16, Lembaga Meteorologi dan Geofisika di Jayapura, Departemen Perhubungan.

Departemen Perhubungan, 1964-1974, Rainfall 1961-1973, Lembaga Meteorologi dan Geofisika di Jayapura, Departemen Perhubungan, Publications 14, 17, 18, 19, 20, 22, 23, 26, 27, 28, 29, 31 and 32.

Flohn, H., 1974, Contribution to a comparative meteorology of mountain areas. In: J.D. Ives & R. G. Barry (eds.), Arctic and alpine environments: 55-71. London, Methuen.

Hedburg, O., 1964, Features of Afroalpine plant ecology, Acta Phytogeographica Suecica 49:1-144.

Hnatiuk, R. J., McVean, D. N. & Smith, J. M. B., in press, Mt. Wilhelm Studies 2: The Climate of Mount Wilhelm. Dept. Biogeogr. Geomorph. Publ. BG/4. Canberra, Aust. Nat. Univ.

McVean, D. N., 1974, Mountain climates of the Southwest Pacific. In: J. R. Flenley (ed.), Altitudinal Zonation in Malesia, Malesian Ecology 3. Hull, Dept. Geography, Univ. Hull.

Platt, C. M., 1966, Some observations on the climate of Lewis Glacier, Mount Kenya, during the rainy season, J. Glaciology 6(44):267-288.

Riehl, H., 1954, Tropical Meteorology:117-118. New York, McGraw-Hill.

Slatyer, R. O. & McIlroy, I. C., 1961, Practical Microclimatology, UNESCO.

Steenis, C. G. G. J., van, 1972, The mountain flora of Java. Leiden, E. J. Brill.

Sukanto, M., 1969, Climate of Indonesia. In: H. Arakawa (ed.), Climate of Northern and Eastern Asia, Vol. 8 in H. E. Landsberg (ed.-in-chief), World Survey of Climatology. Amsterdam, Elsevier.

Troll, C., 1959, Die tropischen Gebirge. Ihre drei-dimensionale klimatische und pflanzengeographische Zonierung, Bonner geographische Abh. 25. Bonn, Dümmlers.

Verstappen, H. Th., 1964, Geomorphology of the Star Mountains, Nova Guinea (Geology) 5:101-158.

Webb, E. K., 1970, Profile relationships: the log-linear range and extension to strong stability, Q. J. Royal Met. Soc. 96(407):67-90.

Weller, G., 1968, The annual heat energy transfer above and inside Antarctic blue ice, Commission of Snow and Ice, reports and discussions, IUGG/IASH General Assembly of Bern, 1967, IASH Publ. 79:417-428.

# 6

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# CRYOBIOLOGY

## 6.1 INTRODUCTION

The lower parts of the Meren and Carstensz Glaciers appear rough and dirty to the casual observer, by contrast to the white snow and pale blue ice in the crevasses. The ice surface is pitted like rough concrete, especially on gentle slopes, and the pits and cracks are full of dark specks or small black flakes. Scattered across the ice are pools and englacial lakes similar to those noted by Colijn (1937). These vary from a few centimetres to 10 m across, are up to 4 m deep and contain very clear water in which scattered black mats several centimetres in diameter rest on the ice bottom or float across the top. The ice itself is clean and clear, except for a few particles of rock, because the tropical jungle and frequent rains at lower altitudes prevent much dust or other debris from rising in the atmosphere to be incorporated in the snow that forms the glacier. The surface discolouration is due to colonies of algae that occupy this cold, moist habitat to form a cryovegetation.

Observations of cryovegetation comprising many different species and exhibiting varied macroscopic characteristics have been reported from snow and ice in polar, subpolar and temperate latitudes (Kol 1968a). The Mt. Jaya ice supports several different cryophilic associations: black, red and yellow-brown ice growths, black englacial lake growths, red and yellow snow growths (Peterson 1973). The only other equatorial cryohabitat studied, the Pinchincha volcano, Ecuador (Lagerheim 1892) supports red snow growths, but ice communities have not previously been reported from equatorial areas.

Two previous studies have reported changes in albedo resulting directly from cryovegetation. Corte (1970) found that at the time of maximum annual growth, cryovegetation on snow at Cape Spring, Argentine Antarctica, produced an increased snow melting, resulting in an irregular surface with holes and cracks. Similarly Gerdel and Drouet (1968) reported increased snow melting resulting from cryovegetation on snow fields at Thule, Greenland. Black ice associations appear to be unique to Mt. Jaya and they possibly have a great influence on the ablation rate of the Meren and Carstensz glaciers. This chapter describes the algae occupying ice and snow areas and comments on their effect on the ablation process.

## 6.2 SPECIES IDENTIFICATION AND DESCRIPTION

Samples were collected by Peterson or brought in by the glaciologists from many parts of the glaciers and snowfields. Algae were preserved in formalin or by drying samples on sterile filter papers which were then sealed in plastic bags. Most species form resting spores when exposed to dessication, and these can be cultured even after a considerable period. Preliminary identification of the species present in fresh samples collected from the ice and snow of the Meren and Carstensz glaciers was performed in the field (by Peterson) using a simple light microscope (Russian MBD-I). These identifications (Peterson 1973) have been confirmed and extended after more detailed laboratory analyses of preserved and cultured samples (by Kol). The following species were found growing on the various ice and snow areas examined:

Chlamydomonas antarcticus (misidentified as C. Nivalis (Bau.) Wille in Peterson 1973)
Chlorosphaera antarctica
Scotiella antarctica
Scotiella nivalis
Scotiella norvegica var carstenszis
Mesotaenium berggrenii
Nostoc fuscescens var carstenszis

### CHLOROPHYTA

Chlamydomonas antarcticus Wille (see Fig. 6.1:26-28)
Spherical, red resting cells, 6-30 μm diameter, many with thick gelatinous sheaths. Flagellate cells not observed. Chloroplast campanulliform, pyrenoid absent, low starch and high fat content.

Chlorosphaera antarctica F. E. Fritsch (see Fig. 6.1:1-5)
Spherical yellow cells, 10-20 μm diameter, single or grouped, each cell with thick, sometimes laminate cell wall, usually surrounded by a sheath of mucilage to give a total diameter of 50-60 μm. Chloroplast spherical, pyrenoid not observed, fat droplets adjacent to cell wall forming a continuous ring in many instances, occasionally starch also present.

Scotiella antarctica Fritsch (see Fig. 6.1:7-10; 15-16)
Wide oval cells, 24-32 μm long, 18-22 μm wide, with six longitudinal, wing-like sinuous ribs. Chloroplast single, pyrenoid not observed, low starch content, abundant orange-yellow fat. Autosporangia observed.

Scotiella nivalis (Shuttlew) Fritsch
Oval cells, 20-22 μm long, 12-13 μm wide, with 5-8 longitudino-spirally decurrent ribbing ridges.

Scotiella norvegica Kol var. carstenszis nova var. (see Fig. 6.1:11-14)
Long oval orange-red cells, 12-14 μm wide and 27-36 μm long, with spiral decurrent ribs similar to Scotiella nivalis (Shuttlew.) Fritsch. High fat content localised to one pole. Chloroplast centrally located, pyrenoid present. Differing from Scotiella norvegica Kol in the number of decurrent ribs and the shape and size of the cells.

Scotiella norvegica Kol var. carstenszis nova var.
Proximum adest ad Scotiella norvegica Kol (1968a) sed differt ab eo:
1. forma et dimensione cellularum; 2. numero et flexu processorum.
Habitat: in nive flava glacie Meren montibus Carstenszis, Irian Jaya, New Guinea.

Mesotaenium berggrenii (Wittr.) Lagerheim (see Fig. 6.1:6)
Cylindrical purple or brownish violet cells, 6 μm wide, 10-25 μm long, with one chloroplast and one pyrenoid.

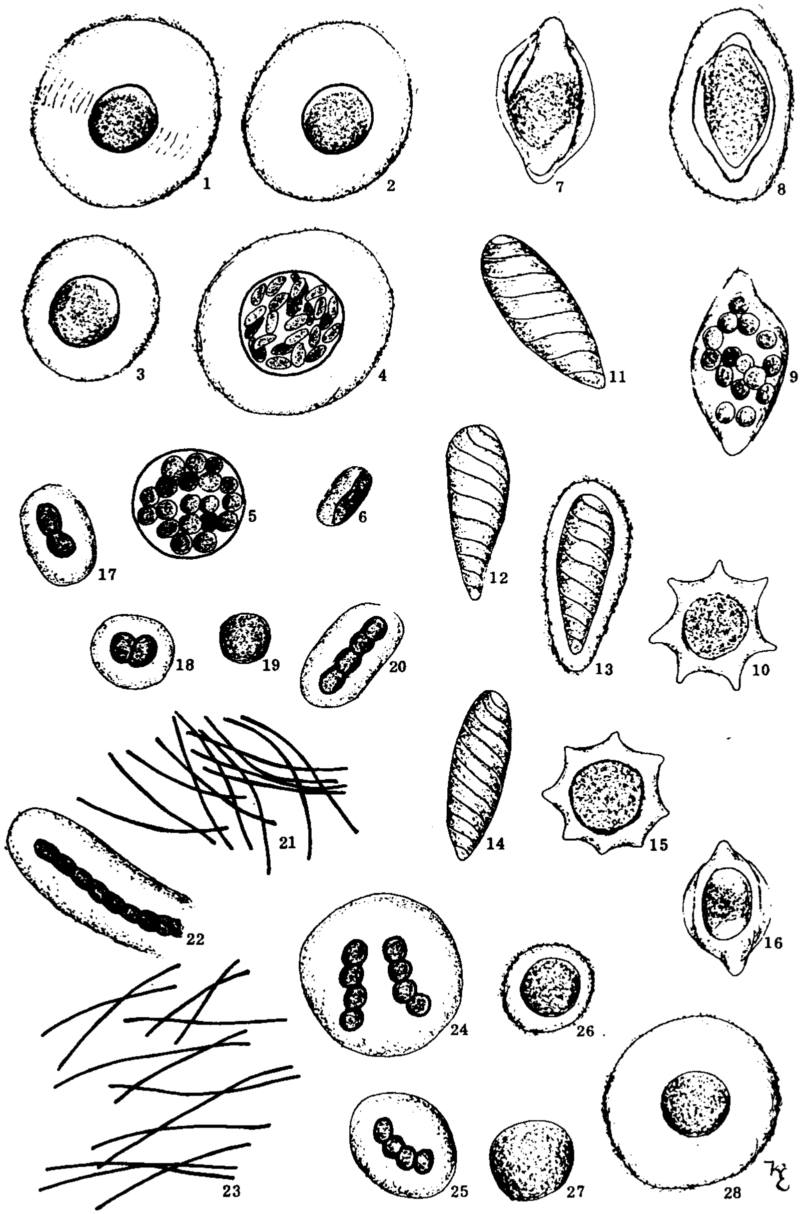
### CYANOPHYTA

Nostoc fuscescens Fritsch var. carstenszis nova var. (see Fig. 6.1:6)
Brown to black cells, nearly spherical to barrel shaped or elliptical, 4.5 μm diameter. Forming filaments coated in two thick sharply differentiated mucilagenous sheaths. The outer sheath diffluent and hyaline, pale yellow to brown in colour. The inner sheath denser and brown to black in colour. Filaments grouped to form flattened irregularly shaped thalli 4.5 μm diameter. Heterocysts spherical 7-9 μm diameter, occasionally somewhat elliptical, spores not observed. Differing from Nostoc fuscescens in the size of the cells, the size of the colonies, the form and size of the heterocyst and in the cryohabitat.

Nostoc fuscescens Fritsch var. carstenszis nova var.
Proximum adest ad Nostoc fuscescens Fritsch (1912b) sed differt ab eo:
1. in dimensione cellularum, 4-5 μm dim.; 2. in dimensione plantarum, 4-5 cm in diam.; 3. in flexu filamentorum; 4. in colore plantarum, et 5. in forma et dimensione heterocistarum. Habitat in glacie nigra in montibus Carstenszis, Irian Jaya, New Guinea.

Mesotaenium berggrenii is a common cryobiont in the northern hemisphere and has been recorded in purple-brown ice associations growing on the Colombia glacier in Alaska (Kol 1968a). It was one of the species present in the red snows of the Pinchincha volcano, Ecuador (Lagerheim 1892) and has been recorded in red snows from Antarctica.

The absence of Ancyclonema nordenskjoldii Berggr., a species characteristic of ice associations in the northern hemisphere and commonly found in close association with Mesotaenium berggrenii (1968) is of interest. This species has not been identified with certainty in the southern hemisphere (Kol 1968a) and the possibility exists that the absence of A. nordenskjoldii from southern hemisphere cryohabitats is either the result of habitat limitations or of dispersal limitations.



Both the red and yellow associations are most similar in their species composition to similarly coloured associations growing in Antarctica (Kol 1968a). Red snows containing Chlamydomonas antarcticus were first collected by Gain (1912) on the island of Wienke in the Penguin Rocks area and on Petermann Island. This species is also found in red snows of New Zealand (Kol 1968b) and appears to be a species characteristic of the southern hemisphere (Kol 1968a).

Yellow snow formed from Chlorosphaera antarctica and Scotiella antarctica has been found in the South Orkneys (Fritsch 1912a). While both these species are present in northern and southern hemisphere locations in red and pink snows, the yellow snows have only been previously found in the Antarctica (Kol 1968a). Fritsch (1912b) first described the species Nostoc fuscescens from freshwaters in the Antarctica, but the authors are unaware of any previously reported observations of this organism growing in cryohabitats.

## 6.3 FLORISTIC ASSOCIATIONS

The species composition of the cryoassociations determines their macroscopic appearance and seems to reflect physical rather than chemical differences in the habitats. Table 6.1 lists the associations and their component species.

The most extensive growth occurs in the ice ablation zones of the Meren and Carstensz glaciers and consists of the black ice and the yellow-brown

**Figure 6.1 Morphology of cryoalgae from the Carstensz Glaciers**
**1-5 Chlorosphaera antarctica (×1000)**
**1-3 Cells with very thick mucilage sheath with stratification**
**4 Zoosporangium**
**5 Autosporangium**
**6 Mesotaenium berggrenii (×1000)**
**7-10 Scotiella antarctica (×100)**
**8 Young cell with mucilage sheaths**
**9 Autosporangium**
**10 Optical section**
**11-14 Scotiella norvegica var. carstenszis nova var. (×1000)**
**15-16 Scotiella antarctica (×1000)**
**15 Optical section**
**17-25 Nostoc fuscescens var. carstenszis nova var.**
**17, 18, 20 Cell division, division of the heterocyst (×1500)**
**19 Heterocyst (×1000)**
**20-21 Trichomes with very thick and hyaline mucilage sheath, the inner one very dark brown, the outer sheath hyaline (×1500)**
**22-23 Filaments in the old colonies**
**24-25 Young sphaerical colonies (×1500)**
**26-28 Chlamydomonas antarcticus (×1000)**
**26 Cell with thin mucilage sheath**
**27 Cell without mucilage sheath**
**28 With very thick mucilage sheath**

Table 6.1 Species composition of the different cryoassociations on the Meren and Carstensz Glaciers

| Species | Association | | | | | |
|---|---|---|---|---|---|---|
| | Black ice | Black lake | Yel.-bro. ice | Red ice | Yel. snow | Red snow |
| Chlamydomonas antarcticus | - | + | - | + | - | + |
| Chlorosphaera antarctica | - | + | + | + | + | + |
| Scotiella antarctica | - | + | + | + | + | + |
| Scotiella nivalis | + | + | + | + | + | + |
| Scotiella norvegica var. carstenszis nova var. | - | - | + | - | + | - |
| Mesotaenium berggrenii | + | + | + | + | + | + |
| Nostoc fuscescens var. carstenszis nova var. | + | + | + | + | - | - |

ice associations. In general, the more horizontally oriented surfaces support the black associations and the steeper slopes the yellow-brown associations (see Photo 6.1). Thus areas of ice ablation crust with relatively large ice crystal structure supported discrete, dense black colonies ranging in size from just visible up to 3-4 cm in diameter. Groups of these colonies formed the most common and extensive cryovegetation in the ablation zones. They are dominated by *Nostoc fuscescens* var. *carstenszis*, whose filaments are purple in transmitted light.

Areas of the glacier with a fine to medium ice crystal structure supported diffuse yellow-brown communities. These yellow-brown discolourations were also extensive. They showed a distinct variation in colour intensity which reflected a variation in numbers rather than species. This association, when observed in the field, was dominated by *Mesotaenium berggrenii*. However, laboratory studies (by Kol) on preserved and cultured samples did not confirm this dominance. Similarly the field observations on the red and yellow snows indicated that this species was present but this was not confirmed by the laboratory analyses. Post-expedition checks indicate that M. berggrenii was identified correctly in the field, and had evidently failed to survive transport to the laboratory. This result is of interest, since virtually all previous studies of cryovegetation reported in the literature are based wholly on preserved material. The analysis of in situ cryovegetation might result in revision of some results in previously studied areas.

Towards the snow line smaller communities of diffuse pink and diffuse crimson ice existed. These were much less common, and relatively small in area, in comparison to the black and yellow-brown communities. Only the occasional steep slope with a south-easterly aspect was completely free from biological discolouration in the ice-ablation zone. The englacial lakes of the Meren glacier, which ranged in size from a few centimetres to several metres in depth and diameter, were universally colonised by large (15-30 cm diameter × 3-7 cm depth), discrete, dense black colonies (see Photo 6.2).

Cryovegetation above the snow line was dominated by a diffuse yellow-brown community. However small areas of crimson firn were not infrequent. Discrete black colonies were present in this region between the snow line and the firn line but they were always small and very scattered, never forming the extensive communities so characteristic of the lower slopes of the glacier. Above the firn line cryobiota were much less in evidence. Patches of diffuse crimson and diffuse yellow communities were observed in this region of the glacier.

According to Kol's classification scheme for cryohabitats (Kol 1968a) the Mt. Jaya ice body would be classified as calcareous. However pH values obtained from the ice, snow and surface meltwater ranged between pH 4-5 and were thus lower than are usually encountered on permanent ice bodies lying over limestone bedrock in the northern hemisphere. Certainly the species composition of the snow associations is more typical of a silicotrophic than a calcareous habitat.

Total hardness measurements (Pallin Test) on the ice, snow and surface meltwater gave low readings between 3-15 ppm. The concentrations of specific minerals were too low to be detected with the methods available. There were no consistent differences between the different communities in pH or total hardness characteristics. Rock fragments were a variable but ever present constituent of all the communities.

The thermal environments of the ice and snow areas are given in Chapter 4. All are equable and at or only a little below freezing point.

## 6.4 CRYOVEGETATION AND ABLATION RATES

The snow and higher firn communities appeared to be too sparse to greatly affect the albedo of the snow masses. However the lower ice areas show considerable evidence of modification by cryovegetation, particularly the stagnant gentle slopes towards the snout of the Meren Glacier. Two aspects can be considered; first, what effect does the present concentration of algal growth have on ablation rates, and second, are the observed concentrations of algae maintained over long periods?

### 6.4.1 Ablation rates

Rough measurements of radiation absorption were made with a Sekonic exposure meter. These indicated that 90 per cent of the light radiation reflected from the surface of bare ice was not reflected, and therefore was absorbed, by the black colonies. The use of Kodak Wratten Gelatin Filters demonstrated that these colonies were selectively absorbing most strongly in the blue-green region.

Temperature measurements were taken from the surface of clean ice and from the larger discrete black colonies growing on the surface in the ablation zone. Temperature measurements were also taken in various lakes (see Table 6.2). All the figures in the table were taken during periods of

Table 6.2 Temperature differences (°C) between the discrete black colonies and their surrounding habitat

| Location | Site number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Bare ice | 0.0 | 0.0 | 0.0 | | |
| Black ice colony | 7.5 | 6.0 | 6.2 | | |
| Lake water | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Black lake colony | 2.5 | 1.2 | 3.2 | 3.2 | 2.0 |

uninterrupted sunlight. It can be seen that heat was accumulated by the black colonies. They showed an increase in temperature over the surrounding ice and water from 1.2°C to 7.5°C. This heat content of the cryovegetation was probably the result of absorption of the incoming radiation, since metabolic heat would be insufficient to raise and hold the temperature of the colonies 1-7°C higher than the surroundings (Fogg 1967).

Most discrete black ice colonies over 4-5 cm in diameter were located in circular holes containing water from 2-3 cm deep (see Photo 6.3). A continuum of lake sizes from this smallest, water filled hole to the largest lakes, 6-7 m diameter, were present on the Meren glacier in the rapidly ablating zone. Many of the smaller lakes were situated along obvious lines of weakness in the ice. These lines were marked by concentrations of small black colonies forming distinct streaking patterns on the ice surface (see Photo 6.4). It is possible that the increased local surface melting required for the formation of the englacial lakes is initiated by an aggregation of these discrete, black, radiation-absorbing colonies in indentations of the glacier which form the channels for surface meltwater runoff. Since the temperatures recorded from the black lake growths growing at the base of the englacial lakes indicate that they are 1-2°C warmer than the surrounding water it is probable that they continue to promote melting of even the largest englacial lakes. Corte (1970) has described similar algal initiated ponds in Antarctica.

### 6.4.2 Persistence of cryovegetation

Observations have not been made on the Mt. Jaya cryovegetation at seasons other than summer but the extensive nature of the growths on the ice suggests that these at least are permanent rather than seasonal. Certainly no macroscopic changes were observed in the growth pattern during January and February 1972. If the vegetation is not seasonal then the total biomass must represent the product of many years of sustained growth, and this would be especially true of those areas with reduced rates of surface runoff. The meltwater streams on the ice always carried black associations which often lodged on the ice-surface at the channel edge.

Three experimental plots were marked out on the Meren glacier on the ablation crust. The sites were cleared, as much as possible, of black colonies in an attempt to determine the rate and method of recolonisation.

However within three days all three cleared plots were densely covered in growth and were indistinguishable from the surrounding ice. It is apparent that the continuous surface runoff which is augmented during occasions of heavy rain, carries with it cryovegetation from higher regions of the glacier. Steeper parts of the ice surface in the ablation zone neither supported extensive algal growth nor contained englacial lakes. Meltwater from these steeper surfaces probably removes much mobilised vegetation from the ice altogether. Localised accumulation of radiation absorbing algal growths over time thus appears to be a pre-requisite for extensive albedo modification by the algae, and occurs most readily on gently sloping or level surfaces.

## 6.5 DISCUSSION

The present equatorial nival environment differs markedly from temperate or polar glaciers, and the occurrence of rather similar cryovegetation is surprising. Even the snouts of temperate glaciers are covered by snow for long periods in each year, whereas below the firn line on Mt. Jaya, the ice is rarely snow covered for more than a few hours. Solar insolation is high all the year round at Mt. Jaya, but drops to low levels during the winter months in temperate areas, providing a changing thermal and hydrologic regime. Studies by Fogg (1967) on snow algal communities in South Orkney indicated low metabolic rates. He concluded that the apparent rapid growth of algal colonies on snow firn surfaces is in fact the result of cell concentration consequent on ablation rather than cell replication. Accumulation of snow algae will persist from year to year and exceptional thaws will result in very dense colonies. On Mt. Jaya above the equilibrium line there are no long periods of thaw or wind clearance so that accumulation proceeds fairly steadily all year round. This presumably explains the absence of dense snow algae communities there. The situation below the equilibrium line is one of constant thaw and it is not surprising that very dense colonies have built up. More work remains to be done, but it seems likely that cryovegetation controls the surface morphology of the ice areas and may be causing accelerated melting rates several times those that would be expected if a clean surface was present. The blue englacial lakes act as efficient radiation traps and retain meltwater on the glacier surface.

Under the conditions of continued retreat that have prevailed for probably 100 years (Chapter 3) the black ice community has enjoyed access to substantial new areas of ice as the equilibrium line crept higher. Although cryovegetation can have had little effect on the altitude of the equilibrium line, it has obviously accelerated the adjustment of ice areas to changes in the mass balance. This effect was probably more pronounced when the ice occupied the level floor of the upper Meren and Yellow Valleys; photographs by Colijn (1937) show great numbers of englacial lakes over the terminal kilometre of the Meren Glacier at that time.

Times of glacier advance and lowering of the snowline may have restricted or even eliminated some cryovegetation during periods in the past (see Chapter 9). An abrupt snowline depression would lead to the ice areas being snowbound and nival regions being constantly buried by fresh snow, until the glacier extended to a new equilibrium. It could possibly take years or decades for ice fronts to protrude below the snowline. It is not known if the black ice community could withstand long-term burial, but it would probably survive on firns at locations exposed to melting. When ice fronts extended into the valleys colonisation could then occur. The effects of this on the resultant position of the maximum advance would depend on the rate of colonisation (which is unknown) and the valley topography. It is possible to envisage a significant ice front retreat despite stable climatic conditions as cryovegetation occupied newly exposed ice areas.

The effects of recent glacier advance and of possible complete withdrawal of ice from Mt. Jaya during climatically milder periods postulated at 8,500-5,000 years ago (Hope & Peterson 1975) raise the question of the sources of the present species and communities. If cryohabitats have been absent from time to time then possibilities include inoculation of new ice areas from alternate non cryohabitats or long distance dispersal of spores from other cryohabitats in air currents or on birds. Soil samples collected from areas adjacent to the Meren and Carstensz glaciers did not support any algae.

Mt. Jaya and other New Guinea glaciated peaks form the most isolated present or past ice areas in the world, being at least 5,500 km from the nearest southern ice fields in New Zealand, 5,800 km from the nearest northern ice areas in the eastern Himalayas at present. Even during times of maximum ice advance the ice in south eastern Australia was 4,100 km distant, and the isolated ice cap on Mt. Kinabalu lay 2,600 km to the north west. Long distance dispersal of aerial spores over such distances and through several climatic zones must have a very low chance of occurring (Gregory & Monteith 1967). Hence if the Mt. Jaya species are due solely to migration from principally southern ice areas, an extremely long history for the persistence of cryohabitats on the mountain is implied.

The presence of many species of birds on the ice (Chapter 10; Schodde et al. 1975) raises the possibility that migrating birds may have introduced some of the cryoalgae. Several species were in fact migrants from Asia or Australia not usually noted in New Guinea, although none inhabit cold northern or southern habitats. However while active bio-transport of the cryoalgae would greatly improve the chance of successful migration of a species, the development of the present cryovegetation on new ice and snow habitats would still take a considerable time.

Further work on the habitat limitations and dispersal mechanisms of the algal species is needed to clarify the possible original and secondary sources of inoculation of the Mt. Jaya cryohabitats.

## 6.6 REFERENCES

Colijn, A. H., 1937, Naar de eeuwige sneeuw van tropisch Nederland. Amsterdam, Scheltens & Giltay.

Corte, A., 1970, Bioecological aspects of the snow plant communities of Cape Spring, Argentine Antarctica. Proc. Helsinki Symp.:101-104.

Fogg, G. E., 1967, Observations of the snow algae at the South Orkney Islands, Phil. Trans. Roy. Soc. Lond. B. 252: 279-294.

Fritsch, F. E., 1912a, Freshwater Algae of the South Orkneys, Sc. Rcs. Scottish Nat. Antarctic Exp. 3:95-134.

Fritsch, F. E., 1912b, Freshwater Algae. In Discovery Reports of the Nat. History Vol. VI (Zoology and Botany), London.

Gain, L., 1912, La Flore Algologique des Régions Antarctiques et Subantarctiques. Deuxième Exp. Antarctique Française 1908-1910. Sc. Nat. Doc. Sc., 1-202.

Gerdel, R. W. & Drouet, F., 1968, The cryocanite of the Thule area. U.S. Army Snow, Ice and Permafrost Research Establishment. Research Report 50.

Gregory, P. H. & Monteith, J. L. (eds.), 1967, Airborne Microbes. 17th Symp. Soc. Gen. Micr., Cambridge Univ. Press.

Hope, G. S. & Peterson, J. A., 1975, Glaciation and vegetation in the high New Guinea mountains, Bull. Roy. Soc. N.Z. 13:155-162.

Kol, E., 1968a, Kryobiologie-Biologie und Limnologie des Schnees und Eises. I. Kryovegetation, Die Binnengewässer 24.

Kol, E., 1968b, Algae from the Antarctica, Ann. Hist. Nat. Mus. Nat. Hung. 60: 71-77.

Lagerheim, G., 1892, Die Schnee Flora des Pinchincha. Ein Beitrag zur Kenntnis der Nivalen Algen und Pilzen, Ber. Deutsch Bot. Ges. 10: 517-534.

Peterson, J. A., 1973, Preliminary report of the second Carstensz Glaciers Expedition, 1973. Unpubl. Rep. Meteorlogy Dept. Melbourne, Vic.

Schodde, R., Tets, G. F., van, Champion, C. R. & Hope, G. S., 1975, Observations on the birdlife at glacial altitudes on the Carstensz massif, Western New Guinea, Emu 75: 65-72.