ANTARCTICA, A CONTINENT FOR ALGAE

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Amongst the six continents there is one that stands alone when its botany is considered. The vegetation of five is dominated by seed-forming plants, only on the sixth, Antarctica, do the simplest plants on the Earth reign supreme. Algae are ubiquitous and abundant both in habitats where you would expect to find them from experience elsewhere, and in some of the most bizarre and fascinating of habitats anywhere.

The other vegetation includes just two flowering plants which exist marginally where a relatively moist, warm climate allows. The grass *Deschampsia antarctica* and the pink *Colobanthus quitensis* are found in the maritime Antarctic, that is on the north-western portion of the Antarctic Peninsula and offshore islands such as the South Shetland and South Orkney Islands. Here also are the most extensive and abundant stands of mosses and liverworts which can form lush carpets and turfs covering a hectare or more. Additionally, most of the rocks are splashed with the bright colours of lichens. Red, yellow, orange and green crusts delight the eye, especially close to bird colonies where fertiliser is inexhaustible.

This, of course, is where the algae enter the picture. Every lichen contains millions of microscopic algae co-existing with their essential partners in survival, the fungi. However, although lichens are often stated as being the most widespread and diverse of plants in the south polar regions, it is the free-living algae which really attain this importance. These algae can grow, reproduce and disperse without requiring a fungal partner. This article aims to convince you of the ability of algae to survive in this most inhospitable of places by living in a variety of weird and wonderful habitats. In this way they are of an ecological importance unequalled by the bryophytes or even the lichens.

Let us briefly consider the stresses experienced by the hardy colonists of this frigid land. Yes, it is cold. Except in the maritime Antarctic the mean air temperature during the short summer does not rise above freezing, and in winter it plunges below -30°C. Even during summer there is often a daily rise and fall in temperature which will regularly freeze and then thaw soil and rock surfaces.

Light intensities change hugely over the year. South of the Antarctic Circle there are periods of complete darkness during winter and constant bright light during high summer. Because of the exceptionally clear, dust and pollution-free air and the high reflectivity of snow and ice, the summer sun can be very intense.

Water availability is often scant. Antarctica is essentially a desert and contains some of the driest areas on our planet. Snowfall is usually slight, the air very dry and, in addition, the cold temperatures lock liquid water into solid, unavailable ice. Only during the brief summer does water flow from glaciers and snowfields.

Even if water is liquid, it can be extremely salty. Salts are still being released from the rocks and several regions have been covered by the sea in geologically recent times. Rocks and soils can be thickly encrusted with sodium chloride, mirabilite (sodium sulphate), antarcticite (hydrated calcium chloride) and even sodium nitrate amongst others. Ponds and lakes can be up to fourteen times the salinity of sea-water and streams can contain disgustingly unpalateable water.

The availability of good quality nutrient salts also varies widely. The lakes include the most nutrient-poor on Earth and, in contrast, close to nesting birds and particularly penguins, nutrients can reach toxic concentrations.

To cap it all, Antarctica is the windiest of continents and if a plant dares to expose itself more than a centimeter or two it will soon be blown out to sea!

Well, with all those difficulties it is a wonder that anything survives there! In which case, what has made it possible for botanists to have been attracted to, and excited by, the study of antarctic plants?

A flora exists because in places there are suitable illuminated surfaces with an adequate temperature regime, sufficient water and a balance in quality and quantity of salts which provides for the plants' needs. Such surfaces are extremely limited in area when the whole continent is considered. Perhaps two per cent of the total consists of ice-free rock. The remainder is predominantly high altitude ice plateau, comprising the most sterile of deserts. The majority of plant biomass is found on the fraction of ice-free land which is low altitude and coastal. These areas vary from many hundreds of square kilometers in extent, for instance along the Antarctic Peninsula, at the Vestfold Hills and in southern Victoria Land, to the numerous, small, coastal rock outcrops of less than one square kilometer. It is at these locations that the botanist, and particularly the phycologist, is in his or her element.

On the continental ice plateau vast expanses of white snow and ice cover millions of square kilometers. However, at the coast, where melt can trickle through soft snow and where dust can be blown onto the surface, it initially comes as a shock to see green and pink snowfields. A peer down the microscope shows this to be due to unicellular algae, usually "green algae" (Chlorophyta) some of which can accumulate orange pigments in their cells. These tinted snows are commonest in the maritime Antarctic and become rare further south. The presence of bird populations appears to be important as their furthest south occurrence on Ross Island occurs close to an Adelie penguin rookery.

Another community of algae that would rarely experience a temperature above freezing is that which dwells in small melt pools on the surfaces of glaciers. So far these have been recorded only from Victoria Land but no doubt they are much more widespread. The ponds form where dark sand and grit accumulate on the ice-surface; this may have arrived there by wind transport or in the glacial ice flow. The particles absorb the sun's rays and melt cylindrical holes into the ice. These are usually about 20 to 30 centimeters wide and more or less the same depth. During summer they contain water overlying a thin sediment. In this there are algae taking advantage of the water and the nutrients in the melt. Perhaps surprisingly these algae are quite different from those in the snowfields. The communities comprise the smallest of diatoms (Chrysophyta) and a few species of "blue-green algae" (Cyanobacteria). This illustrates a feature of antarctic algae; the distinct differences in the species composition of communities in different habitats, even where superficially the habitats might appear similar.

For most of the year the sounds of Antarctica are the howling of the wind and the sharp crack or groan of imperceptibly moving ice. Summer is arriving when the drip, drip of water can be heard falling from icicles. These drops can merge into trickles and the trickles can flow into channels which become substantial streams and even rivers. Although strictly a desert, during summer the continent has thousands of water courses flowing from glaciers, ice fields and snowdrifts down to lakes and the sea. Many of these contain beds rich with algae which have survived the winter desiccated and frozen. Within minutes of the first flows of summer their metabolism will once more be in action. Some streams are verdant green with long skeins of filaments trailing in the flow, but the channels of most are marked by orange and brown felts of "blue-green algae" which coat stones and gravels with their sheet-like expanses. Sometimes a stream may appear sterile but on the lower surfaces of stones there may be abundant ribbons of a green alga called Prasiola sheltering from the harsh light. Here is another lesson that the antarctic phycologist must learn; look carefully, do not believe that there is nothing present until stones have been turned over or rocks cracked open with a hammer!

The continent has thousands of streams, but it also has tens, if not hundreds of thousands of ponds. These are filled by streams, by water seepage through the ground and by the melting of permafrost. For our purpose a pond can be defined as a body of water which might dry up completely during summer and is shallow enough to freeze completely during winter. In area they are anything from less than a meter square to a hectare or more. In contrast a lake is deep enough to contain liquid water the whole year. The character of the pond environment can fluctuate widely. The salinity can increase as water evaporates or freezes and the temperature can shoot up during bright sunny periods. Some pools can be seen steaming! The algae suffer intense desiccation when the ponds dry out. Despite this almost every pond encountered is thick with slimy growths covering the bottom (benthic algae) and some become bright green with suspended algae (phytoplankton). The latter are vividly illustrated in penguin colonies where pools receive a hearty supply of guano and dead bodies! A single species of Chlamydomonas (a unicellular, swimming Chlorophyta) thrives in these stinking conditions! Most ponds contain the ubiquitous, filamentous "blue-green algae", particularly those which form simple chains of cells embedded in a sticky mucilage (e.g. Phormidium). Some are constantly saline and this is often reflected by the presence of particular species of diatoms. One pond, the famous Don Juan Pond in southern Victoria Land, is so saline with calcium chloride that it has yet to be proved that algae can live there, except where relatively fresh water trickles in at the side.

The beauty of Antarctica is enhanced by many gloriously scenic settings containing large lakes at the bottom of steep-sided valleys. Phycologists can be inspired not only by the unique nature of many of the lake environments but also by the magnificent surroundings. The lakes are numerous and can be large in area and deep. At the Vestfold Hills, an ice-free area of about 400 square kilometers, there are over 200 lakes. They can reach ten square kilometers in area and be over 100 meters deep. Some can remain with a permanently frozen ice-cover which may exceed five meters in thickness. Excellent examples of this type are found in the "dry valleys" of southern Victoria Land. The most famous intensely studied of all antarctic lakes, Lake Vanda, has ice floating on water which is as warm as +25°C at the bottom! Solar heating of dense, saline bottom water is the cause. The lakes can be super-fresh with little salt content, or they can be hypersaline. Deep Lake at the Vestfold Hills is seven times more saline than sea-water and contains 270 grams of salt in each litre of water. The water temperature can fall as low as -19°C without ice being formed. The only alga found in this lake continues swimming through the water at temperatures at least as low as -14°C!

In lakes with an ice-cover different species of suspended phytoplankton can be found at different depths. This is largely because there is very little stirring of the water layers as wind turbulence is almost completely cut out by the protective ice. Different species can remain at the particular depth that is best for their growth. Those that require brighter light but less nutrients can develop just below the ice whereas at lower, darker depths there are algae which require the richer nutrients found in the deeper waters. However, even just below the ice the light levels are very low, being only about one per cent of the light striking the ice surface, so the algae in the depths exist in extremely dim conditions. In contrast, at the surface of lakes lacking an ice cover the light can be so intense that photosynthesis is inhibited.

As in the ponds, most biomass of algae in the lakes is benthic, thickly coating the stones and sediments where illumination is sufficient. Again, "blue-green algae" are dominant although there can be very large populations of associated diatoms. Because of the usually calm conditions, and due to the absence of large burrowing worms and crustaceans, the felts of algae can build layer upon layer over hundreds and thousands of years. In the ice-covered lakes these felts accumulate to depths of many tens of centimeters with little decomposition. A core taken from these sediments has numerous laminae sitting one on top of the other and resembles the fossil "stromatolites" which were formed by very similar"blue-green algae" during the dawn of life more than a thousand million years ago.

So far we have considered only algae that grow when they are covered by a substantial quantity of water, that is the aquatic algae. Outside the streams, ponds and lakes abundant algae also occur on rocks, soils and coating mosses and liverworts. These habitats might be termed "semi-aquatic" where the ground is boggy or they might appear extremely dry with no visible presence of water. The environment can fluctuate even more widely than that of ponds. Temperatures in particular can vary hugely with season, time of day and even over minutes as clouds pass by the sun. Dark soils and rocks can be solar heated to greater than +30°C although the air temperature might be around freezing. Once in the shade the surface temperature would quickly plummet to close to that of the air.

In many alpine regions of the world, mountain rock faces are streaked with black crusts of algae where water trickles down. Similar "epilithic" growths are found in Antarctica. In fact the flora is dominated by identical unicellular "blue-green algae" (<u>Gloeocapsa</u> spp.), sticking to the rock faces with their glue-like mucilaginous coatings and protecting themselves from the intense light with dark, shading pigments. However, these communities are relatively rare due to the general absence of water percolations and to the scouring effects of gale-force winds which blast sand and ice particles against exposed surfaces. To escape these harsh external conditions and to find and retain some moisture the algae have retreated inside the rocks! This is where a hammer becomes a vital piece of equipment!

For years it was thought that some of the driest areas of the continent, in southern Victoria Land, were completely free from actively growing algae. Then an enlightened person started hitting rocks. Below the surface crust of certain rock types vivid green and blue-green algae were revealed. These rocks are mostly sandstones which contain a high proportion of quartz crystals. Light can penetrate into the rock and, between the individual crystals, are tiny micro-pores in which algae and lichens can live and where moisture can be retained. These "cryptoendolithic" communities grow about 2 to 10 millimeters below the surface. Here they receive light, moisture, from the effectively sponge-like rock tissue, and they are warmed by the sun. At the surface, just millimeters distant, nothing can survive. There is rarely any moisture from snowfall, light is intense, winds are strong and, perhaps most importantly, the temperature can fluctuate much more frequently, passing through the freezing point many times a day. The algae include the smallest of photosynthetic organisms, "blue-green" unicells down to a thousandth of a millimeter in diameter,ideally sized for inhabiting and spreading through the micro-pores.

Other rock types have a flakey texture and can also contain "hidden" algal communities. These have been termed "chasmoendolithic", a mouthful meaning "growing in cracks which penetrate the rock surface". Granitic rocks at the Vestfold Hills are well suited for their growth and these superficially invisible plants form the most widespread vegetation in the whole area! Perhaps it is in protected niches such as these that life will be found on Mars?

Antarctic soils hardly deserve the name "soil" as most have an extremely low organic content and very little microbiological activity. In effect they consist of ground up rock material (lithosols) deposited by retreating glaciers and since added to by the fragmentation of boulders and rock faces. Large areas appear devoid of vegetation largely because of the absence of moisture at the surface. However, again appearances can be deceptive. Some localities have a rich scattering of milky white quartz stones resting on the soil. In a similar way to the sandstone and granite rocks, these stones allow algae to grow in the protection of the so-called "sublithic" or "hypolithic"niche. Turn over a stone and the desert turns green! The quartz is translucent and so light can penetrate, additionally below the stones moisture is conserved in the soil.

Abundant algae are visible only where a good supply of water reaches the soil surface. Gentle inclines downslope from melting snowdrifts are particularly favourable and can be covered by hundreds of square meters of algal felts. "Blue-green algae" once again assume dominance and come in a surprising range of colours, confounding the use of their popular name. The expansive sheets may indeed be blue-green, or bright orange, red-brown, almost black and even purple and pink! As well as the simple filamentous species there are also some important ones that are slightly more complex. These filaments possess specialised cells called heterocysts which give the algae the ability to take nitrogen from the air in order to make proteins. This nutrient can later be passed onto other vegetation when the algae decay. A common species is Nostoc commune which forms crumpled gelatinous colonies, often circular in outline and thirty centimeters or more in diameter.

Where there is abundant nitrogen already in the soil nitrogen-fixing algae are absent and species comprise those specialised in coping with huge quantities of nitrogen and phosphorus. Such conditions are found in and around penguin colonies and amongst the wallows of snorting, argumentative elephant seals. Here the soils are mostly highly organic, being composed of the excrement and corpses of centuries. This is another way in which the surrounding oceans can affect the land. All of this material is essentially of marine origin having come through the food web of marine phytoplankton to krill and fish, to birds and seals. Particularly indicative of these conditions is a bright green alga (Prasiola crispa) forming irregularly contorted sheets which can spread over large areas of moist guano, so long as they are not trampled by myriads of penguin feet.

Of course, most antarctic soils remain deeply frozen for at least eight or nine months each year. However, amazingly, there are some which cannot freeze, and these occur at altitudes of up to 3700 meters where summer air temperatures hover around -20°C. They are also extremely restricted in area, just a couple of thousand square meters on the whole continent. Two major antarctic volcanoes are still producing steam from their summits, Mt. Melbourne in a small gentle way, and Mt. Erebus with violence from its active crater. On both there are locations where steam rises from exposed ground and maintains the surface at temperatures as high as +60°C. Here can be found algae which are completely different from those anywhere else in Antarctica. One alga in particular is "thermophilic", that is it grows best at temperatures above +40°C and it will not grow below +25°C. How these algae survive the long periods of constant darkness in winter is a mystery. It is relatively easy for other algae whilst deep frozen and inactive but these cannot freeze on the warmed soil. Also, how did they get there? Perhaps they have been wind blown from the northern continents. Living algae have been detected in the air over Antarctica.

It should now be obvious that algae are considerably more widespread than the bryophytes which, on the whole, grow only where climate, microclimate and water availability are particularly favourable. Additionally, even where the vegetation might be described as "an extensive stand of bryophytes" the algae associated with these can often be of equal or greater abundance. These "epiphytic" communities can thickly encrust moss and liverwort stems and leaves, darkening the surfaces of cushions and masking the green bryophyte tissue below. "Blue-green algae" are common, especially nitrogen-fixing Nostoc, from which nitrogen might pass and stimulate bryophyte growth. Even where algal crusts are not visible their populations can still be large. Numbers as high as ten million cells over each square centimeter of moss turf are commonplace in the South Orkney Islands.

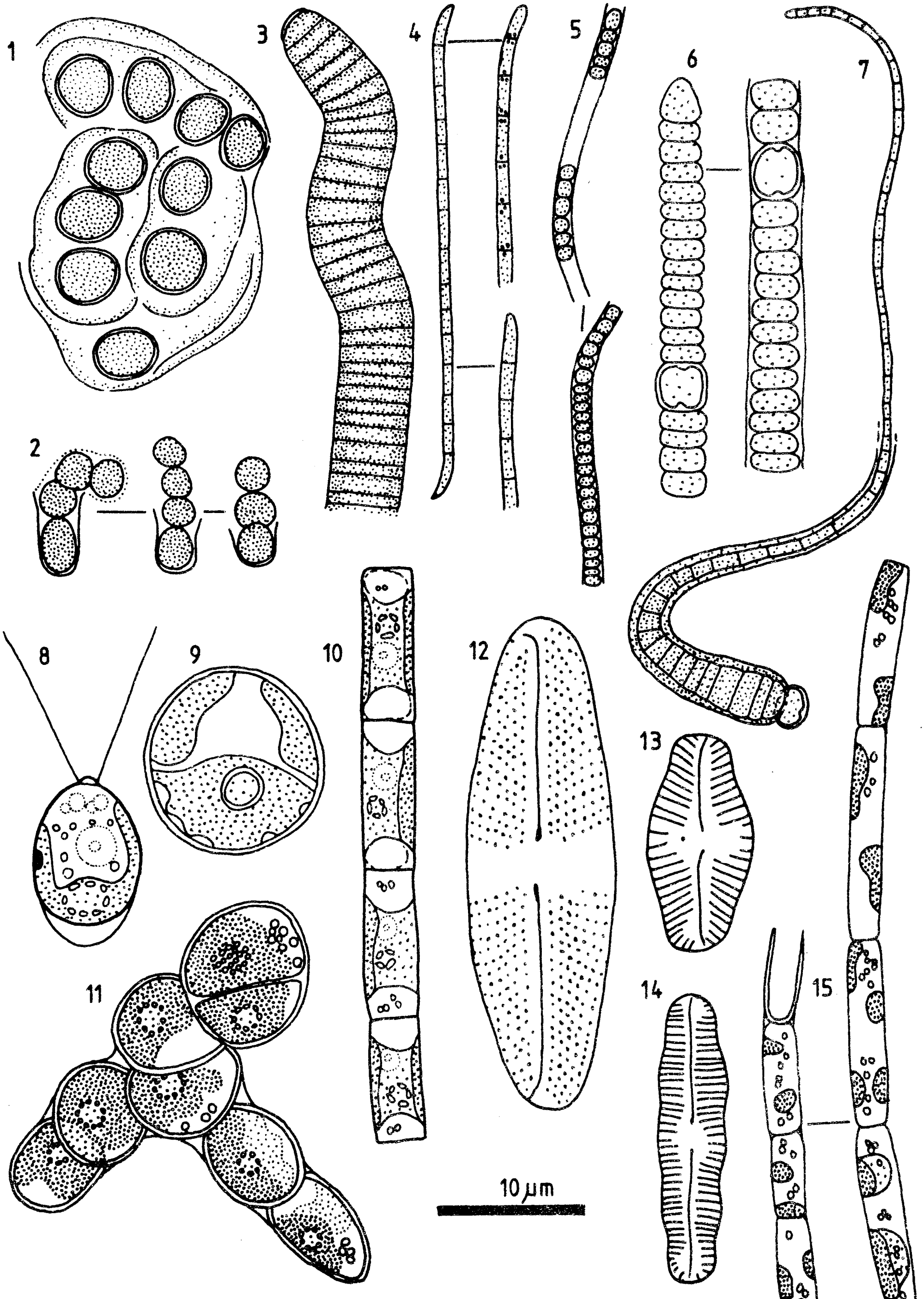
So, algae are antarctic plants par excellence. The group as a whole can survive and grow in a region which is largely inhospitable for other forms of vegetation. As such they are also of prime importance ecologically due to their interactions with physical, chemical and biological aspects of their environment. They are initial colonisers of newly exposed rocks and soils, aiding in the erosion of rock and the binding together of small soil particles. Their secretions and dead cells add to the nutrient and organic status of soils paving the way for the growth of bryophytes and stimulating the heterotrophic microbes. For instance, algal mucilage is richly colonised by bacteria and fungi. Also, algae are grazed by a range of invertebrate animals. Some lakes contain copepod crustaceans

Figures 1 - 15. Examples of genera of microscopic algae from Antartica.

Figs. 1 - 7. Cyanobacteria, 'blue-green algae'. 1, *Gloeocapsa*, single cells embedded in mucilage. 2, *Chamaesiphon*, cells budding off exspores. 3,4, *Oscillatoria*, long unbranched filaments. 5, *Phormidium*, similar to *Oscillatoria* but embedded in mucilage. 6, *Nodularia*, filaments with specialised heterocyst cells responsible for nitrogen fixation. 7, *Calothrix*, a long tapering fiament with a basal heterocyst.

Figs. 8 - 11. Chlorophyta, 'green algae'. 8, *Chlamydomonas*, a motile unicell. 9. *Chlorococcum*, a non-motile unicell. 10, *Klebsormidium*, an unbranched filament. 11, *Coccobotrys*, small branching plants.

Figs. 12 - 15. Chrysophyta; 12 - 14, diatoms, 15, a 'yellow-green alga' of the class Tribophyceae. 12, *Achnanthes*, 13, *Navicula*, 14, *Pinnularia*, all showing the markings on the cell walls. 15, *Tribonema*, a long unbranched filament.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and many habitats support nematode worms, tardigrades, rotifers and protozoa. Guts squeezed from the primitive soil arthropods, commonly called mites and springtails, frequently have algal contents.

These are examples of their importance now, but what will the future bring? Is Antarctica still being colonised, will new species be found as successful plants establish? Is the climate ameliorating, especially as global carbon dioxide levels rise? Will this allow the development of novel vegetation?

Human impact on the continent continues to increase. Presently this is due to increased scientific activity and the erection of new year-round stations, but there is the possibility of industrial exploitation in the future. If this occurs there will be greatly increased use of the coastal ice-free areas where most of the wildlife, both plant and animal, is found. Lakes and streams could be polluted, as has already happened on a small but locally significant scale. Whole areas of this impoverished but fascinating vegetation could be scraped away by bulldozers.

It is essential that, at the very least, large areas including representatives of all habitat types are carefully preserved. Outside these areas any development must be sympathetically managed in order to conserve the essential features of landscape and wildlife. Ideally the whole continent will be free from mining and oil extraction and the region will remain one of international co-operation and goodwill and for the inspiration of ourselves and future generations through its natural beauties and wonders.