

Badmenangidongwa Lake This is a small lake of about 10 ha in a short valley which drains the southeastern side of Enduwakombuglo Peak about 6 km southeast of the lower Pindaunde Lake (Fig 4.1). The Badmenangidongwa Valley starts at a cirque at about 3,800 m and runs south for 3 km. The lake, at 3,550 m, is 1 km from the head wall, between relatively low steep walls 300 m apart which rise 150 m above the valley floor. The drainage area is about 0.5 km² and a permanent inlet stream enters the lake. The outlet stream drains to the end of the valley and down a step before turning southwest and joining the Koronigl Creek near the southern limit of glaciation to flow through Kerowagi into the Wahgi River. The Badmenangidongwa Valley has been overdeepened by a relatively small glacier with a limited snow accumulation area at 4,000-3,800 m, which may have been separate from that of the main summit area. The valley is shaded from morning sun by the Enduwa Ridge and cold air drainage is probably not as severe as for the major valleys so that the diurnal temperature range is probably low.

The lake is shallow and elongate, with a very extensive marginal fen of tussock grass and sedge associations (Plate 30). The slopes support *Coprosma-Poa* subalpine tussock grassland with scattered trees of *Dacrycarpus compactus* as in the other subalpine sites. Closed forest is about 1 km away but *Rhododendron* shrublands occur in gullies nearby. The vegetation has been disturbed by human activity.

A single core was raised by piston sampler from the edge of the lake and no other stratigraphic investigations took place. The coring site was 2 m from the present northern shoreline on the marginal fen, a situation analogous to that at Brass Tarn. The main inlet creek is 30 m away and is slightly incised into the surface peats. The stratigraphy is very similar to that from Brass Tarn, consisting of a surface peat to 20 cm, and algal gyttias below that to 711 cm. The lowest sediment obtained (711-730 cm) is a laminated volcanic ash band and several other ash layers occurred throughout the core. The sampler broke while the lowest material was being recovered and the sediments were probably not completely penetrated. The ¹⁴C sample, 10,080 ± 270 BP (ANU-814), was collected at 710 cm from the basal ash layer and the overlying gyttia.

A single sample was pollen analysed from the base of the Badmenangidongwa core at 730 cm in volcanic ash is probably only

slightly older than the dated level. The spectrum is given at the base of Fig 9.2 and matches very well with the Imbuka spectra, with *Nothofagus* values similar to the base of zone IB 2, at a level of about 365 cm. The *Dacrycarpus* and *Rapanea* values are similar to the 360 cm sample of Imbuka and the local elements also agree. The inferred age of the 360 cm level in Imbuka is about 10,200 to 10,800 BP which agrees remarkably well with the date for the Badmenangidongwa, and raises the possibility that vegetation was similar at widely separated sites at the same altitude.

Lower Pindaunde Lake The lower Pindaunde Lake has already been described as site 11 in the modern pollen study. It is about 420 m by 250 m. The banks shelve steeply to 10 m depth on most sides and then more gradually to a central basin 20 m deep. The bathymetry (Fig 4.2) suggests that a low ridge bisects the central basin. On the eastern side there is a wide bedrock area less than 2 m deep on which sit a few erratics.

The outlet stream flows out over this bedrock sill. The lake occupies the floor of a U-shaped valley and also that of a small cirque to the northwest. The drainage is restricted to intermittent streams from the cirque and immediate valley walls (about 0.5 km²) and a large inlet stream which flows from the upper lake down a rock step of about 100 m.

The upper lake is much deeper (65 m) and about twice as big as the lower one. Its catchment, of about 2.5 km² extends to the summit ridge crest at 4,480 m. The rock bar which forms the step between the lake and the backwall of the cirque above the lower lake evidently constricted the ice flow derived from this large catchment. As noted previously, this ice was able to overtop the Imbuka Ridge below the step and flow north. Below the lower lake no rock basins have been found and moraines and till sheets mark major and minor stillstands of the glacier.

The climate as recorded at the station on the eastern shore of the lower lake has been discussed in Chapter 2. The vegetation consists of scattered areas of lower subalpine forest around parts of the margin with tussock grasslands and fen communities around the remainder.

The sediment forming at present in the lower Pindaunde Lake is a very soft and fluid algal ooze. There are only restricted shallow

areas where *Callitriche verna* grows, and no other aquatic plants have been noted. No native fish inhabit the lake but there is an abundant invertebrate fauna including minute molluscs. The lake is possibly polymictic and has a surface temperature of $10.5 - 12^{\circ}\text{C}$ (Thomasson 1967). Bottom samples recovered from the central basin indicate no extensive layer of suspended organic debris and the organic sediments did not smell of hydrogen sulphide or otherwise show strongly reducing properties (unlike some fen peat samples). This suggests that mixing occurs and night frosts or the relatively cool inflow stream may be responsible. The presence of gyttia sediments suggests that Thomasson (1967) was premature in considering the lake 'ultraoligotrophic'.

Two cores were raised from the sediment lying on the central ridge in the middle of the lake. The Mackereth corer did not anchor itself correctly during the first run and a core of only 261 cm (Core I) was obtained. The second coring run was satisfactory and a 418 cm core (Core II) was raised from the same area as Core I. Ooze from the anchor chamber exhaust hose was collected as a surface sample during the second run; this is described as sample MS 11A in the modern pollen deposition study.

Core I might have been expected to match the upper half of Core II, but in fact they differ considerably. The upper 60 cm of Core I sediment is loose and gelatinous and the gyttia becomes firmer with depth. Core II consists of firm gyttia throughout. Occasional leaves, twigs and lumps of wood are present in the lower metre of Core I and in all of Core II. Only one volcanic ash layer is present in Core I, at 84-103 cm, dated at 600 ± 145 BP (ANU-819), but four were found in Core II, at 145, 200, 240 and 410 cm. The lowest two ashes are dated at $2,860 \pm 220$ BP (ANU-817) and $4,060 \pm 185$ BP (ANU-816). None of the ashes in Core II resembles the ash in Core I.

The dates and stratigraphic differences suggest that Core I overlies a considerable part of Core II. If the accumulation rate between the pair of dates in Core II is extrapolated upwards (Table 9.1), the top of Core II is about 900 BP. However, the pollen analyses suggest that the base of Core I and the top of Core II match closely without any overlap, and the accumulation rate between the dated level in Core I and the upper date in Core II provide an inferred age of 1,350-1,650 BP for the base of Core I. The same rate extrapolated

above the dated level in Core I suggests that the top of this core is at least 100 years old. The pollen sample from the top of Core I differs from the surface ooze sample, and that differs in turn from the underwater sediment traps. Although further dating could clarify the possibilities of duplication or discontinuity between Core I and Core II, the pollen sequence is not important enough to justify the expense.

For convenience in considering the results, the cores and samples have been assigned arbitrary depths below 'sediment surface', as if they are part of a single stratigraphic sequence:

0 cm	Underwater sediment trap sample
10 cm	Mackereth hose sample
30-291 cm	Core I
300-718 cm	Core II.

The results of pollen analysis are presented in Fig 9.3. The sampling interval is very wide but the spectra are quite similar. The χ^2 analysis shows that the basal sample (718 cm) differs slightly from the higher samples, that change occurs near 250-170 cm and again between the top of Core I and the hose and sediment samples (30 cm and 0 cm). The differences between the cores are very small, the 290 cm sample (in Core I) being closest to the 300 cm sample (in Core II). The 300 cm sample is also close to the 400 cm sample, while both are close to the 250 cm sample. There are no differences in the within sum elements in the diagram sufficient to justify a zonation, or a break between the base of Core I and the top of Core II.

Nothofagus, *Rapanea* and *Dacrycarpus* dominate the spectra. *Casuarina* is significant but low above 250 cm in Core I, but is only important in the two top samples where *Nothofagus* declines. Forest edge shrubs, *Quintinia*, *Ericaceae*, *Haloragis* and *Drimys*, form low consistent percentages throughout. The grasses show a slight decline to the middle of the diagram and a distinct rise from 170 cm upwards. *Cyathea* follows a parallel pattern with a rise from 140 cm.

The spectra are regional in nature with no local peaks and probably contain a large proportion of washed in pollen. This tends to favour the representation of major subalpine trees which overhang the water. The grass percentage at the top is surprisingly low,

however, in view of the grasslands in the catchment and around the lake shore. It seems likely that the pollen recorded in the diagram is mainly derived from vegetation around the lake edge. The time span covered places the section within the upper subzone of IB 3 and all of IB 4. The appearance of traces of *Casuarina* pollen from 250 cm in the lake section corresponds to the same appearance above 60 cm in Imbuka Bog. The inferred age based on stratigraphically close dates at both sites is 900-1,100 BP. The rises in grass pollen near the top of both sites also seems to be correlated, with an inferred age of about 800 BP for the start of the increase.

Vegetation reconstruction from the subalpine sites

Zone IB 1 and Pengagl sample The low levels of all herbaceous and forest elements suggest that the subalpine sites 12-13,000 years ago had only just been deglaciated and that the local vegetation was very sparse, principally scattered *Ranunculus* and possibly tufts of grass. In this respect, the Pengagl sample indicates even bleaker conditions than the base of Imbuka. This may have been due to the larger tarn occupying the Pengagl site, its higher altitude or some unknown local factors. At Imbuka *Astelia* increases from the base, suggesting the presence of a marginal alpine *Astelia* bog community, but the level of grasses actually declines, while *Rapanea* rises. This may mean that large areas of grassland at lower altitudes were contracting and that *Rapanea* shrublands were migrating up the mountain; the drop in *Cyathea* supports this interpretation. As noted for Brass Tarn, closed grasslands may have been absent from the margin of the tarn at Imbuka because of the lack of soil and because the till was unsatisfactory for colonisation. On the Carstensz Mts a time lag in colonisation is apparent, with prostrate shrubs and mosses instead of grasslands occupying boulder moraine. The fine particles are quickly washed out of some tills, leaving bare open rock heaps. The clay layer at the base of Imbuka suggests that this process may have occurred there.

This interpretation of the local environment of IB 1 supports the use of the dates ANU-815 and 820 as minimum deglaciation dates, as only a short time can have elapsed between deglaciation and the presence of the first colonising vegetation, at most (using observations from the Carstensz Mts) 100-400 years. The subalpine and

cloud forest was restricted in area at the start of the zone. The implication of the very high *Nothofagus* levels will be dealt with later. Grasslands, including *Cyathea* may have been extensive at lower altitudes.

Zone IB2 and Badmenangidongwa sample There was a general increase in grass in this zone, although the percentages remain low, but sedges evidently were important in forming a fen, with *Astelia*, around the tarn. The local vegetation was possibly subalpine because *Coprosma* and *Styphelia* were probably present extralocally. These shrubs may have occupied discontinuous areas of tussock grassland or may have been primary colonists. *Ranunculus* varied in the zone but was probably a component of a marginal fen.

The subalpine forest elements increased throughout the zone, presumably reflecting the approach of the treeline. *Rapanea* formed an open shrubland by the end of the zone, perhaps 9-10,000 years ago, but *Dacrycarpus* did not become extralocal until some time later. Cloud forest and oak forest apparently increased, possibly at the expense of *Nothofagus* forest.

The sample from Badmenangidongwa fits into this zone, with a subalpine extralocal community and the treeline possibly approaching. In broad terms this suggests that the belt between 3,000 and 4,000 m on Mt Wilhelm was one of subalpine conditions, with a progressive increase in the area beneath subalpine forest.

Zone IB3 and lower Pindaunde Lake Subalpine forest occupied the site locally throughout this zone and the tarn was partly overtopped by the tree canopy and gradually filled up. On the wettest parts *Astelia* and sedges were present at least during the lower subzone, but the low levels of grass pollen suggest that the site was grass free. A high pollen production by local dominant trees probably depressed the representation of all other elements, including the grasses. So even the slight rise in grasses between 220-150 cm may reflect an opening of the forest and the establishment of local grasses. The local woody plant pollen certainly depresses the regional pollen percentages. Thus *Castanopsis* percentages of more than 5% demonstrate relatively high PDR in the lower subzone. In the upper subzone *Castanopsis* is very low. The high *Dacrycarpus* values for the upper subzone suggest a

reduction in the relative cover abundance of *Rapanea* at the site. As the herbaceous elements decrease still further as well, there was probably a closed canopy of *Dacrycarpus*. The trees may have occupied the swampy peats or fallen into them.

The lower Pindaunde Lake spectra below 170 cm are consistent with the upper subzone of IB 3, as the spectra show very restricted grassland areas and continuous cover of forest similar to the subalpine forest which is today restricted to isolated patches.

Zone IB 4 and the lower Pindaunde Lake The forest occupying the Imbuka site was abruptly destroyed less than 1,000 years ago. *Dacrycarpus* appears to have suffered first, though the surface sample ratio probably reflect differential pollen transport of *Rapanea* and *Dacrycarpus* from extralocal sources. The removal of the forest permitted the present bog and fen communities to invade the site. The sedimentation rate increased, possibly because water, trapped by the grass litter layer, reflooded the surface. The thick moss layer that occurs in the subalpine forests acts as a sponge and water tends to flow through it; 'sediment' (litter) accumulation rates are much slower.

At the lower Pindaunde Lake the grassland increased somewhat before 600 BP and some reduction of forest presumably took place then also. The ratio of grass to tree pollen stayed fairly stable until perhaps 100 years ago. Since then the grass percentages have risen greatly.

Casuarina appeared somewhat earlier than the Poaceae/forest disturbance at both sites, but remained at low levels until the top samples. *Nothofagus* declined with the major *Casuarina* rises. This must reflect gardening and clearance in the upper Chimbu Valley, and it is thus probable that the subalpine forest was destroyed by man. *Casuarina* pollen is valuable as a time marker on Mt Wilhelm. High levels (usually exceeding those of *Nothofagus*) imply modern samples probably less than 100 years old. This result has already been applied to the interpretation of Brass Tarn and the Summit Bog. Scattered, earlier, occurrences of *Casuarina* pollen appear to have no stratigraphic value.

Summary

Imbuka Bog formed as a small tarn impounded behind a lateral moraine, possibly at a time when a substantial ice tongue still persisted beyond the lower Pindaunde Lake. Only a scattered alpine vegetation grew near the tarn between 12,600 and about 10,800 years ago. Grasslands then developed and shrubs became more common prior to the arrival of the *Rapanea*-dominated treeline at about 8,500-9,500 BP. Forest occupied the site continuously from that time, and it was dominated by *Rapanea* until about 4,300 BP when *Dacrycarpus* increased proportionally. About 800 BP clearance commenced and a grass bog occupied the mire. The results from the other subalpine sites are consistent with the vegetation reconstruction and chronology of changes at Imbuka site.

CHAPTER 10

KOMANIMAMBUNO MIRE 2,740 m

A site outside the glaciated area was sought in order to extend the investigated time period beyond the post-glacial records obtained from the higher sites and to examine the vegetation history of an area which is at present occupied by montane forest. A small quaking mire was found, with help from Chimbu guides, ideally situated in the same valley system as some of the higher sites. The locality is known as Komanimambuno and is reached by the Mt Wilhelm access track 2 km west of Keglsugl airstrip at about 2,740 m (Fig 4.1). The mire lies 200 m northwest of the foot bridge over Pengagl Creek and is about 220 m southeast to northwest and 50-70 m southwest to northeast (Fig 10.1). It occupies a shallow basin bounded by steep banks formed from large ill-sorted boulders. The catchment is only 0.06 km² with gentle slopes to the southeast; its farthest point is about 400 m from the mire centre and about 30 m above it. There are no streams in the catchment but small channels up to 20 cm deep and 20 cm wide cross parts of the mire surface. These are usually empty or just flowing but after heavy rain large areas of the mire are flooded. The mire drains into a single stream to the northeast which runs down a stony channel into Pengagl Creek. This creek drains the eastern end of the Bogunolto Ridge (see Pengagl Site, Chapter 9) but has only a small area of alpine and subalpine catchment above 3,500 m compared with the valleys which extend into the summit ridge. Pengagl Creek drains a larger area of cloud forest and flows into the Pindaunde Creek about 200 m east of Komanimambuno, and 50 m lower down. The catchment and area around the mire face east and are at about the same altitude as a major gap in the Bismarck Ranges 6 km to the east. The slopes are exposed to morning sun but are sheltered in the afternoon. The gap in the range (Mondia Pass) sometimes permits the moist, cloudy, northerly air to enter the Upper Chimbu from where it is diverted into the Komanimambuno area. This results in dense afternoon mist and light rain of slightly higher frequency than on other slopes in the Chimbu valley. Thunderstorms also ascend the Chimbu valley and usually penetrate to Komanimambuno, though less commonly to higher levels. These are generated by rising

air in the lower Chimbu-Wahgi valley. The mean temperature is about 12°C with minimum usually 5°C to 10°C . Frost is occasionally known as low as 2,300 m but a ground frost in the forest is unlikely. Cold air drainage would not be extensive in the Pengagl valley and the Pindaunde valley is lower than the site, but in the past cold air drainage may have been an important factor in determining minimum temperatures.

The nearest undoubted terminal moraines are at the end of the flat upper section of the Pindaunde valley about 1.7 km to the northwest and at about 3,200 m (Plate 31). A relatively smooth slope, averaging 8° , extends down to the Keglsugl airstrip at 2,470 m. This slope is being incised from the south by Gwaki creek and is also being eroded by the Pindaunde creek. The slope is composed of boulders and ill-sorted debris which is probably more than 100 m deep in places. Boulders up to 5 m across occur, although the normal size is 0.5 - 1 m, and a fine clay matrix has formed from weathering of the boulders and possibly some originally deposited finer gravels. Low ridges are imposed on the general slope and both are dissected by steep walled valleys, presumably recently eroded. The boulders have originated in the Pindaunde/Pengagl catchment and must pre-date the large terminal moraines. The slope could be an outwash deposit or even a till. Reiner (1960) mapped the boulder area as fluvioglacial outwash now terraced by the streams near Keglsugl. The reworked material, which occurs in Gwaki creek and as far as the junction with the Chimbu River, he regards as 'post-glacial river terraces'. In view of the rapidly increasing erosive power with distance from sources of streams in the upper Chimbu, it is likely that an outwash fan could only form when an overwhelming supply of rock was made available by non-fluvial processes. If the boulders had been supplied purely by fluvial transport it is hard to understand why they would have been deposited at Keglsugl and not carried on. Thus a fluvioglacial origin, in which the glacier supplied rock faster than it could be removed by the rivers, is consistent with the evidence.

The other possibility is that the slope is composed of till of considerably greater age than the moraines in the U-shaped valleys. The degree of weathering of the boulder beds is consistent with a greater age and the lack of bedding or sorting in the boulders also suggests a non-fluvial origin. An extension of the Pindaunde glacier to about 2,400 m, with a total length of 8 km would be involved. The

apparent absence of large terminal moraines can be explained by postulating a relatively short period of maximum extension, and smaller moraines would have since been eroded or weathered. The evidence from other tropical mountains is not inconsistent with this possibility. On Mt Giluwe, which supported an ice cap with some protruding valley glaciers, the Akura river ice lobe apparently descended to 2,750 m (Löffler 1972) with a total length of 9.5 km from the head wall. On the Carstensz Mts, Dozy (1938) and Peterson and Hope (1972) found till down to 1,705 m which was deposited by a glacier about 15 km in length. This till is virtually unweathered, compared to both the Mt Wilhelm terminal moraines and the boulder slope, and is less than 10,100 years old. Because of the weathering and erosion it is not possible to decide between a fluvioglacial or glacial origin for the boulder apron which the Komanimambuno mire and cloud forest occupy.

The vegetation has been described by Brass (1964, p.189) using the site name 'Pengagl Camp' for the area. Dense lower cloud forest grows in the catchment and around the mire. This forest can be distinguished, by the presence of *Pandanus giulianettii* and the climbing bamboo, from the upper cloud forest and the proportion of dominants and height of the canopy also differ in the two vegetation associations. However, from the modern pollen spectra it is impossible to differentiate the associations because local dominance (eg Myrtaceae or *Dacrycarpus*) can occur in a forest type which is usually otherwise typified by different major dominant taxa. Although the mire lies about 100 m below the boundary between the two associations, the floristics are so similar that past changes in the boundary cannot be identified.

The vegetation around the boring site (Plates 32,33) was sampled for modern pollen and the results are described as Site 18 and a list of species given in Appendix 1. The dominant trees on the mire include *Pandanus giulianettii* and *Dacrycarpus cinctus*. Some individuals of both are dead or dying. Most shrub species are stunted, especially in the northeastern open part of the mire, but a low woodland occupies the southern, better-drained, areas. A few species on the mire are shared with subalpine grasslands. These include *Deschampsia klossii*, *Ranunculus pseudolowii*, and *Coprosma papuensis*, and there are several other species which are sources for pollen types also common above

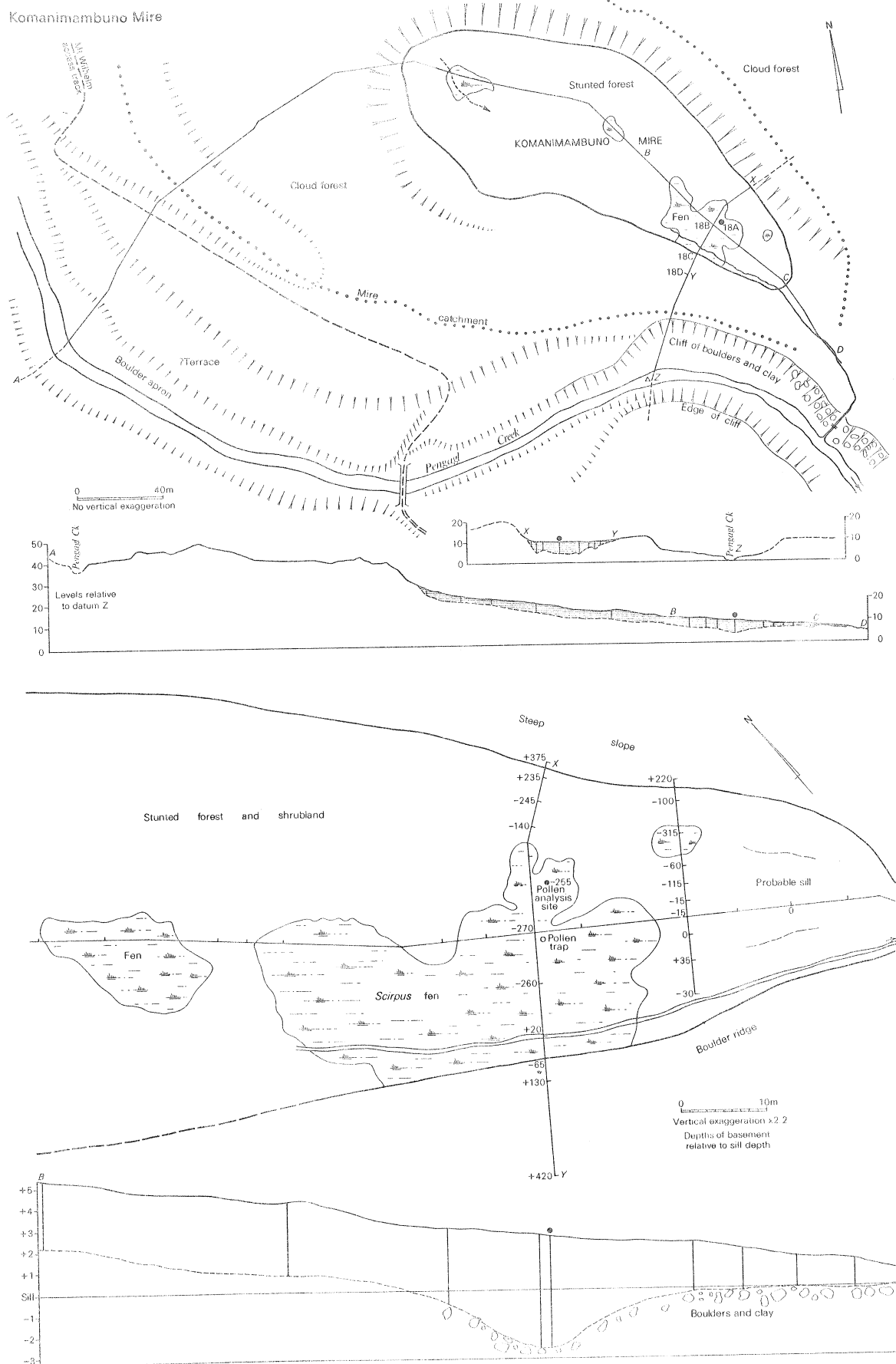
3,200 m, eg *Rapanea*, Asteraceae, *Dimorphanthera*, *Parahebe*, and *Cyathea*. The wettest part of the mire is occupied by a sedge mat of *Scirpus subtilissimus*. These areas quake and are very soft and treacherous. Fallen logs in the mire raise the level locally and often support ground ferns and small shrubs. On drier areas low shrubs of many species grow, with a dense undergrowth of orchids, ferns and herbs. The forest forms a closed wall all around the mire, but shrubs are not especially prominent at the forest edge.

Stratigraphy

Fig 10.1 shows the shape of the mire and the position of the transects and pollen analysis site, as well as the profiles along the transects. All levels are shown relative to a local datum in the bed of Pengagl Creek. The mire has formed in a possibly closed hollow between two low boulder ridges which intersect at the outlet stream. The longitudinal section established that the base of the mire is a gently sloping boulder bed, except for a basin at the northeastern end, formed behind a sill made by the intersection of the ridges. This basin may not be closed because two transverse profiles show a deep gully along the northern edge which has a base at 4.5 m above datum, the same depth as the floor of the basin. However, the outlet creek flows along a boulder bed between a notch in the ridges, suggesting a sill at 7.6 m above datum. If the boulder ridges had contained no matrix when the basin formed, water may have been able to flow between the boulders so that the presence of a closed basin does not guarantee that a pond was present at any time.

The survey of the ridges showed that they are low and broad-topped, the southern one paralleling the present bank of Pengagl Creek, while the northern one has an arcuate shape around the mire and rises about 15 m above it. The bed of Pengagl Creek to the west is about 30 m higher than the mire but the creek cuts down 40 m while curving around to the east to lie well below the sill depth. A catastrophic flood and landslide in 1960 was reported by Brass (1964) as being responsible for the broad rocky bed of Pengagl Creek down to the altitude of Komanimambuno. The creek bed changes in character at this point and enters a vertical-sided gully. The air photo (Pl. 31) taken in 1955, suggests that this gully extended further up the creek before the

FIGURE 10.1
Location and stratigraphic diagram



landslide. The relative levels of the creek and mire suggest a possible secondary origin for the ridges around the mire; Pengagl Creek may once have had its channel through the mire and then later moved and built a 'levee' bank of reworked boulders which cut off the old stream channel.

All cores taken from the mire consist of organic sediments but local lenses of peaty sand or clay are common. Individual cores could not be correlated using the sequence of mineral horizons, and it is likely that such horizons reflect the changing position of small drainage streams which have run irregularly over the surface. Fragments of plants are almost absent from the deeper sediments but it is likely that the organic material is terrestrial or telmatic peat formed by humification of plant debris derived from communities growing on the mire. Hence the small stream channels may have disturbed the sediments of this deposit but the small catchment and gentle slope of the mire surface, together with the impounding action of local vegetation, has probably prevented major interruptions of sedimentation.

The core for pollen analysis was obtained with a D-section corer and a piston sampler from the centre of the main basin, at the southeast end of the mire. The total depth sampled was 520 cm with a base on boulders, the lowest 250 cm coming from below the present apparent sill level. Organic material from the base of the core gave an age of $21,760 \pm 350$ BP (ANU-808). The preliminary pollen analyses suggested that a discontinuity was present at 112 cm depth in the core, because subalpine grasslands were indicated below that level and cloud forest above, with no transition zone between. The organic material showed only a slight colour change at 112 cm and it was penetrated by well preserved woody roots. Because a large dating sample was required so that roots could be removed from the peat, additional material was collected by Mr J.M.B. Smith. He re-excavated a pit which had been dug in an unsuccessful attempt to recover a piston sampler from the site. This pit meant that material from the exact coring location could not be obtained, and pit spoil also prevented an accurate comparison of levels. A monolith was extracted from a cleaned pit face covering the interval 50-150 cm below the apparent surface. The levels probably differed by less than 10 cm from the levels given in the main core. The monolith site is about 0.5 m west of the coring site.

On pollen analysing the monolith to pinpoint the discontinuity, it was found that the stratigraphy and pollen spectra from the core and monolith matched very well below 115 cm (depth from surface) in each, but that, above this level, the monolith presented a sequence of vegetation change missing from the core. The core discontinuity is evidently extremely local. No spectrum in the monolith matches the cloud forest spectrum at 110 cm in the core above the discontinuity, but that from the top (50 cm) level of the monolith is the most similar. It thus appears that the record from the monolith above 115 cm covers part of the discontinuity, leaving a much smaller discontinuity between the top of the monolith and the upper 112 cm of core (the 'upper core').

The within sum and without sum χ^2 coefficients of the pollen spectra were used to match the core and monolith in the interval 105 cm - 140 cm.

TABLE 10.1

χ^2 Comparisons between samples

Level	$I\chi^2$	$O\chi^2$	Level	$I\chi^2$	$O\chi^2$	Level	$I\chi^2$	$O\chi^2$	Level	$I\chi^2$	$O\chi^2$
M105	11	169	M105	11	269	M105	15	250	M105	15	250
M115	16	377	M115	16	377	C115	16	377	C115	16	377
C115	6	172	C115	25	405	M115	42	270	M115	16	308
C125	53	127	M130	53	127	C125	53	127	M130	53	127
M130	16	302	C125	72	284	M130	16	302	C125	72	284
C140			C140			C140			C140		
Total	103	1,247		177	1,462		142	1,326		172	1,346

M = monolith, C = core, I = within sum, O = without pollen sum χ^2 values.

This shows that the spectra fit most closely in the sequence M105 - M115 C115 - C125 - M130 - C140 which in turn suggests that the monolith levels are probably less than 5 cm higher than corresponding core levels. The ^{14}C age determinations (Table 10.2) on a monolith sample 115-120 cm (centre 117.5 cm) thus definitely date very close to the 115 cm level in the core. Two other monolith sections dated have no correlative in the core but provide maximum limits to the age of the uppermost 112 cm of core.

TABLE 10.2
KOMANIMAMBUNO MIRE -- SUMMARY OF ^{14}C DATES

^{14}C age yrs BP	Dated section Interval/Median depth cm (see p 133)	Av. organic accum. rate between median depths cm/100 yrs	Depth from surface cm	Inferred age yrs BP
			0	Present
ANU-825A		-	UPPER 5	ca 80
1,780 ± 30	see text	? 6.2	CORE 110	? 1700
			Discontinuity	
ANU-824A, B*	50		50	1,900-2,200
2,740 ± 80	} 52.5	-	52.5	2,600-2,900
Pooled Mean				
		0.3 (option a)		
			67.5	(a) 6,900-7,250 (b) 10,000-10,300
ANU-822A, C1, C2, D*	80		MONOLITH	
11,570 ± 80	} 82.5	-	82.5	11,400-11,600
Pooled Mean				
		1.1 (option b)	95	12,400-13,000
ANU-825B, C*	115			
14,710 ± 200	} 117.5	-	M117.5 =	14,500-14,900
Pooled Mean			C115	
			LOWER 150	15,100-15,500
		5.6	270	17,250-17,750
			290	17,600-18,200
ANU-808	495		CORE	
21,760 ± 350	} 508	-	508	21,400-22,100
			520	21,600-22,300

* ^{14}C ages of individual fractions of samples 822, 824, 825 are given in Appendix 2.

Because of problems with contamination by young roots, several fractions were dated from each sample. The results are discussed in Appendix 2; the conclusion is that reliable dates could be obtained from the fine sieve (<200 μ) fractions. Pollen analysis indicated little remanié pollen incorporated in the samples and hence older fine organic material was not a significant contaminant. Although woody roots in the sediment gave a significantly younger date than the whole sample, the fines and the humic acid extracts were also old and indicate no rootlet contamination.

The age given for the base of the upper core (about 1,700 BP) is only speculative and is inferred from a date (1,780 \pm 430 BP, ANU-825A) on the contaminative roots in the monolith at 117.5 cm, approximately 50 cm horizontally from the discontinuity in the core. But, of course, the root growth might well have taken place at any time after the commencement of sedimentation of the upper core material or may not be related to it. Woody matter 35 cm above this level has an age of 4,130 \pm 170 BP (ANU-822B) but may not all be roots. The factor supporting the correlation is that roots do not presently grow so deep in the waterlogged, reducing sediments and the most probable time for this level to have been better drained, and thus able to support root growth, was when a channel was cut in the old sediment 30-50 cm distant. The channel hypothesis is the most probable explanation of the extremely local discontinuity in the core. The upper core consists of peats with silt bands and wood fragments. Many tree trunks and roots were encountered while excavating the pit through this level.

The major question in relation to the monolith section from 50 - 117.5 cm is whether it represents more or less continuous deposition or not. The dating sequence suggests average sedimentation rates of more than 5 cm/100 yrs between 22,000 and 14,500 BP which drop 75% to about 1.2 cm/100 yrs between 14,700 and 11,600 BP and by 75% again to 0.3 cm/100 yrs until 2,700 BP. The pollen evidence is considered later but there is no marked anomaly to indicate a discontinuity. There are varying amounts of silt in the profile but no distinct horizons. A progressive slowing of peat accumulation rates from the base of the mire upwards could be expected as the mire built up and became better drained. Trees colonised the local bog surface during the time represented by the accumulation of monolith material above 67 cm,

which suggests relatively dry conditions then. Under present lower cloud forest, litter accumulation is very slow, with loam soils occurring under the moss mat on well drained locations and only a few centimetres of peat present in locally wet areas. Thus the extremely low average sedimentation rate of 0.3 cm/100 yrs may be possible although the rise to an average rate of 1.9 cm/100 yrs between the top of the monolith and the presumed modern surface must then be explained.

The possibility remains that a discontinuity exists in the monolith section 52.5 cm - 82.5 cm, the most likely time being after the forest vegetation became local at 67 cm. If the sedimentation rate between 117.5 and 82.5 is extrapolated upwards, the 67 cm level has an inferred age of about 10,000 BP. If so, at least 5,000 years is unrepresented, or 7,500 years is recorded by 15 cm of sediments.

The core section from 115 cm to the base consists of black slightly fibrous peats to 280 cm and yellow-brown fine textured organic material with varying amounts of plant debris below this. Bands of greater clay content were found at 509, 445, 305, 180 and 145 cm and increased sands or gravels at 520 (the base), 512, 477, and 220 cm but the whole core is organically rich. A pair of samples, one in sandy peat at 476 cm and the other in pure organic matter at 480 cm give very similar pollen spectra, suggesting that the presence of running or open water made little difference to the pollen deposition. No marked pollen or anomalous pollen spectra changes were observed that correlated with the zones of increased mineral matter. Other cores have similar clay and sand bands, some of which are associated with rootlets or stem debris, and occasionally are mottled. This suggests a growth of the mire with a near-surface water-table, forming from decomposed litter of the local vegetation growing on the spot.

The basal age of 22,000 BP provides a minimum date for formation of the boulder apron and the basin. The colonisation of the basin by a bog or fen could have been quite swift. Observations on boulder beds created by landslides or stream action at 2,750, 3,300, and 3,500 m were made during the three visits from 1969-1972. After one year scattered herbs were present at all sites and within three years shrubs were growing on the lowest site and a thin but continuous grass cover was present on the higher beds. It seems likely that re-vegetation

and soil formation will be well advanced within 50 years, leaving only the large boulders exposed. The event that created Komanimambuno basin may have preceded sediment accumulation by only one or two centuries. If the stream action was responsible for the basin then a considerable period may have intervened between the primary origin of the boulder apron and the secondary formation of the retaining ridges.

Pollen analysis

The results of pollen analysis of the core and monolith are shown in Fig 10.2 with the samples from the monolith inserted between 110 and 115 cm in the core, which is thus broken into upper and lower sections. One monolith sample is interpolated as 130 cm in the lower core record. The lower core/monolith interface is stretched in the diagram for the interval 115 cm in the monolith to 130 cm in the core and monolith, this being at twice standard scale. Sample interval for the upper core (0-112 cm) and the core below 140 cm is 20 cm, covering an average of 350 years, which appears to be adequate in view of the consistent vegetation changes. The monolith was sampled below 65 cm at 10 cm intervals (about 900 years between levels) and at 5 cm intervals from 50-65 cm (up to 1,500 years interval).

The within sum χ^2 shows a considerable variation throughout the profile with a major zone of change around 70 cm in the monolith, and two minor phases of change, at 80 and 30 cm in the upper core. The outside the sum χ^2 has major changes in the lower core monolith at 210, 150, and 70-90 cm but less change in the upper core. Accordingly the lower core + monolith is divided into four local zones and the upper core treated as a fifth zone (KM 1-5).

KM 1 520-290 cm. Inferred age 22,000 - 17,800 BP

The major components of the pollen sum in this zone are *Nothofagus* with levels 65% - 73% and *Rapanea*, around 10%. Other woody components include *Styphelia*, *Drapetes*, *Dacrycarpus*, *Podocarpus*, *Phyllocladus* and *Castanopsis* which are all low but consistent through the zone. The herbaceous component is dominated by moderate levels of grasses and relatively high levels of *Cyathea* and there are consistent levels of *Ranunculus*, sedge and *Astelia* pollen.

KM 2 290-150 cm. Inferred age 17,800 - 15,300 BP

Castanopsis and *Nothofagus* rise slightly at the start of this

FIGURE 10.2 Komanimambuno Mire pollen diagram - woody plants

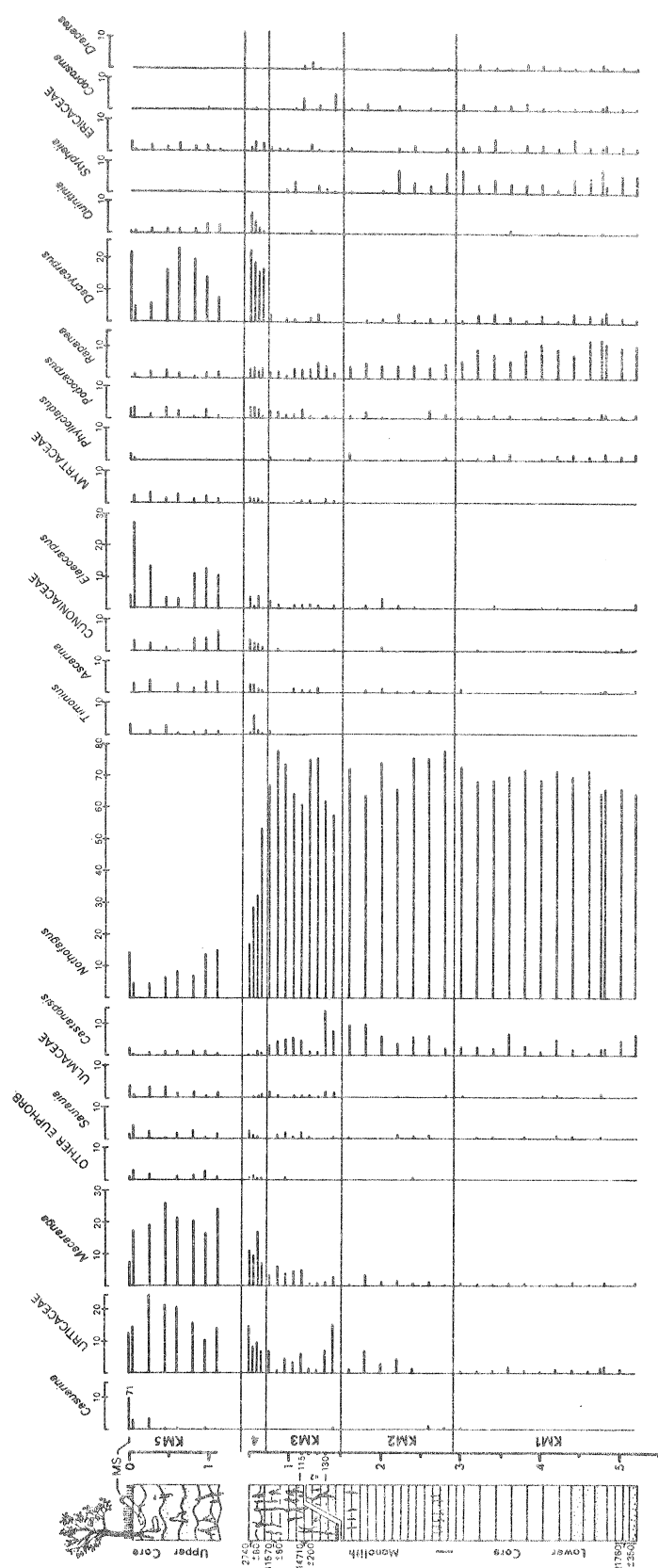


FIGURE 10.2 Cont. Komanimambuno Mire pollen diagram - herbs and ferns

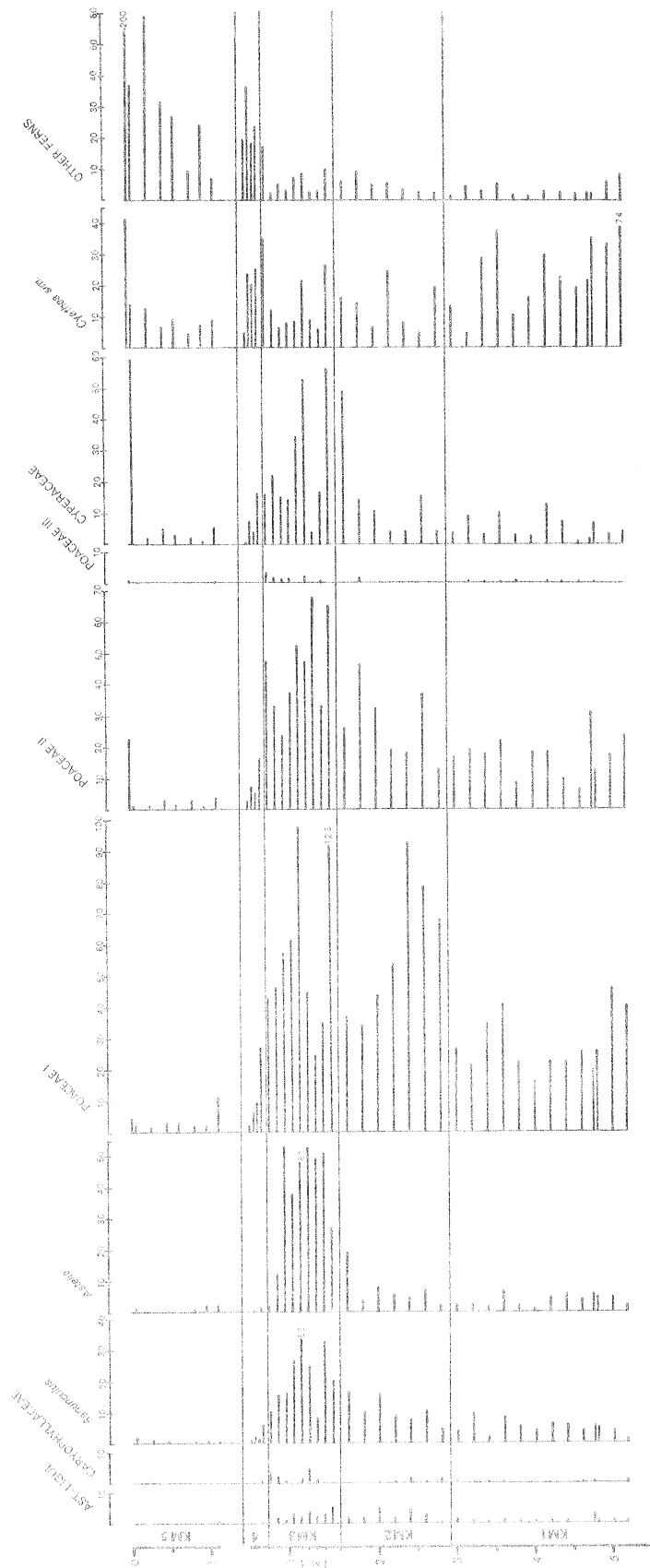
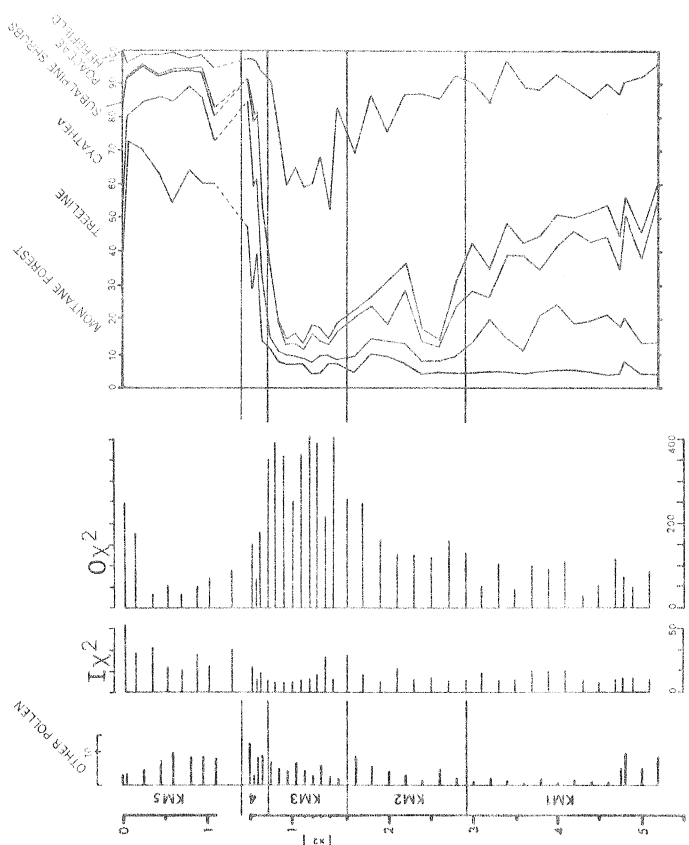


FIGURE 10.2 Cont. Komanimambuno Mire summary diagrams



zone and this is matched by a fall in *Rapanea* and *Dacrycarpus*. *Styphelia* also increases slightly up to 220 cm but is virtually absent from the zone above this. Above 240 cm Urticaceae, Euphorbiaceae and *Elaeocarpus* increase to a small extent. The herbaceous pollen show more distinctive changes, with a marked increase in both *Deschampsia* group and other Poaceae to levels between 70% and 115%, and distinct rises, somewhat above the zone boundary, in *Ranunculus* and *Astelia*. Sedge and *Cyathea* pollen remain important but erratic through the zone.

KM 3 150-75 cm. Inferred age 15,300 - ca10,600 BP

There is little significant variation in woody plant pollen in this zone, although *Nothofagus* shows a temporary minimum at 115 cm (at dating level 14,700 BP) and at the base of the zone where maxima occur for Urticaceae and *Castanopsis*. *Styphelia*, *Coprosma* and *Drapetes* are of scattered occurrence in the zone. The herbaceous pollen reach very high levels with maxima for *Ranunculus*, *Astelia*, Poaceae, and Cyperaceae, and variable tree fern levels. The top of the zone is uneven, marked by declines in all the more important pollen taxa of the lower core, but the declines are initiated at different levels. *Ranunculus* declines from 105 cm, *Astelia* above 95 cm, *Nothofagus* above 85 cm (below the dated level, about 11,700 BP) and Poaceae above 75 cm.

KM 4 75-50 cm. Inferred age ca10,600 - 2,200 BP

The beginning of this zone marks the greatest change in the woody plant pollen for the diagram. *Nothofagus* declines throughout, with the most marked drop around 67 cm, and *Castanopsis* also declines. Other tree and shrub pollen show a rise, particularly *Dacrycarpus* and *Quintinia* but also Urticaceae - Moraceae, *Macaranga*, *Timonius*, *Ascarina*, Cunoniaceae, *Elaeocarpus*, Myrtaceae, *Podocarpus*, and Ericaceae. *Rapanea* remains at low levels through this zone.

The rise in woody plant pollen types is matched by a continuing fall in all herbaceous types through the zone, although Poaceae remain important in the interval 65-75 cm. Sedge pollen declines but *Cyathea* and other ferns have local maxima in the lower part of the zone. *Belvisia* and *Pteris* are the most important components of the fern maxima.

KM 5 110-0 cm (upper core). Inferred age ?1,700 - Present

The actual lower pollen boundary of this zone and the upper boundary of KM 4 cannot be defined because of the discontinuities. A check was made to compare samples in KM 5 with the highest level (50 cm) in KM 4 within the zones.

TABLE 10.3

χ^2 comparison of upper core and monolith samples

Levels compared:	UC110-M50	UC95-M50	UC80-M50	UC110-M60	UC95-M60	M50-M55
χ^2 within sum	31	41	55	38	35	33
χ^2 without	77	40	73	75	69	101
Total	108	81	128	113	104	144

UC = upper core

and the χ^2 results are shown in Table 10.3. The within sum χ^2 values indicate that 110 cm matches the 50 cm monolith sample most closely, and that the variation is less than that found between samples within zones KM 4 and KM 5. The outside sum χ^2 is greater for this than for other pairs but the herbs are not very important to the spectra and the difference may be due to contamination of the UC110 cm sample from remanié sediments. This is suggested by low percentages of *Astelia* pollen which are probably derived from underlying lower core sediments at LC115 cm where *Astelia* shows a maximum of 80%. If all the *Astelia* is taken to be remanié pollen, then 5% contamination has resulted and 3% of *Nothofagus* and 7% Poaceae pollen in the UC110 spectrum could also be contaminant. It is apparently the relatively high Poaceae levels and the presence of *Astelia* in UC110 cm that has determined the high outside the pollen sum χ^2 between UC110 and M50. This suspected contamination has little effect on within sum χ^2 values

The pollen content of zone KM 5 is quite varied, but is characterised by relatively high levels of Elaeocarpaceae and other cloud forest trees such as Urticaceae - Moraceae, *Macaranga*, Cunoniaceae, Myrtaceae and *Dacrycarpus*. *Dacrycarpus* and *Elaeocarpus* appear to have an inverse relationship, with *Elaeocarpus* maxima at the base and top of the zone and a *Dacrycarpus* maximum in the centre. Shrub pollen is low although *Rapanea*,

Quintinia, Ericaceae and *Drimys* are common. This zone sees the appearance of *Casuarina* pollen at 60 cm which rises to 4% at 5 cm in the surface sedge mat, a lower percentage than that recorded from traps and moss mats (0 cm sample) in the area. This suggests that the 5 cm sample may be significantly older than present.

Herbs are generally unimportant. Traces of *Astelia* reflect remanié deposition but low consistent grass, *Ranunculus* and sedge levels probably come from local plants. There is a local peak in sedge pollen at 5 cm. The Pteridophytes (of many kinds but including *Belvisia*, *Blechnum* spp. and *Microsorium* sp.) maintain the high levels that first appeared in KM 4. through the zone.

Vegetation reconstruction

The nature of the sediments and the pollen diagram show that, unlike the higher sites, Komanimambuno sediments are terrestrial peats rather than telmatic peats or algal gyttja. Because of this more caution is needed in differentiating 'local' from 'regional' pollen since the structure of the vegetation on the bog itself will affect the process of deposition. The results of modern pollen sampling are less applicable in this special situation also but the same general problem remains, namely to try and sort out the type of local vegetation and the relative contributions of the regional vegetation groups.

Zone KM 1 Unlike the higher sites, Komanimambuno Mire lies within the present altitude range of *Nothofagus* forest (although insufficient moisture possibly prevents its establishment in the upper Chimbu), and the suggestion that the high *Nothofagus* levels of this zone do not reflect any close occurrence of *Nothofagus* must be justified. The relative unimportance of the pollen of all other woody plants resembles the surface sample from within the *Nothofagus* forest but there *Nothofagus* pollen contributes more than 80% to the total pollen whereas in KM 1 (and 2 and 3) *Nothofagus* pollen is usually only 30-40% of all pollen. This is largely due to grass and *Cyathea*, and a local grassland surrounded by *Nothofagus* would also be a feasible, if unusual, explanation, were it not for the presence of *Astelia* and *Drapetes*, which are subalpine and alpine in distribution. No modern samples exactly fit the spectra of the zone but similar ratios of *Rapanea* to *Dacrycarpus* are found in tussock grasslands around the Pindaunde Lakes today, in samples about 100 m from

the subalpine forest edge. Although scattered tree ferns grow in this area, the spore levels are only exceeded in the surface sample from the *Cyathea atrox* subalpine grasslands at 3,200 m. *Astelia*, *Drapetes* and *Ranunculus* are noted as occurring together in subalpine short grass bog (Wade and McVean 1969) which is found above 3,400 m today, often as a mosaic with *Deschampsia klossii* tussock grassland. It thus seems likely that the local bog community included grasses and sedges whilst a fairly dense growth of tree ferns in extensive tussock grasslands surrounded the site. The levels of *Rapanea* and *Dacrycarpus* suggest that subalpine forest may have formed distant or isolated stands. The cloud forest elements are low but *Castanopsis* and *Nothofagus* forests must have been extensive some distance away. Fluctuations in the grass and *Cyathea* levels seem to reflect relative dominance changes in the surrounding grasslands but the subalpine community appears to have been stable over a long period.

Zone KM 2 This zone shows an increase in local grass, *Astelia* and *Ranunculus* suggesting an expansion of the mire and changes in the grasslands around it. Total *Cyathea* and the *Rapanea* levels drop slightly, suggesting a decline in subalpine forest areas, but the bog probably remained a short grass bog, for which the present upper limit found by Wade is 3,745 m. There is an increase in Liguliflorae (Asteraceae) pollen, probably from *Lactuca*, and the surface of the mire was probably supporting a closed grassland on damp terrestrial peats as *Lactuca* does not occur in very wet areas.

Zone KM 3 Rises in *Astelia*, *Ranunculus* and grasses and the decline in *Cyathea* suggest that the bog type changed to one dominated by *Astelia*. In the Pindaunde Valley at 3,300 m, Wade noted a subalpine *Astelia* bog community within areas of *Brachypodium* - *Carex* fen, which is dominated by non-tussock grasses and *Ranunculus*. Although no modern pollen samples were taken from these associations it is probable that the Komanimambuno Mire supported a mosaic of the two. The *Cyathea* levels are too high to allow interpretation as an alpine bog. The low *Dacrycarpus* and *Rapanea* values show that subalpine forests were still either fragmented or distant during this zone, yet there is a distinct rise in Urticaceae (which may have had a local source), *Castanopsis* and other cloud forest tree species. These changes may reflect forest change at this time or a relative decrease in the rate of *Nothofagus* pollen deposition. The

gradual disappearance of the bog community occurs at the top of the zone with a reduction in *Astelia* and then *Ranunculus* possibly by an overgrowth of grasses.

Zone KM 4 If the possibility of disconformities is rejected and a very slow but continuous humus build-up is assumed for this zone then it seems likely that the grassland mire area was colonised by a cloud forest dominated by *Dacrycarpus* at some time about 9,000-10,000 years ago. There is no evidence for a preliminary subalpine forest colonisation because *Rapanea* levels remain low. The rise in *Dacrycarpus* appears abruptly but the very large sample interval may explain this. A forest, probably fairly similar to that found at present around and above Komanimambuno, occupied the site by $2,750 \pm 80$ years BP; some moss mats taken from the mire today have high *Dacrycarpus* and low *Elaeocarpus* levels so that the general relative importance of these taxa in the forest cannot be defined.

Although the results will be discussed later, the changes suggested here are consistent with other sites in the Pindaunde Valley in the suggested relative stability of the cloud forest for the last 9,000 years. On the other hand, a discontinuity in this section could be undetectable because of this stability. It is interesting to note that the marked reduction in *Nothofagus* pollen had taken place possibly several centuries after the forest colonised the area whereas, at higher sites, a similar reduction coincided with or preceded forest establishment.

Zone KM 5 The zone shows no change from cloud forest, and although local species compositions have changed, the variations are no greater than those found in modern spectra from the mire. It seems likely that *Dacrycarpus* increased to dominate the area around the site and then gave way to *Syzygium* or *Elaeocarpus*. The stunted and dead trees of *Dacrycarpus cinctus* in the open mire areas may be the actual trees responsible for the pollen maximum; their present status, and the increase in sedge pollen, shows that this part of the mire has become appreciably wetter recently. This is probably due to local changes such as the blockage of a stream channel by fallen tree trunks which would tend to flood the upstream area, kill the shrubs and initiate a wet and open bog. Within the areas of bog occupied by shrubs or trees, the drainage channel is usually incised. No definite evidence was found for human interference

in the forest composition, although the presence of *Casuarina* pollen in the upper 60 cm of the zone suggests that garden areas were becoming established in the upper Chimbu. Brass (1964) regarded the Komanimbuno forests as primary and little affected by man, with the exception of scattered tree killing by bark stripping. This mainly affects *Papuacedrus papuana* and may be of very recent occurrence, for abundant *P. papuana* trees were available for exploitation at Keglsugl in 1940 (Fr J. Nilles personal communication). Hence the clearance and disturbance of cloud forest is apparently spreading from the gardened edge of the forest.

Summary

Komanimbuno Mire is a peat deposit in a basin between boulder ridges on a deep, extensive, boulder apron which may be a fluvioglacial outwash deposit or even glacial till. The basal age for peat accumulation of 22,000 BP provides a minimum date for a maximum glacial phase that can be inferred from either possible origin. The environment at that time was subalpine to alpine and was maintained for about 12,000 years until perhaps 10,000 years BP. The forest boundary was some distance below, although scattered shrublands may have occupied slopes near the site. Between 14,500 BP and about 11,000 BP a subalpine *Astelia* bog was present but this changed to grassland and the site was then occupied by cloud forest. There is no evidence that subalpine forest formed a zone above the cloud forest at this time. A final decline in *Nothofagus* values took place after the cloud forest became established. The cloud forest has probably remained around the mire, with changes in the local dominant species, throughout the last 9,000 years. The fen areas on the mire have become locally more extensive in the recent past.

CHAPTER 11

VEGETATION HISTORY OF MT WILHELM AND COMPARISON
WITH OTHER SITES IN MONTANE NEW GUINEA

A. MT WILHELM

Correlation of pollen zones between sites

Several major vegetation changes have been recognized from the Mt Wilhelm pollen diagrams. To understand their significance, extent and possible causes it is necessary to compare the diagrams and identify changes that are common to some or all of them. There are five characteristic pollen zones which occur in more than one pollen diagram and so may be regionally correlated.

- (1) A zone in which *Nothofagus* pollen dominates the spectra.
- (2) A zone in which *Nothofagus* declines, but remains more important than any other woody species.
- (3) A zone in which *Castanopsis* forms 5-10% of woody plant pollen and the cloud plus oak forest pollen total count exceeds the *Nothofagus* pollen count in each spectrum.
- (4) A zone in which *Nothofagus* and cloud + oak forest pollen percentages are approximately equal. The ratio of *Nothofagus* to cloud forest is <2.0 and >0.5 .
- (5) A zone in which *Casuarina* pollen exceeds 1% and becomes dominant.

The presence and inferred ages of these zones are noted below for each site. Where more or less synchronous zone boundaries seem to have been established, stratigraphic problems at individual sites are discussed.

(1) High *Nothofagus*

Summit Bog	Absent
Brass Tarn	$>11,000$ to $10,000 \pm 300$ BP
Imbuka Bog (+ Pengagl Mire)	$>13,000$ to $10,800 \pm 400$ BP
Komanimambuno Mire	$>22,000$ to $7,000 \pm 300$ BP (a) or $10,200 \pm 300$ BP (b)

This is a very characteristic zone which is evidently regional. Its absence from the Summit Bog supports the inferred basal age of about