FRESHWATER BIOLOGY AT ROTHERA POINT, ADELAIDE ISLAND: II. ALGAE

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ABSTRACT. Samples of freshwater algae from pools on Rothera Point, Adelaide Island, were composed mainly of blue-green algae. Several species of diatom were also identified. Extracts of photosynthetic pigments showed light absorption spectra typical of algae from several Antarctic shallow pools, with high absorption at short wave-lengths associated with large amounts of carotenoid pigments.

CONSTRUCTION of the British Antarctic Survey station at Rothera Point (lat. 67°34′S, long. 68°07′W), Adelaide Island, started in the summer 1975–76. A biological sampling programme was initiated to assess the effects of the new station on the environment of the point. This paper describes the algae occurring in some small freshwater pools, and absorption spectra are given for the photosynthetic pigments. The data obtained in this study not only provide a base line for the local investigation but provide valuable additional information on taxonomy and ecology of freshwater algae in the maritime climatic zone of the Antarctic Peninsula (Holdgate, 1964).

STUDY SITES

Rothera Point is a small peninsula on the eastern coast of Adelaide Island. It is low-lying (maximum height 40 m above sea-level) and partly covered with permanent snowbanks, the remaining areas being mainly shingle with few rock exposures (Fenton, 1976; Dartnall, 1980). There are nine small pools on the point.

Samples were collected by Drs J. H. C. Fenton and R. I. L. Smith from two pools. The following descriptions are based on those of Fenton (1976).

Pool 4 lies between a raised beach and a permanent snowbank close to the top of the small plateau at the end of the point, 30 m above sea-level. It is approximately 70 m long, 12 m wide and at least 2.2 m maximum depth, but it may drain during the winter. The catchment is small. The bottom is composed of scree and an algal mat 1–2 cm in thickness was observed in some of the hollows of the sorted ground. Water temperatures taken at three sites at 30 cm depth on 31 January 1976 ranged from 1.8° to 2.1°C. Results of chemical analyses of Pool 4 water and a description of the invertebrate fauna have been given by Dartnall (1980). The water had a low ionic content.

Pool 7 is situated on the north side of the narrow part of the point, about 15 m from the sea, and is dammed by the beach. Its surface is approximately 25 m by 15 m and the average depth is about 50 cm. The bottom is silty and a melt stream maintains a constant flow of water through the pool. Sea spray may be blown into it.

METHODS

Samples used for taxonomic studies were preserved in formaldehyde-alcohol-acetic (FAA) or in Lugol's iodine (duplicate samples collected in February 1977). Preliminary work was also carried out on frozen material.

Pigment analysis was carried out on benthic algal material from Pool 4. Algal felt was frozen at −20°C soon after collection and maintained at this temperature until extraction was carried out at the British Antarctic Survey biological laboratory at the station on Signy Island, South Orkney Islands. Pigments were extracted with 90% acetone at 2°C in the dark for 24 h (Marker, 1972; Strickland and Parsons, 1972) and absorption spectra were measured on a Pye SP 600 UV spectrophotometer. Wave-length intervals were 10 nm, except in the regions of sharp peaks

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where readings were taken every 5 nm, and between 550 and 630 nm where readings were taken every 20 nm. To assess the effect of freezing on the pigment content of the samples, comparable algal material was collected from shallow water in Heywood Lake, Signy Island. Half was extracted and measured soon after collection, whilst the remainder was frozen at the same temperature and for the length of time ($2\frac{1}{2}$ months) as the Rothera Point material. The absorption spectra for the Heywood Lake material before and after freezing showed no difference in either the absolute amount of pigment extracted or the relative proportions of different pigments.

Results

Algal communities

The following seven samples were collected by Dr R. I. L. Smith on 17 February 1977:

Pool 4

(a) "Algae from stones 15 cm deep".

Two samples (BAS specimens 77/215 and 77/216 (Freshwater)) consisting of a resilient algal felt, grey-green in preserved material but reddish when alive (personal communication from J. H. C. Fenton).

(b) "Algae from stones 75 cm deep".

Two samples of a very pale green algal felt (BAS specimens 77/218 and 77/219 (Freshwater)).

Pool 7

"Algal mat on stones and sandy mud at deepest part, 0.3 m".

Three samples of grey-green algal felt (BAS specimens 77/212–214 (Freshwater)).

Apart from the slight differences in colour, all samples were similar in appearance and texture. The preserved specimens were all "flaky" but experience with comparable material in the lakes on Signy Island suggests that they would form a continuous layer when alive.

The samples from Pool 4 contained the same species, the felt being composed predominantly of *Phormidium* sp. A and ? *Microcystis* sp., often growing intermixed. A *Chroococcus* sp. and more rarely trichomes of *Phormidium* sp. B were present. Eight taxa of diatoms were found but only the two varieties of *Achnanthes austriaca* were common and these probably grew on the surface of the felt.

The Pool 7 felt consisted almost entirely of *Phormidium* sp. B filaments. Frustules of nine diatom taxa were found including some, such as *Thalassiosira gracilis* and *Cocconeis costata*, which were probably blown in from the sea.

Pigment spectra

Fig. 1 shows the absorption spectra for extracts from three Antarctic benthic algal communities composed predominantly of blue-green algae (one from Rothera Point and two from Signy Island). The material from Pool 4 on Rothera Point (Fig. 1a) had a very high absorption at short wave-lengths ($\lambda<500$ nm), indicating a high content of acetone-soluble carotenoid pigments in relation to the amount of chlorophyll *a*. This was compared with spectra of felts obtained from two lakes on Signy Island—a shallow community from Heywood Lake (Fig. 1b) and a deep-water community from Sombre Lake (Fig. 1c). The climate of Signy Island is slightly less severe than that of Adelaide Island but the shallow-water felt from Heywood Lake experiences similar physical conditions (temperature and irradiance) to the Rothera Point pool and has a similar specific composition. The absorption spectrum for this community indicates a high carotenoid content. By contrast, a felt from a depth of 5 m in a shaded part of Sombre Lake produced a spectrum with a much lower carotenoid absorption (Fig. 1c). As well as receiving much less radiation than the other two algal felts, this community was also growing too deep to be frozen in winter.

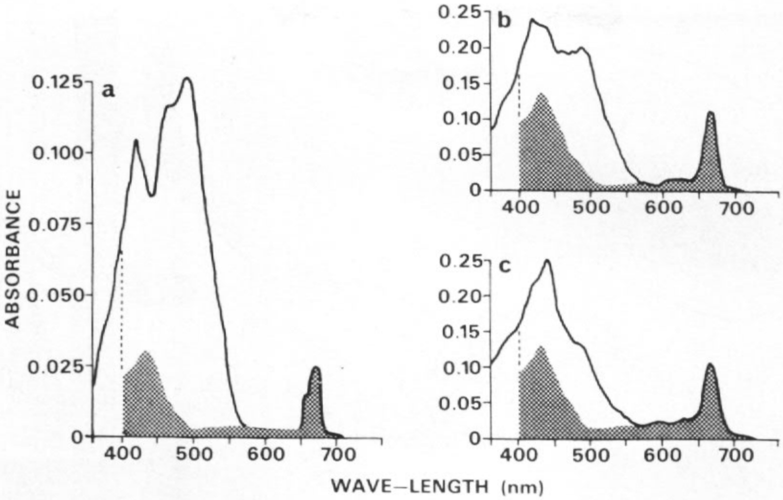

Fig. 1. Absorption spectra of 90% acetone extracts from algal felts (predominantly blue-green algae) from three Antarctic freshwater sites. Different amounts of algae were used for each extraction. Theoretical absorption for chlorophyll *a* alone above 400 nm is shown stippled (calculated from the height of the 664 nm peak after Strickland (1960)). a. Algal felt from about 10 cm depth in Pool 4, Rothera Point, Adelaide Island; b. Shallow-water (10 cm depth) *Phormidium* felt, Heywood Lake, Signy Island; c. *Tolypothrix–Plectonema* felt from 5 m depth Sombre Lake, Signy Island.

Without exhaustive testing of the extraction process, no absolute measure of pigment content can be given and blue-green algae are often notorious for giving poor extraction. However, the Rothera Point Pool 4 material yielded approximately 60% of the chlorophyll *a* (per unit acetone-insoluble dry weight) given by the shallow-water felt from Heywood Lake.

Taxonomic Descriptions

Cyanophyta

Classification of blue-green algae from preserved material is unsatisfactory and no definite identifications are given here.

Chroococcales

Chroococcus sp. (Fig. 2a). Aggregations containing up to *c*. 30 cells observed but composed of distinct pairs, approximately 30 μm long (excluding the mucilage sheath). Cells brown in FAA preserved material, with prominent granules. Mucilage greenish with moderately distinct stratification. Pool 4, more numerous in shallow samples (77/215 and 216).

? *Microcystis* sp. (Fig. 2b). Cells round to oval, diameter 2 μm (sometimes smaller in dense aggregations). No stratification of the mucilage was visible except for a very thin layer around each cell. The absence of discrete colonies makes it impossible to assign it to any described species. Common in Pool 4; occasional in Pool 7.

Oscillatoriales : Nostocinales

Phormidium sp. A (Fig. 2c). Trichome 1 μm wide, pale green-blue. Cells 1.5–2 times as long as broad. Cross walls distinct with cells rounded at ends. Sheath scarcely visible. No granules apparent in the cells of preserved or frozen material. Apical cell undifferentiated, except that some may be rather more conical than rounded. May form very dense, aligned bundles

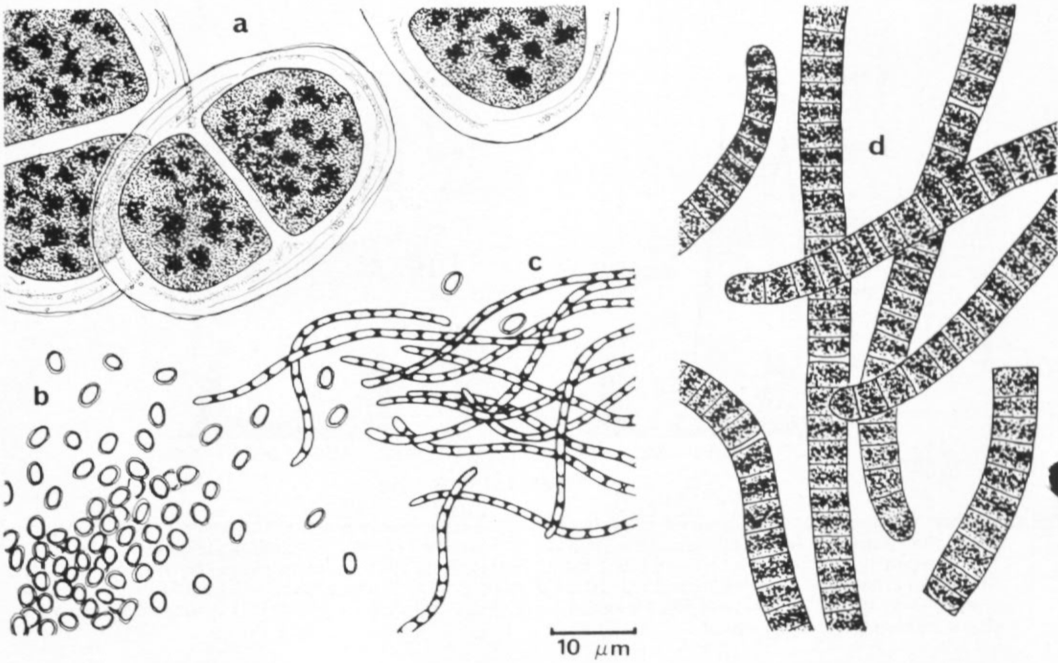

Fig. 2. The four main taxa of blue-green algae from pools at Rothera Point (all to the same scale). a–c. Diagrammatic view of part of Pool 4 algal felt, based on camera lucida drawings of the three main taxa: a. *Chroococcus* sp.; b. ? *Microcystis* sp.; c. *Phormidium* sp. A; d. The dominant alga in Pool 7, *Phormidium* sp. B.

resembling *Microcoleus* spp. Some trichomes with noticeably thicker sheaths are interpreted as having been separated from such bundles, since they were otherwise identical with this species.

The alga agrees with *Phormidium mucicola* Hub.-Pestalozzi et Naumann except that the cells of the present species are free of granules. Desikachary (1959) stated that the contents of *P. mucicola* are granular, whilst Geitler (1932) described the contents as slightly granular. The Rothera Point species also resembles *P. mucicola* in its close association with coenobial Cyanophyta; the latter species is commonly associated with *Microcystis* spp. Pool 4, abundant.

Phormidium sp. B (Fig. 2d). Trichome 5–6 μm wide, pale green in preserved material. Cells short with the ratio length : breadth varying from 1 to 0.5. Cross walls distinct; sheath thin and colourless. Cells contain granules evenly distributed. The tip of the trichome tapers from about the sixth cell back and there is usually a pronounced curve. The apical cell is rounded and lacks a calyptra or terminal thickening. Pool 7, dominant.

Chlorophyta

Oedogoniophyceae

Oedogonium sp. Some green algal filaments referable to this genus by having cap cells were seen in material from Pool 4. No further identification was possible as the cell contents were mostly unrecognizable.

Bacillariophyta

Most diatoms are referred to known taxa, although there are sometimes slight differences from published descriptions. Detailed discussion of these taxa will be given in a paper on the freshwater diatoms from several localities in the maritime Antarctic (Belcher, Carter and Priddle, in preparation). Other published Antarctic freshwater records (south of lat. 60°S) are given where possible. Most taxa have since been found in material from Signy Island.

Centrales

Thalassiosira gracilis (Karst.) Hust. Pools 4 and 7, occasional. Probably of marine origin.

Pennales : Araphidineae

Fragilaria sp. with oblique striae (Fig. 3n). Electron micrographs of material from Signy Island show a pseudoraphe. Pool 7, occasional.

Pennales : Monoraphidineae

Achnanthes sp. (Fig. 3a and b). Pool 4, occasional.

Achnanthes sp. (Fig. 3c and d). Pool 4, abundant and many broken frustules.

A. brevipes Ag. Pool 7, occasional.

A germainii Bourrelly et Manguin (Fig. 3e and f). Pool 4, occasional.

A. ninckei Guermeur et Manguin (Fig. 3g and h). Pool 4, occasional.

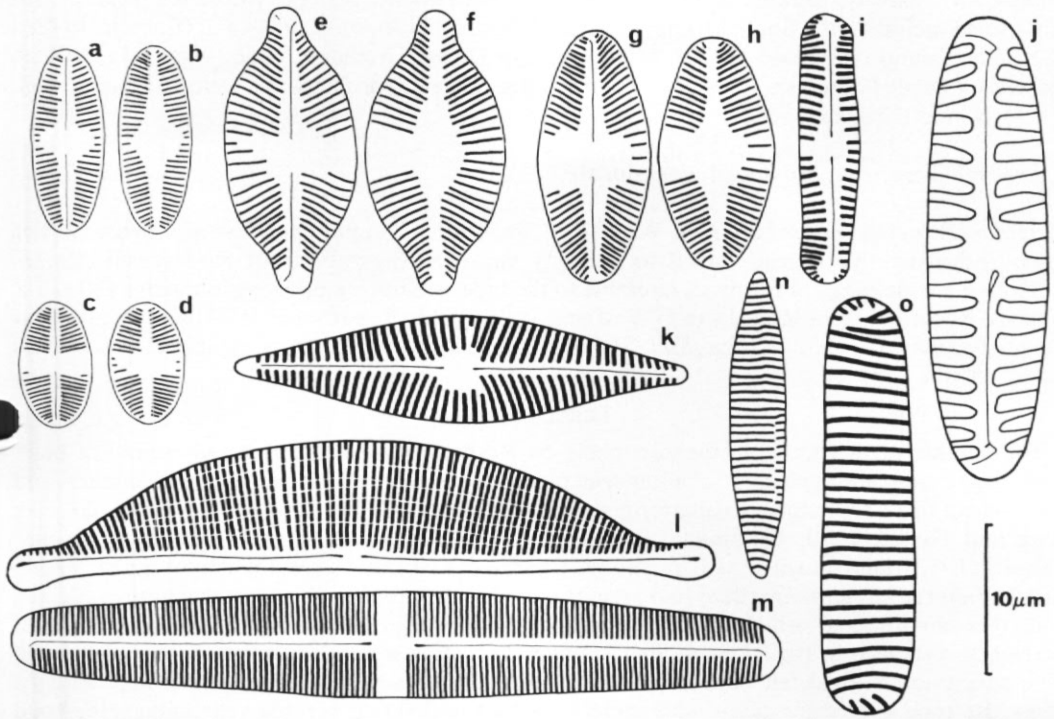

Fig. 3. Diatoms from pools on Rothera Point (line drawings from photomicrographs, all to the same scale). a and b. *Achnanthes* sp.; c and d. *A.* sp.; e and f. *A. germainii*; g and h. *A. ninckei*; i. *Pinnularia krookei*; j. *P. borealis*; k. *Navicula cryptocephala* var. *intermedia*; l. *Amphora* sp.; m. *Tropidoneis laevissima*; n. *Fragilaria* sp.; o. *Nitzschia curta*.

Cocconeis costata Greg. Pool 7, occasional frustules (probably blown in from the sea). Antarctic freshwater records from the South Orkney Islands (Fritsch, 1912*a, b*) and Molodezhnaya Oasis (Opaliński, 1972*a*).

Pennales : Biraphidineae

Amphora sp. (Fig. 3l). Pool 7, common.

Navicula cryptocephala Kütz. var. *intermedia* Grun. (Fig. 3k). Pool 7, common. Other record from Prince Olav Coast, including some brackish pools (Fukushima, 1962).

N. muticopsis van Heurck. Pool 4, occasional. A typical and widely recorded Antarctic endemic. For discussion of variability and forms see Ko-bayashi (1963*a*). Other records include the South Orkney Islands (Fritsch, 1912*a, b*), Ross Island (West and West, 1911; Fritsch, 1912*c*), South Victoria Land (West and West, 1911; Baker, 1967), East Ongul Island (Fukushima and others, 1973) and Molodezhnaya Oasis (Fukushima, 1966).

Nitzschia bicapitata Cleve. Pool 7, occasional. Probably of marine origin.

N. curta (Van Heurck) Hasle (Fig. 3o). Pool 4, occasional. Probably of marine origin.

N. cylindrus (Grun.) Hasle. Pool 7, occasional. Probably of marine origin.

Pinnularia borealis Ehrenb. (Fig. 3j). Pool 4, occasional. Several published records for Antarctica including the South Orkney Islands (Fritsch, 1912*a, b*), Ross Island (Fritsch, 1912*c*), Alexander Island (Heywood, 1977), Molodezhnaya Oasis (Lavrenko, 1966; Opaliński, 1972*a*), Haswell Island (Opaliński, 1972*b*), Schirmacher Oasis (Aleshinskaya and Bardin, 1965; Komárek and Růžička, 1966).

P. krookei Grun. (Fig. 3i). Pool 4, occasional.

Tropidoneis laevissima W. & G. S. West (Fig. 3m). Pool 7, common. West and West (1911), when describing this species, failed to find any striae on the valves but Ko-bayashi (1963*b*) illustrated a wide range of forms all referable to the type and having easily visible striae (20–28 in 10 μm). Recorded from Ross Island (West and West, 1911; Fukushima, 1964) and Prince Olav Coast (Fukushima, 1962: Ko-bayashi, 1963*b*). The species appears to be typical of brackish or saline water.

Discussion

The benthic algal felts from the two pools on Rothera Point are composed mainly of blue-green algae and are typical of shallow-water communities in Antarctic freshwater lakes and pools where these are subject to intermittent freezing (West and West, 1911; Fritsch, 1912*a, b, c*; Fogg and Horne, 1970; Goldman and others, 1972; Heywood and others, in press). Holm-Hansen (1963) has shown that filamentous Cyanophyta from shallow water of Lake Vanda (South Victoria Land, Antarctica) had greater viability after freezing than other groups collected from this environment which only thawed for a few weeks in summer. The importance of freezing is also seen in the lakes on Signy Island. The shallow sub-lacustrine shelf is dominated by a species-poor algal felt composed mainly of *Phormidium* spp., whereas the lake troughs below the zone of freezing often have more abundant and varied benthic vegetation (Heywood and others, 1979, 1980; Priddle and Dartnall, 1978; Priddle, in press).

Taxonomic comparison of the Rothera Point material with other Antarctic freshwater collections is only possible for the diatoms, since the identifications given for the blue-green and green algae are incomplete. Most of the diatoms described here have been recorded from other sites in the Antarctic and many occur in several localities all round the continent and Antarctic Peninsula. The majority has recently been found in material from Signy Island and from Elephant Island, South Shetland Islands (Belcher, Carter and Priddle, in preparation), and consists mostly of taxa with world-wide distributions. The flora of Pool 7, being close to the sea, contains an abundance of marine or brackish forms probably blown in with spray.

The pigment spectra obtained for the Rothera Point benthic algae resemble those from shallow-water algae from Heywood Lake on Signy Island, and those found by Goldman and others (1972) in benthic algae from pools on Ross Island (lat. 77°38′S, long. 166°24′E). All these algae are growing under similar conditions and the pigment spectra probably indicate a response to the same factor or complex of factors. Two questions need to be asked. First, do the absorption spectra result from an increased production of carotenoid pigment or from the selective breakdown of chlorophyll? Secondly, if carotenoid pigments are present in increased quantities, what is their function?

The origin of the apparently high ratio of carotenoids to chlorophyll is hard to determine. No previous investigation has been made of the degradation of pigments under freezing conditions but several authors have studied the break-down in sediment. Fogg and Belcher (1961) and Wetzel (1970) showed that the first stage in pigment degradation in lake sediments resulted in an elevated carotenoid to chlorophyll ratio. However, although frozen Rothera Point felt yielded less chlorophyll *a* per unit acetone-insoluble dry weight than fresh material from Heywood Lake, this difference could be attributed to natural variation both in pigment content and its susceptibility to acetone extraction (Marker, 1972). The Heywood Lake material, which was frozen as a control for testing the extraction from the Rothera Point felt, was apparently not affected after $2\frac{1}{2}$ months, but this does not preclude different behaviour after longer periods of freezing or selective break-down taking place when the algae are completely thawed. Possibly the most important evidence is the comparison of the absorption spectra of shallow- and deep-water algae (Fig. 1a, b and c), which suggests that the high carotenoid content is at least partially environmentally determined.

It is more difficult to suggest a function for this large amount of carotenoid pigment. Goldman and others (1972) noted the importance of carotenoids in protecting the photosynthetic apparatus and the same authors had earlier demonstrated both light inhibition (reversible) and light injury (irreversible) during periods of long day length and high insolation in the Antarctic summer (Goldman and others, 1963). In a laboratory study, Sager and Zalokar (1958) found that a carotenoid-deficient strain of *Chlamydomonas reinhardii* was unable to survive except in the dark and subsequent work has firmly established that a major role of carotenoids in algae is the protection of chlorophyll from photodestruction (see Nakayama, 1962; Krinsky, 1968). However, this protection is achieved at the molecular level and does not appear to require the high levels of carotenoid found in the Antarctic samples. Cogdell (1978), working with a photosynthetic bacterium *Rhodopseudomonas sphaeroides*, has shown that the photosynthetic unit is stable with a ratio of 30–40 molecules of carotenoids to 100 molecules of bacteriochlorophyll. It appears more likely that the carotenoids are fulfilling some other protective function. Krinsky (1978) noted several ways in which carotenoids may protect the cell. Irreversible photobleaching of the carotenoids themselves (Fujita, 1978) may in itself necessitate the high levels.

ACKNOWLEDGEMENTS

We thank Drs J. H. C. Fenton and R. I. L. Smith for collecting the specimens and providing environmental information. Erica Swale drew Fig. 3 and Dr R. J. Cogdell made useful comments on the function of carotenoid pigments.

MS received 18 May 1979

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