NOTES

THE CHLOROPHYLL CONTENT OF ARCTIC SEA-ICE

A number of observers (see, e.g., ref. 1, 2), working in arctic and antarctic waters, have commented on the discoloration of sea-ice caused by unicellular algae, mainly diatoms, that are frozen into the ice. The discoloration is usually seen when the ice is broken and overturned, because it occurs principally on the lower surface of the ice and occasionally on its sides. The brown or greenish-brown colour is due to the chloroplasts in the algae and undoubtedly indicates the presence of a potential source of food in polar seas in addition to the phytoplankton and the benthic algae.

The algae associated with the ice present interesting problems concerning the adaptation of protoplasm to life under conditions of low temperatures (maximum about −1.68°C.) and of the adaptation of photosynthetic activity to low light intensities. Although they have been frequently observed, these algae have been very little studied, partly on account of collecting difficulties. Investigations of algae frozen into sea-ice have been started at the Devon Island station (75° 42′N.) of the Arctic Institute and some preliminary results are reported here.

All samples were taken about 200 yards from shore from level, undisturbed ice, which was about 65 inches thick and covered with 8.0 to 9.5 inches of snow until June 12. At that date the snow began to melt and almost all of it had disappeared by June 20. The sea, within a radius of at least 30 miles, was covered everywhere with similar amounts of ice and snow. The minimum depth of water in the sampling area was 16 feet.

Samples were collected by coring with a 3-inch-diameter SIPRE ice corer. Until June 26 the bottom of the core had a characteristic pattern of narrow and very regular parallel ridges, which were approximately 2 mm. high, 0.2 mm. wide, and spaced about 0.9 mm. The ridges were the most intensely brown part, the colour faded gradually until the ice was colourless and clear at about 1.5 inches from the bottom.

The entire coloured part of each suitable core was melted in a polyethylene container and the volume of water measured. Either the whole sample or a large aliquot was filtered through an HA millipore filter and the pigments were extracted for at least 20 hours with 5 ml. of 90 per cent acetone in the cold and dark. The sample was then hand-centrifuged and the optical density of the extract measured in a Klett-Summerson photoelectric colorimeter with a No. 66 red filter. I follow Wright[3] in assuming that 1 Klett unit equals approximately 0.28 mg. chlorophyll *a* per m^3. The results of the measurements, which are listed in Table 1, show that the chlorophyll concentrations are very large, as can be seen from comparison with the values in Table 2. Ryther[4] has discussed the relative primary plankton productivity of oceanic and coastal waters and pointed out that, although the values may be similar per area of sea surface, the shallow coastal waters with a denser concentration of phytoplankton offer more favourable feeding conditions to zooplankton. The high concentration of algae under sea-ice would seem to provide abundant food for the amphipods that are a conspicuous part of arctic marine life. English[2] reports that "amphipods have been observed to graze along the bottom and sides of ice floes, appearing to wear away small areas of the ice." It is interesting to note that on June 9 for the first time the corer brought up many very small amphipods who were presumably feeding on the attached algae. It is possible that newborn amphipods find their first food on the bottom of the ice and that they either stop feeding or change to plankton feeding when the ice disintegrates.

Table 1. Chlorophyll *a* concentrations (μg./l.) from snow-covered sea-ice.

Date	*Klett units*	*Chlorophyll* a
June 4	165	46.2
June 5	444	124.0
June 6	480	150.4
June 7	243	68.0
June 9	474	132.7
June 11	164	45.9
June 12	378	104.8
June 13	160	44.8
	average	89.6

The large chlorophyll values imply that the algae require large amounts of nutrient salts, such as nitrates and phosphates. Several measurements of phosphate concentration in sea-ice have been made, using the standard ammonium molybdate method. Samples from five levels in each of several cores were analyzed. The lowest section of each core was, after melting, filtered through Whatman No. 2 filter paper in order to remove the algae before analysis. The amounts of phosphate varied rather irregularly through the central part of the cores and averaged about 0.5 μg.A PO_4-P per l. At the bottom of the cores they varied from about 1.0 to 3.0 μg.A PO_4-P per l. These amounts are large and if available for use by the algae frozen into the ice would support high chlorophyll concentrations.

In addition to the foregoing work a simple experiment was made in order to determine the effect of increased light intensity on the chlorophyll concentration at the lower surface of the ice. On June 3 a 10-foot square of ice was cleared of snow. The results of the measurements of chlorophyll made after June 9 are shown in Table 3. It was obvious while taking the cores that much less chlorophyll was present under the cleared area. The brown colour at the bottom of these cores was only about one-fifth as intense or less as that of the cores taken from the snow-covered ice. The most intense colour in the cores from the clear area occurred only in small flecks between the ridges, which were much reduced in size and distinctness. All cores from the cleared area had the same appearance.

Table 2. Chlorophyll *a* concentrations (μg./l.) from several areas.*

Locality	*Chlorophyll* a
N.W. Atlantic Ocean,	
4 northern stations	2.1
14 tropical stations	1.0
Long Island Sound, March-May 1952	7.2
East Sound, Washington	15.0
Gulf of Alaska	2.5
Woods Hole Harbor, Massachusetts	3.35
	1.69
	2.80
Allen Bay, Cornwallis Island, N.W.T.	1.38

*With the exception of the last value, this table was taken from Table 2 of ref. 6. Full references may be found in that paper. The value from Allen Bay is an average of my unpublished data.

Table 3. Chlorophyll concentrations (μg./l.) from cleared sea-ice.

Date	*Klett units*	*Chlorophyll* a
June 10	63	17.6
June 10	61	17.1
June 11	58	16.2
June 12	78	21.8
June 13	38	10.6
	average	16.6

A second area was cleared on June 10, the chlorophyll concentration was measured on the 16th, and the results confirmed the first test.

Further measurements of the ice-bound chlorophyll concentrations were made during and after the natural melting and the disappearance of the snow cover. The results are listed in Table 4 and they show a marked decrease from the earlier values. In these samples the parallel ridges generally maintained their characteristic appearance until June 23, when they became rather indistinct, but they did not disappear almost completely as they did on the ice from artificially cleared areas.

The decrease of chlorophyll concentration as a result of increased light intensity may have either a biological

Table 4. Chlorophyll *a* concentrations (μg./l.) in sea-ice after snow melt.

Date	*Klett units*	*Chlorophyll* a
June 20	60	16.8
June 20	98	27.4
June 23	24	6.7
June 26	30	8.4
June 27	28	7.8
June 27	18	5.0
	average	12.0

or a physical cause. It is well known that unicellular algae have optimal light intensities for growth and can be inhibited by excessive light through photo-oxidation of their photosynthetic pigments. This may be the biological basis for the decrease of chlorophyll in the present work.

The effect of light on the structure of the ice itself must also be considered. The structure of sea-ice has been examined by Weeks [5] who states that "Sea ice crystals, therefore, consist of alternating layers of pure ice and brine. . . . The distance between the planes of brine inclusions varies from 0.2 to 0.8 millimeters and averages 0.45 millimeters. . . . In a cross section of a growing sheet of sea ice [*in*] the lower 2.8 centimeters . . . the ice platelets that make up the single crystals are completely separated by layers of brine." It seems clear that in the cores from snow-covered ice at Devon Island the main growth of algae occurred on the platelets of pure ice described by Weeks. The cores taken from the cleared ice showed very much reduced and indistinct ridges or platelets, and it is quite possible that their disintegration is the cause of the disappearance of the algae. By acting as a heat absorber the algae themselves could cause the break-down of the platelets and thus destroy their own micro-habitat.

During the natural melting of the snow, however, the ice ridges or platelets persisted in their characteristic form after the chlorophyll concentration had decreased. It would thus appear that physiological inhibition is the main cause of the disappearance of the pigment from sea-ice.

The question of how much light reaches the underside of sea-ice is particularly interesting. In the latitude of the Devon Island station the sun is above the horizon continuously from about April 20 to August 20. In May and early June of 1961 the sky was generally clear and the weather bright. The full solar radiation program of the station was not yet under way when this note was written, but a few spot readings indicate that at noon about 90 per cent of the total radiation was reflected from the surface of the snow. Further, when values of about 3600 foot-candles were measured at the snow surface at noon, no more that 50 foot-candles penetrated 9 inches of snow, the density of which was 0.3 gm./cm.^{3}. Ryther and Yentsch[6] give 100 foot-candles as the intensity at which the photosynthetic production of energy just balances the energy requirements of a general phytoplankton population in temperate regions. It is thus evident that algae under snow and ice receive far less than the minimal amount of light required by phytoplankton of temperate regions. These algae living on the underside of the ice must therefore be adapted to carry out photosynthetic activities and to grow under much reduced light intensities and they would probably be completely inhibited by intensities in which algae of temperate zones normally flourish.

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