

No.	Pollen taxa	Probable sources in field area	Source ecology	Alt. range x100m	Veg. %	PDR	LOCAL %	R _L	LP%	REGIONAL Summit Pindaunde PDR %	PDR %
57	<i>Drapetes</i>	<i>D. ericoides</i>	Subalpine and alpine shrub	33-44	4		1	0.3	+		
58	<i>Drimys</i> sim.	<i>D. piperita</i> , <i>Bubbia</i> spp.	Forest and subalpine shrubs	<41	5	40	1	<0.2	1	+	x
		(e) Herbs									
63	Apiaceae	<i>Oreomyrrhis</i> spp.	Subalpine and alpine herbs	32-44	8	10	3	0.4	+		
64	Asteraceae IV	<i>Trachymene</i> spp. <i>Gnephaliun</i> spp.	Subalpine and alpine herbs	33-44					+		
65	Liguliflorae	<i>Lactuca</i> spp. <i>Sonchus</i> sp.	Subalpine and alpine herbs	31-43	5	5	2	0.4	+		
66	Caryophyll-aceae	<i>Sagina papuana</i> , <i>Cerastium</i> spp.	Subalpine and alpine herbs	32-45	1	Nil	1	1.3	+	+	x
71	<i>Ranunculus</i>	<i>Ranunculus</i> spp.	Subalpine and alpine herbs	27-45	6	10	2	0.3	1	+	x
73	<i>Potentilla</i>	<i>P.</i> spp.	Subalpine herb	32-43	10	Nil	<1	<0.1	+		
74	<i>Trigonotis</i>	<i>T.</i> spp.	Subalpine and alpine herbs	27-45	+	Nil			+		
81	<i>Astelia</i>	<i>A. papuana</i>	Subalpine and alpine bog herbs	34-44	5	20	2-6	0.4-0.6	+		
82	Poaceae	incl. <i>Festuca</i> spp., <i>Deschampsia klossii</i>	Subalpine and alpine grasses	31-44)						
84	"	incl. <i>Festuca</i> <i>papuana</i> , <i>D. klossii</i>	")	47	300	45-60	1.0-1.2	8	50	6 35 4
86	"	D=ca28.5µ incl. <i>Poa</i> spp. <i>Danthonia</i> spp.	")							
87	"	D=ca32µ <i>Deyeuxia brassii</i> , <i>Danthonia vestita</i> , <i>Hierochloa redolens</i> , <i>Anthoxanthum</i> sp.	Subalpine grasses	31-40	25	100	35	1.4	8	70	9 90 9

TABLE 5.7

Pollen types and sources

No.	Pollen taxa	Probable sources in field areas	Source ecology	Alt. range x100m	Veg. %	PDR	LOCAL %	R _L	LP%	Summit Pindaunde PDR %	REGIONAL %
(e) Herbs (cont'd)											
89	Poaceae D<38 μ	<i>Ischaemum</i> , <i>Nastus</i> , <i>Pennisetum</i> , <i>Mono-stachya?</i> , <i>Miscanthus?</i>	Montane and garden grasses	<32		500		<1.0	2	+	x
93	Cyperaceae	(a) <i>Cyperus</i> , <i>Carex</i> , <i>Scleropogon</i>	Fen and bog sedges	27-44	75	20		0.1-1.3	+	+	x
		(b) <i>Schoenus curvulus</i>	Sedge of forest edge	31-39	23	Nil	+		+	+	x
(f) Ferns and fern allies											
101	<i>Cyathea</i> sim.	incl. <i>Cyathea</i> spp.	Tree ferns of sub-alpine grasslands or forests	<37	9	3500	40-80	4.5-9.6		70	9 100 10
105	<i>Pteris</i>	<i>Pteris</i> sp.	Prominent ground fern in subalpine forest	<37	6	200	3	0.5	1	5	x 5 x
111	<i>Lycopodium</i>	<i>Lycopodium</i> spp.	Subalpine grasslands or epiphytic in forest	<42	2	25	+	<0.4		2	x 5 x
112	<i>Blechnum</i>	incl. <i>Blechnum</i> spp.	Ground fern of forests	<36	+	600				25	3 15 2
115	<i>Microsorium</i>	incl. <i>Microsorium</i> spp.	Epiphytic in montane forest	<29	NA	40				2	x + x
117	<i>Belvisia</i>	incl. <i>Belvisia</i> spp.	Epiphytic in forests	<38	NA	50				8	1 4 x

Notes on selected pollen types

(a) *Casuarina*. *Casuarina* pollen is the major element of the modern pollen deposition. A value of 70% was obtained at site 19, where *C. oligodon* is planted extralocally; probably values of 80-90% would be reached if it were local to the site. The genus is very productive and its pollen transported easily. Because it is monoecious the pollen production of plants forming a given percentage of the vegetation must be double that of a dioecious species of the same vegetation percentage. The natural habitat of *C. oligodon* is probably along stream courses in the mountains, or on sandy soils near the coast, but it has been introduced to a great extent following human disturbance of the highland vegetation and this makes it difficult to estimate what the natural distribution might have been in the past. I have seen large *Casuarina* (possibly *oligodon*) trees in lower cloud forest on steep slopes, at 2,000 m in the Carstensz Mts, in areas which are not settled. Lam (1945) records a treeline species of *Casuarina* growing 2,700-3,500 m on Mt Doormantop, West Irian. One problem in assessing the possible pollen contribution of *Casuarina* sp. in a 'natural' forest is that the dispersal of its pollen from closed forest is probably far less than from the optimum situation of isolated trees or groves of trees in the gardens. An increase in the density of *Casuarina* plantings would probably not add much extra *Casuarina* pollen to the regional pollen and could even reduce it by trapping 'trunkspace' pollen. *Casuarina* as a natural closed forest element may have an R_r value considerably lower than that given here, although some over-representation could still be expected.

(b) Urticaceae-Moraceae The source of the high regional pollen rain of the Urticaceae-Moraceae type was not satisfactorily determined. All Moraceae appear to be under represented (as Powell (1970a) found), as are the higher altitude shrub and herb Urticaceae. The largest catches were made in the lower cloud forest where Urticaceae taxa are not very common, so it may be that sources at even lower altitudes are responsible. There must be a wide range of R_r values for individual source species. The pollen type is taken as representing cloud and lower forests and garden areas, or a specialised local forest edge niche (eg 16B).

(c) *Castanopsis/Lithocarpus* Powell (1970a) found *Castanopsis* to have equal-representation when local and to have equal or over-representation in the regional modern pollen spectra. In the Upper Chimbu oak trees are scattered through the garden area below 2,200 m and low but consistent values occur in the regional pollen spectrum.

(d) *Nothofagus* Although the R1 value for *Nothofagus* is close to 1.0, this is because the percentage of the tree in the vegetation and the pollen percentage are both close to 100%. Powell (1970a) has shown that when beech is in mixed beech forests it demonstrates great over-representation. This is certainly borne out by the regional pollen deposition in which *Nothofagus* is the second most important element, despite a fairly restricted modern area of growth on the steep northern side of the Bismarck Range. Forest areas to the south of the range near Goroka and in the Upper Chimbu include only very scattered trees, for reasons not yet clear but possibly related to relatively infrequent cloudiness (see Brookfield 1964). The trees in the northern forest are very large and tend to form an open canopy on ridge crests, which must greatly favour pollen dispersion and transport. The pollen, even if crumpled or torn, is so characteristic that a slight counting bias towards it can be suspected.

(e) Araliaceae (*Schefflera*) Powell (1970a) has suggested that Araliaceae (*Schefflera* sp.) can be locally over-represented but *S. chimbuensis* has extreme local under-representation on Mt Wilhelm and forms no part of the regional spectrum.

(f) *Papuacedrus* The pollen of *Papuacedrus* can be recognised but is easily damaged or crumpled. Even if care is taken in searching for it, a negative counting bias contributes to the extreme under-representation. In many fossil slides, many grains were seen which could not certainly be attributed to *Papuacedrus* although it may have been the source. This under-representation is regrettable, because *Papuacedrus* spp. occupy rather different niches on the different mountain ranges of New Guinea. On the Carstensz Mts, (where its taxonomic and ecotypic status is unknown) it is a treeline species up to 3,600 m altitude. In contrast, *P. papuana* on Mt Wilhelm appears to be restricted to cloud forest, and it was important 30 years ago in the Keglsugl garden area (J. Nilles personal communication). The bark is used for roofing and so the species tends to be preferentially destroyed by man.

(g) Other forest trees Other forest trees tend to be locally under-represented and are either absent from or present as minor elements in the regional spectrum. This agrees in general with the results obtained by Powell (1970a), although in contrast with her results no equal-representation for *Prunus*, *Saurauia*, *Quintinia*, *Drimys* or *Podocarpus* was obtained at any site, even though the 'local' pollen sum method employed at Mt Wilhelm should lead to higher representation. No pollen attributable to *Pandanus giulianettii* was detected at sites 18 and 20, whereas Powell found equal local representation for a different species at Mt Hagen. *Timonius belensis*, although under-represented, dispersed consistent low amounts of pollen at Mt Wilhelm, but Powell did not find this pollen type at all. Other tree pollen types not recorded by Powell, but found locally at Mt Wilhelm, are *Polyosma*, *Phyllanthus* and *Eurya*. The other pollen sources with no local pollen representation agree well with the list given by Powell (p. 127 Table 7.3). These may be determined by comparing site species lists with pollen percentages (Appendix 1).

(h) Asteraceae The low representation of most Asteraceae is interesting in view of the local abundance of source species. Quite high percentages of Asteraceae pollen were recorded from the African high mountains for various genera (Coetsee 1967). On Mt Wilhelm the large tomentose leafed tree of the subalpine forests (*Senecio* sp.) was the only species to provide an R_l value of more than 1.0. The small shrubs (eg *Tetramolopium* spp.) did not disperse as much pollen but low Asteraceae (Tubuliflorae) levels are taken to indicate *Danthonia vestita* subalpine grassland, unless the level of treeline species suggests the lower subalpine forest edge.

(i) *Rapanea vaccinioides* This low tree or shrub usually has local over-representation. Although the treeline community (upper subalpine forest) in which it is dominant is restricted altitudinally, *Rapanea* pollen forms an important part of the regional pollen deposition and thus probably has an R_r greater than 1. The pollen is evidently dispersed and transported well. There is a large variation in the morphology of the pollen type, and some other pollen type may have inadvertently been included in the totals.

(j) *Dacrycarpus* Trisaccate *Dacrycarpus* pollen comes mainly from the *D. compactus-cinctus* group. *Dacrycarpus compactus* is remarkable as a treeline species, because it tends to decrease in frequency as a component of the upper subalpine forest with increasing altitude, yet it occurs as isolated trees well beyond the closed forest, especially in sheltered areas. The behaviour of the pollen is also peculiar. Generally the tree is slightly over-represented locally, but in the regional spectrum and often the extralocal spectra it appears to be seriously under-represented, for *Dacrycarpus* is a common tree over a wide altitude. The result is that rather large fluctuations in *Dacrycarpus* pollen percentages can be expected as a result of only minor changes in the distance of the nearest source, where this is local or extralocal to a fossil site.

Apparently the pollen of *Dacrycarpus* is not transported easily, because of its large size. In this respect it differs from other trees with vesiculate grains, such as *Podocarpus*, which forms a very prominent part of the pollen deposition in the African Mountains. There it behaves similarly to *Nothofagus* and *Casuarina* on Mt Wilhelm, being deposited in large amounts up to the very highest parts of the mountains. It is possible that vesicles are not so favourable for dispersion in a very wet climate as they make a pollen grain more liable to impaction by water droplets. By comparison with *Podocarpus* or *Pinus*, *Dacrycarpus*, *Phyllocladus* and *Dacrydium* in the New Guinea mountains have vesicles reduced in size relative to the diameter of the pollen grain.

(k) Subalpine shrubs The shrubs tend to have slight or very great under-representation, with the exception of *Haloragis halconensis* and *Coprosma divergens*, which indicate subalpine grasslands especially when found together. All except *Haloragis* and *Drapetes* have forest representatives, but the local representation of these tends to be lower than for grassland species (eg *Styphelia suaveolens* and *Trochocarpa dispersa*).

(l) Grasses (Poaceae) The Poaceae from a number of sites and habitats gave rather consistent equal or slight over-representation. Grass pollen was classified into 8 categories during counting on the basis of diameter, surface pattern and pore dimensions, but comparative material and electron micrographs showed that many species produce pollen

of more than one size (J. Guppy personal communication). Five categories were finally distinguished and the most probable sources are indicated in Table 5.7. As even this distinction is probably artificial, the grass pollen is shown in only three categories in the pollen diagrams. These are (a) alpine and subalpine grasses including *Deschampsia klossii*; (b) alpine and subalpine grasses excluding *D. klossii*; and (c) grasses with large diameter pollen ($>38\mu$), including the lower altitude species and possibly *Monostachya oreoboloides*. The last group is probably under-represented, as the only high percentages found were of the introduced grass, *Pennisetum clandestinum*, at Keglsugl. The climbing bamboo and the 'pitpit' apparently do not produce much pollen.

The Local Presence value for grasses given in Table 5.7 (8%) depends to some extent on the regional within sum deposition. In an extensive forest area, about 2% could come from local grasses, while the summit figure (14%) comes entirely from extralocal sources. The existence of a local closed tussock grassland usually results in a minimum of 60% grass pollen. Values lower than this mean either scattered local grasses or extensive extralocal tussock grasslands (eg sites 7 and 11). These two situations can be distinguished by other elements of the pollen spectrum. The relatively high totals for grass pollen in the lower forest sites suggest that part of this is regional pollen coming from lower garden areas, or that some downslope transport of grass pollen does occur. The extralocal grass pollen deposition (and percentages) from the garden area site (19) are high enough for the former possibility to be reasonable.

(m) Mire pollen sources Mire sedges, *Astelia*, *Ranunculus* and other mire species show equal or over-representation in some surface samples, but extreme under-representation extralocally. These plants probably produce abundant pollen which is washed to the ground and not dispersed. Since sedges have inconspicuous flowers, presumably anemophilous, it is hard to see why their airborne pollen deposition is so much lower than that of grasses. The presence of even small amounts of pollen of these species, therefore, implies that they are local, extremely abundant extralocally, or that a water-borne component has been included in the sample. Very high values, on the other hand, do not necessarily imply dominance at a site.

(n) *Cyathea* *Cyathea* spp. (tree ferns) are an important element of the montane forest communities, forming an almost continuous understorey in some places. They also occupy large areas of subalpine grassland as scattered but dominant 'shrubs'. Treefern dominated associations cover hundreds of square kilometers in New Guinea. They are regarded as fire-induced seral communities by some authors (eg Paijmans and Löffler 1972), although frost frequency is seen as a maintaining factor (Wade and McVean 1969). Some *Cyathea* species are common to both types of habitat but others are restricted to either forest or grassland communities. The interpretation of *Cyathea* spore records is thus very difficult. In general the grassland habitat is more efficient in allowing spores to be dispersed into the regional pollen deposition, but extralocal sites near forest margins also have moderate levels of *Cyathea*. Both forest and grassland species seem to be locally over-represented and the Rr values must also indicate over-representation. *Cyathea* behaves like a shrub from the pollen analytical point of view and could be included in a pollen sum of woody plants. However other Pteridophytes produce trilete, psilate spores which may be confused with those of *Cyathea*, so the percentages must be regarded as maxima for *Cyathea*. Consequently, *Cyathea* has been excluded from the woody taxa pollen sum.

(o) Other ferns Most other fern species inhabit the forests. Those that are epiphytic tend to have a higher representation than ground dwelling species, presumably because they are more favourably placed for pollen dispersal. Unfortunately, reference material for ferns in the study area is incomplete, and the identifications are tentative in spite of the variety of morphological features that can be used to discriminate the spores. The habitat ranges of most fern species are also poorly known. *Papuapteris linearis* is an important component of some alpine communities but no spores could be attributed to it. This is unfortunate since it is one of the few obligate alpine species, occurring only above 3,600 m on Mt Wilhelm and Mt Giluwe.

Pollen type ratios

Maher (1963) has shown that it is possible to calculate the approximate distance from a particular vegetation type to a site. If the ratios of two pollen types are compared at different distances from

a common modern source community, then the ratio of the more easily transported pollen type to the less easily transported (heavier?) type should increase with distance. If the ratios are calculated for fossil spectra at a given site, it should be possible to estimate the distance to the source community. This method is based on the assumption that the ratio at any given distance is stable through time, which in turn implies a constant relationship between the pollen sources in the vegetation. It entails a careful selection of sources from presumed stable associations with well known ecological tolerances. Errors in interpretation may result in cases where, for instance, a community moves away from a site unevenly, so that the relative distribution of species within the source region changes. For this reason, Maher may have rather oversimplified the concept, although he obtained some interesting results. The value of the approach lies in the fact that the ratio is independent of influence by other pollen types, and is in effect a pollen diagram of two components only. Such ratios can provide a check where particular changes in the spectra are suspected of being due to changes in the overall pollen deposition rate.

For Mt Wilhelm, the ratio of *Rapanea* to *Dacrycarpus* was first considered, as a means of fixing the relative position of the treeline to a site in the grasslands. The results (see Table A3.1, Appendix 3) are not encouraging, because the variation is too great, mainly due to fluctuations in *Dacrycarpus*. These two trees are the only elements of the treeline forest that reach levels in the regional pollen spectra high enough to be used. However the ratio was calculated for all fossil spectra, in the hope that it would indicate the relative proportions of the two taxa during times when the treeline appeared to be constant.

Other ratios were considered but suitable species pairs appeared to be lacking. However, ratios of groups of pollen taxa have been used to differentiate mutually exclusive communities. The usual ratio, arboreal to non-arboreal, was of little value because pollen production in some non-arboreal communities was less than the regional woody plant pollen deposition; a change from grassland to fen or tundra could mean a large change in the ratio with no real change in the arboreal PDR. An improvement was obtained by including pollen types from arboreal and non-arboreal sources that tend to be inversely related, eg treeline species (mainly *Dacrycarpus* and *Rapanea*) as opposed to Poaceae and

herbfield species. In the lower forests, *Nothofagus* can be contrasted with cloud forest plus oak forest elements. The latter ratio is fairly constant over most of the modern samples, but shows variation in the past. This may imply that the forests are complementary, or that an increase in one has taken place while the other remained unchanged. This ratio may be dependent on distance, however, and *Nothofagus* pollen deposition could be expected to increase relative to all montane forest elements if both forests retreated. The greatest modern *Nothofagus* to cloud-oak forest ratios occur in the summit area of Mt Wilhelm.

The fourth ratio given is herbfield and mire taxa, which usually only occur locally, against grass, which may be local, extralocal or regional. High ratios suggest significant local mire vegetation and this in turn means that local woody plants are probably rare. Equal or low ratios mean either the presence of substantial local or extralocal grassland or the absence of local mire herbs. This ratio accentuates local vegetation changes and is not liable to be influenced by varying distances of sources.

The pollen sum

Earlier it was stated that a pollen sum of elements that have remained regional throughout the history of a given site would be the most suitable standard against which to measure change, both locally and regionally (p.62). A second consideration is that the size of the pollen sum relative to the total count should be sufficient so as not to exaggerate minor differences between samples, yet to display variation adequately. This second criterion is subjective but it should be remembered that a pollen diagram is a visual method of comparing a large amount of data and that the proportions can reflect the reliability placed on a certain amount of change. By different choices of a pollen sum, the reduction of a component by half could be made to appear either as a drop from 60% to 30%, or from 6% to 3%.

Two previous workers in New Guinea have each discussed the question of pollen sums and agreed, with Faegri (1966), that the actual sum used depends on the problem under investigation. Flenley (1967) used total forest pollen and total dry land pollen, while Powell (1970a) used total woody taxa pollen. These sums require decisions about the allocation of pollen taxa to sources in more than one group (eg Urticaceae), but this can usually be settled by study of modern pollen samples.

The project on Mt Wilhelm involved sedimentation sites over a wide range of altitudes, and pollen analyses showed that changes in the local vegetation had occurred at all of them. At only one site had herbaceous taxa alone been present for the full deposition period. At the other sites, a wide range of woody taxa were present extralocally at some time. This left a choice between using a pollen sum made up of the very few totally regional elements with *Nothofagus* and *Casuarina* as the only two significant components and one made up of all woody taxa. The pollen sum of all woody taxa was chosen, after computing results for the first alternative which gave very exaggerated values to many pollen types. However, two pollen types *Casuarina* and *Cyathea* were excluded from the woody taxa sum. *Casuarina* is the dominant pollen type of the modern spectra but was virtually absent in the past. Its recent increase has so changed the PDR that its inclusion in the pollen sum would make interpretation of local and extralocal changes difficult for the period of its increase. *Cyathea* is excluded because it cannot be identified certainly from some other ferns. Although the choice of this pollen sum compromises the first principle noted above, the summary diagrams and pollen taxa ratios can be used to interpret the effects of changes in the within sum PDR on the individual taxa that were extralocal at any time in the past at a given site. This sum is much the same as those of Flenley and Powell and permits comparisons of the spectra from all modern and fossil sites.

Conclusions

This study of the modern pollen deposition on Mt Wilhelm is fragmentary and conclusions are necessarily tentative. However, the pollen spectra of the twenty plant associations tested are distinctive both in terms of the local elements and in terms of the effect of the community pollen production on the regional spectrum. An increase in the percentages of regional elements coming from lower altitudes was noted in the open communities above the tree line. Pollen trapping results have shown that this is due to a reduction in local within sum PDR in these communities, as the regional elements showed similar, though variable, PDR values in all communities. The high altitude grasslands of Mt Wilhelm are apparently so small in area that no distinct reduction in regional PDR values takes place because of distance. This may be due to the orographic winds and complete rainout of pollen on

an almost daily basis. This mechanism also hinders downslope pollen transport. Although the PDR of a given regional element tends to be more or less constant above the altitude of occurrence of its main source, the rate diminishes rapidly down slope. This process, combined with the generally higher within sum PDR of the lower communities, results in the absence or very low values of high altitude elements in the lower altitude spectra.

The analysis of pollen transport components by Tauber (1965,1967) can be applied to Mt Wilhelm. The trunkspace and above canopy components appear to be very reduced by comparison with the regional component. The roofed traps show that this is probably due to the frequent rainfall which deposits the regional pollen and inhibits the transport of other components. Although the results are inconclusive, filtering and probably also reflotation, are not important processes affecting the PDR. Two important processes of pollen deposition, however, are surface washing and litter fall, both leading to very high local values for some pollen types which do not contribute appreciably to the wind transported component.

CHAPTER 6

POLLEN ANALYSIS - SITE SELECTION AND METHODS

Selection of sites

Sites suitable for pollen analysis were sought in four areas on Mt Wilhelm.

Summit area This area has undoubtedly been the most sensitive to past climatic changes, as it is near the present theoretical snowline and minor temperature fluctuations would have affected snowfall frequency and the nature of the vegetation there, while perhaps not influencing altitudinally lower communities very much. However, the summit area has been the most recent to be deglaciated so that the fossil record would be expected to have been short or interrupted.

Treeline Present day 'natural' treeline is at about 3,800-4,000 m and is rather diffuse. This is well above the margin of the former glaciated area. A site in this altitudinal zone could be expected to show the process of upper subalpine forest development and whether the treeline has ever been substantially higher than at present. The status of a primary shrub-rich subalpine grassland could also be investigated.

Lower glaciated region (subalpine) The longest record could be expected from a site near the margin of the area affected by glacial action. The lowest points are characterised by depositional glacial landforms which are generally not suitable for sediment accumulation, so low altitude basins on the walls of the glacial valleys or similar points of probable early deglaciation were investigated. Subalpine forest occurs in this altitudinal zone (3,400-3,700 m) but it has been partly replaced by subalpine grasslands of apparently very recent origin, since forest remnants or stumps persist in the grasslands. Thus sites in this grassland could be expected to show not only the process of revegetation to forest after deglaciation, but also the recent removal of the forests.

Outside the glacial area Deposits in the above three areas must all have built up since the most recent deglaciation. Pollen analysis outside the glaciated area is necessary to discover the nature of the

vegetation during or before full glaciation, and to provide direct information about the cloud and lower forests. Other pollen analysis sites in New Guinea are at or below 2,550 m (Walker 1970) so that a site in cloud forest on Mt Wilhelm at about this altitude can provide a means of linking the glacially-related results to those from lower altitudes.

Numerous sites exist in the treeline and subalpine areas on Mt Wilhelm, in the Pindaunde Valley and to the south and west, because the altitude zone of 4,100 to 3,400 m experienced severe glacial erosion which has resulted in many rock basin tarns and lakes and a few moraine-dammed tarns. Most of the summit area is ice-smoothed or very steep and only one site was found there. Sites are also rare on the flanks of Mt Wilhelm where fluvial erosion is very vigorous. Eight sites were investigated by preliminary stratigraphic borings; one summit site at 4,420 m, one treeline site at 3,910 m, four lower in the glaciated region (3,500-3,700 m), one in lower cloud forest at 2,740 m and one in a garden area surrounded by mixed forest at 1,300 m. The summit site and one of the subalpine sites lie on the southern side of the mountain, and the remaining five sites lie on the eastern slopes within the Pindaunde-Pengagl catchment.

Field methods

Borings to study stratigraphy and collect cores for pollen analysis were made during the two main field trips in 1969 and 1970. In 1969, a Hiller peat sampler, a piston sampler (Walker 1964) and a newly developed D-section sampler were used. Piston cores were obtained from four sites, and Hiller samples from a fifth. The D-section sampler was too fragile and was not used. In 1970 it was planned to duplicate some piston cores. Unfortunately, the piston sampler was lost in 4 m of mire, so that the strengthened D-section sampler had to be used to collect final cores. This type of sampler collects completely undisturbed cores, but cannot obtain the lowest 17 cm of sediment because of its design. A Mackereth sampler (Smith 1959) was brought to the lower Pindaunde Lake, and two lake sediment cores obtained, from 20 m water depth. The D-section sampler broke while penetrating clays in a test hole. The difficulties with the samplers hindered the stratigraphic investigations. In most of the

rock basin turns the results available suggested that the stratigraphy was straightforward, the sediments consisting of horizontally bedded pure algal gyttias with lensed ash layers and usually with a surface layer of fen peats. The morphology of the basin floors was checked by probing with corer extension rods; the bedrock could be distinctly felt and heard. In the more complex cloud forest peat site, transects of probings and borings were made. A Kern level was used to obtain relative levels of probe and core holes and to survey some of the sites. As a rule, final cores for pollen analysis were obtained from the deepest sediments that could be found at each site, D-section cores being used where possible.

Laboratory techniques

The cores were wrapped in plastic and returned to the laboratory in Canberra where they were sampled for ^{14}C dating and pollen analysis. The Hiller samples and D-section cores are uncompressed and the sampling interval corresponds to a true depth interval. Piston cores and Mackereth cores usually show some degree of compression. Each piston core (covering a depth of 1 m of sediments) was measured after collection and again in the laboratory. The organic matter in each core was assumed to have been compressed evenly (the sandy layers are regarded as incompressible) and the core was sampled at points corresponding to estimated stratigraphic depths (eg if a core was compressed to 75%, then 7.5 cm interval was taken to represent 10 cm in the true stratigraphic column). The depth of the pollen samples given in this thesis are accurate for the D-section and Hiller samplers but approximate where they refer to piston cores. With the Mackereth cores, the true depth reached by the sampler is unknown, and samples were taken at selected depths in the recovered cores.

Samples for pollen analysis were removed from cores in the laboratory. The surface was cleaned and the sample excavated with a spatula giving a sample depth of about 8 mm. The Hiller sampler was opened in the field and similar samples removed from the middle of the core. Samples so collected were placed in vials. The samples were broken up if necessary, wet-sieved (0.15 mm mesh), centrifuged, and about 3-5 ml of sediment obtained. Almost all samples consisted of fine-grained, highly organic sediments which passed

easily through the sieve, leaving a small proportion of easily washed debris. A few samples contained appreciable amounts of clays or silt-sized volcanic ash but all were non-calcareous. Standard chemical treatment was used, following Faegri and Iversen (1964):

- (a) Removal of silica. All samples were left for 24 hours in cold 40% hydrofluoric acid in a sealed plastic vial. Those samples with a high volcanic ash content reacted vigorously with the acid. They were centrifuged after one hour and were then left to stand in fresh acid.
- (b) A subsample of 0.5-1.5 ml was drawn from the resultant organic sediment for subsequent treatment.
- (c) Hydrolysis with hot 10% potassium hydroxide.
- (d) Acetolysis by the Erdtman method.
- (e) Chlorination.
- (f) Dehydration, safranin staining and transfer to silicon oil in a labelled sample tube. Ether or terbutanol was preferred to benzene as the final washing agent before the silicon oil.

Pollen counting and treatment of data

Slides were made and counted, using a Zeiss (Oberkochen) photomicroscope, at a routine magnification of 400. Pollen was identified at x1,000 by comparison with reference slides in a collection which includes pollen of many species from Mt Wilhelm previously collected by Dr. K. Wade. The modern surface sample study was very useful because the plant species list for a given site suggested probable sources for any unknown pollen types from the surface samples. The extensive collections of photomicrographs taken during the work of J.R. Flenley, J.M. Powell and J.C. Guppy were also used. Flenley (1967) and Powell (1970a) have figured nearly all the pollen types found in this study. Not every pollen type encountered could be linked with a pollen source. In view of the many thousands of source species growing within 25 km of Mt Wilhelm, many of them unrecorded and possibly undiscovered, it was felt that it would be a misplaced effort to try to identify all unknown pollen types, especially those that appeared only occasionally in the samples. Unknowns that reached significant levels or which occurred commonly were coded and checked against an extensive data bank of modern reference grains (Walker *et al* 1968).

This produced a list of possible matches against which the unknown could be checked, and in some cases it led to identification.

Pollen was counted in transects across the slides and the counting continued until pollen sum components exceeded a total of 200. Each pollen type was allocated a number and the counts for each type were transferred to a position on a computer card. 120 numbers were used. Most unknowns that reached significant levels were also allocated a number, although some were grouped. The data cards for up to 80 samples were run through three programs (Dodson in press). The first listed the percentages of all components based on a pollen sum that could be made up of any or all components. A subroutine listed the pollen sum and total counts and calculated four sets of ratios of any two components or groups of components. An advantage of this program is that mistakes in entering or punching the data can be easily picked up from anomalous results or results in supposedly blank categories. The second program calculated percentages for nominated pollen types or groups of pollen types against any nominated pollen sum. The output of this program was suitable for the preparation of pollen diagrams by hand or by computer plotter. The third program calculated χ^2 values using the percentage values of pollen types in adjacent spectra, the within and without sum components being calculated separately. By comparing the values for sets of spectra, regions of greatest change can be identified. The values almost always imply significant differences between all spectra pairs, if the probability tables are used, because of count variations. The χ^2 values are only used as an aid to zoning pollen diagrams by locating the sections showing the greatest changes. Single samples can also be compared to a section of several samples to find the sample pair with the lowest χ^2 values. The χ^2 program can be used only as an aid in problems of correlation because in practice change in some components is given greater weight than change in others, whereas the program integrates the differences between all components without discrimination.

In this thesis the printouts from the first program, using all pollen data, are given in Appendix 3, instead of a table of the original pollen counts. The pollen sum used (all woody plants excluding *Casuarina*) is the same as for the pollen diagrams, so these printouts can be used as a supplement to the diagrams, to provide the data on minor elements or the components of grouped pollen types (eg Poaceae). A summary table

before each listing gives the pollen sum count, outside pollen sum count and total count. The original counts for any pollen type can be obtained from the tables. The summary table also gives the four selected ratios of pollen types;

- (a) *Nothofagus*/cloud + oak forest. This provides a measure of the relative importance of undoubtedly regional elements.
- (b) *Rapanea/Dacrycarpus*. The relative composition of the treeline.
- (c) Treeline/Poaceae. The probable distance to the forest boundary. 'Treeline' shrubs include *Cyathea*.
- (d) Mire/Poaceae. The presence and nature of local vegetation on mire sites. This ratio is of value only when mire and/or Poaceae values are significant.

The abbreviations of the pollen names, degree of certainty of identifications, components of the pollen sum and of groupings of pollen types are also given in Appendix 3.

The pollen diagrams are given with the relevant fossil site descriptions. They are broken into two parts. The first consists of a stratigraphic diagram with radiocarbon dates, followed by the pollen curves for selected woody taxa and within-sum, between-sample χ^2 values. The second part contains the pollen curves for herbaceous taxa, ferns and unknowns, and the outside-sum, between-sample, χ^2 values, as well as a summary diagram based on the pollen types of sources occurring above 2,700 m in the Pindaunde Valley. These latter fall into six main groups: cloud forest, treeline, *Cyathea*, subalpine shrublands, grassland, and herbfield, the pollen sum being the pollen taxa in each of the groups, an approximation to a 'local' pollen sum.

¹⁴C dates and sediment accumulation rates

Where possible, ¹⁴C dates were obtained from the same cores as the pollen analysis samples. Sections of cores were cleaned, samples for pollen analysis were removed, and the remainder placed in double plastic bags with identification tags, as recommended by Polach and Golson (1966). Generally about 20-30 cm sections of core were required for dating. In some cases, multiple piston or D-section cores had been taken within 1 m of each other and here sections as small as 5 cm from each of up to four cores, yielded enough material for dating when combined. Samples from the base of deposits were submitted for dating first. Preliminary pollen analyses were then carried out before

the final sites for more intensive dating and pollen analysis were chosen. At the base of the deposit at some sites were dark silty sediments which appeared to be highly organic. Subsequent tests showed these to be volcanic ash beds, and dating attempts on them were unsuccessful. The immediately overlying algal gyttia from 4 sites was then submitted to the Gakushuin Laboratory, but only one sample contained sufficient carbon for dating. These samples were resubmitted to the Australian National University dating laboratory and analyses done on the whole dried gyttia instead of on the macroremains from sieved sediment. Many of the samples of gyttia were too small and required dilution with 'dead' benzene to bring them up to standard volume, but the relatively young age (<12,600 years BP) meant that satisfactory error terms were nevertheless obtained. Some cores contained peats which in general presented no dating problems, but at Komanimambuno mire penetration of older material by younger roots was indicated from pollen analysis results. Mr H. Polach of the ANU Radiocarbon Laboratory, dated several fractions of single samples from this site, and the results of this cooperative study are given in Appendix 2. The gyttia samples coming from small, cold, freshwater tarns formed in granodiorite rock basins are regarded as free from problems of old carbon incorporation or root contamination.

The methods of preparation, counting and calculation of dates from the ANU and Sydney University laboratories have been discussed by Polach (1969). The Libby ^{14}C half life of 5,560 years is the basis of all dates quoted in this thesis and, in general, references to years before present (BP) refer to radiocarbon years not recalculated to take into account the more accurate ^{14}C half life determination or data on changes in atmospheric ^{14}C production rate. Appendix 2 lists all dates from New Guinea that are discussed in this thesis.

^{14}C ages obtained in this study are also reported in tables included with the relevant pollen analysis results. The sample interval for each date is given and inferred ages have been calculated for various depths below surface in the sediment sections. Each date is regarded as applying to a median depth which is the central point of the organic sediment section submitted for dating. In most cases this is simply the middle of the sample interval; for example ANU-812 consisted of a gyttia core section extending from 330-310 cm depth and the median depth is 320 cm (Table 7.1). In a few cases the

sample interval includes mineral segments or the interval was irregularly sampled; then the median depth is the centre of gravity of the organic segments. For example ANU-811 consisted of gyttja from 538-516 cm depth, volcanic ash from 516 to 501 cm and gyttja from 501-496 cm in a core. The median depth is 522 cm although the centre of the dated section is 517 cm.

Average accumulation rates of organic sediments have been calculated between each pair of dated median depths. Mineral layers are excluded because it is assumed that these accumulate virtually instantaneously (over a few months perhaps) by comparison with gyttja or peat accumulation. Some of the ash layers encountered do contain organic material so that this assumption must be treated with caution. The rates are used to provide inferred ages for given levels in the sediment that are not directly dated. The net depth of organic sediment lying between the given level and the median depth of the nearest ^{14}C date is divided by the average accumulation rate to give the approximate difference in age between the level and the date.

The inferred ages are generally given as an age range, rounded up or down to give a range \geq the error term of 1 σ of the date on which the estimate is based. A few age estimates are given which are based on correlations of pollen sequences which have been dated at other sites. These are clearly indicated.

Presentation of results

Only one site from each of summit, treeline, subalpine and montane zones was selected for detailed pollen analysis. The most complete and detailed sequence for postglacial time was obtained from the treeline site, BRASS TARN and this is described first (Chapter 7). The SUMMIT BOG (Chapter 8), the subalpine site, IMBUKA BOG (Chapter 9) and the montane site, KOMANIMAMBUNO MIRE (Chapter 10) follow. Other sites that received only a superficial investigation are described in Chapter 9.

Each major site is described in terms of location, environment, geomorphological setting, local vegetation, stratigraphy and pollen analytical results. The local and extralocal vegetation is reconstructed from the pollen record, and the preliminary results from other sites related where possible. The results for all sites are correlated and the regional vegetation of Mt Wilhelm reconstructed in Chapter 11.

CHAPTER 7

BRASS TARN 3,910 m

A small tarn lying at 3,910 m in the Pindaunde catchment was chosen for investigation because it lies at the apparent natural upper limit of the treeline (Plate 21). Evidence of changes in this vegetation boundary in the past could be expected to be preserved in the tarn sediments.

The Pindaunde Valley broadens above 3,400 m as the Bogunolto Ridge veers south around the upper lake from its commencement at the eastern bluff of the summit ridge. Between 4,000 and 4,200 m a broad slope extends to the north and east of the summit ridge for about 0.5 km, then drops abruptly to form the head and side walls of the U-shaped valley above the upper Pindaunde Lake (Fig 4.2). This slope was a snow accumulation zone during glacial times, and near the cliff edges ice movement has cut many rock basins and minor cirques. The upper part of the slope is smooth with a fossil apron of periglacial debris derived from the summit ridge crags. The drainage to the upper Pindaunde Lake is by means of several small streams, some of which are interrupted by rock basin swamps. The easternmost stream drains several such swamps below the eastern summit ridge before cascading down to Brass Tarn (named by the Sixth Archbold expedition for Mr L.J. Brass), the largest rock basin and the only one in the area to hold open water. From the tarn the stream flows 40 m north through a notch to plunge 300 m into the upper Pindaunde Lake.

The catchment of Brass Tarn is about 0.25 km² and lies between the altitudes of 4,350 and 3,910 m. It supports alpine fern meadows, *Carpha alpina* fen, *Deschampsia klossii* alpine tussock grassland and *Danthonia vestita* subalpine tussock grassland. The tarn lies at the upper limit of upper subalpine forest since the cliff edges 40 m to the east and north support patches of closed shrubland of *Rapanea vaccinioides*, *Rhododendron* spp. and *Drimys piperita*. Isolated contorted trees of *Dacrycarpus compactus* occur nearby. But above the cliff edges there are open grasslands and areas of bare rock or fens, with scattered shrubs of *Coprosma divergens*, *Styphelia suaveolens*, *Detzneria tubata* and *Drapetes ericoides*, and less commonly *Rhododendron* spp. and *Drimys piperita*. At the foot of the cliffs below the tarn, around the

margin of the upper lake, are the dense upper subalpine forests of *Rapanea vaccinioides* described for sites 14A and 14B.

The area enjoys intense insolation for at least a few hours on most mornings as it slopes to the northeast. This results in a quick melting of the needle ice that normally forms there at night. These slopes probably reach very cold ground temperatures but no ice has been observed on the tarn which is fairly warm (10°C). Snow occasionally falls to about the level of the tarn. The Imbuka Ridge tends to deflect the moist northern air, so the area may be relatively dry. However persistent cloud cover was often observed above the upper Pindaunde Lake, and daytime insolation may be no higher than in other areas. Cold air drainage usually clears the slopes of cloud at night, so the local climate can be summarised as relatively cold and dry for its altitude on Mt Wilhelm.

Brass Tarn is about 20 m across and approximately circular. The water deepens sharply to one metre at the edges and then the floor shelves gradually to a maximum depth of about 3 m at the centre. Wade and McVean (1969 p.129) provide a diagram of the tarn and its surrounding fen vegetation and little change seems to have occurred since 1967, the time of Wade's study. The inlet stream channel runs east, then south through the surrounding fen before entering the western side of the tarn, while the outlet stream flows north over a rock barrier. The tarn floor and margins are covered with a conspicuous algal growth but the only aquatic angiosperms are *Callitriche verna* and *Scirpus* sp. A partially submerged layer of *Carex gaudichaudiana* occupies the zone forming the margin of the lake. The sedge colonises bare organic sediment surfaces and forms a sward in drier parts in which other species can grow (Plate 22). An outer zone consists of *Carpha alpina* fen which includes grasses, *Ranunculus* sp. and *Astelia papuana*. The areas of fen quake, particularly near the edge of the tarn.

A belt of *Deschampsia klossii* grassland extends around the fen areas and there are numerous bushes, including some tall *Coprosma*, *Rapanea* and *Drimys* near the overhanging 20 m cliff bounding the tarn to the south and west. A large *Dacrycarpus compactus*, 8 m in height and 50 cm in basal diameter, also grows in this sheltered position about 12 m from the tarn. There are no tree ferns in the area, but *Papuapteris linearis*, near the lower limit of its range, forms extensive stands in gullies to the south of the tarn.

The tarn is in a deep, glacially excavated rock basin with limited drainage but it has not yet infilled with sediment so that an uncomplicated stratigraphy could be expected. The steep cliffs 10 to 15 m south and west of the tarn form the rock basin limits. Vegetation has thus colonised about 80% of the presumed original tarn area.

Stratigraphy

Preliminary probings were made near the margin of the tarn on the southern side where the sediment surface was being newly colonised by sedges and the fen association belt was 10 m broad. A horizontal rock base about 9 m down was present in this area and a coring site was selected in *Carex gaudichaudiana* fen about 1 m from the tarn edge. A piston corer was used from 150 cm to 902 cm depth. The cores showed varying degrees of compression. Some difficulty was experienced in forcing the sampler through fine silt bands (which proved to be volcanic ash layers) up to 12 cm in thickness. The top 120 cm was obtained by the D-section sampler. The stratigraphy of this sediment column is shown in Fig 7.1. Except at the top it consists of fine algal detritus (gyttja) interspersed with eight ash layers. There is relatively little macro-organic debris, except within 1 m of the surface where root and stem material from monocotyledons increases. The surface root and stem peat is 18 cm deep, showing that the site has only recently been colonised by vegetation and must previously have been covered by water of varying depth. The organic deposits overlies a basal 2 cm of sands on a bedrock surface which slopes gradually up to the south for 8 m before rising sharply to form the edge of the basin.

The relative positions of five ^{14}C age determinations are shown on the stratigraphic column. These are summarised in Table 7.1, which gives the date and median depth in the core, the calculated sedimentation rates between the dates and some inferred ages based on these rates. Between 11,000 and 5,000 years BP the accumulation rates were lower than between 5,000 and 2,000 years BP. This can be attributed to a combination of increasing compaction with depth and a slower rate of organic build up when the tarn was deeper and the vegetated edge at a greater distance. Compaction probably plays the greater part since the gyttja contains few plant remains larger than 150 μ at any point below 175 m. The uppermost levels (surface to 180 cm) show a very much lower average accumulation rate. It seems likely that

TABLE 7.1
BRASS TARN - SUMMARY OF ^{14}C DATES

^{14}C age yrs BP	Dated section Interval/Median depth cm (see p133)	Av. organic accum. rate between median depths cm/100 yrs	Depth from surface cm	Inferred age yrs BP
			0	Present
			40	<50*
			120	500*
			160	600-900*
		? Discontinuity		
ANU-813 1,880 ± 120	160 } 182 } 200 }	-	182	1,750-2,000
		8.7		
ANU-812 3,470 ± 170	310 } 320 } 330 }	-	320	3,300-3,650
		9.5		
			490	4,750-5,000
ANU-811 5,140 ± 120	496 } 522 } 538 }	-	522	5,000-5,300
		5.3		
ANU-809 8,330 ± 240	700 } 718 } 735 }	-	718	8,100-8,600
			750	8,300-8,800
		5.5		
			835	9,700-10,200
ANU-810 10,660 ± 270	865 } 878 } 902 }	-	878	10,400-10,950
			902	10,700-11,400

* Inferred from correlation with dated pollen sequence Imbuka-Lower Pindaunde Lake (Ch. 9).

sedimentation was interrupted either by the growth of a floating root mat or by the inwash of the ash layers. The overall stratigraphy of the bog margin was not studied but four borings made to 1 m suggested that the upper ash formed lenses of varying thickness. Such lenses are probably due to water transport of airfall ash. It is possible that the peats and sediments of the topmost 60 cm have been disturbed by fluctuations in the course of the inflow stream. This could have cut channels in the older peats and filled them with ash washed from the slopes. The pollen content of samples from above 160 cm suggests a correlation with a zone in Imbuka Bog and lower Pindaunde Lake sites. This zone has a maximum age of about 900 BP and contains volcanic ash layers. Thus it is possible that the interval 1,800-900 BP is missing from the section.

Compared with all other bog or tarn sites, the Brass Tarn section shows the greatest number of distinct ash bands. This suggests that the tarn has acted as a settling tank for ash washed down from the catchment. This is supported by the discovery of 5 ash layers in the cores from lower Pindaunde Lake (Chapter 9) which settled out there over the same period in which the uppermost 4 ash layers occur in the Brass Tarn sediments. The Pindaunde Lake would also have had a settling tank effect. With the exception of the topmost 150 cm, the stratigraphy of Brass Tarn appears undisturbed and the lower ash bands probably show a greater correlation across the sediment though doubtless varying greatly in thickness. The present bottom of the tarn appears to slope conically to a concave centre; in the past when the tarn was larger and deeper the central area was probably flat or gently dished. The initial phase of ooze accumulation presumably left high points of rock uncovered before a more even distribution of sediment occurred. In the Pindaunde Lakes at present, the bottom is a flat or gently sloping surface even opposite the creek entrances, as the algal detritus is a very fluid ooze before compaction. The inferred age for the base of the boring site at Brass Tarn (11,050 years BP) is thus a minimum date and older sediments may exist in deeper parts of the basin. However there is no definite reason to suppose that deeper holes exist in the centre (which could not be cored), since rock basins are often asymmetrical with the deepest parts closer to the headwall, where the boring site was placed. The sediments at the base of the column consist of a thin band of fine sands and silts which may represent final

fluvioglacial outwash, although rock flour or the deep clays that formed the base of the deepest hollows of the Imbuka Bog site were not encountered. Because the central part of the rock basin sediments at Brass Tarn could not be investigated, the lapse in time between formation of the tarn and the start of sediment accumulation remains uncertain.

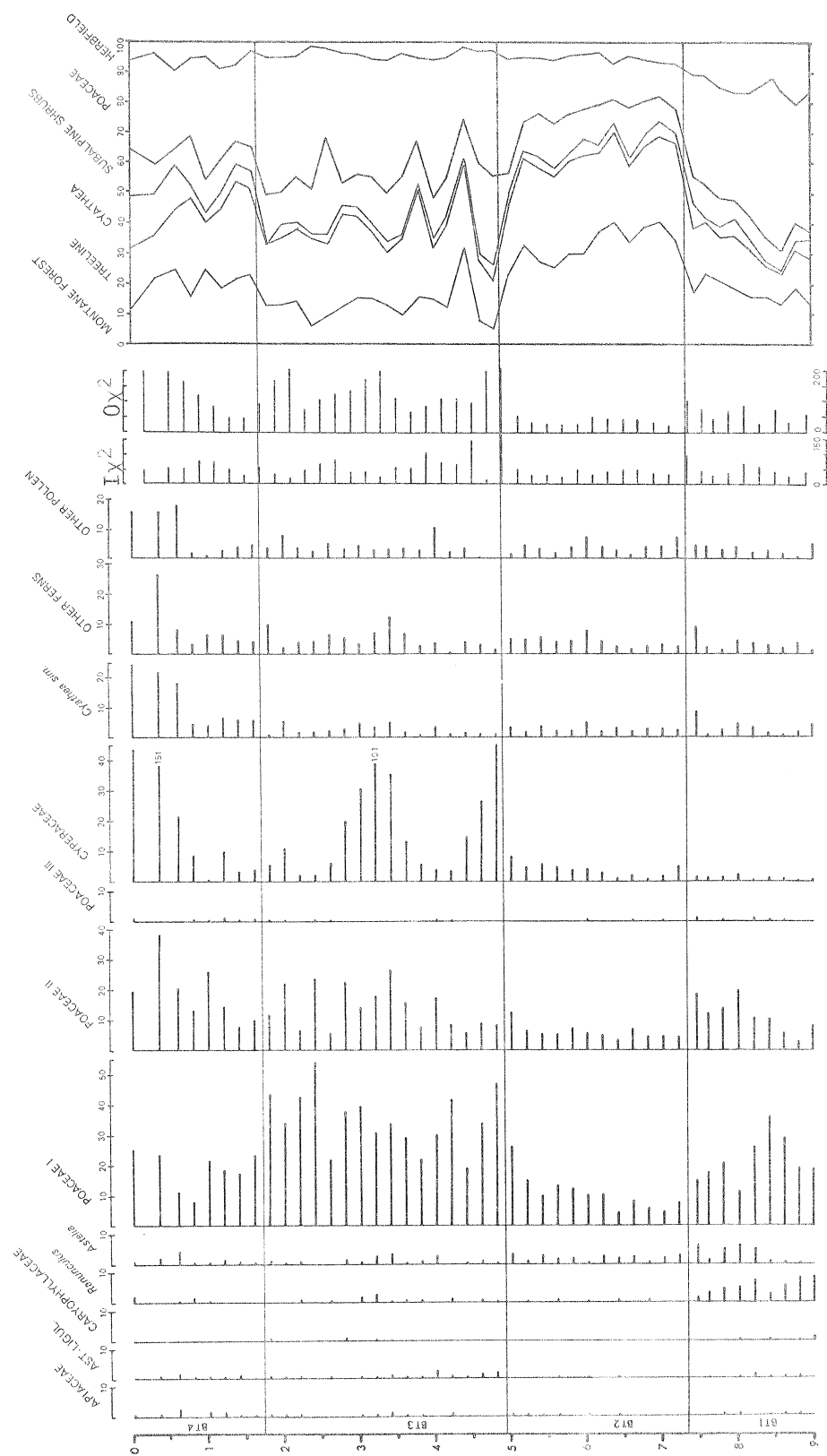
Pollen analysis

The results of pollen analysis of the core from Brass Tarn are shown in Fig 7.1. A counting interval of 20 cm was used, covering an average time span of about 240 ^{14}C years. The reasonably consistent changes in percentages suggested that this interval gave sufficient detail and no extra intermediate samples had to be prepared. The within-sum χ^2 variation showed major changes at 750 cm and at 500 cm, and a zone of change at 240-260 cm. In the outside the sum χ^2 the changes at 750 cm and 500 cm are also well-defined but there is evidence of great variation in a wider zone from 180-320 cm and in the uppermost metre. The ratios of treeline/Poaceae and *Nothofagus*/cloud forests also show distinct changes at 750 cm, 500 cm and at 160 cm. On the basis of these changes the diagram has been divided into four zones, BT1, BT2, BT3 and BT4. These are not erected as defined regional pollen zones, and no correlation with other sites is implied. The zones are based on local and regional pollen spectral changes and are for convenience in discussion only.

BT1 902-750 cm. Inferred age 11,100-8,550 years BP

The major feature of this basal part of the core is the very high levels of *Nothofagus*, exceeding 50%. Pollen from other woody plants are at low levels, with only *Macaranga* and *Rapanea* exceeding 10% in the zone. *Nothofagus* decreases from the base upwards but all other elements, except *Cyathea*, show an increase. The Poaceae I reach 43% at 840 cm and the treeline/grass ratio is low throughout the zone. Alpine herbs are important relative to upper parts of the core, with *Ranunculus* prominent and Caryophyllaceae a constant element. *Astelia* shows a low peak near the top of the zone. The percentages based on total pollen show no major differences from the diagram.

FIGURE 7.1 Cont. Brass Tarn pollen diagram - herbs and ferns



BT2 750-490 cm. Inferred age 8,550-4,900 years BP

A marked drop in *Nothofagus* pollen percentages marks the lower boundary of this zone. This is accompanied by a decrease in the grass and herbaceous elements. The other woody plants increase, particularly *Castanopsis*, *Elaeocarpaceae* and other lower cloud forest groups, and also *Dacrycarpus*, which reaches its highest levels in this zone. *Rapanea* pollen rises in the top half of the zone and the subalpine shrubs, *Styphelia*, *Haloragis*, *Coprosma*, *Drimys* and the Ericaceae are constant throughout. Poaceae levels between 10% and 15% and the high subalpine/grass ratio suggest that there were no major local sources of the subalpine shrub-rich grasslands.

BT3 490-160 cm. Inferred age 4,900-1,800 years BP

Compared to the previous two zones, this one shows a greater variability especially in the herbaceous elements. It is distinguished by very high grass levels of up to 50% of the woody plant pollen, and by the highest percentages in the diagram for subalpine shrubs and *Rapanea*. These correlate with generally low subalpine/grass ratios, with occasional peaks coinciding with high shrub percentages (eg at 420 cm). *Nothofagus* continues at moderate levels, but *Dacrycarpus* and cloud forest elements tend to be lower in this zone than in others. This is evident from the *Nothofagus*/cloud forest ratio which shows a relative increase in *Nothofagus* above 260 cm to the top of the zone. Significant levels of Cyperaceae occur and indicate that the colonisation by fen communities of the tarn edge had taken place, since the modern pollen studies indicate that sedge pollen is deposited in significant amounts only when it is local and transported by water.

BT4 160 cm to surface. Inferred age ? 900 BP to present.

The reasons for defining this zone as distinct from BT3 are the presence and increase of *Casuarina*, the abrupt relative increases in treeline pollen compared to grass, and the decrease in *Castanopsis* and *Nothofagus* compared to cloud forest pollen. There is a clear increase in the amount of *Casuarina* pollen and probably a simultaneous real decrease in *Nothofagus*. The other changes in this zone must be considered in the light of the probable reduction in the total pollen sum components deposited. If the other components have had a constant

deposition rate, they could be expected to show slight rises in percentages. The rises in *Dacrycarpus* and *Rapanea* may thus be 'artificial', although those of *Trema* and *Cyathea* may be real. The grass pollen is erratic and probably actually declines in this zone, except for the top sample which contains pollen from local grasses.

Because of the volcanic ash horizon and the very watery layer just below the sedge mat, the deposits of this zone probably did not accumulate at a steady rate. The high *Casuarina* levels at 40 cm and 0 cm suggest that this section built up rapidly, or has become mixed, as similar *Casuarina* percentages are found only in the surface sample at the Imbuka Bog site. Some of the differences between the surface sample and that at 40 cm may be due to a reduction in the waterborne component in the former.

Vegetation reconstruction

A comparison of the fossil spectra from Brass Tarn with the modern surface samples suggest that 'local' (tarn edge) vegetation has always had low pollen production. Hence the fossil spectra are unlikely to have been distorted by local factors. The considerable extralocal changes in the vegetation (as shown by the values for various woody plants in BT2 and peaks in *Styphelia* in BT3) have presumably influenced the pollen sum and introduced changes in the regional spectra distinct from actual changes in regional pollen depositional rates. An additional factor is the unknown proportion of pollen transported to Brass Tarn by water from the catchment area. This component tends to offset the finding that the regional pollen results represent only down valley regional sources but in the case of Brass Tarn the higher productivity of the subalpine communities will tend to render the alpine component inconspicuous. With these factors in mind the probable vegetation around Brass Tarn, and regionally, has been reconstructed.

Zone BT1 Throughout the time represented by this zone, the extralocal vegetation near Brass Tarn was evidently sparse and alpine in character, though it shows a development towards the subalpine from the base to the top. The relatively high levels of *Ranunculus* and Caryophyllaceae and moderate Poaceae at the base suggest that vegetation was already well established when deposition began. The grass, at least, can also be

interpreted as being due to a high regional deposition derived from extensive areas of grassland at lower altitudes. If this were so, then the herb pollen spectra suggest the presence of wet tundra with scattered grasses analogous to the present day summit community, the vegetation colonising bare rock and moraine. If most of the grass pollen came from sources around the tarn, the *Ranunculus* values are still consistent with an open alpine tussock grassland. However, since this community is only well developed on peaty soils, a considerable time would be required between the initial colonisation of the area and the development of this community. That soil development progressed through the zone is suggested by the increase in *Astelia*, *Styphelia* and Poaceae, which by the middle of the zone also reach levels consistent with the extralocal presence of closed alpine tussock grassland, and possibly scattered areas of dwarf shrubland and alpine *Astelia* bog. This development through the zone makes it likely that the first interpretation given above is the correct one; and that a colonising herbaceous community was present at the base of the zone. In areas in the Carstensz Mts that have been deglaciated within the last 35 years (Plate 23), at 4,200 m the pioneer vegetation consists of tufts of a viviparous variety of *Deschampsia klossii*, hummocks of *Sagina* and mosses and plants of *Epilobium detznerianum* and *E. prostratum*. *Tetramolopium* cf. *alinae* follows and a low open community with prostrate *Vaccinium* sp. and more continuous moss layer occupies older moraines. Grasslands occupy nearby slopes not affected by recent ice advances; evidently some centuries must elapse before closed grasslands can develop on the moraines. The difference in rock type between Mt Wilhelm and the Carstensz Mts makes any comparison difficult. The limestone of the Carstensz Mts is softer and fine rock flour derived from it forms a good soil parent material, whereas the granite of Mt Wilhelm is very resistant to erosion and the till there may have been more blocky. On the other hand, the fine limestone tills absorb water readily whereas the granite surfaces remain wet. Although future evidence may not support the idea, the Carstensz moraine environment may be more favourable for grassland development than were the smoothed granite rock surfaces of Mt Wilhelm. The presence of a colonising vegetation in the lowest samples from Brass Tarn could be consistent with a period of some centuries having passed since deglaciation.