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7

THE LAKES

7.1 INTRODUCTION

For geomorphologists and biologists, lake basins often have special interest. The glaciologists of the CGE came to share this interest when they found englacial lakes inhabited by colonies of algae. In this chapter the englacial lakes, and the glacial lakes beyond the ice fronts, are described separately. The limnological programme had lower priority than the basic cartographic tasks and also the glaciological, meteorological and palaeoenvironmental studies; it received a major setback by the subsequent loss of most of the water samples and many of the biological samples. Nevertheless the remaining data and discussion in this chapter will facilitate the planning and execution of further work and contain information referred to in previous chapters. All the lakes examined, except Lake Discovery (3, 747 m), are above 3, 950 m. Equatorial lakes between 2, 100 and 3, 000 m are rare (Loffler 1968a, Fig. 4). Some lakes were passed by the second expedition on the Kemabu Plateau at about 3, 000 m elevation on the fifth day of the trek between Ilaga and the high valleys of the Mt. Jaya area, but time did not permit their limnological investigation.

7.2 LAKES BEYOND THE ICE FRONTS

7.2.1 Methods

The morphometric data (Table 7.1) were compiled from the isobathic maps (reproduced in Figures 7.1-7.4). An xy digitiser interfaced with a B6700 computer was used to obtain the basic morphometric parameters, which were symbolised (Table 7.1) and computed after Hutchinson (1957). The isobaths were drawn after analysis of echo-sounding traces from a Koden SR385 Sea Recorder. The manufacturers quote an accuracy of ± 5 per cent which is greater than the fresh water/sea water adjustment of 3 per cent (Washburn 1926-33, 6:464). The manufacturer's calibration is based on the average velocity of sound at 12^0 (1, 493 m/sec). No adjust-

Table 7.1 Morphometric parameters

Name of lake	Max. depth (Zm) (m)	No. of contours	Contour interval (m)	Length in m	Mean breadth in m	Volume m³ × 10³	Area m²	Area/mean depth	Mean depth	Shoreline development (Ds)	Volume development (Dv)	Mean/max. depth ratio	Relative depth
Base Camp L.	3.2	4	0.91	159	63	13913	10040	7245	1.3	1.19	1.30	.433	.003
L. Biru	12.8	7	1.83	305	80	123310	24516	4874	5.0	1.30	1.18	.396	.007
L. Coprosma	10.1	6	1.83	146	47	21490	6966	2258	3.1	1.35	0.92	.307	.011
Discovery L.	16.2	7	2.50	431	187	658300	80684	9889	8.2	1.18	1.52	.205	.005
L. Dugundugu	8.8	5	2.00	685	182	387470	124970	40307	3.1	1.47	1.05	.351	.002
Harrer L.	6.4	7	0.91	197	32	12550	6331	3191	2.0	1.60	0.93	.340	.006
L. Hijau	5.1	6	0.91	254	82	39066	20806	11081	1.9	1.33	1.09	.392	.003
L. Ketel	2.7	2	1.83	165	43	11965	7195	4327	1.7	1.35	1.82	.606	.002
L. Larson	22.8	5	5.49	673	355	3348000	238710	17019	14.0	1.37	1.84	.614	.004
Lower Muddy L.	4.6	3	1.83	175	50	15524	8790	4977	1.8	1.80	1.16	.386	.004
L. Rochiman	10.1	6	1.83	419	121	139240	50968	18656	2.7	1.27	0.81	.272	.004
L. Senewe	13.7	8	1.83	229	115	147000	26452	4758	5.6	1.31	1.22	.405	.007
Shoal L.	6.7	8	0.91	115	55	20900	6401	1959	3.3	1.12	1.46	.487	.007
Upper Muddy L.	10.1	6	1.83	143	52	25520	7500	2204	3.4	1.34	1.01	.338	.010

ment was made for temperature. Depth calibration was tested in each lake while taking temperature profiles.

The lakes were sounded from an inflatable rubber kayak, the depth recorder being balanced on the knees, the transducer held over the side on a flexible wire frame, and the boat propelled by uniformly timed and powered paddle strokes. Most sounding runs were made on calm days between features on the lake shore identified on the aerial photographs. Beam angle errors (Margrett 1955) were minimised by reducing the sensitivity of the receiving amplifier so that weak echoes from areas other than beneath the oscillator were eliminated as far as possible. Temperature readings were taken from the kayak with a pair of thermistors (G.T. 13B with 1.2K resistor shunt) calibrated with long leads, resistance being read with a small battery-operated Wheatstone bridge (1,000 Ω with a ten-turn potentiometer and made up of high tolerance components). The thermistors were calibrated before and after the first expedition and no significant drift recorded over that time.

Zooplankton and phytoplankton were sampled with nets towed behind the kayak. The nets, preservatives and specimen bottles were supplied by I.A.E. Bayly (Monash University) and Joan Powling (State Rivers and Water Supply Commission of Victoria). A temperature profile was recorded and plankton collected from each lake at times convenient to the schedule designed for other programmes. More intensive sampling would certainly be desirable. Dates and times of temperature profile recording and plankton sampling are given in Table 7.2 together with grid references and elevations.

Table 7.2 Location and some sampling data for lakes and ponds in the Carstensz area (temperature data are given in Figures 7.6 and Table 7.4)

Name of water body	Elevation m	Morphology (Figure or Table)	Date/time (plankton)	Date/time (temperature)	Grid ref. (Map 2) E	N
Base Camp L.	4, 238	F 7.1	721221/1630	720121/1700	20000	10070
L. Biru	4, 021	F 7.2	720223/1600	720223/1630	18600	10850
Cache L. (Pond 17)	4, 240	T 7.3	720213/1800	720213/1800	19720	10000
L. Coprosma	4, 209	F 7.1	720212/1000	720212/1030	19450	10300
Discovery L.	3, 747	F 7.4	720203/1300	720203/1400	23000	13900
Drink-Water Tarn	4, 238*	T 7.3	720224/1000	720224/1000	19850*	10000*
L. Dugundugu	4, 150	F 7.3	720209/1400	720209/1430	20000	13000
Harrer L.	4, 232	F 7.1	720125/1600	720125/1630	19900	10280
L. Hijau	3, 949	F 7.2	720226/1100	720226/1130	17600	11000
L. Ketel	4, 014	F 7.2	720226/1000	720226/1030	18250	10820
L. Larson	3, 975	F 7.4	720207/1500	720207/1600	22800	12750
Mapala L.	4, 360	T 7.3	720222/1500	720222/1500	20000*	9880*
Lower Muddy L.	4, 231	F 7.1	720211/0930	720211/1030	19800	10180
L. Rochiman	4, 140*	F 7.3	720209/1030	720209/1100	20120	13500
L. Senewe	3, 974	F 7.4	720207/1100	720207/1030	23300	13300
Shoal L.	4, 213	F 7.1	720211/1600	720211/1645	19480	10500
Upper Muddy L.	4, 242	F 7.1	720221/1530	711221/1600	20150	10000
Route-foot L.	4, 230	T 7.3	720211/1500	720211/1530	19640	10450
Pond 13	4, 200	T 7.3	720213/1600	720213/1600	19320	10450
Pond 15	4, 200	T 7.3	720213/1630	720213/1630	19290*	10400*
Pond 16	4, 240	T 7.3	720213/1700	720213/1700	19100	10370
Pond 19	4, 260	T 7.3	720222/1600	720222/1600	20380*	9880*

* Values approximate only.

7.2.2 Age, morphology and drainage

The basins exhibit glacial features although some may occupy the sites of enclosed depressions in karst landscapes of the pre-glacial times. Those basins that have filled since emergence from beneath ice cover hold the most accessible record of post-glacial events, and are dealt with in Chapter 9. The echo soundings made of the modern lakes showed that lake bottoms were often "soft" and in process of infilling by delta encroachment (Photograph 7.1). Nearly all of the lake basins are underlain by limestone of high purity, and although some are in depressions completely underlain by clay tills, any of the lakes might become emptied from below as a result of solution weathering in the bedrock. Surface streams are relatively important only on the most recently glaciated bedrock, on thick clay till, or between lakes situated very close together, one directly downhill from the other. Many of the lakes therefore are without surface outlet, inlet, or both of these. The source of lake water varies and this is reflected in physical and biological aspects of the data collected from the lakes.

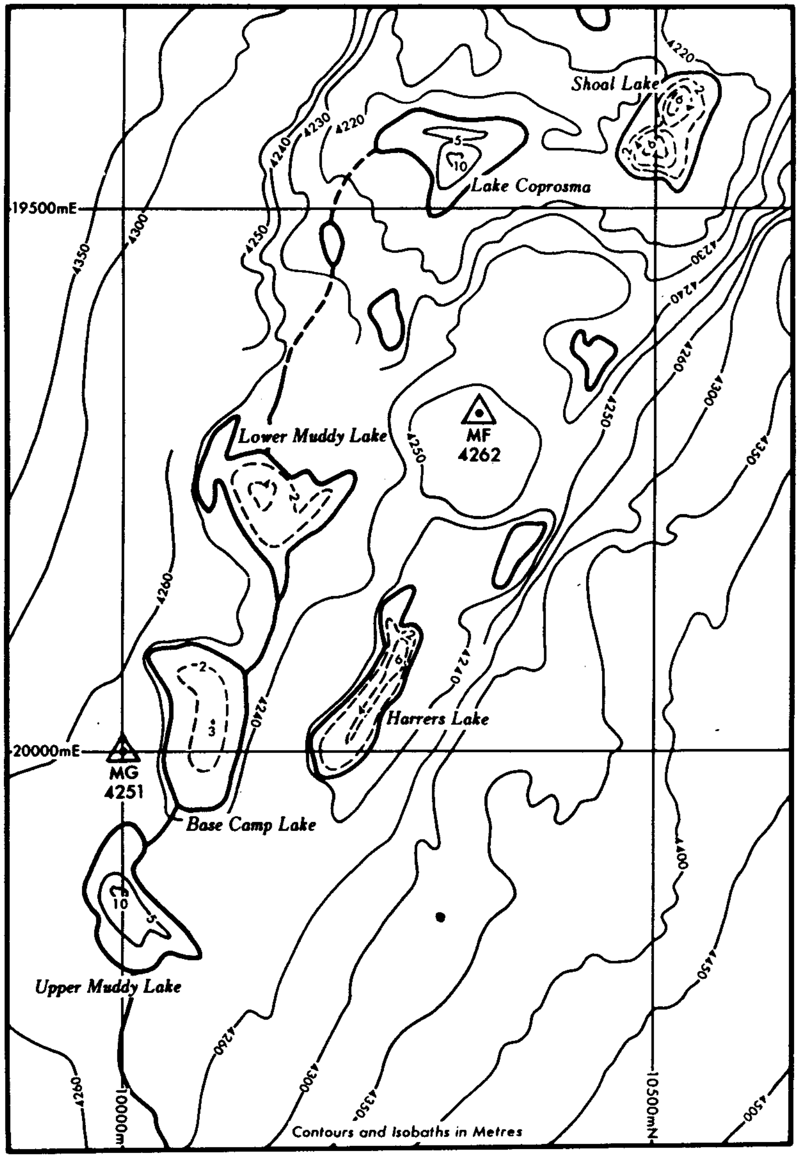

Figure 7.1 Morphology of lakes in the Upper Meren Valley

Suspended particles are the main cause of the marked differences in turbidity. Accounts by visitors to the area (e.g. Harrer 1964) convey the fascination of the turquoise waters of the lakes in the Upper Meren Valley and the blue and green waters to be found in the Lower Meren Valley lakes: the Groenemeer and the Blauwemeer of Dozy (1938). These clear waters contrast to the pale grey waters of the lakes fed by glacial meltwater charged with rock-flour.

The youngest lakes are those closest to the retreating ice fronts. Most of these are found in the Upper Meren Valley at about 4, 250 m (Fig. 7.1) and are 50 or less years old (see Chapter 3). Because of the lens of rock-flour on the sides and bottom, these bedrock basins can hold water, despite being surrounded and partly subjected to underground drainage. These lakes were formed in a zone of glacial erosion, where the Meren glacier excavated bedrock weaknesses in the floor of the valley. The morphology of the lakes may also reflect pre-glacial and pre-neoglacial karst landscape features now scraped clear of soils and partly plastered with rock-flour and glacial cobbles; all of these keep some of the drainage on the surface.

The lakes of the Lower Meren Valley (Fig. 7.2) lie in moraine basins and are probably some 70 to 1,000 years older than those of the Upper Meren Valley. Lakes Biru and Ketel occupy the upper tread of the Lower Meren Valley (4,020 m). They lie in enclosed depressions in glacial till but are not dammed back by moraine ridges. Lake Biru lies directly beneath the steep bedrock valley step which marks the boundary between bedrock and till on the floor of the valley. There is no evidence that the dimensions of either Lake Biru or Lake Ketel are determined by irregularities of the bedrock under the till. The lakes represent the area where ice stagnated below the valley step during retreat. Lake Biru is rather

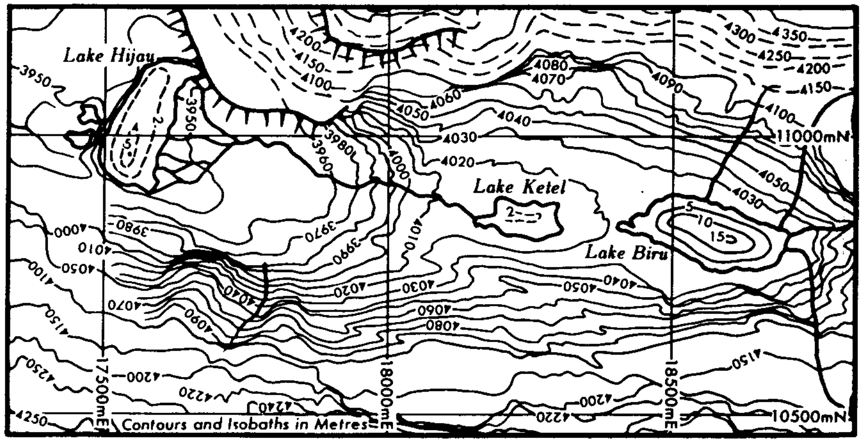

Figure 7.2 Morphology of lakes in the Lower Meren Valley

large for a kettle, however, and is probably at least partly a legacy of rotational slip of the glacier below the valley step. Bedrock appears as an outcrop at the foot of the step between Lake Ketel and Lake Hijau (see Fig. 7.2) but, for the most part, the step is plastered with till incised by the creek draining Lake Ketel towards Lake Hijau. This lake is dammed by one of the ridges in the complex of end moraines at the limit of the neoglacial advance. The inlet stream below the valley step fans out, probably reflecting the braided pattern of the glacifluvial drainage which causes sedimentation and encroachment into the lake along the whole of the eastern shore.

The lakes north of the high valley and the Northwall fall into two groups. Lakes Dugundugu and Rochiman (4,150 m, Fig. 7.3) are close to the wall, face north, and had the same bottom temperatures on 9/2/72 (see Fig. 7.5). The basins are mainly in bedrock on the sandy members of a breached anticline. The area was probably deglaciated by 9,000 BP and is outside the limits of the neoglacial advances. However, increased icefalls from the Noordwand Firn during neoglacial times would have affected water temperatures and sedimentation rates at Lake Dugundugu and, as a result, Lake Rochiman also. Ice avalanche boulder tongues on the southern shore have reduced the size and probably the depth (max. depth, Zm = 8.8 m) of Lake Dugundugu, and the eastern shore has been progressively altered by delta and vegetation encroachment. Lake Rochiman (Zm = 10.1 m) is out of reach of avalanche debris and has probably not altered in size since deglaciation. These basins appear to be largely glacially excavated although the pre-glacial karst landscape may have contributed.

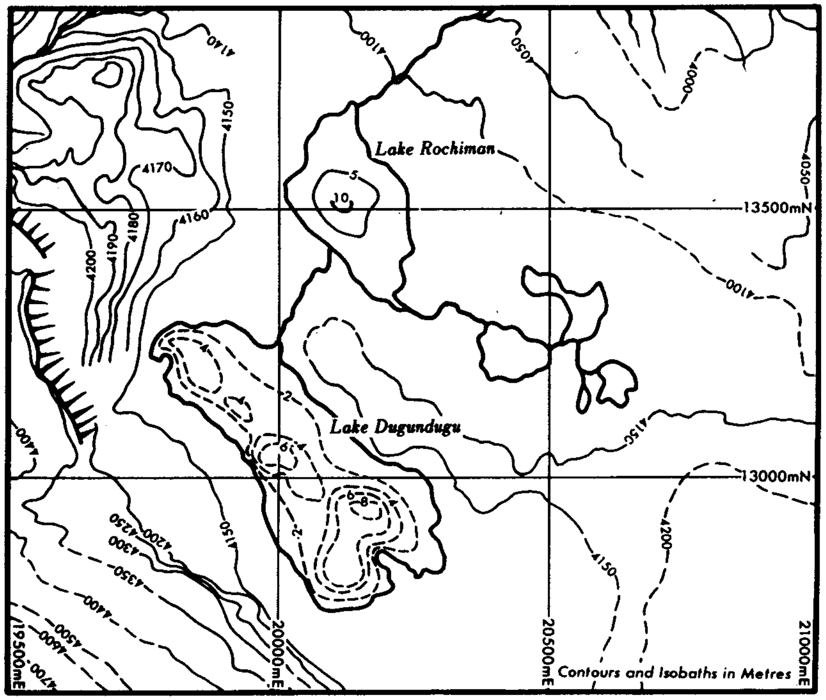

Figure 7.3 Morphology of Lake Dugundugu and Lake Rochiman

Lakes Larson and Senewe (3,975 m altitude, Fig. 7.4, Photo 7.3) occupy basins in a much larger enclosed depression of limestone, which may represent the base of a pre-glacial karst landscape. The stream between the two lakes, almost certainly perennial, flows across till, outwash gravels, and bedrock. Both lakes have some surface influent streams, but there is no surface effluent to this drainage. It is very likely that the resurgence, and main influent stream for Lake Discovery (227 m below), carries water mainly derived from the Larson and Senewe basins. This water would thus pass north-west of Lake Senewe under the much weathered and grike-covered surface forming the lowest part of the depression rim. Lake Discovery occupies the lowest part of a larger enclosed depression in limestone which is mantled with till and glacifluvial deposits up to the lowest part of its rim; the latter also was once scoured by ice and is now traversed by well developed grikes. The Lake Discovery effluent disappears in a sink in the stream-bed close to the lake.

Ice retreated from the Lake Discovery basin between about 14,000 and 10,000 years ago, and hence Lake Discovery appears to be the oldest lake investigated. Much of the basin has been infilled, partly by glacifluvial material. Lower down the valley the basins of Ijomba have all but completely infilled during the last 14,000 years or so (Chapter 9).

The various origins and ages of the basins are reflected not only in their morphology (Figs. 7.1-7.4) and morphometry (Table 7.1) but also in graphs of change of area with depth.

7.2.3 Thermal structure and turbidity

Temperature profiles taken are summarised in Fig. 7.5. Temperature profiles were measured only once. Most lakes were sampled and profiled in mid-afternoon (Table 7.2).

7.2.3.1 Lakes of the Upper Meren Valley — Base Camp Lake and the lakes upstream of it are fed by glacial meltwater. Temperatures seem at first glance to be somewhat high (Fig. 7.5). The lakes are very turbid, with absorption of solar radiation by the suspended inorganic matter in these latitudes of high sun angles. These meltwater lakes, draining into one another, show progressive increase of temperature downstream. In each case the coldest water is at the bottom of the lake and is warmer than 4^0C. The steepest temperature gradient is recorded in the Lower Muddy Lake; its bottom waters have the same temperature as those of Base Camp

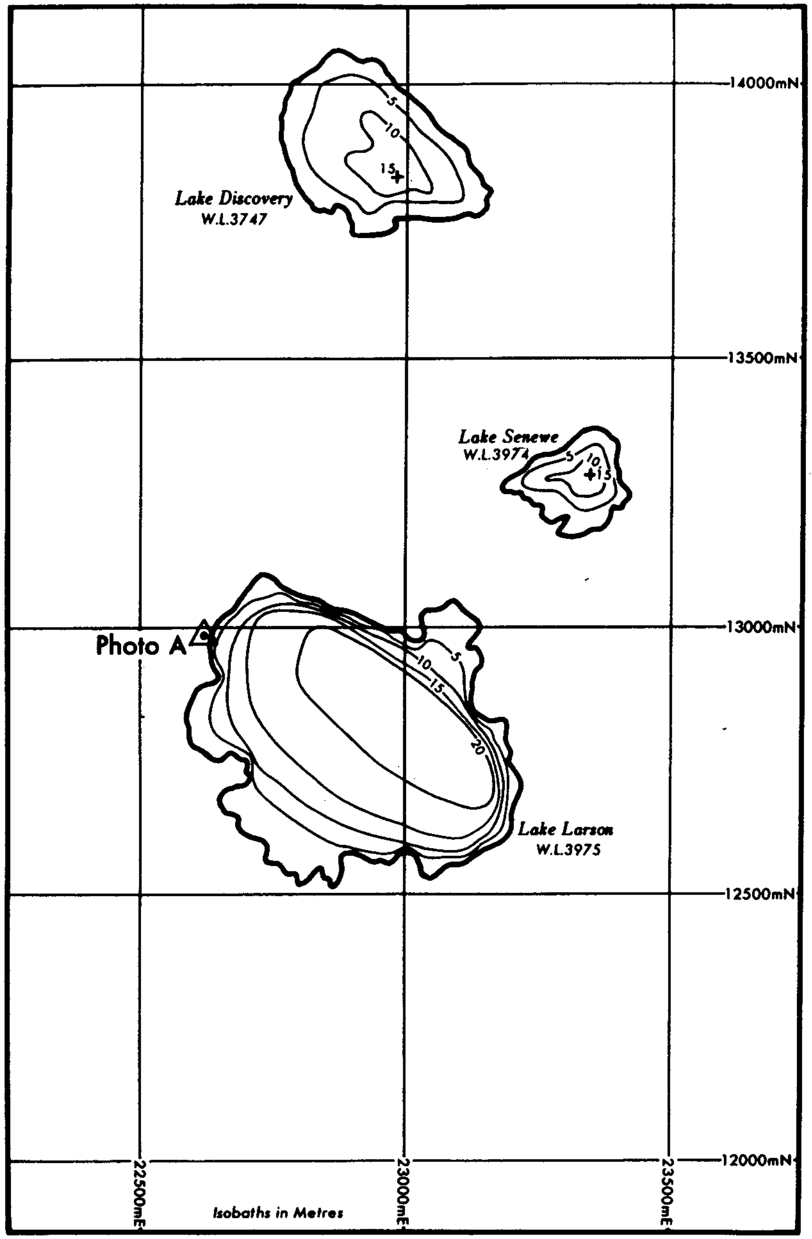

Figure 7.4 Morphology of Lakes Larson, Senewe and Discovery

Lake. Lower Muddy Lake overflows irregularly into the less turbid Lake Coprosma, which has no surface effluent.

The temperature profile for Lake Coprosma reflects its position at the discontinuous end of an intermittent surface drainage pattern. While the expedition occupied the Meren Valley, the Lower Muddy Lake overflowed about five times and at irregular intervals, and only twice did the overflow reach lake Coprosma. Shoal Lake and Harrer Lake are not fed by glacial meltwaters at present and lack suspended inorganic matter, although the

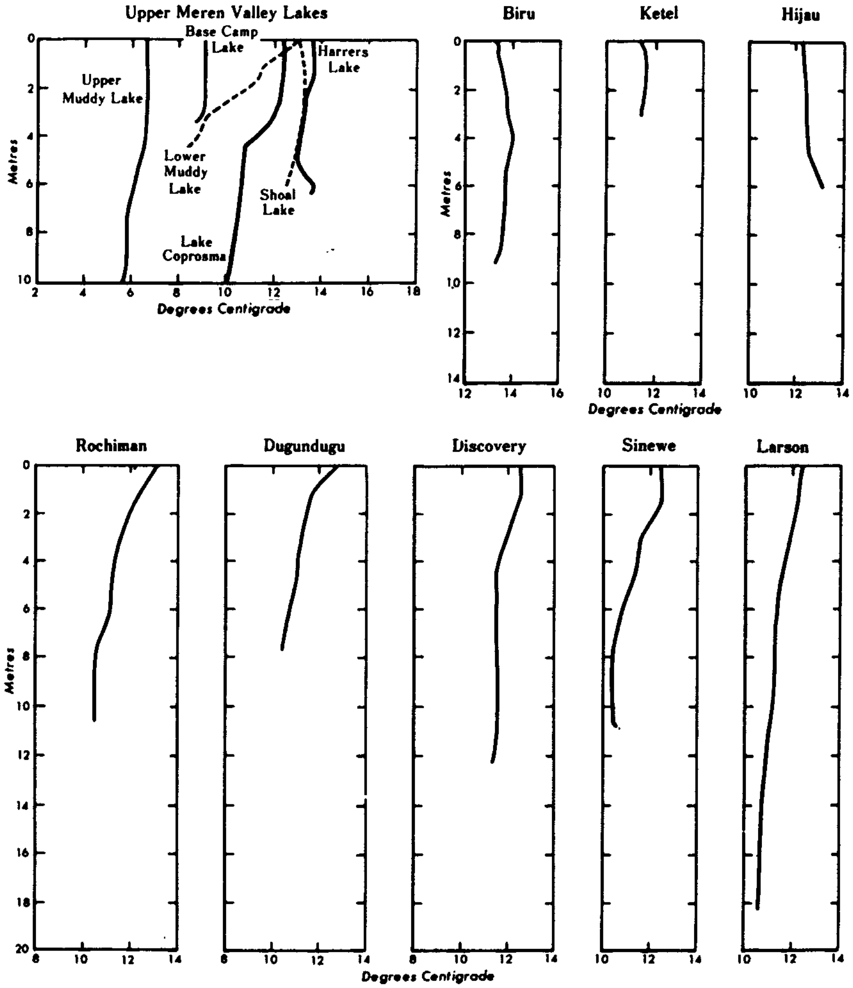

Figure 7.5 Temperature profiles in lakes

1942 USAF aerial photographs show turbidity in Shoal Lake as well as in Lake Coprosma. These are now the turquoise lakes through which, in the case of Shoal Lake and Harrer Lake, the yellow clay lining the bottoms can be easily seen. This is especially so for Harrer Lake; its temperature profile suggests the possibility of a continuous heat transfer from the lake bottom during the day. On the day it was sampled the bottom water was warmer than the overlying water layers, and this could well be a common feature for all sunny days except perhaps during the melting of snow falls, when Harrer Lake and Shoal Lake have some small influent streams. The temperatures of some of the smaller lakes of the Upper Meren Valley also reflect the difference between clear lakes, i.e. those without inlet or outlet, and the meltwater-fed turbid lakes (Table 7.3).

7.2.3.2 Lakes of the Lower Meren Valley — Lakes of the Lower Meren Valley are not turbid. The bottom of Lake Hijau (Photo 7.2) (Zm = 5 m) can be seen through the green waters, which support prolific algal communities, during windless periods. The two higher lakes are somewhat more shaded and the larger, Lake Biru, which has clear blue water, and is too deep for the bottom to be seen (Zm = 12.8 m). The temperature profile for Lake Hijau is similar to that for Harrer Lake and probably for the same reason: i.e. the bottom water layers received heat transferred from bottom sediment warmed by direct insolation. The difference in the temperatures of Lakes Biru and Hijau, rather than reflecting their elevation differences (72 m) and relative positions within the valley, show that the water warms up during the day, with higher temperatures during the afternoon (Table 7.2). This effect is accentuated in the case of these two particular lakes because the northern half of Lake Hijau is in shade under the cliffs of Wachter Mountain (see Fig. 7, Dozy 1938).

7.2.3.3 Lakes North of New Zealand Pass — The temperatures of Lakes Dugundugu and Rochiman reflect the position of Lake Rochiman further from the shade of the Northwall (Fig. 7.3). The surface temperatures recorded for Lakes Larson, Senewe and Discovery are roughly the same although the waters of Lake Senewe between 6.5 m and 10.5 m are colder than those of the other two. Bottom temperatures for Lakes Senewe and Larson were about the same but they were taken on different days and at different times. The bottom-water temperature of Lake Discovery, when recorded, was about one degree warmer than the bottom of the other two. As with Lakes Biru and Hijau, differences in temperature profiles recorded for Lakes Senewe and Larson probably arise because the former is closely surrounded by steep walls on several sides; also the temperatures there were measured in the morning some six hours earlier than in Lake Larson.

7.2.3.4 Small lakes and ponds of the Upper Meren Valley (Table 7.3) — In this group of water bodies, shade and turbidity seem to be the major factors influencing temperatures of the water.

Table 7.3 Approximate maximum depth, temperatures, and some related factors for ponds of the Upper Meren Valley (for elevations and dates of measurement see Table 7.2)

Name	Zm (m)	Temperature (^{0}C)		Aspect etc.	Colour/ Turbidity
		Surface	Bottom		
Mapala Lake	1.2	11.3	12.8	On Southwall of Valley. Not as shaded as 16, 17	Turquoise water Yellow clay — bottom visible
Route-foot Lake	3.0	13.7	13.6	North side, valley floor beneath steep cliff.	Somewhat turbid but slightly turquoise
Pond 13	1.5	13.7	13.3	On Valley floor: well shaded by valley sides	Clear rocky bottom with algae visible
Pond 15	1.9	12.3	12.3	On Valley floor: well shaded by valley sides	Clear rocky bottom with algae visible
Pond 16	3.1	11.3	12.3	Southwall of valley beneath steep cliff	Turquoise water — yellow clay and rocky bottom clearly visible
Pond 17 (Cache Lake)	1.2	10.6	10.7	Southwall of valley beneath steep cliff	Turquoise water — yellow clay and rocky bottom clearly visible
Pond 19	1.8	11.9	12.2	Glacier fed pool below trig point FA	Turbid

7.2.4 Plankton sampling

The small plankton collections made were analysed by I.A.E. Bayly (zooplankton, Appendix 7.4) and J. Powling (phytoplankton, Appendix 7.5). *Acanthocyclops viridus* from Lake Larson, Lake Dugundugu and Pond 15 was identified by D. W. Morton (Zoology Department, Monash University).

Although the collections are very fragmentary they are the first such data from the highest mountains of Irian Jaya. This data not only starts an ecological inventory but is also of interest to students of tropical high mountain lakes in general, especially if palaeolimnological data can be used to show the history of colonisation, and thereby the origin of the present planktonic biota (Loffler 1973).

7.2.5 Discussion

None of the temperature profiles taken in the lakes beyond the ice fronts of the Carstensz area suggest that any of them develop stable stratification, although more extensive investigation would be necessary to eliminate this possibility. It is most likely that the lakes documented here are cold polymictic lakes of the *Paramos* type, described for other tropical regions by Loffler (e.g. 1972). No particular pattern for such oligothermic lakes, which circulate at frequent intervals, can be expected in temperature profile data taken only once and almost at random (day) times. However the turbid lakes of the Meren Valley (Upper Muddy Lake, Base Camp Lake, and Lower Muddy Lake) have distinctive thermal characteristics (Fig. 7.5) due to the presence of glacial meltwater which discharges from the glacier during the day and evening. Also of interest is the possibility that the heat budget of the turquoise and clear lakes is influenced by heat transfer from the lake bottom which appears to absorb the direct rays of the sun due to the high water transparency. The water, in all measured cases is of comparative chemical purity. The effect of shade seems to be as important as that of altitude in determining the temperatures of the lakes studied.

Because plankton collecting was so restricted little can be said of the biogeographical importance of the lakes in the Carstensz area. Some features are worth comment however. *Acanthocyclops viridus* was present in collections from Lake Larson, Lake Dugundugu and Pond 15, and Bayly remarks on this as a first record for the Australasian region (Appendix 7.4).

Perhaps a significant negative feature is the absence of pigmented species. For instance Daphnids are less common or absent above 4,200 m, but no pigmented species were found (Appendix 7.4). This was also the case in high East African Lakes (Loffler 1968b) but not in high lakes of the Andes (Loffler 1964). Cryoalgae from the glacier surface were of course pigmented (Chapter 6) but associated Rotifera and Paramecia were not. Pigmentation is thought to be a result of the higher level of insolation, lower atmospheric pressure, low humidity and lower ozone content of the atmosphere of the high tropics. High UV radiation occurs in such conditions. Thomasson (1967) has suggested that increased ultra violet radiation may be responsible for the presence of triradiate facies of usually biradiate taxa in high altitude waters.

Unfortunately most of the plankton collections were not well enough preserved for extending all identifications to species level. Further comment must await more comprehensive collection in the future.

The contrast in age between lakes north of the Northwall firn, and in the high valleys has no obvious ecological parallel. Salvadore's Teal (*Anas waigiuensis*) was observed by CGE members on Lake Discovery as well as on the lakes of the Lower Meren Valley, between December 1971 and February 1972 (Schodde et al. 1975) and there seems no reason why Lake Discovery should not have been a local dispersal centre for some 10,000 years (Chapter 9). Unfortunately no plankton was recovered from the Lower Meren Lakes, but plankton collections and bird observations from the Upper Meren Valley support the idea that dispersal by birds alone would account for much of the colonisation of newly deglaciated basins in front of retreating glaciers in the high valleys.

7.3 THE ENGLACIAL LAKES

7.3.1 Nature and occurrence

These lakes were photographed by Dozy (1938, Bild 5& 6) who commented on their abundance and steep walls. They also appear on the vertical photographs of the USAF trimetrogon series (1942). In that year many were found in the ablation zone of the Meren Glacier near the ice margins at the junction of the Meren and Northwall firn, and further west on the Northwall firn. The oblique USAF photos include views of the Carstensz Glacier. As today, the Carstensz tongue was steeper than the Meren and had fewer englacial lakes restricted to the less steep zone above the snout.

The lakes occupy enclosed depressions in the glacier surface; the wider depressions as a rule contained the deeper lakes. Few of the lakes have surface outflows, and certainly no more than half are fed directly by englacial streamlets. The surface of the glacier has a pronounced weathering crust which causes the depression walls to be whitened and toughened. These walls commonly hold fresh snow if nearer the firn line, and less commonly further down-glacier. Both snow and ice cryovegetation can be found on these walls, which slope outward in most cases giving most depressions the shape of a funnel with a short, wide, rounded and closed-off outlet. The lakes are contained in the closed end and their steep walls are entirely in blue ice, there being, of course, no weathering crust beneath water level.

In 1972 the largest englacial lakes occurred in the ablation zone beneath survey station FB, on the south side of the glacier. They are also found directly down-glacier from the lowest part of the accumulation zone.

The development of these lakes may be favoured by lower ice velocities. An additional factor may be the greater compression of ice on the south side of the glacier, where a southward component in the glacier flow pushes ice against the Midden-ridge. Thus the permeability of the ice is reduced and any tendency for transverse crevasses to develop is diminished. In 1942, however, the largest englacial lakes were beneath the junction of the Meren Glacier and the Noordwand firn and above what is now Harrer Lake (USAF air photographs). Perhaps here the lack of a steep bed and the convergence of ice flow from the Noordwand firn and the Meren Glacier may have increased the impermeability of the glacial ice.

The role of cryovegetation in initiating these depressions is discussed in Chapter 6. The algae were most prolific in hollows in the bottoms of the deeper lakes and temperatures inside the colonies were above 0°C and as much as 4°C during the daytime. Absorption of radiation by the algae led to a marked daytime thermal gradient from the surface (0°C) to the bottom (generally from 2°-4°C). This would have begun breaking down before sunset but only rarely did surface freezing occur in the higher lakes overnight. The heat generated is apparently dissipated into the meltwater and glacial ice, and a rather equable thermal region is established in which the lakes remain above 0°C at all times, even though meltwater from elsewhere on the glacier almost ceases during cold nights. A very minor amount of mineral matter can be seen in the bottom of some of the lakes, but never enough to account for what we should now regard as the biological equivalent of cryoconite holes.

7.3.2 Discussion

Cryoconite holes result from dust on ice and snow surfaces. The dust considerably reduces the albedo of the ice or snow surface. Solar radiation absorbed by the dust layer causes excessive melting in the immediate vicinity so the layer sinks into the glacier, forming cryoconite holes. Both direct and indirect solar radiation is involved. In low latitudes direct radiation would be by far the most important. The thickness of the cryoconite layer is an important variable, the optimum melting resulting from an evenly distributed coating that is not thick enough to have any significant insulation capacity (cf. dirt cones, Swithinbank 1950).

That organic material may play the same role as dust in the formation of cryoconite holes appears to have been first noted by Steinbock (1936). Both organic and inorganic debris, predominantly wind-blown, was recognised, and the thickness of the layer regarded as capable of increasing with time. The Carstensz englacial lakes are formed by a cryoconite process, but the layer is predominantly organic and, rather than being detrital and wind-blown, it is composed of mainly living and regenerating cryovegetation (Chapter 6). Perhaps then the term cryovegetation lakes is more appropriate to this phenomenon than would be the term cryoconite lakes.

These cryovegetation lakes are the largest reported. The particular factors that favour their formation in the Mt. Jaya area are probably the optimum balance between incoming radiant energy, proportion of ultraviolet radiation, partial pressure of oxygen, suitable glacier physiography, and ice impermeability. By contrast, in high latitudes where most work on melt phenomena appears to have taken place (e.g. Van Autenboer 1962; Gajda 1958; Nordenskjold 1875) indirect radiation is important and cryovegetation (never as prolific as at Mt. Jaya) is insignificant; inorganic debris predominates at these latitudes, holes more frequently freeze over and meltwater is rare or absent. The cryovegetation lakes of Mt. Jaya add a new dimension to the study of cryoconite phenomena, and further detailed micrometeorological, glacioclimatic and biological programmes should be mounted while sections of the retreating glaciers still exist that are favourable to the formation of these lakes.

7.4 APPENDIX I. REPORT ON CGE WATER SAMPLES AND ZOOPLANKTON COLLECTION

by IAN A. E. BAYLY (Dept. of Zoology, Monash University)

7.4.1 Water conductivity

The conductivity of the water samples measured is given in Table 7.4.

It should be borne in mind that the conductivities of these samples were not measured until July 1973 — i.e. some 18 months after collection. The tendency during the period of storage, especially for those in glass containers, would be for conductivity to increase. It should also be noted that some of the screw-top plastic vials had rather loose fitting lids.

The conductivity of the meltwater on the Carstensz Glacier is very low indeed, and can be compared with a range of 4.6–5.3 μS/cm for five glacial lakes on the Kosciusko Plateau, Australia (Williams, Walker & Brand 1970:103-116). The conductivities may also be compared with a mean value of 102 μS/cm obtained for samples from fifteen lakes on Fraser Island, Queensland (January 1972). These are very dilute lakes with a mean salinity of ca. 40 mg/l (Bayly 1964:56–72).

In summary, three of the conductivities are exceptionally low for natural waters and may be considered as "distilled water". The remainder indicate very dilute waters, and may be presumed to have a salinity of less than 100 mg/l; most would have a salinity considerably less than this.

7.4.2 Zooplankton samples

The result of the zooplankton hauls are included in Table 7.5.

In summary it may be said that Daphnia sp., Bosmina sp. and Acanthocyclops sp., were all common elements amongst the planktonic Crustacea. Although Rylov (1963) regards Acanthocyclops viridis as a cosmopolite it has not hitherto been recorded from the Australasian region.

Table 7.4 Conductivity of water samples

Origin of sample	K_{18} μS/cm
Carstensz glacier meltwater	2.25
Meltwater lake at snout of Carstensz glacier	
east sample	10
west sample	10
Lake Biru	112
Cache Lake (Pond 17)	145
Lake Coprosma*	120
Lake Discovery	152
Shoal Lake*	115
Route-foot Lake*	112
Pond 15	117
Pond 19	125
Meren ice front Lake	104

Mean cond. = 103 μS/cm. * Stored in glass containers.

Table 7.5 List of phytoplankton and zooplankton collected from Mt. Jaya lakes

Plankton	Name of lake (elevation m / max. depth m)															
	L. Discovery (3747/16.2)	L. Senewe (3974/13.7)	L. Larson (3990/22.8)	L. Rochiman (4140/10.1)	L. Dugundugu (4150/8.8)	L. Ketel (4014/2.7)	Pond 13 (4200)	Pond 15 (4200)	L. Coprosma (4209/10.1)	Shoal L. (4213/6.7)	Route-Foot L. (4230)	Lower Muddy L. (4231/4.6)	Harrer L. (4232/6.4)	Drink-water Tarn (4238)	Pond 16 (4240)	L. Mapala (4360)
PHYTOPLANKTON																
CYANOPHYTA																
Stigonematales																
Stigonema							?								+	
Chroococcales																
Anabaena								+								
Merismopedia				+												
Nostocales																
Aphanocapsa							+									
Lyngbya															+	
Nostoc						+	+		+						+	
Oscillatoria						+	+	+						+	+	
Scytonema							+								+	
PYRRHOPHYTA																
Peridiniales																
Gymnodinium		+				+		+	+				+	+		+
Dinococcales																
Ceratium		+		+++			+		+		+	+				
EUGLENOPHYTA																
Euglenales																
Trachelomonas				+												
T. volvoeina													+			
CHRYSOPHYTA																
Crysophyceae																
Dinobryon				+												
Xanthophyceae																
Triboneura													+			
Bacillariophyceae (diatoms)																
Acnanthes						+										
Amphora	+										+		+			
Caloneis													+			
Cymbella	+			+		+		+		+	+		+	+	+	+
Denticulata										+						
Epithemia	+							+							+	
Eunotia	+++							+		+			+			
Gomphonema															+	
Navicula				+	+	+							+			
Nitzschia	+															
Pinnularia	+					+	+						+			
Stauroneis													+			
Synedra													+			
CHLOROPHYTA																
Chlorococcales																
Actinastrum																+
Botryococcus braunii				+	+						+	+				
Dactylococcus				?												
Elakatothrix				+												
Pediastrum				+												
Scenedesmus					+	+										
S. bijuga				+												
Tetrasporales																
Coelastrum							+				+					
Volvacales																
Gloeocystis							+									
Zygnematales																
Mougeotia									+							
Pandorina							+									
Spirogyra					+											
Staurastrum					+											
Dedogoniales																
Cosmarium				+		+							+		+	
Oedogonium							+						+			

Table 7.5 continued

Plankton	L. Discovery (3747/16.2)	L. Senewe (3974/13.7)	L. Larson (3990/22.8)	L. Rochiman (4140/10.1)	L. Dugundugu (4150/8.8)	L. Ketel (4014/2.7)	Pond 13 (4200)	Pond 15 (4200)	L. Coprosma (4209/10.1)	Shoal L. (4213/6.7)	Route-Foot L. (4230)	Lower Muddy L. (4231/4.6)	Harrer L. (4232/6.4)	Drink-water Tarn (4238)	Pond 16 (4240)	L. Mapala (4360)
ZOOPLANKTON																
PROTOZOA																
Difflugia	+												+			
Nematode								+								
ROTIFERA																
Asplanchma		+														
Brachionus						?							+			
CLADOCERA																
Bosmina	+++	+	+	+	++							+				
Daphnia	++++++		+	+	++++											
Harpacticoid		+														
COPEPODA																
Acanthocyclops				+												
A. viridis			++		+											
Calanoid													+			
Cyclopoid	+	+	+			+	+				+					
Cyclopoid nauplii						++					++					
INSECTA																
Chironomid larvae	+			+	+								+			
Collembolans														+		
Midge larvae							+				+					
Mosquito larvae	+			+		+	+				+		+			
Mites		+											+			

Name of lake (elevation m / max. depth m)

+ Present ++ Common +++ Very Common ++++ Dominant

Mosquito and chironomid larvae were also commonly present in the plankton collections and collembolans occurred in one sample.

Mites occurred in two samples. A significant negative feature was the complete absence of calanoid copepods in the zooplankton trawls although some specimens were recovered in the phytoplankton tow from Harrer Lake.

7.5 APPENDIX II. REPORT ON CGE PHYTOPLANKTON COLLECTION

by JOAN POWLING

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7.5.1 Methods

Phytoplankton samples were collected in a silk trawl net (61 micron mesh size), towed behind an inflatable rubber boat. The samples were preserved in medicinal iodine rather than Lugol's Iodine and consequently were not as well preserved as intended. The examination of many fragile genera was therefore impossible.

Some of the collections were very sparse and some, after remaining for some twelve months in custody, had developed a few fungal hyphae. However most enabled an examination of some kind and the results are included in Table 7.5.

In most cases it has been impossible to take the identification to species level but an attempt has been made to determine the genus of each alga present.

7.5.2 Discussion

This collection suffers from the same disadvantages as that described by Thomasson (1967) in that there are sparse chemical data. Desmids are numerous in water with low pH and poor conductivity, and Thomasson (1967) records large numbers of desmid genera and species from the Mt. Wilhelm Lakes in PNG which are at elevations comparable to that of Lake Discovery. There are very few desmids among the CGE samples which is surprising because the dominant cations in the Mt. Wilhelm waters are Ca and Mg (Loffler 1973) as they would be in the Carstensz lakes

Much more work needs to be done on the taxonomy of the small diatoms at Harrer Lake, Lake Ketel, Lake Discovery, and Lake Rochiman. In most cases these small diatoms were the dominant algal genera present but at Lake Rochiman and Lower Muddy Lake the dinoflagellate Ceratium was dominant. The species was not C. hirundinella and is so far unidentified. Botryococcus braunii was dominant in Lake Senewe.

With so little information available no attempt will be made to make broad generalisations of the lake types but it is hoped that on any future expedition more collections can be made and greater attention given to water chemistry.

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8

VEGETATION

8.1 INTRODUCTION

The change from a sea of humid green jungle in the tropical lowlands to a frost shattered alpine tundra adjacent to the deep blue of glaciers and soft dazzling snow provides the most dramatic biological contrast on this planet. On equatorial mountains, only a few kilometres sees the most luxuriant rainforest replaced by successively simpler forests with fewer species and life forms until a timber line is reached. Above this lies a zone of scattered tall shrubs, set amongst grasslands or heaths and above this again, up to the snowline, is an alpine zone of grasslands, heaths and rocky tundras.

The Sudirman Range is formed from sediments laid down in deep early Tertiary seas, perhaps forty million years ago. The date of uplift is not known, but is far more recent. It seems likely that the mountains have been formed only since the late Pliocene, that is over the last few million years, and that tectonic movements, predominantly lateral but possibly vertical, are still affecting the Mt. Jaya area (Dow 1968).

This means that alpine and subalpine environments have appeared relatively recently and in isolation from other mountain areas or cool temperate regions. The specialisation of the New Guinea subalpine and alpine floras is remarkable, in that the herbaceous and heath species have apparently had to migrate or develop over a relatively short period. However the alpine flora can be regarded as depauperate and unspecialised compared to older temperate mountains (Wade & McVean 1969) and to be still rapidly evolving rather than well adapted. Smith (1974), working on Mt. Wilhelm, has discussed the development of the alpine and subalpine herbaceous flora and concluded that elements have migrated from both northern (e.g. *Potentilla*, *Vaccinium*) and southern (e.g. *Scleranthus*, *Styphelia*) temperate regions. Some immigrants are more recent than others, and hence show less adaptation to the peculiarities of the equatorial high mountain environment.

The vegetation on nearly all of New Guinea's high mountains has a similar appearance but this conceals real variation which may also reflect