Environmental change and fire in the Owen Stanley Ranges, Papua New Guinea

Geoffrey Hope

Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, the Australian National University, Canberra, ACT 0200, Australia

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A B S T R A C T

Kosipe, an upland valley at 2000 m altitude in the Owen Stanley Ranges of southeastern New Guinea, is known for the discovery of large stone waisted blades dated to 31,400 cal a BP. The purpose of these tools and the nature of occupation are unknown. The altitude is too high for most food crops today and may have stood close to the treeline during the last glaciation. Three pollen and charcoal diagrams from a large swamp in the Kosipe Valley provide a record of swamp and dryland changes for more than 50,000 years. There have been considerable fluctuations in vegetation on the slopes and on the swamp which reflect both environmental change and anthropogenic influences. A gymnosperm-rich forest at the base is replaced by montane forest dominated by Nothofagus about 42,000 years ago. Fire first becomes apparent across the swamp around 40,000 years ago but is not common during the time when subalpine herbs reach their best representation. Tree fern-rich grasslands form a mosaic with montane forest in a near-treeline environment. The Pleistocene–Holocene boundary is marked by a decline in Nothofagus and increase in lower montane mixed forest taxa. Charcoal increases before this time and the swamp vegetation becomes more grass-rich. Charcoal is at its maximum through the last 3000 years possibly reflecting climate variability as well as sedentary occupation and agriculture on the swamp margin. Supplementary pollen diagrams from two higher altitude sites support the evidence from the Kosipe Swamp cores. Charcoal, local catchment erosion and increases in disturbance taxa become more widespread in the last 5000 years at these sites, suggesting that local settlement at Kosipe may have lagged behind general landscape use by populations from lower altitudes.

1. Introduction

Kosipe is an intermontane valley at 1995 m altitude and 8°S latitude, in the Owen Stanley Ranges 110 km north of Port Moresby, the capital of Papua New Guinea (PNG). It leapt into prominence in 1964 when Pleistocene stone tools were recovered from an excavation of church foundations (White et al., 1970). A C14 date of 26,870 ± 590 a BP on charcoal was obtained from towards the base of the tool-bearing layer which yielded large and medium sized waisted blades that may have been hafted. Archaeologists have commented on the site as one proving early highlands settlement (O’Connell and Allen, 2004) but have refrained from doing much further work there until recently, when a major archaeological investigation led by Glenn Summerhayes and Matthew Leavesley from Otago University commenced. It is hard to model what may have drawn people to the site in the late Pleistocene because although the nut-bearing Pandanus julianetti grows well at Kosipe at present and is an important storable food source, its status in the Pleistocene is uncertain. Kosipe today is marginal for the principal high altitude crop, sweet potato, and so it may have been too cold for any known starchy food plants at the height of the last glacial. Vegetation histories from the central highlands of PNG which have >25,000 year records include Siruniki (2500 m altitude) which stood above treeline from 28,000 to 14,000 C14 yrs BP (Walker and Flenley 1979) and Haeapuaga (1650 m) which was a grassland from 20,000 to 12,000 years ago (Haberle, 1998).

Kosipe remains one of the few substantial Pleistocene open archaeological sites in the western Pacific, most other Pleistocene occupation in New Guinea having been studied in caves and rock shelters (Evans and Mountain, 2005; Hope and Haberle, 2005; Fairbairn et al., 2006). The archaeological site occurs on a ridge crest adjacent to a large swamp which was shown to have a record exceeding 35,000 cal years (Hope, 1982). There is thus an unusual opportunity to obtain a parallel record of environmental change from pollen and other proxies to compare to the archaeological record. It also provides an interesting parallel to the intensively studied wetland occupation site at Kuk, in the Western Highlands, where Holocene occupation and manipulation of a swamp have been detailed (Denham et al., 2004).

Kosipe is at a critical altitude to allow the nature of near-treeline vegetation at the Last Glacial Maximum (LGM) to be assessed. Based on available pollen data from across New Guinea, Hope
suggests that Pleistocene near-tree line vegetation differed from the modern day simple subalpine forest of *Rapanea vaccinioide*, *Rhododendron culminicolium* and *Dacrycarpus compactus* by being far more complex and diverse. No long records of vegetation change have previously been reported from the southeastern ranges of New Guinea. Kosipe lies on the flank of a major mountain range hence there is an opportunity to examine parallel records from higher altitude sites at the possible climatic treeline at LGM and at the margin of a former rival zone.

2. Regional setting

The Kosipe Valley occupies a N–S trending bench on the western flank of Mt Albert Edward, at 3990 m one of the highest mountains of the Owen Stanley Ranges. The Ivani River drains the 28 km² Kosipe Swamp northwards and then turns west to flow to the Lovo River near Tapini (Fig. 1). The Kosipe river, a prominent tributary of the Ivani, falls from slopes to the east and blocks the northern end of the valley with a gravel floodplain formed from schist and other metamorphic rocks. This aggradation may have backed up the Ivani and initiated swamp build up. The Kosipe Mission archaeological site occurs on one of several gently sloping basaltic ridges that are found at the northern end of the valley. A weathered basalt boulder from the ridge crest near the archaeological site gave an \( ^{40} \text{Ar}/^{39} \text{Ar} \) date of 5.07 ± 0.07 Ma (ANU Laboratory-J. Dunlap pers. comm.).

The modern Kosipe river has incised the floodplain by up to 15 m but away from reworked terraces and point bars the gravels are mantled by 0.5–1.5 m of light brown silts which contain volcanic ash. The gravels and subsequent possible ash are sealed by a distinctive 50 cm layer of black peaty clay that also occurs at the archaeological site and hence must be around 31 500 years old. White et al. (1970) identified an ash component in the archaeological section which they considered might be sourced from Mt Lamington, the nearest active volcano 116 km to the southeast.

Ten kilometres east of Kosipe the Neon Basin (25 km²) occupies a similar bench at 2870 m. This grassland is drained by the Guimu River which flows north to the Waria River before turning north east. To the east above the Neon Basin, Mt Albert Edward is a dissected plateau of schist at 3600–3990 m with well developed glacial landforms that include numerous rock basins infilled by swamps and small lakes. In the Pleistocene the summit plateaux of Mt Albert Edward supported an ice cap of 80 km² with a snowline 20 m whose fruits are an important seasonal staple for the area.

Below Kosipe the forests are more mixed and have an increasing lowland component such as palm species. But these have not been investigated closely although they were extensively collected by the First Archbold Expedition in 1933 (Archbold and Rand, 1935). Above 2200 m the forest loses many taxa such as *Castanopsis–Lithocarpus* and *Calophyllum* and the proportion of confiers increases together with *Xanthomyrtus, Raphanea, Polypomos* and *Eriocaceae*. *Nothofagus* forms gregarious patches up to 2500 m but is nowhere extensive.

The subalpine and alpine vegetation is better known (van Rojen, 1967; Pajimans and Lofller, 1972; Hope, 1975) and undisturbed areas support a low forest of *D. compactus*, *R. vaccinioide* and *R. culminicolium*. The Neon Basin has a frost and fire affected tussock grassland of *Poa, Deyeuxia* and *Deschampsia* species with numerous subalpine herbs such as *Astelia papuana, Potentilla foersteriana* and *Ranunculus* spp. Large areas are dominated by frost-tolerant fern forests, mainly *Cyathea macgregoriae* and these form a zone 15 m above the floor of the basin with regrowth shrubs of *Dodonea viscosa*. Extensive treeless areas above 3400 m are occupied by a short *Poa* grassland that differs from grasslands on other New Guinea mountains. Tarns and ponds are common and colonised by the aquatic fern ally *Isotea neoguineensis*. The area was first described by Monckton (1908, 1922) who ascended Mt Albert Edward in May 1906. It was also visited by the First Archbold Expedition from June until August 1933 when comprehensive plant collections were made by L.J. Brass. Both expeditions recorded evidence of fire and wild pig damage. Cassowary and the New Guinea monotreme *Zaglossus bruijni* are still relatively common in the grassland–forest boundaries while wild pigs graze the grasslands.

The Kosipe valley is in the Goilala District of Central Province. The local population consists of about 1000 Tauade speakers spread around in several hamlets. This high valley is situated between substantial montane populations around Tapini to the north and Wotape to the south. It lies on major routes between these areas and is also connected by tracks across the range to the east. No other archaeological sites have been described in the surrounding montane region but coastal sites show the settlement of people in the Papuan Gulf by 13 000 cal a BP (David et al., 2007) and as late as 4000 cal a BP around the Port Moresby region. Catholic missionaries established a network of graded mule tracks in the Goilala region after 1913 and Kosipe Mission was set up about 1958. Kosipe hosts
a primary school and one remaining building of the Bereina diocese, the remainder of the mission having been destroyed by a fire in 1998 that also burnt the swamp. A road and mission airstrip have fallen into disuse and the nearest open airfield and permanent government and mission presence are at Woitape, 22 km to the south.

3. The coring program

The stratigraphy of the Kosipe Mission archaeological site (code AER, 8°27′12″S, Long: 147°12′34″E, 1965 m altitude), was described by White et al. (1970) from a 120 cm section on the crest of a ridge. Between ca 40 and 100 cm there is a prominent black peaty clay that provided dates of 31500 cal a BP on charcoal. The age of this clay has now been extended by further dating at substantially the same site to at least 33 ka (Fairbairn et al., 2006). During fieldwork in 1980 and 1981 it was established that the stratigraphy of the archaeological site is draped over the valley on other ridge crests, slopes and the gravel river terraces of the Kosipe River. This persistent sequence confirmed that landscape features have been stable throughout the late Pleistocene and that the black peaty clay possibly represents the slow accumulation of volcanic ash with organic matter.

Given the evidence for landscape stability a coring program was instituted in Kosipe Swamp to provide a parallel record in the organic sediments. Most coring was carried out with a D section corer but a Livingstone corer and a piston corer utilising a tripod and winch were employed in stiff basal sediments at Kosipe A (KPA) and Neon Basin sites. Selected cores from five sites were described in the field and then wrapped and returned to the Australian National University (ANU) in Canberra. In the laboratory 8–15 cm
sections of peat were sieved and the fine fraction (<200 μm) submitted for radiocarbon dates to the Sydney, Geochron and ANU laboratories. To clarify the stratigraphy of KPA and KPC, further dates were extracted from 1 to 2 cm core sections. The fine fraction was pre-treated with acid–alkali–acid before submission to ANSTO for AMS dating. Other samples were collected at 20 cm intervals and analysed for pollen and microcharcoal using standard preparation methods.

A preliminary core (KPE) was obtained in June 1974 from Kosipe Swamp, about 1 km east from the archaeological site near the boundary of sedgeland forest on the eastern side of the swamp (Fig. 1). The base of the peat at 590 cm above silty clay was more than 33 000 years old. More comprehensive stratigraphy of the site was defined in 1980 and 1981 on a transect from the north, near the Kosipe River floodplain, to the south in the largest extent of sedgeland. The peat layer was found to be around 4–6 m deep across the basin, overlaying silty clays containing organic matter and wood. About 450 m east of the archaeological site, at the northern end of the swamp (Fig. 2a,b), an 800 cm section (KPA 8° 27’ 2.9”S, 147° 13’ 0.8”E 1932 m) was chosen for detailed study and dating. To aid the interpretation of this record another core (KPC 8° 28’ 47”S, 147° 13’ 30”E 1936 m) was analysed from the geographic centre of the swamp about 4 km south of KPA. This site is at least 2 km from the edge of the swamp and could be expected to have a regional dryland pollen influx. Coring in the Dacrydium–Podo-carpus swamp forest demonstrated that the eastern side of the swamp is marked by a layer of gray silty clay that occurred in the top metre of the peats. The base of these upper clays was dated at KPE and from a short core (KPB) ca 2 km south within the swamp forest. These clays were derived from the slopes to the east of the swamp and transported by streams that spread out over the swamp.

In order to relate events at Kosipe to environmental changes at higher altitudes, the Neon Basin, which is situated at the montane forest–subalpine forest boundary at 2875 m, was investigated. The Neon is large plain of grassland and sedgen fern overlying dissected gravel fans. Swamps on the plain have 1–2 m of fibrous peat over blue–gray fine clay with laminations dipping gently from the north east. A core (ANBZ 8° 27’ 27.3”S, 147° 21’ 16.5”E) was taken in late 1979 from the center of the plain south of the mainstream.

The high altitude post-glacial history was investigated within the formerly glaciated area on the northern plateau of Mt Albert Edward at Laravita Tarn (ALV 8° 23’ 22.51”S, 147° 21’ 39.8”E 3560 m). The site is a shallow peaty pond in grass bog and Carpha alpina fen, on an ice-eroded shelf on the northern slope of the largest formerly glaciated valley on Mt Albert Edward. This valley drains the summit plateau westwards to the northern end of the Neon Basin. Today remnant patches of subalpine forest occur 150 m from the site but most of the slopes have been burnt and support tussock grassland with tree ferns or short alpine grassland. A core obtained in June 1974 consisted of fibrous peats above a basal gyttja and rock flour. The hollow, possibly moraine dammed, would have formed when the glacial ice last retreated above the altitude of the site.

4. Stratigraphy and dating

4.1. Kosipe A (KPA)

This site was chosen as the main core because it was the deepest and longest section and was relatively close to the archaeological section on the ridge to the west. The northern end of the swamp is a sedgeland with scattered shrubs of Rhododendron and Melastoma. The stratigraphy consists of fibric to hemic peat over peaty silts and clay which became stiff with depth (Table 1).

The age of the transition from silts to peat is defined by a carefully pre-treated AMS date on organic fines from the clayey silts and dates on peat above the silts. This transition at 590 cm occurred around 42 000 cal years ago (Table 2). However one bulk date (KPA-4) from organic material within the silts at 600 cm returned a Holocene age that must reflect the incorporation of young material during coring and this age is rejected.

The remainder of the dates shows that there may be a hiatus or highly compressed record between 500 and ca 400 cm. In fact the inversion between dated levels at 490 and 430 cm suggests that either date may be in error. Above ca 400 cm is a full section of post-glacial and Holocene peats. An age model has been constructed assuming continuous sedimentation using selected dates (KPA 1, 2, 3, 9, 10, 11, 8 and 12). This places the Holocene boundary at around 370 cm with an average accumulation rate of 32 mm/100 yr above this level and 7.3 mm/100 yr below it (Fig. 3).

The basal silts may be partly derived from volcanic sources but incorporate pollen, peat and wood indicating gradual accumulation. If the very slow accumulation rate indicated by the upper silts is extrapolated to the base at 800 cm, the accumulation commenced at a maximum age of 70 000 years and is unlikely to be less than 55–60 000 cal years in age.

4.2. Kosipe East (KPE)

The KPE core has not been analysed in detail but can be correlated with the main core in terms of stratigraphy and pollen signatures. The site lies about 450 m east of KPA site in a shrubby tall sedgeland on the margin with Dacrydium swamp forest. Approximately 110 cm of peaty silty clay overlay 465 cm of fibrous brown peat with peaty clay from 575 cm to 610 cm and laminated gray clay to 640 cm (Table 3).

The ages suggest that the peatland may have expanded onto the basal silts more recently than at the KPA site in the centre of the valley. However the basal date at KPE on peaty silts is based on a small sample and appears to be too young by comparison with the same horizon in KPA. If the basal age for KPE is rejected then the age structure of the peat at the two sites is similar although the section at KPE is compressed compared to that at KPA (Fig. 3).

The silt layer in the upper metre of KPE is derived from the slopes to the east after 2700 cal a BP. About 1 km south of KPE at site KPB, within the Dacrydium swamp forest, 115 cm of peaty silts have accumulated above black fibrous peat after 3900 cal a BP. The silt layer may correlate with an expansion in swamp forest into the sedgelands. The two dates mark the initial spread of inorganic sediment and suggest that there were increased sediment yields from the catchment after 2700 cal years ago.

4.3. Kosipe Centre (KPC)

The site was selected to aid the interpretation of the KPA sequence because it is distant from grassland and forest on the surrounding slopes. The core was taken from the centre of the swamp, about 400 m from the edge of the swamp forest, ca 4.5 km south of Kosipe Mission and 1.5 km from the southern edge. The vegetation is an extensive 2 m tall sedgeland of Scirpus sp. in standing water. A small swamp species of Pandanus was occasional with Melastoma sp and Polygonum amongst the sedges. An isolated shrub of Dacrydium was present as an outlier from the forest. The sequence resembled that at KPA but with less peat (Tables 4 and 5).

The upper 370 cm is Holocene and hence a similar peat sequence to that recovered at KPA. However the transition from peaty silts to fibrous peat at 520 cm occurs at 26 500 cal a BP several millennia more recent than the same transition at KPA (Fig. 3). This may reflect a gradual encroachment of the valley floor to the west.
by peatlands after an initial paludification at the downstream end of the valley.

**4.4. Neon Basin (ANB)**

This extensive grassy plain was cored in several places and proved to be a relatively shallow peatland, the surface of which has numerous pits indicating recent peat loss from illuviation. The subalpine grassland of *Poa* and *Deschampsia* species is rich in herbs and ferns including *A. papuana*. It is treeless but is surrounded by a ring of shrubs of *D. viscosa* and tree ferns 15 m above the valley floor. The area is frequently burnt and is also a frost hollow, discouraging shrub growth. Shallow peats deepen gradually to the south and are generally 1.5–2 m deep on the centre and south over gray–blue clays that dip from the north. A SEM analysis of surface chatter marks on fine sand grains include in the clay was
consistent with glacial weathering. The clays are therefore interpreted to be a possible sub-aqueous fan of glaciogenic outwash.

Core ANB2 was taken in a sedge fen near the bridge on the Kosipe–Chirima track and 45 m from a gravel bank to the south. It was the deepest peat encountered in several cores taken across the basin. However the sediments beneath the peat were silts, not the clays seen elsewhere (Table 6).

These sediments lie within a basin formed by gravels that have been dissected. The gravels are undated but may reflect an earlier glaciﬁuvial fan deposit that was later re-ﬁlood by a lake which formed due to outwash deposition across the outlet to the basin. The fen peat is the result of build up in swampy conditions which have gradually become drier as the Guimu river has incised its barrier.

Dating establishes that the transition from silts to peatland occurred in the early Holocene. The date at 107 cm may have been inﬂuenced by younger roots since over a metre of dense ﬁbrous peat is unlikely to have accumulated so quickly. An age of 1800–2500 cal a BP for the dated level is indicated by extrapolation from the older date near the base of the peat (Table 7).

4.5. Laravita Tarn (ALV)

The tarn is a shallow peaty pond set in a sod tussock bog of Deschampsia klossii. The basin is probably dammed by a lateral moraine but the barrier is now under peat. The tarn is on a steep south-facing slope surrounded by Poa–Danthonia short grassland with nearby tree ferns and remnant patches of forest (Table 8).

These sediments lie within a basin formed by gravels that have been dissected. The gravels are undated but may reflect an earlier glaciﬁuvial fan deposit that was later re-ﬁlood by a lake which formed due to outwash deposition across the outlet to the basin. The fen peat is the result of build up in swampy conditions which have gradually become drier as the Guimu river has incised its barrier.

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5. Pollen and charcoal analysis

5.1. Methods

Samples of 2 ml of sediment were removed from cores and the fine fraction (<150 μm) subjected to standard preparation techniques of HF, alkali and acetolysis. Total pollen counts generally exceed 500 and identiﬁcations are based on the pollen database.html. Charcoal fragments larger than 5 μm were counted using a point method to assess density in the slides. The results are presented as an area/concentration measure (mm²/ml).

Table 2

<table>
<thead>
<tr>
<th>Code</th>
<th>Depth (cm)</th>
<th>Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>Black fibrous peat</td>
<td></td>
</tr>
<tr>
<td>50–70</td>
<td>Root debris and wood</td>
<td></td>
</tr>
<tr>
<td>70–100</td>
<td>Brown clayey silt with rootlets</td>
<td></td>
</tr>
<tr>
<td>100–300</td>
<td>Dark brown fibrous sedge peat</td>
<td></td>
</tr>
<tr>
<td>300–500</td>
<td>Brown sedge peat</td>
<td></td>
</tr>
<tr>
<td>500–600</td>
<td>Light brown–gray peaty silts</td>
<td></td>
</tr>
<tr>
<td>600–650</td>
<td>Gray silt clay</td>
<td></td>
</tr>
<tr>
<td>650–800</td>
<td>Gray–yellow silty clay with peaty lenses and scattered wood fragments</td>
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</table>

Table 3

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (cm)</th>
<th>C14 date</th>
<th>Cal 2σ</th>
<th>Lab</th>
<th>Method/materials</th>
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<tr>
<td>KPA-1</td>
<td>71–82</td>
<td>2070 ± 70</td>
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<td>C14 peat fines</td>
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<td>3520 ± 80</td>
<td>3710–3910</td>
<td>ANU93038</td>
<td>C14 peat fines</td>
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<tr>
<td>KPA-3</td>
<td>185–198</td>
<td>4190 ± 80</td>
<td>4600–4820</td>
<td>ANU9305B</td>
<td>C14 peat fines</td>
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<tr>
<td>KPA-9</td>
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<td>6640 ± 100</td>
<td>7450–7600</td>
<td>OZ469</td>
<td>AMS fines</td>
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<td>KPA-10</td>
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<td>8160 ± 80</td>
<td>9030–9250</td>
<td>OZJ460</td>
<td>AMS fines</td>
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<td>KPA-5</td>
<td>359–361</td>
<td>9390 ± 250</td>
<td>10270–10980</td>
<td>OZ404</td>
<td>AMS fines</td>
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<td>KPA-11</td>
<td>430</td>
<td>18200 ± 130</td>
<td>22310–22900</td>
<td>OZJ461</td>
<td>AMS fines</td>
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<tr>
<td>KPA-7</td>
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<td>18491–19320</td>
<td>OZ450</td>
<td>AMS fines</td>
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<td>35900 ± 850</td>
<td>39450–41710</td>
<td>OZ405</td>
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<td>13330–13580</td>
<td>ANU93048</td>
<td>C14 macro</td>
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<tr>
<td>KPA-12</td>
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<td>47800 ± 2100</td>
<td>48730–55290</td>
<td>OZJ462</td>
<td>AMS fines</td>
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</table>

Fig. 3. Calibrated age models for the dated Kosipe cores.
Table 4
Stratigraphy of KPC.

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–30</td>
<td>Water and sedge bases</td>
</tr>
<tr>
<td>30–60</td>
<td>Sedge rootmat (not sampled)</td>
</tr>
<tr>
<td>60–100</td>
<td>Watery fibrous peat</td>
</tr>
<tr>
<td>100–186</td>
<td>Soft light brown sedge peats</td>
</tr>
<tr>
<td>186–256</td>
<td>Yellow–black gritty silt, possible ash</td>
</tr>
<tr>
<td>196–256</td>
<td>Brown sapric peat</td>
</tr>
<tr>
<td>256–283</td>
<td>Gray and yellow silt with wood fragments</td>
</tr>
<tr>
<td>283–476</td>
<td>Brown dense fibrous sedge peat (32.59 ± 1.46% C @ 370)</td>
</tr>
<tr>
<td>476–600</td>
<td>Light brown silty sedge peat becoming more silty below 560 cm.</td>
</tr>
</tbody>
</table>

Table 5
Dating results from KPC.

<table>
<thead>
<tr>
<th>Code</th>
<th>Depth</th>
<th>C14 date</th>
<th>Cal 2r</th>
<th>Lab</th>
<th>Method/materials</th>
</tr>
</thead>
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<tr>
<td>KPC-3</td>
<td>35–40</td>
<td>132.5%Modern</td>
<td>ANU-2742</td>
<td>C14 Peat</td>
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<tr>
<td>KPC-2</td>
<td>110–115</td>
<td>2540 ± 90</td>
<td>2470–2730</td>
<td>ANU-2741</td>
<td>C14 Peat</td>
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<tr>
<td>KPC-4</td>
<td>210–216</td>
<td>4270 ± 100</td>
<td>4660–4980</td>
<td>ANU-2743</td>
<td>C14 Peat</td>
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<tr>
<td>KPC-13</td>
<td>370</td>
<td>9010 ± 370</td>
<td>9690–10660</td>
<td>OZJ 643</td>
<td>AMS Acid/base insol fines</td>
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<td>KPC-1</td>
<td>510–530</td>
<td>22200 ± 330</td>
<td>26120–27460</td>
<td>ANU-2498</td>
<td>C14 Peaty fines</td>
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</table>

5.2. Kosipe A

The pollen diagram for KPA is shown in Fig. 4. The figure spans ca 60–75 000 years and shows major changes in the relative importance of Nothofagus and mixed montane forest. Zone KOS-1 (800–610 cm, ca 70–45 ka BP) correlates with the peaty silts and is characterised by relatively low Nothofagus and very high levels of Dacrycarpus, Podocarpus and Myrtaceae. Dacrydium is not prominent but reaches the highest levels in the diagram. Sedges, grass and ferns are moderate to low and herbfield taxa very low. Cyathea and other ferns decline from high levels at the start of the zone. Between 690 and 750 cm all tree taxa are very poorly represented but there is a short-lived spike in secondary taxa, especially Pandanus as well as both large and small Myrtaceae. Rounded opaque carbonised material is present but distinct charcoal and burnt plant material are absent suggesting that the black particles associated with the silts may be derived in the sediment, for example from volcanic activity.

At the start of Zone KOS-2 (610–330 cm, 45–11 ka BP) Nothofagus increases dramatically to dominate the diagram, reaching a peak at 520 cm and declining thereafter but always more than twice as frequent as all other woody taxa combined. Dacrycarpus declines steeply and then more gradually into the zone but both Podocarpus and Phyllocladus increase slightly and maintain a consistent presence. Both grass and Cyathea increase together with a range of grassland herbs, notably Plantago first and later Astelia. Although shrubs such as Coprosma, Ericaceae, Rapanea and Tasmannia are present throughout they achieve their best representation in this zone. Secondary taxa, notably Macaranga and above 520 cm Pandanus (probably a swamp taxon) become prominent. Charcoal made up of clearly carbonised plant remains is at low but consistent concentrations above 580 cm.

Zone KOS-3 (330–230 cm, 11–6 ka BP) marks a significant fall in Nothofagus that is matched by a small increase in Castanopsis at the start of the zone. The fall in Nothofagus is interrupted by a spike at 280 cm above which Castanopsis rapidly increases and Nothofagus becomes a minor component. Phyllocladus reaches its highest levels in the diagram and Podocarpus increases in importance. Cyathea and the shrubs decline gradually through the zone while the grassland herbs continue before steep declines near the top of the zone. The swamp changes with a marked increase in Poaceae and increases in ferns such as Gleichenia, monolete and Lycopodium types as well as the aquatics Myriophyllum and Melastoma. The Pandanus type becomes rare but the disturbance taxa Urticaceae–Moraceae, Macaranga and Dodonaea all increase. Charcoal of clear plant origin increases significantly before the KOS-3 zone boundary and remains high throughout.

The upper peats and silts of Zone KOS-4 (230–0 cm, 6 ka BP–Present) provide relatively minor changes in forest elements, Nothofagus remaining low and Castanopsis increasing slightly in the upper part of the diagram. Phyllocladus declines at the start of the zone boundary but Ilex, Myrtaceae and Paupeae become more consistent suggesting that the forest became more mixed. Cyathea and shrubs are less important although there are slight increases above 110 cm in Ericaceae. Herbs other than Ranunculus are unimportant except for the appearance of a Lamiaceae. In the swamp Gleichenia becomes unimportant near the base of the zone and monolete fern spores also decline before returning above 110 cm. Poaceae continues to dominate throughout the zone but declines slightly above 110 cm. Melastoma increases markedly as does Myriophyllum particularly above 110 cm while there is a small increase in sedges in the zone. Disturbance taxa are well represented with Celtis, Trema, Acalypha, Alphitonia and Macaranga all prominent. Casuarina, present as isolated grains in other zones, is consistently present in the uppermost 60 cm. Charcoal concentrations continue at high levels from Zone KOS-3 but then decline before abruptly rising to very high levels above 110 cm.

5.3. Kosipe East

The KPE core is summarised in Fig. 5 and provides a check on the KPA record. It clearly mirrors the KPA diagram with equivalent zone boundaries at 530, 290 and 230 cm defining four broad zones. The close concordance between KPE and KPA supports the rejection of the age obtained on wood from the base of KPE which the pollen spectra correlate with Zone KOS-1. The better dated KPA section shows that the KOS-1/2 zone boundary is more than 42 000 cal years BP. Below 530 cm in KPE there are high Myrtaceae, Dacrycarpus and Cyathea and low Nothofagus values. Above this is a late Pleistocene high Nothofagus with herbfield, Cyathea and moderate grass values. There is an early Holocene decline in Nothofagus and increasing mixed forest with Castanopsis and Phyllocladus in a grass swamp with elevated Pteris. The final zone in the late Holocene shows a decline in Phyllocladus but small increases in Dacrycarpus and Dacrydium and substantial increases in disturbance taxa including Casuarina in the top 100 cm. The swamp spectra have

Table 6
Neon Bridge 2 Stratigraphy.

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–145</td>
<td>Dark brown fibrous peat</td>
</tr>
<tr>
<td>145–215</td>
<td>Brown partly humified peat with rootlets</td>
</tr>
<tr>
<td>215–250</td>
<td>Light brown silty clay grading to peat above with abundant rootlets</td>
</tr>
<tr>
<td>250–350</td>
<td>Blue–gray finely laminated clays with occasional rootlets</td>
</tr>
<tr>
<td>350–390</td>
<td>Coarser silty band 273–305</td>
</tr>
<tr>
<td>&gt;390</td>
<td>Gravels not sampled</td>
</tr>
</tbody>
</table>

Table 7
Dates from Neon Bridge core.

<table>
<thead>
<tr>
<th>Code</th>
<th>Depth</th>
<th>C14 date</th>
<th>Cal 2r</th>
<th>Lab</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANB-2</td>
<td>105–110</td>
<td>320 ± 90</td>
<td>275–465</td>
<td>ANU-2740</td>
<td>Peat</td>
</tr>
<tr>
<td>ANB-1</td>
<td>270–285</td>
<td>8280 ± 110</td>
<td>9110–9400</td>
<td>ANU-2497</td>
<td>Peaty silt</td>
</tr>
</tbody>
</table>
increased Cyperaceae, Myriophyllum and Lycopodium but no Mela-
stonia. Differences with KPA include low Podocarpus in Zone KOS-1,
a relatively short and small peak in Astelia in Zone KOS-2 and a
decline in Castanopsis in Zone KOS-4. The carbonised particle
curve generally matches that in KPA in showing a low but
increasing charcoal concentration from the base of zone KOS-2 and
rising near the top to a maximum. However at KPE the rise to very
high concentrations above 100 cm is absent.

5.4. Kosipe Central Core

The KPC section (Fig. 6) is distant from the swamp margin and
thus provides a comparative record with less influence from local
dryland changes. It is a shorter record than the northern cores as it
lacks Zone KOS-1, the earlier high Dacrycarpus phase, reflecting the
fact that the site did not contain older peaty silts. The KPC record
commences with moderately high Nothofagus levels that may
correlate with the upper half of Zone KOS-2, after the extreme high
beech influx around 35 000 cal a BP seen at KPA. This supports the
basal age of ca 28–30 000 years inferred from accumulation rates
(Fig. 4). The lower peats display the decline from the high Nothofagus
of Zone KOS-2 to low Nothofagus and increased Castanopsis in KOS-
3–4. Castanopsis values are generally increasing through the zone as
are Ericaceae while herbs including Astelia, Apiaceae, Plantago,
Potentilla and Ranunculus are prominent. Grass and tree ferns reach
their highest levels in this zone, but tree ferns decline above 460 cm.
Sedge pollen is very low and other aquatic plants almost absent but
algae are present. Disturbance taxa such as Macaranga are at
moderate levels and charcoal influx is consistent though not high.

Zone KOS-3 is marked by a fall in Castanopsis, the appearance of
Dacrydium and a rise in Podocarpus, Phyllocladus and later Dacry-
carpus and Dodonaea. Nothofagus continues to decline steadily to
very low levels after 10 500 cal a BP but Castanopsis rises to low
levels in the upper part of the zone. Subalpine herbs decline
abruptly but Asteraceae increase markedly. Major changes take
place in the swamp with an abrupt increase in Cyperaceae and
Myriophyllum and a return of grass without Cythea. Disturbance
taxa decline through the zone but charcoal increases. Zone KOS-4
sees Castanopsis reach its highest levels around 5000 cal a BP before
a slight decline. The gymnosperms remain prominent although
Dacrycarpus fluctuates. Asteraceae pollen declines but Cythea,
grasses and herbs fluctuate before a final decline in the upper
60 cm. This accords with a final peak in Cyperaceae. Disturbance
taxa increase in importance in the zone and charcoal reaches its
highest values early in the zone, declining towards the top.

Table 9
Carbon dates from Laravita Tarn.

<table>
<thead>
<tr>
<th>Code</th>
<th>Depth cm</th>
<th>C14 date</th>
<th>Cal 2σ</th>
<th>Lab</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALV-3</td>
<td>190−200</td>
<td>4475−110</td>
<td>4060–5278</td>
<td>SUA-597</td>
<td>C14/peat</td>
</tr>
<tr>
<td>ALV-2</td>
<td>490−500</td>
<td>11 400 ± 200</td>
<td>13 090–13 520</td>
<td>SUA-596</td>
<td>C14/peat fines</td>
</tr>
<tr>
<td>ALV-1</td>
<td>525–538</td>
<td>12 850 ± 300</td>
<td>14 780–16 227</td>
<td>GX-3659</td>
<td>C14/Limnic mud</td>
</tr>
</tbody>
</table>

5.5. Neon Basin

The clayey silts below 290 cm in the ANB2 site contained
extremely low pollen concentrations down to 340 cm and were
barren below this. They are more likely to be sediments eroded from
the gravels than lake materials as even clay-rich glacial pond sedi-
ments contain abundant regional pollen in New Guinea (Hope and
Peterson, 1976). The silts below 260 cm contain a phase of high
Nothofagus that is probably the final KOS-2 zone and indicates an age
of up to 12 000 cal a BP (Fig. 7). Above this Castanopsis and Notho-
agus maintain low but consistent percentages throughout the
pollen diagram. There is relatively little change in the diagram
through the Holocene even though the site is adjacent to well
drained slopes that could support upper montane forest. However
there is no evidence of a major clearance in the record. There is
a moderate increase in grass and decline in Dacrycarpus and some
shrubs including Ericaceae and Rapaenea after 8000 cal a BP. This
coincides with an increase in herbs such as Astelia. The bog is herb
and grass dominated with a relatively constant input from Cyper-
aceae. Gleichenia, probably Gleichenia vulcanica, increases to the top
and there is a short phase of Isotes dominance that may reflect
ponding. Disturbance taxa are present throughout but there is
a recent small increase in Macaranga, Asteraceae, Coprosma, Maca-
raea and Cythea that may represent the development of the current
marginal zone around the basin. Charcoal is at moderate to high
concentrations throughout with an increase in the top 80 cm.

5.6. Laravita Tarn

Although the tarn preserves only a post-glacial sequence it
extends back to the period of high Nothofagus and low Castanopsis
and thus provides a high altitude record from late KOS-2 time
(Fig. 8). This interpretation is supported by the well dated upper
downward boundary at ca 29 1700 cal a BP, marked by the rapid decline in
Nothofagus. Before this time increasing Cyperaceae together with
grass and herbs such as Caryophyllaceae and Ranunculus suggests
an initial colonisation by an open tundra and the spread of a
riparian fen in Zone KOS-2b. Rapaenea increases from the base
showing that shrubland started to develop soon after deglaciation,
perhaps replacing Cythea-rich grasslands. In Zone KOS-3 there is
a general increase in subalpine forest including Podocarpus and
Dacrycarpus reflecting an increasingly diverse treeline forest
reaching the altitude of the site around 11 300 cal years BP. Herbs
and grass increase but sedges decline suggesting a developing grass
and herbfield that replaced a more aquatic fen. Rapaenea achieves its highest representation between 420 and 250 cm. Aster-
aceae, Cythea and Ericaceae also increase which may reflect an
opening up of the subalpine forest. charcoal has an occasional
presence in the basal zone and is then present at times in KOS-3
even though the subalpine forest is well represented. Castanopsis expands in the mid-Holocene late in zone KOS-3.

In KOS-4 time three subzones are based on local changes. Cas-
panosis declines above 200 cm but Nothofagus increases at the
subzone boundaries. The site continues to be dominated by grass
and herbs but these are reduced in subzone KOS-4c. In this subzone
the sediment changes to gyttja and records increasing inorganic
content above 50 cm suggesting paludification and possible fire
damage. Despite a period from late in KOS-3 that has no charcoal,
pollen percentages for subalpine shrubs and forest decline early in
subzone KOS-4a. Above 180 cm charcoal becomes consistent and is
frequent throughout the zone. In Subzone KOS-4b there is an initial
upsurge in Rapaenea, Podocarpus, Dacrycarpus and Asteraceae fol-
lowed by a gradual decline in woody plants until Cythea, together
with other disturbance taxa such as Dodonaea, Macaranga and
monolete fern spores, start to increase near the top of the subzone.
Subzone KOS-4c is marked by increases in the regional elements *Nothofagus* and *Phyllocladus* as well as potentially local woody plants including *Rapanea*. This change commences before the change in sediment type which indicates the development of ponds at the core site. This may reflect a relative increase in the influx of regional pollen due to a reduction in the extent of local forest.

6. Discussion

6.1. Landscape histories

The Kosipe–Mt Albert Edward landscape elements are established well before the late Pleistocene with Pliocene volcanic flows...
indicating that the Kosipe valley is a few million years old. The landscape may reflect the general step faulting that has stranded old surfaces at Kosipe, the Neon and the Albert Edward summit plateau. Since then there has been a regime of general downcutting but there have been accumulative episodes. In the Kosipe River valley fluvial gravels and sands have aggraded. The Kosipe and Ivani valleys are mantled by 30–150 cm of white feldspar-rich ash which may be more than 60–80 000 years BP, in general accordance with an estimate for the initiation of Mt Lamington of 70 000–110 000 cal BP (Ruxton, 1966) based on ash fall and cone development rates. At Kosipe the ash fall or reworked ash built up in a shallow swampy lake that occupied the northern part of the modern swamp. To the south the ash formed a plain without a swamp. By about 38–42 000 cal yrs BP the ash supply was reduced and a peatland developed on the swampy plain. The peat swamp spread southwards and reached the centre of the plain about 33–36 000 years ago after which a gradually thickening peatland has covered the whole Ivani basin.

At higher altitudes the southern part of the Neon Basin has had at least one phase of infill by gravel fans and colluvium that subsequently eroded. The white feldspar-rich ash at Kosipe was not found on the eroded slopes on the gravels so this erosion may be younger than that ash fall. An undated terminal moraine form is visible where the largest valley glacier fed from the summit plateau just reached the Neon. A glaciofluvial outwash fan from this valley may have infilled the northern Neon Basin with gravels and dammed the Guimu River temporarily, causing a short-lived shallow lake to cover the southern part of the basin. The shallow peat infill suggests that the valley only became swampy around 11 000 cal a BP.

It is likely that Mt Albert Edward has been glaciated several times in the Pleistocene, given the evidence (Löffler, 1972; Prentice et al., 2005) for extensive glaciation of Mt Giluwe with possible tills and palagonite dated at 810, 700 and 306 ka BP. Cosmogenic dating of preserved moraines identified three younger glaciations at 145 000, 62 000 and 17 500 cal a BP. Final deglaciation occurred there, and on other mountains in New Guinea, with ice retreat from 15 700 until 11 340 cal a BP. Deglaciation ages elsewhere in New Guinea are in good agreement with Laravita Tarn where the basal rock flour shows that when the record commences at 15 500 cal a BP the ice had only recently retreated up valley. The thermal change associated with lowered snowlines equates to ca 6 °C based on snowline depression but there may have also been local effects caused by cold air drainage.

The Laravita Tarn core has four apparent volcanic ash layers at, approximately 500, 5700, 7200 and 13 800 cal a BP. No distinct ashes were seen in the upper 600 cm of KPA but at KPC silt bands at 4400 and 6800 cal a BP may also reflect mid-Holocene ash influx. The increases in inorganic sedimentation and possibly reduced peat growth in the uppermost metre of the deposits at Kosipe Swamp may mask the most recent ashes. White et al. (1970) correlated ash horizons in the AER archaeological section with a sequence established 29 km to the southeast of Mt Lamington by Ruxton (1966). Such correlations are probably premature as the ashes are not well defined away from the volcano, with only a selection of ashes reaching Kosipe and poor age control at this stage.

6.2. Environmental change

The general agreement in the local pollen zonation between all the sites suggests that the major vegetation changes reflect a direct climate control extending from Marine Isotope Stage 4 to present. The ratio of the two well dispersed pollen types of the Fagaceae...
(Nothofagus and Castanopsis) helps define Zone boundaries and probably reflects replacement of less diverse upper montane forests dominated by Nothofagus by lower altitude more diverse montane forest containing Castanopsis–Lithocarpus. Another major marker, the treeline, lay below Laravita Tarn at the end of Zone KOS-2 time but was never as low as Kosipe where significant forest cover has been maintained around the swamp throughout the record (Table 10). The regional nature of the Nothofagus decline suggests that the discrepancies are most likely due to faults in the age models of individual sites.

The KOS-1 upper boundary occurs at 40–43,000 a BP but coincides with the development of a peat swamp so may in part reflect changing edaphic conditions from a swamp forest at the site or fringing a shallow lake to open wet bog. The KOS-2 upper boundary appears to be around 11–12,000 cal a BP which indicates that the age model at KPA may be too young in the early Holocene. Better agreement exists for the rise in Castanopsis at the KOS-3–4 boundary around 6500 cal a BP.

A PCA analysis of all samples (Fig. 9) using major non-swamp taxa but omitting Nothofagus, found that Neon and Laravita overlap
but are generally distinguished from the combined KPA and KPC samples by herb, tree fern and subalpine shrub levels. Discriminating the Kosipe samples by zone shows that Kosipe in KOS-2 time has an overlap with some early and late Holocene Laravita Tarn samples at which time the grass levels at the subalpine were relatively low. By contrast, the low Nothofagus-high gymnosperm vegetation of Zone KOS-1 has no modern analogue even in the present fringing swamp forest. KOS-3 is a transitional period with short-lived peaks in Phyllocladus and low Fagaceae. It is followed by KOS-4 marked by Castanopsis peaks and increased secondary taxa, especially grass.

The KOS-1 environment of dominance by the conifers Dacrycarpus and Podocarpus with abundant Cyathea may reflect swamp forest or a type of cool wet subalpine forest. The two conifer genera have wide altitudinal ranges but Dacrycarpus is usually dominant above 3300 m. As the area was mantled by young dacitic ash falls this may have

Fig. 7. Pollen diagram Neon Basin (ANB2). The upper date appears to understated the true age.
depressed the other montane forest types, including Nothofagus. This limits the environmental inferences that can be made but it is likely that Kosipe was cool and moist but not subalpine.

The transition to KOS-2 time sees the local vegetation on Kosipe Swamp include a range of subalpine herbs such as Plantago, Gentiana and Potentilla which are prominent on the Neon through the Holocene and also important at Laravita Tarn. Astelia, which is a clear indicator of cold conditions, only appears after 31,000 cal a BP suggesting increasing cold then. Relatively low Cyperaceae and moderate levels of grass occur in KPA and KPC in Zone KOS-2 which increases the similarity with the modern Neon Basin. An analysis of phytoliths from Level 4 at the archaeological site shows that the grasses present there were festucoid, as are all the modern subalpine grasses. Hence the swamp vegetation at Kosipe was peat-forming cushion bog or subalpine herbfield maintained by frosts and occasional fires. This evidence demonstrates that the KOS-2 zone reflects cooling temperatures for late MIS 3 (35–25,000) and cold temperatures during MIS 2 (25,000–12,000 cal a BP). The temperature lowering indicated by vegetation depression of ca 900 m change relative to present could be 4–6 °C but is difficult to quantify because vegetation similar to that at the Neon occurs up to 700 m higher today. The conditions around the swamp were

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**Fig. 8.** Pollen diagram Laravita Tarn (ALV).
forested, with an upper montane forest in which *Nothofagus* was prominent but which included some subalpine shrubs such as Ericaceae, *Tasmannia* and *Coprosma*. The altitudinal treeline may thus have been quite close, lacking a distinct subalpine forest such as occurs today. The controls on the treeline may have included low CO₂ concentrations and more severe frosts. At this time extensive shrubby grasslands with tree ferns would have extended the whole length of the Owen Stanley Range.

The remarkable fall in *Nothofagus* at the end of KOS-2 represents a significant change in local forest composition. What may have been extensive beech stands were replaced by scattered individuals in a mixed montane forest. *Phyllocladus* became extremely important after 11 000 cal a BP. As beech responds to minor disturbance (Read and Hope, 1996) it is possible that the early Holocene was a time of stable climate. The glacial retreat and development of the subalpine forest of first *Rapanea* and later *Dacrycarpus* above Laravita demonstrates that temperature and CO₂ levels were rising. It is also possible that seasonality was enhanced and cloud lie disrupted, which would not favour *Nothofagus*.

While the Holocene has seen only minor changes in montane forest composition there does seem to be a shift around 6000 cal a BP to a more diverse forest with increased *Castanopsis*. At the same time secondary taxa become more significant suggesting increased species turnover. More dramatic changes occur in Kosipe swamp with the development of grass–sedge mires and increasing wet conditions due to drainage disruption. Temperature increase allowed new mire species to invade and peat growth accelerated, possibly impounding streams and capturing surface flows.

### Table 10
Correlation of zone boundaries between sites based on age models.

<table>
<thead>
<tr>
<th>Zone</th>
<th>KPA cal ka (depth)</th>
<th>KPE cal ka (depth)</th>
<th>KPC cal ka (depth)</th>
<th>ANB cal ka (depth)</th>
<th>ALV cal ka (depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOS-1-2</td>
<td>43 (580)</td>
<td>42 (520)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>KOS-2-3</td>
<td>9.1 (340)</td>
<td>10.5 (290)</td>
<td>12.5 (390)</td>
<td>9.0 (265)</td>
<td>11.5 (410)</td>
</tr>
<tr>
<td>KOS-3-4</td>
<td>5.8 (215)</td>
<td>6.5 (220)</td>
<td>6.7 (270)</td>
<td>6.1 (220)</td>
<td>7.1 (270)</td>
</tr>
</tbody>
</table>

#### 6.3. Fire histories and anthropogenic impact

The relationship of fire, inferred from charcoal, and human activity is complex, but in a very wet montane setting consistent or extensive fire is largely the result of human activities (Haberle et al., 2001; Hope and Haberle, 2005). It is notable that burnt plant debris first becomes significant at KPA site early in KOS-2 time at ca 38–41 000 cal a BP. This age is older than published dates on charcoal from the Kosipe Mission site (White et al., 1970; Fairbairn et al., 2006) but quite feasible for initial human impact since occupation is known for New Guinea from cal 44 000 cal BP. Charcoal is also common throughout the KPC core record suggesting that the fires affected the whole basin. This may reflect the fact that the herb-rich cushion bog at both sites provided an open and firm footing and the whole valley floor would have been much more accessible than it became in the Holocene. Fire remains important in the Pleistocene, except for a brief decline around 23–20 000 cal a BP, at KPA. It becomes more prevalent in KPC in the Holocene as the vegetation shifts to tall sedgeland. The effect of burning on other vegetation is not readily seen except that it may have influenced the extent of shrub-rich subalpine grasslands as shown by high levels of tree ferns and shrubs, at the expense of the forest. This implies extended ecotones which would maximise the hunting potential of the area. Although this is the current situation for subalpine forest at the Neon and above, the forest at Kosipe was not subalpine as it had many montane taxa. This suggests that it was warm enough for several taxa present today to have been present then. A notable element is *Pandanus* which is altitudinally limited today to below 3000 m but which was common at Kosipe at the same time as *Astelia*. The pollen type is most likely a swamp species but its presence indicates that economic *Pandanus* species could also have been present on the slopes around the swamp. Burnt *Pandanus* nut shells have been dated to 33 500 cal a BP (Fairbairn et al., 2006) showing that *Pandanus* exploitation was taking place at early stages of settlement.

Both the Laravita and Neon records record burning from near their bases. At Laravita Tarn charcoal fluctuates as forest surrounds the site but reappears around 4000 cal a BP as an indicator that the subalpine forest was being affected by fire. By contrast, throughout the record at the Neon Basin, fire has a consistent impact and the forest is restricted. Thus it is likely that the high altitude areas were being used throughout the Holocene but that the extensive retreat of the subalpine forest occurs in the late Holocene. At Kosipe there is a marked and sustained increase in charcoal about 3000 years ago that may mark increasingly sedentary populations. The swamp flora at KPA changed to include *Melastoma*, Lamiaceae and high levels of grasses reflecting the disturbed state of the mire, while the aquatic *Myriophyllum* colonised depressions. As shown by recent fires the swamp is most easily burnt during El Niño drought events, which are hypothesised to have become more common in the last few thousand years (Gagan et al., 2004; Conroy et al., 2008). Possible clearance on slopes is also indicated by the inwash of silts and fine sand onto the swamp from the east, after 3000–2500 cal a BP, which encouraged the spread of *Dacrydium* swamp forest.

There is less evidence for late Holocene disruption of the forest. Secondary species such as *Trema* and *Macaranga* are important from 6000 cal a BP and indicate that disturbance and possible

![Fig. 9. PCA analysis of simplified pollen spectra omitting Nothofagus and aquatics. KPA and KPC samples are combined as “Kosipe” and Neon Basin and Laravita Tarn are combined as “Subalpine”.

### Fig. 9. PCA analysis of simplified pollen spectra omitting Nothofagus and aquatics. KPA and KPC samples are combined as “Kosipe” and Neon Basin and Laravita Tarn are combined as “Subalpine”.

clearance was common from that time. *Casuarina*, though present throughout the record, becomes more consistent after 2000 cal a BP suggesting that it may have been spreading into clearings or derived from plantings in the Woitape Valley. There *Spenceley and Alley* (1986) dated wood under alluvium back to 2000 cal a BP demonstrating substantial erosion in the late Holocene presumably following widespread clearance in that valley.

6.4. Regional correlations

The long but discontinuous record from the composite Haeapugua–Kugubara sequence at 1630 m in the Tari region of central PNG, demonstrates a transition from gymnosperm dominated vegetation to high *Nothofagus* at an unknown age of more than 50 000 a BP (Haberle, 1998). The possible swamp or riparian forest has *Castanopsis, Dacrycarpus, Dacrydium, Myrtaceae* and *Pandanus*. Remarkably *Astelia* and *Coprosma* appear during the end of this phase as the forest changes to one dominated by *Nothofagus*. The record has parallels to the transition from KOS-1 to KOS-2 but the poor dating at depth at both sites prevents possible correlations. It is tempting to consider that the early evidence for cold conditions at both Kosipe and Haeapugua coincides with the Komia Glaciation on Mt Giluwe dated by cosmogenics to 62 ± 4 ka (T. Barrows unpublished). This glaciation involved larger ice volume but possibly less extreme temperature depression than that around 20 000 cal a BP. It is interesting to note that the co-existence of montane forest with subalpine elements at Kosipe is also seen at Haeapugua at still lower altitude.

At Haeapugua *Nothofagus* declines after 22 000 cal a BP but cool subalpine elements increase before the final decline of *Nothofagus* and its replacement by mixed montane forest around 14 500 a BP. The later Kosipe record is in general agreement with this and other vegetation changes recorded in the central highlands of Papua New Guinea (Hope and Haberle, 2005). Several highlands sites (Sirunki, Komanimambuno, Supulah Hill) show a significant decline in *Nothofagus* pollen concentrations after 18 000 cal a BP reflecting a rise in the boundary of the mixed mountain forest. The well-studied site at Kuk Swamp, near Mt Hagen shows a swampy montane forest with dominant *Nothofagus* on the slopes being replaced by mixed montane forest at the Holocene boundary. This climate change coincides with evidence for human disturbance of the catchment and manipulation of the swamp after 9000 a BP (Denham et al., 2004; Hope and Haberle, 2005). While disturbance at Kosipe continues across the late Pleistocene forest changes, there is much less damage to forests in the catchment although the influx of pollen from secondary plants increases. The highland valleys were apparently more intensively settled than the higher altitude forests around Kosipe.

*Nothofagus* forests still dominate large areas in the New Guinea mountains west of Mt Hagen, but to the east on Mt Wilhelm the decline at Komanimambuno may reflect a real decline in total cover mountains west of Mt Hagen, but to the east on Mt Wilhelm the altitude. Annual coral records of oxygen isotopes from the Huon Peninsula show damped ENSO magnitude and decreased ENSO frequency from 7600 to 5400 years BP and both extreme (2 times the amplitude of the 1997–1998 event) and prolonged (4–7 years) El Niño events between 2500 and 1700 years BP (Gagan et al., 2004; McGregor and Gagan, 2004). These events have a strong influence on the spread of fires and their penetration of normally moist forest.

Humans reach Greater Australia by 50–45 000 cal a BP and are present in the Huon peninsula by 44 000 cal a BP (O’Connell and Allen, 2004). Kosipe provides the earliest inland record for settlement in New Guinea and demonstrates that adaptation to mountain forest and the subalpine ecotone had occurred quite soon after the initial arrival. The record for fire and disturbance vegetation since around 40 000 cal a BP, suggests that occupation has been continuous since then, even through the cold times of the last glaciation. It is clear that the plant resources of upper montane forest, including *Pandanus*, have been available throughout the time despite the large changes in forest dominance that have occurred.

The charcoal record from Kosipe provides an interesting parallel to the record from Lynches Crater, 980 km to the south in north eastern Queensland (Turney et al., 2001; Kershaw et al., 2007). There a major increase in burning and decline in rainforest gymnosperms commences around 44 000 a BP during MIS stage 3. While some evidence of sclerophyll forest had started to appear before the increase in fire, the increase in charcoal was succeeded by much more open eucalypt forest and more dramatic vegetational change than at Kosipe. In contrast charcoal does not appear until ca 20 000 cal a BP at Haeapugua and 11 500 cal a BP in the 60 000 year record from lower montane Lake Hordorli, 980 km to the north west in northern New Guinea (Hope and Haberle, 2005). The charcoal rise follows the post-glacial fall in *Nothofagus* pollen and coincides with warmer and possibly more seasonal climates.

Further work is in train in both sedimentary records and archaeology at Kosipe. This study shows that the area has great potential for refining the timing and way of life of the early settlers as well as their impact on the environment through time.

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Appendix. Supplementary information

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References


