>
<td>+</td>
<td>(Taylor, 1990)</td>
</tr>
<tr>
<td>Rwenzori swamps, Uganda</td>
<td>≤2750</td>
<td>–</td>
<td>+</td>
<td>(Hamilton, 1969)</td>
</tr>
</tbody>
</table>
Radioisotope dates older than 25,000 cal BP for sediment under Muchoya, Kamiranzovu and Kashiru Swamps (Hamilton, 1982; Bonnefille and Riollet, 1988; Taylor, 1990; Bonnefille et al., 1992). The dates are placed in order of depth within each core and grouped according to pollen zone. Depths and dates for Kashiru follow (Bonnefille et al., 1992). Calibration of these dates and others given in the present paper was by OxCal 4.3 (update of 11 April 2017) (Bronk Ramsey, 2009), using the IntCal13 calibration curve (Reimer et al., 2013). The 14C values for the ‘greater than’ dates are given in the text.

## Table 2

<table>
<thead>
<tr>
<th>Pollen zones</th>
<th>Dates and inferred past environments</th>
<th>Relationship of sediment samples used for 14C dating to pollen zones</th>
<th>Laboratory reference number</th>
<th>Locality and core (in brackets)</th>
<th>Depth (m)</th>
<th>(14C BP)</th>
<th>Age (cal BP)</th>
<th>Age (95% probability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zones younger than the Cliffortia Zone (but see comment on SRR-1617 in column to right).</td>
<td>From the end of the Cliffortia Zone to ~29 cal BP or later during the last glacial period. Ericaceae belt-type vegetation on dryland around the mires, few trees. Cyperaceae common on the mires at all sites. Erica kinigoti on the mire at Kamiranzovu. Particularly wet conditions in the three sedimentary basins at ~34,000 cal BP, with lacustrine conditions at Muchoya and a Phragmatozoon (Restio) Sphagnum community at Kamiranzovu and Kashiru (Bonnefille et al., 1990). Temperatures lower than now and climate usually drier.</td>
<td>All sediment samples postdate the Cliffortia Zone (but SRR-1617 might contain some inwashed old carbon).</td>
<td>UQ-875</td>
<td>Kashiru (MC4)</td>
<td>6.76–6.85</td>
<td>25,500</td>
<td>1000</td>
<td>31,570–27,740</td>
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<td>SRR-2956</td>
<td>Muchoya (MC4)</td>
<td>6.40–4.90</td>
<td>26,360</td>
<td>300</td>
<td>31,080–29,860</td>
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<td>SRR-1614</td>
<td>Kamiranzovu (MC2)</td>
<td>6.70–6.90</td>
<td>27,855</td>
<td>+380/–365</td>
<td>32,790–31,100</td>
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<td>SRR-1615</td>
<td>Muchoya (MC2)</td>
<td>8.70–8.90</td>
<td>28,875</td>
<td>+385/–365</td>
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<td>UQ-1246</td>
<td>Kashiru</td>
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<td>31,000</td>
<td>1500</td>
<td>35,600–32,200</td>
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<td>UQ-1278</td>
<td>Kashiru</td>
<td>8.00–8.30</td>
<td>29,000</td>
<td>1100</td>
<td>35,430–31,080</td>
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<td>SRR-2953</td>
<td>Muchoya (MC2)</td>
<td>16.80–17.40</td>
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<td>Pta-3535</td>
<td>Muchoya (MC2)</td>
<td>30.55</td>
<td>290</td>
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<td>SRR-2963</td>
<td>Muchoya (MC2)</td>
<td>18.00–18.60</td>
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<td>290</td>
<td>41,420–36,260</td>
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<td>SRR-1616</td>
<td>Kamiranzovu (MC2)</td>
<td>10.70–10.90</td>
<td>34,270</td>
<td>+1145/–1000</td>
<td>49,350–43,110</td>
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<td>SRR-1617</td>
<td>Kamiranzovu (MC2)</td>
<td>11.55–11.85</td>
<td>37,630</td>
<td>+1150/–1010</td>
<td>49,190–40,060</td>
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<td>&gt; 35,000</td>
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<td>Kashiru</td>
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<td>&gt; 40,000</td>
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<td>&gt; 43,600</td>
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<td>Muchoya (MC4)</td>
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<td>+670/–620</td>
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<td>SRR-1618</td>
<td>Kamiranzovu (MC2)</td>
<td>13.00–13.30</td>
<td>39,240</td>
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<td>Pta-3811</td>
<td>Muchoya (MC2)</td>
<td>19.80–20.40</td>
<td>39,500</td>
<td>1400</td>
<td>46,490–41,500</td>
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<td>SRR-2958</td>
<td>Muchoya (MC4)</td>
<td>15.20–15.40</td>
<td>37,280</td>
<td>+750/–680</td>
<td>42,870–40,430</td>
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<td>SRR-1619</td>
<td>Kamiranzovu (MC2)</td>
<td>14.65–15.00</td>
<td>&gt; 43,040</td>
<td></td>
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<td></td>
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<td></td>
<td>UQ-1456</td>
<td>Kashiru</td>
<td>9.75–9.85</td>
<td>&gt; 31,000</td>
<td></td>
<td>&gt; 35,000</td>
</tr>
</tbody>
</table>

### 5. Conclusions and comparisons

It is concluded that there was a change in climate in the region of the Albertine Rift at about 43,000–40,000 cal BP, marked by a major reduction in temperature and onset of a drier climate. Depressed temperatures then continued until the transition to a postglacial climate.
dating to about 14,000–11,500 cal BP. A tectonic event, causing back-
tilting of the valley, has been suggested as a possible responsible agent for
the creation of the sedimentary basin at Muchoya (Taylor, 1990) and
the same could be true also of Kamarinanzovu and Kashiru. If so,
then a major tectonic event is postulated affecting at least a 240 km-
section of the Albertine Rift. Further research is needed to confirm
these conclusions, utilising a fuller range of analytical tools than those
previously employed.

A similar climatic change to that experienced along the Albertine Rift
may have influenced the vegetation of the Eastern Arc Mountains in
Tanzania, where pollen evidence suggests significant vegetation chang-
es at ~40,000 cal BP (only approximately dated) (Finch et al., 2009,
2014). A pollen diagram for a site at 2000 m on the Udzungwa Moun-
tains shows an abrupt Podocarpus decline and increases in Cyperaceae
and Poaceae at about this time, while another, at 2600 m on the Uluguru
Mountains, also shows a decline, though less abrupt, in Podocarpus, in
this case associated with an increase in Ericaceae. These events have
similarities to those experienced at the transitions between Forest
Zone 1 and the Cliftoria Zone at Muchoya, Kamarinanzovu and Kashiru.
The less abrupt decline in Podocarpus pollen at the Uluguru site, com-
pared with that on the Udzungwa Mountains, may be related to its
greater proximity to the Indian Ocean. Biogeographical considerations
(Lovett, 1993; Fjeldså and Lovett, 1997), plus some palynological evi-
dence (Mumbi et al., 2008; Finch et al., 2014), suggest that the ocean
may have moderated the effects on nearby mountains of climatic fluctu-
ations during the Quaternary.

The magnitude of climatic deterioration and the long persistence of a
cold climate thereafter have similarities with events in western Eurasia
between ca. 40 cal BP and the beginning of the postglacial. In western
Eurasia’s case, climatic deterioration is believed to have been triggered
by a combination of a super-eruption in southern Italy, the Campanian
Ignimbrite (CI) eruption, and the beginning of Heinrich Event 4 (HE4),
when large armadas of icebergs invaded the North Atlantic, influencing
thermohaline patterns and consequently causing extensive modificati-
ons to climates. The CI/HE4 combination is believed to have proved a
tipping point for a climatic system that was unstable at the time, con-
tributing to the longevity of the cold times that followed (Fedele et al.,
2008; Fitzsimmons et al., 2013). The transition from the Middle to
Upper Palaeolithic cultural phases and the replacement of Neanderthals
by modern humans over much of Europe date to about the time of CI/
HE4. There is debate on the level of influence of CI/HE4 over these events
(Sepulchre et al., 2007; Fedele et al., 2008; Hoffocker et al., 2008;
Hoffecker, 2009; Golovanova et al., 2010; d’Errico and Banks,
2015).

The CI super-eruption has been dated at 40,012 calendar years BP_{CGRSP}
based on correlation with Greenland ice core tephrostratigraphy (Fedele et al.,
2008) and at 39,850 ± 140 or 39,280 ± 110 BP according to 40Ar/39Ar
measurements on CI (De Vivo et al., 2001; Douka et al., 2010; Gia
cio et al., 2017). The beginning of HE4 has been dated to 39,700 BP, based on
230Th dating and δ13C analysis of a stalagmite from a site in central China (Zhou
et al., 2014). Our estimated date for abrupt climatic cooling in equatorial Africa of
about 43,000–40,000 cal BP associated with the
230Th/Ca measured at about 330 ± 100,000 years ago (De Vivo et al.,
2001).

The Campanian Ignimbrite (Y-5) reconciles the time-scales of
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