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HOLOCENE EXPLOSIVE ERUPTIONS OF WITORI AND DAKATAUA CALDERA VOLCANOES IN WEST NEW BRITAIN, PAPUA NEW GUINEA

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Witori and Dakataua caldera volcanoes have been very active in the middle to late Holocene. Using tephrochronology, this paper establishes the chronostratigraphy of these eruptions and their magnitude, and the frequency of explosive volcanism at Witori and Dakataua. After a long dormancy, Witori started explosive activity at ca. 5600 conventional radiocarbon years BP, producing in the next 4500 years five major tephra layers (W-K1 to W-K4, W-G) with VEIs of 5 to 6. After the W-G eruption at around 1200 BP, the activity decreased in magnitude but increased in frequency, with some eruptions forming central cones. The major eruption of Dakataua began with alternating ejections of phreatomagmatic ashfalls and plinian deposits followed by the cataclysmic eruption resulting in lithic-rieh pyroclastic flows ca. 1100-1200 BP.

The major tephra layers cover extensive areas in West New Britain due to their large volumes and the prevailing easterly winds, providing valuable time markers for establishing Holocene chronology. The largest eruption, the W-K2 event of ca. 3300 BP, shaped much of the present landscape, with an extensive area significantly devastated by tephra falls and pyroclastic flows. Obsidian and other artefacts buried by the tephras indicate that the area was repeatedly occupied. The major tephra events formed new coastal plains favourable for human occupation. Copyright © 1996 INQUA/Elsevier Science Ltd

INTRODUCTION

In this paper we present the Holocene tephrochronology of part of West New Britain, Papua New Guinea, to establish the chronostratigraphy, frequency and magnitude of explosive volcanism of two caldera volcanoes, Witori and Dakataua (Fig. 1).

In the middle to late Holocene, Witori and Dakataua volcanoes were among the most active of the many volcanic centres in New Britain. The most recent volcanic activity was reported by Cooke (1981) and Branch (1967), respectively. Both Witori and Dakataua are broad, unusually low-angle volcanoes with large calderas that contain active cones, Pago and Makalia, respectively. These geomorphological features suggest repeated catastrophic explosive events. The gentle slopes of these volcanoes and the adjacent coastal plains and mountains are mantled with thick tephra layers including pyroclastic flow deposits.

Blake and Bleeker (1970), Blake and McDougall (1973), and Blake (1976) described the tephra deposits around Witori volcano. The latter authors placed the age of the caldera-forming eruption of Witori at ca. 2600 BP on the basis of the radiocarbon age of charcoal covered by thick tephra layers on the southwest and northeast flanks (ages reported here are uncalibrated conventional radiocarbon ages based on the old half-life). Bleeker and Parfitt (1974), however, suggested that many tephras in the Cape Hoskins area, north of Witori, were derived from Garbuna volcano about 40-50 km west of Witori. The petrography and geochemistry of these deposits were reported by Blake and Ewart (1974). In spite of these papers, fundamental data on the Holocene eruptive history of Witori volcano have been lacking.

Dakataua caldera was investigated by Branch (1967) and Lowder and Carmichael (1970) from geomorphological and geological viewpoints, but little is known of the eruptive products of this volcano except for the recent basaltic lava flows of Makalia.

In addition to establishing a regional stratigraphy of value to Quaternary researchers, identification, mapping, and dating of the tephra-producing events provide an important context for the understanding of human history in this area of West New Britain. Blake and McDougall (1973) and Blake (1976) described obsidian flakes buried in a soil under more than 20 m of tephra on the southwest flank of Witori. Aspects of archaeological research in the area have been reported in preliminary detail elsewhere, particularly noting the utility of tephrostratigraphy for interpreting the archaeological sites (e.g. Specht et al.,...
FIG. 1. Location of study area and sites examined. Volcanoes indicated with ▲. Numbers and ● indicate tephrostratigraphic sections while three letter codes show the location of archaeological sites.
the volcano. Blake and Bleeker (1970) called both pyroclastic fall and flow deposits on the northeastern coast of Hoskins Peninsula, Galilo Pumice, but Blake (1976) limited the name to the plinian tephra. This latter usage matches our W-G tephra.

The stratigraphy of the W-H tephra group is well established in the Hoskins district, on the northern flank of Witori, and around to Buvusi west of the volcano. The W-H tephras are generally smaller scale eruptive products than the older W-K tephra layers. They consist of seven tephras of which the upper five are certainly of Witori origin. The source volcanoes for Hoskins 1 and 2 (H1, H2) are not clear because the deposits are quite thin and fine-grained.

Of eight Holocene tephra layers recognised in the Dakataua and Talasea districts, the andesitic Dk tephra is the major product of Dakataua caldera. It occurs extensively around Dakataua caldera, with plinian and phreatomagmatic airfall tephras at the base of the sequence and phreatomagmatic lithic-rich pyroclastic flows at the top. Total tephra thickness reaches more than 10 m near Dakataua caldera and about 40 cm at Talasea and Garua Island, 30 km from the caldera. This volume of tephra suggests that it is a caldera-forming eruption product.

At least five, thin andesitic local tephra layers of Dakataua origin (D-Wn1 to D-Wn5) occur above Dk, mostly as post-caldera phreatomagmatic products containing accretionary lapilli. A single, thin ash layer, with a patchy occurrence immediately above D-Wn1, is called Wanguwangu tephra (Wn) here. This may be correlated with H1 tephra in the Hoskins and Kimbe areas, consequently forming an important marker tephra, though its source volcano is not known.

Around Talasea and Garua Island a discontinuous ash lies immediately below Dk; this may be W-K3 or W-K4. Identification of this layer is important for determining the tephrostratigraphic position of Dk, but uncertainties remain because of its contaminated nature. Around Dakataua caldera and Talasea to the south, the W-K2 tephra appears in the paleosol below Dk, forming an excellent marker for correlation.
TABLE 1. Summary of the nature of Witori and Dakataua tephra layers

<table>
<thead>
<tr>
<th>Source and tephra name (symbol)</th>
<th>Stratigraphic sequence</th>
<th>Type locality(2)</th>
<th>Age (°C ka)(3)</th>
<th>Eruption type</th>
<th>D</th>
<th>A</th>
<th>VEI</th>
<th>Heavy minerals</th>
<th>Refractive(glass n) index (opx γ) (modal range)(3)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Witori-Hoskins 7 (WH-7)</td>
<td>afa</td>
<td>132</td>
<td>1914 AD?</td>
<td>subpl</td>
<td></td>
<td></td>
<td></td>
<td>(opx, cpx, mt)</td>
<td>n: 1.508–1.511</td>
<td>Source: Pago</td>
</tr>
<tr>
<td>Witori-Hoskins 6 (W-H6)</td>
<td>pfa→afa→pfa</td>
<td>132</td>
<td>&lt;0.5</td>
<td>pl→subpl</td>
<td>4?</td>
<td></td>
<td></td>
<td>opx, cpx</td>
<td>n:</td>
<td>reverse grading</td>
</tr>
<tr>
<td>Witori-Hoskins 5 (W-H5)</td>
<td>alternation of pfa and afa</td>
<td>65, 69, 79</td>
<td>&lt;0.5</td>
<td>phreat</td>
<td>W</td>
<td>3</td>
<td>4</td>
<td>opx, cpx</td>
<td>n: (u) 1.506–1.515 (1.508–1.512) (l) 1.507–1.512</td>
<td>ill sorted</td>
</tr>
<tr>
<td>Witori-Hoskins 4 (W-H4)</td>
<td>fpfa→cpfa→fpfa</td>
<td>66, 69, 79</td>
<td>&lt;0.5</td>
<td>pl</td>
<td>W</td>
<td>3</td>
<td>4 or 5</td>
<td>opx, cpx (ol)</td>
<td>n: (u) 1.502–1.511 (1.504–1.509) (l) 1.502–1.513 (1.504)</td>
<td>largest of W-H tephras</td>
</tr>
<tr>
<td>Witori-Galilo</td>
<td>pfa</td>
<td>66, 79</td>
<td>0.5(1)</td>
<td>phreat</td>
<td>SW</td>
<td>3</td>
<td>4</td>
<td>opx, cpx</td>
<td>n: 1.502–1.513 (1.506–1.508)</td>
<td>ill sorted</td>
</tr>
<tr>
<td>Hoskins 2 (H2)</td>
<td>afa</td>
<td>79</td>
<td>1.0–0.5</td>
<td>?</td>
<td>(opx, cpx)</td>
<td>n: 1.501–1.510 (1.503–1.507)</td>
<td>source volcano: unknown, widespread</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoskins 1 (H1)</td>
<td>afa</td>
<td>79</td>
<td>1.0–0.5</td>
<td>?</td>
<td>(opx, cpx)</td>
<td>n: 1.506–1.511 γ 1.705–1.709</td>
<td>widespread? possible correlation with Wanguwangu ash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galilo</td>
<td>pfa→afa</td>
<td>68, 72, 81, 132</td>
<td>1.2</td>
<td>pl</td>
<td>S</td>
<td>4</td>
<td>6</td>
<td>opx, cpx</td>
<td>n: (u) 1.500–1.514 (1.508–1.512) (l) 1.505–1.514 (1.508–1.512) γ 1.705–1.710</td>
<td>Galileo Pumice of Blake (1976)</td>
</tr>
<tr>
<td>Witori-Kimbe 4 (W-K4)</td>
<td>afa→pfa→pfl</td>
<td>65, 66, 74, 81,132</td>
<td>1.3–1.5</td>
<td>phreat→pl→ign</td>
<td>SW</td>
<td>4</td>
<td>5</td>
<td>opx, cpx</td>
<td>n: (u) 1.513–1.515 (l) 1.508–1.512 γ 1.705–1.710</td>
<td>afa includes accretionary lapilli</td>
</tr>
<tr>
<td>Witori-Kimbe 3 (W-K3)</td>
<td>pfa→afa→pfa</td>
<td>64, 66, 70, 74</td>
<td>1.8</td>
<td>pl</td>
<td>W</td>
<td>3</td>
<td>5</td>
<td>opx, cpx</td>
<td>(u) 1.512–1.515 (l) 1.506–1.510 γ 1.705–1.710</td>
<td>most important widespread marker in West New Britain; reverse grading; silicic (SiO2 = 80%)</td>
</tr>
<tr>
<td>Witori-Kimbe 2 (W-K2)</td>
<td>afa→pfa→ps→pfl→ps→afa</td>
<td>81</td>
<td>3.3</td>
<td>phreat→pl→ign</td>
<td>SW (E)</td>
<td>4</td>
<td>5</td>
<td>(opx, cpx, [ho, qt])</td>
<td>n: 1.507–1.510 γ 1.707–1.711</td>
<td></td>
</tr>
<tr>
<td>Source and tephra name (symbol)</td>
<td>Stratigraphic sequence</td>
<td>Type locality(^{(3)})</td>
<td>Age (^{\text{14C}}) ka(^{(1)})</td>
<td>Eruption type</td>
<td>D</td>
<td>A</td>
<td>VEI</td>
<td>Heavy minerals</td>
<td>Refractive(glass n) (n) index (modal range)(^{(2)})</td>
<td>Remarks</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>------------------------</td>
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<td>------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>(W-K2) Witori-Kimbe 1</td>
<td>pfa→pfl→pfa→pfl</td>
<td>81, 132, 68, 20 5.6</td>
<td>pl→ign</td>
<td>W 4</td>
<td>5–6</td>
<td>opx, cpx</td>
<td>n: (u) 1.498–1.512 (1.501–1.510) (l) 1.500–1.511 (1.509–1.511) γ: 1.706–1.711</td>
<td>wide range in glass composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(W-K1) Dakataua D-Wanguwangu 5</td>
<td>sfa</td>
<td>111, 113 1895 A.D.?</td>
<td>subpl</td>
<td>3–4</td>
<td></td>
<td></td>
<td>Source: Mount Makalia?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D-Wn4) D-Wanguwangu 4</td>
<td>afa</td>
<td>111, 113</td>
<td>phreat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>includes accretionary lapilli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D-Wn3) Wanguwangu ash</td>
<td>afa</td>
<td>113</td>
<td>phreat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>vitric white ash; widespread? possible correlation with HI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Wn) D-Wanguwangu 2</td>
<td>pfa→afa</td>
<td>111</td>
<td>phreat→pl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>includes accretionary lapilli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D-Wn2) D-Wanguwangu 1</td>
<td>afa</td>
<td>111</td>
<td>phreat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>includes accretionary lapilli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D-Wn1) 10 Dakataua (Dk)</td>
<td>afa→pfa→afa→pfa→pfl</td>
<td>110, 111 1.15</td>
<td>phreat→pl→ign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>lithic rich flow, youngest caldera-forming eruption, includes accretionary lapilli</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

afa: ash fall; pfa: pumice fall; fpfa: fine-grained pumice fall; cpfa: coarse-grained pumice fall; subpl: subplinian; pl: plinian; phreat: phreatomagmatic; ign: ignimbrite forming; opx: orthopyroxene; cpx: clinopyroxene; mt: magnetite; ho: hornblende; qt: quartz; (u): upper; (l): lower; D: direction of main distribution axis; A: recognisable distribution area power index of 10 km\(^2\).

\(^{(1)}\) Radiocarbon ages shown in Fig. 4. \(^{(2)}\) See Fig. 1 for type locality. \(^{(3)}\) Small amounts of phenocrysts are shown in a parenthesis.
FIG. 3. Lithostratigraphy of Witori and Dakataua tephras. Section A = Hoskins area; B = Buvusi-Kimbe area; C = Dakataua area. 1 = scoria fall; 2 = ash fall; 3 = pumice fall; 4 = pyroclastic flow; 5 = pyroclastic surge; 6 = accretionary lapilli; 7 = lithic fragments; 8 = soil or paleosol.

PETROGRAPHIC PROPERTIES OF WITORI AND DAKATAUA TEPHRAS

Mineral assemblages of the Witori tephras are similar except for the older Witori-Rikau tephra (W-R). The W-K and W-H tephras bear orthopyroxene and clinopyroxene and magnetite as mafic phenocrysts. W-K2 is poor in mafic minerals and includes minor hornblende and quartz. Younger Witori tephras show similar refractive indices of orthopyroxene ($\gamma = 1.705-1.711$), but in the underlying W-R tephra orthopyroxene has higher indices ($\gamma = 1.710-1.718$).

Some differences in the refractive indices of volcanic glass ($n$) in the younger tephras allow discrimination between them (Table 1). The modal range of W-K1 is generally wider ($n = 1.500-1.510$) than that of the other tephras, while that of W-K2 is generally narrower ($n = 1.507-1.510$). W-K3 has a higher range ($n = 1.506-1.515$) than W-K2 and W-K1. Similarly, W-K4 is characterised by a glass index that differs between the lower fine-grained phreatomagmatic ash fall ($n = 1.508-1.512$), and
the upper coarse pumice fall with the uppermost flow unit 
\((n = 1.513–1.515)\). W-G has glass with a relatively high 
index \((n = 1.508–1.512)\). Slight differences also exist in 
the refractive indices of volcanic glasses in the W-H 
tephras layers (Table 1).

The petrographic nature of Dakataua tephra is distinct 
from that of the Witori tephras. Predominant clinopyrox-
ene is characteristic of the Dakataua tephra layers. These 
layers sometimes contain minor orthopyroxene and 
olivine. The refractive index of Dakataua volcanic glass 
is high \((n = 1.513–1.524,\text{ modal range})\), suggesting a less 
silicic composition.

Dakataua tephras are rich in alkaline elements, and 
relatively poor in SiO2. Several units of the DK tephra 
have similar compositions. The less silicic and more 
alkaline Dakataua tephras are readily discriminated 
from the Witori tephras. As one of the most useful silicic 
marker tephras on Willaumez Peninsula, the W-K2 tephra 
can be identified by its refractive index and the major 
element chemistry of glass shards. Around Talasea and 
Dakataua W-K2 shows a relatively low refractive index 
\((n = 1.506–1.510)\) and a very silicic composition (SiO2 ca. 
80% at sites 47 and 55, unpublished data).

**RADIOCARBON AGE DETERMINATION OF THE 
HOLOCENE TEPHRAS**

The Witori caldera-forming eruption was previously 
dated at ca. 2600 BP on the basis of radiocarbon dating of 
charcoal included in a paleosol just below a thick welded 
tuff at outcrop ‘A’ on the southwest foot of Witori (Blake 
and McDougall, 1973; Blake, 1976). The assignment of 
this tuff to our tephrostratigraphic sequence is uncertain. 
We were unable to relocate outcrop ‘A’, and we have 
many radiocarbon ages older than 2600 BP for the large-

scale W-K2 and W-K1 tephras.

Figure 4 shows newly obtained radiocarbon ages from 
charcoal and other organic materials included in pyr-
oclastic flow deposits and paleosols on the compound 
schematic sections of Witori and Dakataua tephras. 
Despite the variations in dating materials and the

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**FIG. 4. Radiocarbon ages are not calibrated, and are based on T1/2 = 5568 years. Laboratories are as follows: NZA = Institute 
of Geological and Nuclear Sciences Ltd, New Zealand; SUA = N.W.G. Macintosh Centre for Quaternary Dating, University of Sydney; Beta 
= Beta Analytic Inc, Florida; ARL = Australian Radiometric Laboratories. Locality site number [ ] brackets are shown on Fig. 1. Site 
numbers where artefacts occurred are shown in italics. For the key to lithofacies and deposit emplacement mechanisms, see Figs 2 and 3.**
laboratories used, there are no significant discrepancies between radiocarbon ages and stratigraphic sequence within the range of two standard deviations. Ages for paleosol horizons are maxima for the overlying tephra layers. Most samples were taken from immediately below the overlying tephra and imply vegetation destruction by the tephra deposition. Consequently, W-K2, W-K3, and W-G are well dated by ages from charcoals included in underlying paleosols as 3300, 1800 and 1200 BP, respectively. W-K1, at 5600 BP, is dated by charcoal included within the flow deposit, rather than by an age obtained from the underlying paleosol. Similarly, W-K4 is dated at around 1400 BP.

The age of the Dk eruption is uncertain. A single age determination of 1150 BP has been obtained for charcoal included in a pyroclastic flow deposit south of Dakataua. Because the sampling by C. Pain and R. Blong was carried out before the standard sequence for Dakataua was established, we are uncertain whether the sample refers to Dk or to D-Wn1.

A more detailed chronology of the W-K and Dk tephras will be presented elsewhere, using data from archaeological and other sources.

**MODE OF ERUPTION AND EMPLACEMENT OF TEPHRA**

The Witori and Dakataua tephras are classified into three groups on the basis of mode of eruption and emplacement:

- plinian + ignimbrite tephra (pfa + pfl): W-K1, WK-2, WK-4, Dk

A common feature of Witori and Dakataua eruptions is the dominance of phreatomagmatic eruptions. Most of the ignimbrite-forming eruptions and the preceding plinian ones are characterised by ejection of fine-grained ash with accretionary lapilli, as indicated by W-K1, W-K2, W-K4, Dk, and D-Wn1-3. Such features strongly suggest abundant water in the vent area at the time of eruption. Today, no lake exists in Witori caldera, though there may have been a lake in the former caldera. The large-scale W-K1 eruption suggests the formation of a younger caldera, possibly adjacent to or associated with a pre-existing one. Magma-water contact might have introduced the next phreatomagmatic (WK2) eruption. The present morphology of Witori volcano suggests a caldera complex rather than a single caldera (Blake, 1976). Discrimination of individual caldera collapses is difficult because the southern caldera rim is not clear. However, the later dominance of relatively 'dry' and smaller plinian and sub-plinian eruptions after the W-G eruption probably indicates the growth of Pago cone within the caldera.

The largest eruption of Witori, W-K2, produced the most widespread pyroclastic flow deposits together with the preceding phreatomagmatic ash fall and plinian pumice deposits. Around Kimbe town, 40 km west of Witori, a thin and ill-sorted unit composed of ash and pumice at the top of the W-K2 tephra formation suggests a distal pyroclastic flow component. Also, the WK-4 tephra has a relatively thin flow bed in spite of its intermediate magnitude (VEI = 5), suggesting an exceptionally gas-rich pyroclastic flow.

Four of the Dakataua tephra-forming eruptions were phreatomagmatic, including the first major one (Dk). These eruption characteristics suggest that the lake, which currently fills the caldera, existed prior to the Dk eruption. The Dk tephra is also characterised by the presence of a lithic-rich pyroclastic flow at the top. This suggests that the last paroxysmal phreatic eruption might have destroyed a former volcanic cone or cones. More information about the tephrostratigraphy of older Dakataua eruptions is required to understand the history of this caldera volcano.

**DISTRIBUTIONS OF THE TEPHRA LAYERS**

Isopach maps for all plinian tephras except for W-G suggest easterly prevailing winds during the eruptions (Fig. 5A–F), as is common in low latitude areas. The velocities of the winds transporting the tephra were not as high as is common in middle and high latitude areas, as most of the plinian deposits can be identified on the upwind sides of the source volcanoes. This distribution of fallout favours the regional correlation of tephras around Witori volcano. Although Hargy and Lolobau caldera tephras lie to the east of the study area there is no evidence that any of the tephras described here came from these centres.

The W-K2 tephra constitutes the most important time marker for Holocene history in this area on account of its widespread occurrence throughout West New Britain (Fig. 5B). Other Witori tephras, W-K1, W-K3, W-K4, and W-G (Fig. 5), also provide significant datum planes in West New Britain. The main axis of distribution of Dk tephra is uncertain. Dakataua is situated at the end of the Willaumez Peninsula and most of the tephra would have fallen into the sea, irrespective of wind direction during the eruption. At Bitokara (near Talasea) and on Garua Island, 30 km south of the source, it occurs as a 40 cm-thick prominent layer.

Pyroclastic flow deposits of W-K1, 2, and 4 occur in every direction from the source. The W-K2 flow extended more than 40 km from the volcano, and was one of the largest pyroclastic flows from Witori during the Holocene.

W-H3, 4, 5, and 6 consist of coarse-grained pumice at localities on the Hoskins Peninsula, indicating that their source was Witori. Each tephra contains multiple airfall units, with thicknesses <1 m near to the source. Eruption character changed in mode and magnitude between the W-G and W-H3-6 group of tephras. The magnitude of individual W-H tephras clearly was less than those of W-K and W-G tephras. W-H4 and W-H5 occur to the west of the volcano, but W-H3 has a circular distribution.
Holocene Explosive Eruptions of Witori and Dakataua Caldera Volcanoes

indicating that wind strengths were low during this eruption.

OLDER TEPHRA LAYERS

As older Witori tephra layers (those underlying W-K1) are only rarely exposed around Witori caldera, their stratigraphy is incomplete. Notes for the discrimination of these older tephras from younger tephras are set out below.

W-R (Witori-Rikau) tephra

This tephra is recognisable only at the Rikau section (Locality 64; see Fig. 1) about 10 km north of Witori where W-K1 and W-K2 unconformably overlie a silicic
pyroclastic flow deposit more than 10 m thick. This tephra is distinguished from overlying W-K, W-G and W-H tephras by the presence of abundant hornblende, orthopyroxene, and quartz.

BS (Buvusi) scoria

Immediately below the younger Witori tephra layers, highly weathered basaltic scoria fall deposits are exposed at Buvusi pass (Locality 68) on the western rim of the caldera-like depression. The source vent for the scoria is not known but could be the nearby Mount Oto stratovolcano or Witori itself.

W-L1, L2, L3 (Witori-Lalili) tephras

At least three tephra layers are recognisable below the W-K tephra group at Locality 81 on the southern side of Lake Lalili (Fig. 1), south of the Witori caldera. They are called W-L1, W-L2, W-L3 from bottom to top. W-L1 is a pyroxene-dacite pyroclastic flow deposit up to 1 m thick. W-L2 is a plinian andesitic pumice layer with a thickness of 1.5 m, bearing two pyroxenes and magnetite as mafic
phenocrysts. W-L3 is an olivine-bearing basaltic scoria layer, possibly correlating with a part of Buvusi scoria (BS).

*Other tephras*

Little information about older tephras below the Dk and W-K2 tephras in the Talasea area has been obtained so far. However, a lengthy hiatus between older tephras and Dk and W-K2 would explain a well-developed paleosol. Two silicic pyroclastic flow and scoria fall deposits of Pleistocene age occur around Talasea and on Garua Island (Fig. 1).

At the northern tip of Garua Island, numerous scoria falls cover a scoria cone, alternating with paleosols. These layers are weathered and unconformably covered by Holocene tephra layers. The source is not known, but could be a nearby basaltic stratovolcano such as Little Gulu or Gulu volcanoes on Willaumez Peninsula, northwest of the island. A silicic pyroclastic flow deposit at the bottom of the scoria fall layers is characterised by rhyolitic composition with the refractive index of glass in the range of $n = 1.499-1.501$. Similar pyroclastic flow deposits are exposed at Bitokara Mission, west of
Talasea, and on the southeastern foot of Mount Gulu, north of Talasea, where they form basal layers on obsidian lava flows originating from Mount Kutao and Mount Little Gulu, respectively. Additional studies are needed to understand the correlation, origin, and age of these pyroclastic flow deposits.

**VOLCANIC ACTIVITY AND HUMAN HISTORY**

Initial human colonisation of New Britain took place in the late Pleistocene (Specht et al., 1983; Pavlides and Gosden, 1994). Despite the repeated devastation caused by Holocene eruptions, human occupation of the affected areas continued through to the present. The tephrostratigraphy presented here provides an excellent chronological framework for this human history.

Archaeological deposits have been recognised at many locations in the paleosols formed on the various tephras. Blake and McDougall (1973) and Blake (1976) noted obsidian artefacts in a paleosol under thick tephra layers at Waisisi on the southwest flank of Witori. Since then, we have found artefacts in almost all Holocene paleosols of the Witori and Dakataua tephra series (Table 2). The oldest occurrence is at Locality 68 (archaeological site FRK) dated to 7780 BP (Fig. 4).

Our ability to correlate the tephras over large distances allows the placement of these archaeological deposits into a consistent chronological scheme for most of central New Britain. Correlation of archaeological deposits by tephra events, particularly from W-K2 onwards, provides a more secure chronology than is possible from radiocarbon dates alone. Some sites near Talasea, for example, have no dateable materials below W-K2 and between the W-K2 and Dk tephras, yet the position of the archaeological deposits in relation to the tephras allows a regional correlation. The apparent presence of Lapita pottery only in paleosols postdating the W-K2 tephra and prior to W-K3 (Specht et al., 1991) provides firm chronological limits for this distinctive pottery. The widespread W-K2 tephra, furthermore, provides an important marker horizon for correlating archaeological deposits across New Britain from Bitokara, Garua Island, and Walindi Plantation on Willaumez Peninsula (Specht et al., 1991), to Yombon in the centre of the island (Pavlides, 1993), and south-west to Lolmo Cave in the Arawe Islands (Gosden et al., 1994) off the south coast of New Britain.

The persistent human re-occupation of areas affected by these Holocene tephras probably reflects the existence of obsidian near the source volcanoes. Obsidian is a highly-prized resource on account of its excellent flaking properties and its capacity for providing sharp cutting edges. Within Papua New Guinea obsidian occurs in only four areas, two of them on New Britain. There are extensive flows around Talasea on Willaumez Peninsula and at Mopir to the southwest of Witori (Specht, 1981; Specht and Hollis, 1982; Fullagar et al., 1991; Torrence et al., 1992). The exploitation and transport of obsidian from these source regions began in the late Pleistocene (Summerhayes and Allen, 1993), and has continued up to the present century. The major W-K1 and W-K2 eruptions would have severely affected access to the Mopir obsidian, and may have caused access difficulties around Talasea, as well as causing loss of human life or abandonment of these areas. Yet the importance of each obsidian source region was such that exploitation of the Talasea obsidian resumed immediately after each eruption, and probably after only a short hiatus at Mopir (Summerhayes and Hotchkiss, 1992; Summerhayes et al., 1993).

The impact of the Dk and other major tephras on the landscape and biota would have been devastating, especially near the volcanoes where there would have been total destruction of plant and animal life. Soil formation and recolonisation by plants and animals may have occurred quite quickly in peripheral areas to the main impact of the tephras, with human recolonisation

<table>
<thead>
<tr>
<th>Locality</th>
<th>Archaeological site code</th>
<th>Local place name</th>
<th>Stratigraphic context (*Obsidian tools, pottery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H37</td>
<td>FWH</td>
<td>Kimbe</td>
<td>*Between W-K1 and W-K2</td>
</tr>
<tr>
<td>H54</td>
<td>FWI</td>
<td>Kabugara Settlement Block</td>
<td>*Below W-K3</td>
</tr>
<tr>
<td>H63</td>
<td>FWJ</td>
<td>–</td>
<td>*Between W-K3 and W-K4</td>
</tr>
<tr>
<td>H64</td>
<td>FOY</td>
<td>Rikau</td>
<td>*Between W-K2 and W-K3</td>
</tr>
<tr>
<td>H68</td>
<td>FRK</td>
<td>Buvusi Hill</td>
<td>*Below W-K1</td>
</tr>
<tr>
<td>H70</td>
<td>FWK</td>
<td>–</td>
<td>*Below W-K3</td>
</tr>
<tr>
<td>H74</td>
<td>FWL</td>
<td>Kimbe</td>
<td>*Between W-K2 and W-K3</td>
</tr>
<tr>
<td>H81</td>
<td>FWM</td>
<td>Lake Lalili</td>
<td>*Below W-K2; *Between W-K4 and W-G</td>
</tr>
<tr>
<td>H92</td>
<td>FWN</td>
<td>Sarpantavil Village</td>
<td>*Below W-K2</td>
</tr>
<tr>
<td>H101</td>
<td>FOX</td>
<td>Saddle Mound</td>
<td>*Below W-G</td>
</tr>
<tr>
<td>H101</td>
<td>FWD</td>
<td>–</td>
<td>*Between W-K1 and W-K2; *Between W-K2 and W-K3</td>
</tr>
<tr>
<td>H122</td>
<td>FWQ</td>
<td>Ishmi Village</td>
<td>*Between W-K2 and W-K3</td>
</tr>
<tr>
<td>91-3</td>
<td>FRI</td>
<td>Puro (Walindi Plantation)</td>
<td>*Below W-K2; *+Between W-K2 and W-K3; *Above W-K3</td>
</tr>
<tr>
<td>91-6,7</td>
<td>FDQ</td>
<td>Bitokara Mission</td>
<td>*Below W-K2</td>
</tr>
<tr>
<td>91-11</td>
<td>FSZ</td>
<td>Scoria Pit, Garua Island</td>
<td>*Below W-K2; *+Below Dk; *Above Dk</td>
</tr>
<tr>
<td>91-15</td>
<td>FAO</td>
<td>–</td>
<td>*Below W-K2; *+Between W-K2 and Dk; *Above Dk</td>
</tr>
</tbody>
</table>
human populations, however, would have encountered following soon after. Where the tephras were deepest, the landscape would have been well-drained and nutrient-rich. This would have been especially important for slash-and-burn horticulture which was developed or introduced to the area at some point during the Holocene. Thus, with each major tephra fall the landscape experienced devastation and subsequent rejuvenation. The returning human populations, therefore, would not have encountered devastated landscapes, but ones with new potential.

**SUMMARY AND CONCLUSIONS**

*Witori Caldera volcano*

The Holocene eruptive history of Witori is readily reconstructed from tephrachronological studies. After a long dormancy, Witori started its most recent period of activity ca. 5600 BP, producing the plinian falls and pyroclastic flows of the W-K1 tephra. Its bulk volume is estimated at ca. 10 km$^3$, based on the isopach map of the plinian component (see Pyle, 1989) and the area covered by pyroclastic flows. The second major eruption, W-K-2, was the largest in the Holocene, producing phreatomagmatic ash falls, plinian pumice falls, pyroclastic flows, and associated pyroclastic surges. Evidence from Kimbe suggests that a pyroclastic flow travelled at least 40 km from source. The age of this eruption is ca. 3300 BP based on three radiocarbon age determinations. The bulk volume is estimated at about 30 km$^3$. The third event, W-K3, represented by a plinian fall deposit of 6 km$^3$ in bulk volume, took place ca. 1800 BP. The fourth event, W-K4, dated ca. 1400 BP, was predominantly a phreatomagmatic eruption, producing ash falls, plinian pumice and gas-rich pyroclastic flows. The bulk volume was about 6 km$^3$. The fifth major eruption occurred around 1200 BP, producing the W-G plinian tephra of ca. 20 km$^3$ bulk volume. Calderas could have been formed at Witori by any or all of these five major eruptions. The many phreatomagmatic eruptions suggest a lake may have existed in the caldera in former times.

After the eruption of W-G, eruptions of Witori decreased in magnitude but increased in frequency. The younger eruption products, after W-G, are mainly plinian and phreatomagmatic tephras (H-1 to W-H6 from older to younger). The source vents of the H-1 and H-2 tephras are not determined, because they have very thin and patchy occurrences. Radiocarbon dates have not been obtained on all the younger tephras, H-1 to W-H6. However, based on the radiocarbon ages immediately below W-G and W-H3 (Fig. 4) and on the assumptions that soil-forming processes were constant and that the rate of soil formation is linear, the following ages have been assigned: H1: ca. 1000 BP; H2: ca. 1000–800 BP; W-H3: ca. 500 BP; W-H4: ca. 400 BP; W-H5: ca. 250–200 BP; W-H6: ca. 150 BP.

In general, Witori tephras are two pyroxene-bearing dacites with the refractive index of glass ranging from $n = 1.500$ to 1.515, and with the maximum refractive index of orthopyroxene ranging from $\gamma = 1.705$ to 1.710 (Table 1).

Almost all Witori tephra formations have components of phreatomagmatic eruption except for W-G, W-H4, and W-H7. Above all, the W-K2 and W-K4 tephras are characterised by very abundant accretionary lapilli and pyroclastic surge deposits. Such features indicate that a lake or sea water existed near the vent at the time of eruption. The present landscape south-southwest of Witori suggests that there was an extensive caldera lake (possibly of Pleistocene age) with a bay to the east along the present Kapiura River (Fig. 1). The supposed caldera lake might have occupied the area around the present Buru cone, because Pleistocene tephra layers including pyroclastic flows occur extensively around the caldera-like depression.

Isopach maps for all plinian tephras except W-G suggest easterly prevailing winds during eruptions. Identification of W-K2 at remote localities shows that this tephra covered much of West New Britain and constitutes the most important time marker for Holocene history in the area. This tephra and the other W-K units have proved invaluable in providing marker horizons for archaeological sites. Identification of W-K1 at Bitokara mission has established the age of obsidian artefacts there at ca. 5600 BP. Correlation of tephra remnants at obsidian source sites indicate that these resources were exploited again shortly after each tephra fall and establish the importance of these sites for human settlement and trade.

*Dakataua and Caldera volcano*

Pre-WK-2 activity of Dakataua is unclear, because the recent tephra layers, including the pyroclastic flow deposit of Dk, mask the flanks of the volcano. The major eruption of Dakataua caldera started with alternating ejection of phreatomagmatic ash falls and plinian deposits followed by the cataclysmic eruption of lithic-rich pyroclastic flows ca. 1150 BP. The bulk volume of this deposit could be of the order of 10 km$^3$. Part of the present caldera would have been formed by this major eruption. The lithic-rich pyroclastic flow at the top of the Dk tephra may indicate the destruction of a central cone or cones.

After this major eruption, at least five eruptions occurred. These were probably of sub-plinian and vulcanian (phreatomagmatic) type, possibly associated with lava flows from the central cone, Makalia. The most recent eruption occurred ca. AD 1890 (Branch, 1967; Lowder and Carmichael, 1970).

The predominance of clinopyroxene is a characteristic feature of Dakataua tephras, which are rich in alkaline and mafic elements and relatively poor in SiO$_2$. The refractive indices of the volcanic glass are high.

In the space of 4500 years, from 5600–1100 BP, Witori
and Dakataua volcanoes produced six major explosive eruptions with a total estimated bulk volume of > ca. 80 km$^3$. We are unaware of similar eruption rates from such relatively small areas elsewhere. Apart from the profound effects of the eruptions on local landscapes and human history, Witori and Dakataua volcanoes may have contributed significantly to mid–late Holocene volcanic–climate interactions.

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