Ecology and Physiology of Soil Microorganisms in Polar Regions

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Abstract: Growth of microorganisms takes place during the short summer season in the Arctic and Antarctic, although some habitats are sterile. Both polar regions may be characterized by low metabolic activity due to a number of factors which are a result of the physical and chemical environment. In the Arctic in addition to temperature there is low pH, and low oxidation-reduction potential because of low concentrations of oxygen. The Antarctic is characterized by low temperature, moisture, high osmotic pressure, antibiotic(s) in rookeries, limited organic matter in most habitats, and possible toxic ions, especially in those areas where moisture is low.

Polar regions have the common property of being made up of terrestrial habitats which are below freezing for most of the year (9–11 months). These temperatures are sub-optimum for the growth of plants and the majority of animal systems (warm blooded animals being the exception, although in some cases it is necessary for them to hibernate), so that for most of the year the flora and fauna neither grows nor is active metabolically. Despite these extremes, however, the temperatures will rise above freezing for varying lengths of time during the short summer season, and some growth in certain areas is possible. In fact, there are antarctic habitats where due to solar radiation the temperatures may rise to +30°C, the optimum growth range for mesophilic microorganisms (Gressett, 1964).

The arctic regions are less severe and can support the growth of seed-bearing plants, animals, and a human population, although microbial activity is much lower than encountered in the temperate regions. The Antarctic as a whole is much colder and supports no human or animal population on land except insects and related arthropods (Gressett, 1964), although there are migratory birds and indigenous species of penguins and skua which nest on the land but derive their food from the sea. In both cases there are physical and chemical factors of the environment which influence microbial activity, and this paper will consider the role that they play in the microbial ecology of these areas.

Point Barrow, Alaska, is located at 71°20′N latitude on the arctic coastal plain of Alaska. It is typical tundra, wet, with little rain fall, where the vegetation is composed primarily of grasses, sedges, lichens, and mosses as seen in Fig. 1; well drained areas with more thoroughly developed soils can be found on beach ridges of drained lakes as shown in Fig. 2. Figure 3 shows soil at Inuvik, N. W. T., Canada (68°21′N latitude) which is more highly developed and supports

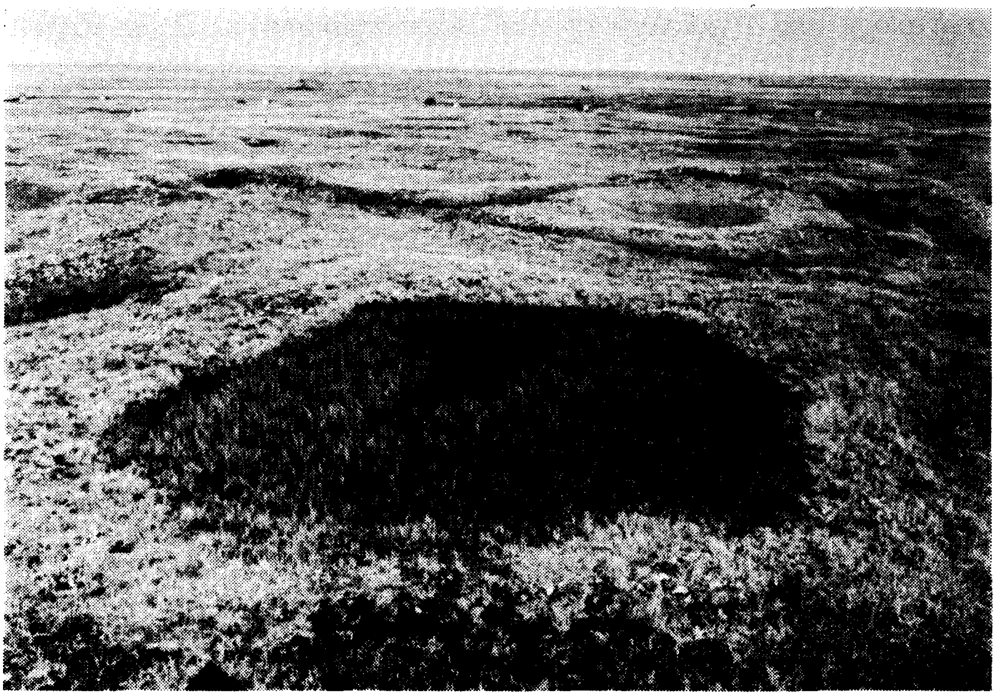

Fig. 1. Typical tundra characterized by low center and high center polygons.

Fig. 2. Oriented lakes of northern Alaska. Periodically, lakes will drain due to natural or other causes forming dry basins with beach ridges where well-developed soils can be observed. The lake in the lower left-hand corner is partially drained.

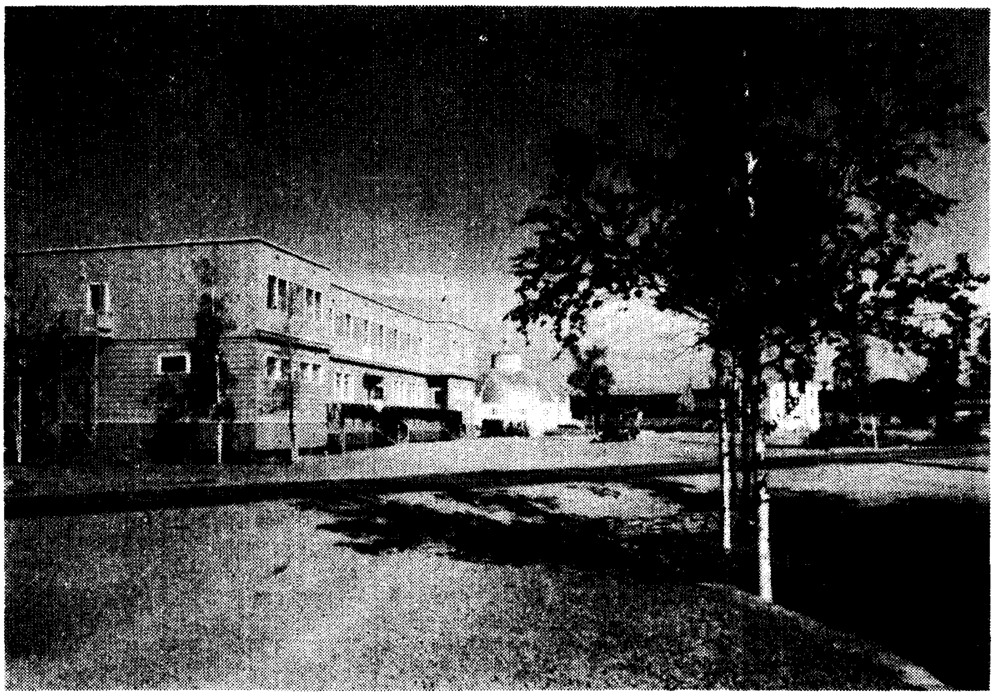

Fig. 3. Highly developed vegetation at Inuvik, N. W. T., Canada.

Fig. 4. Volcanic ash at Cape Royds, Ross Island.

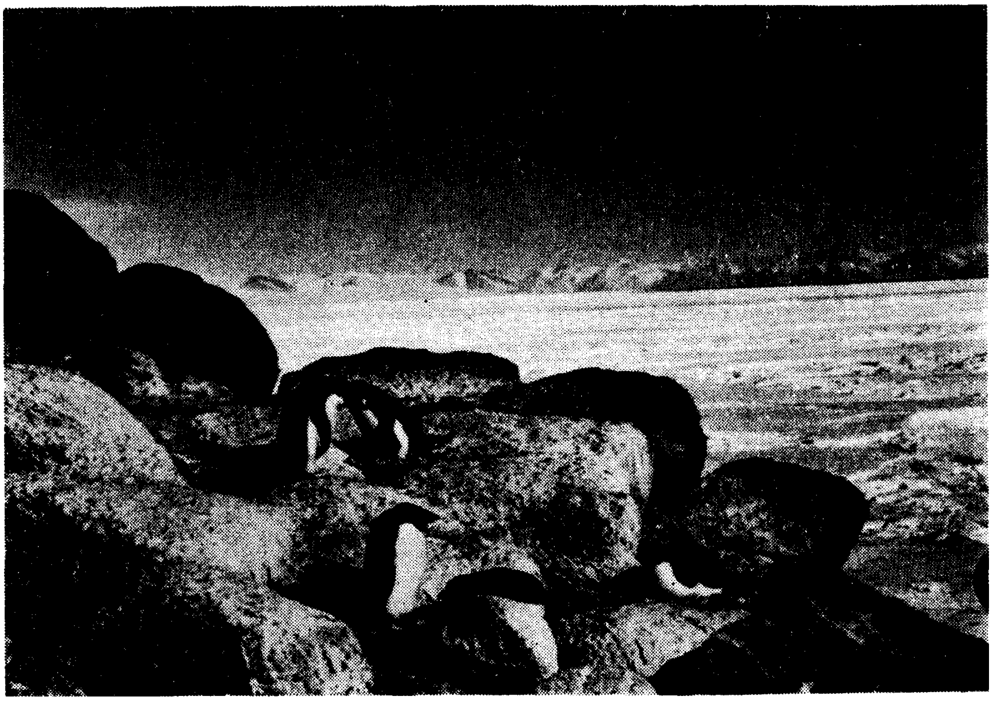

Fig. 5. Adelie penguin rookery at Cape Royds.

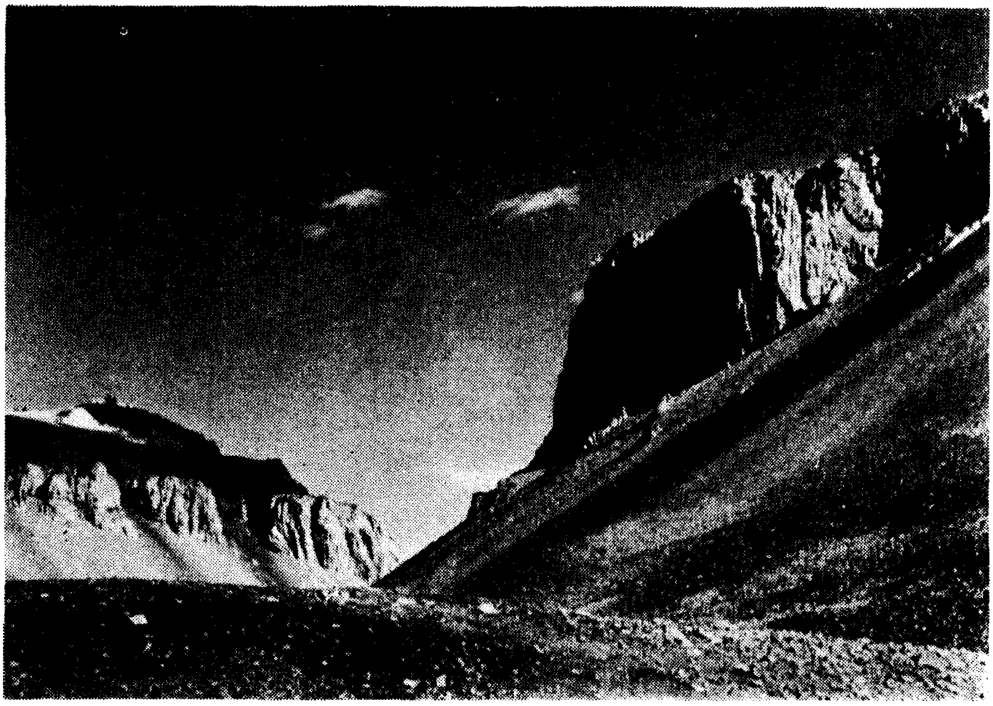

Fig. 6. Typical "soil" of the dry valleys, Victoria Land.

the growth of trees such as birch and spruce with secondary stands of willow and alder. All three areas are underlain with permafrost (permanently frozen ground). Bacterial counts and physiological activity is much lower than encountered in temperate regions, but the soils are true soils which possess all of the phases common to soil such as organic, living, gaseous, inorganic, and aqueous phases. Figure 4 shows the area of Ross Island, Antarctica (77°51′S latitude), at Cape Royds which is composed of the typical volcanic ash, and Figure 5 shows the nearby adelie penguin rookery. Figure 6 shows a typical area in the dry valley, Victoria Land. The south polar "soils" are rudimentary and in some cases do not possess a living phase. For this reason, they cannot be classified as true soils. Ross Island possesses three volcanoes, and one of them, Mt. Erebus, is still active. For this reason, the predominant "soil" is volcanic ash. Over on the mainland in Victoria Land the "soil" is composed of rocks made up primarily of granites, gneisses, and dolomite. In general most of the soils possess a well-defined microflora. In temperate regions the number will vary over the seasons in most areas. Uncultivated soil will possess from 1,000,000 to 50,000,000 bacteria per gram of soil based on viable plate counts, while fungi counts will range between 3,000 per gram to 60,000 per gram of soil (WAKSMAN, 1952).

Polar soils in general do have fewer organisms in the upper horizons (Table 1). Bacterial counts of arctic soils are low when compared to temperate soils, while fungus counts are high as might be expected because of low soil pH. Paradoxically, some thermophiles having an optimum temperature above 45°C can be isolated, particulary in Canadian soils, and in all cases a significant part of the bacterial population is composed of psychrophiles capable of growth at 0°C in a period of two weeks. The low pH has a greater effect on the growth and activity of bacteria than on yeasts and molds, thus resulting in less competition for food. Most of the soil population is composed of mesophilic bacteria (BOYD, 1958). Antarctic soils show a great degree of variation. Some soils on Ross Island and in the dry valleys of Victoria Land are sterile; no microorganisms can be detected on commonly used laboratory culture media, and only when contaminated by man or animals do they show the high counts seen in typical temperate soils. Thermophiles are lacking except for areas which are contaminated. Molds are almost nonexistent except in areas of high human activity or in areas which support the growth of lichens (BOYD and BOYD, 1963).

Some of the ecological factors which influence growth are given in Table 2. The arctic soils are characterized by high moisture since all runoff is at the surface because of the permafrost and the flatness of the coastal plain around Point Barrow, and the soils tend to be water-logged. The water acts as a mechanical barrier influencing the diffusion of gases, particularly oxygen. Since the dissolved oxygen content will be low, once the aerobic organisms utilize it, conditions will become anaerobic so that fermentation will predominate, and respiration will be at a minimum. The oxidation-reduction potential will be low, and the end products of fermentation may be acids or other incompletely utilized products. The fermentation acids will have a low pH, and little activity from bacteria will

Table 1. Counts of microbes in representative polar soils.*

Date	Location	Soil temp. (°C)	Moisture (%)	Nutrient agar 55°C	Nutrient agar 22°C	Nutrient agar 2°C	Sabouraud's dextrose agar	Thornton's standardized agar
	Barrow							
11-24-62	Peat	frozen	90.4	35	13,000	3,200	530	13,000
11-27-62	Arctic brown	frozen	35.2	18	19,000	6,400	10	17,000
	Inuvik, N. W. T., Canada							
7-27-64	Loam	+17	31.3	2,700	980,000	120,000	24,000	130,000
7-27-64	Loam (cultivated)	+19	22.3	13,000	1,300,000	1,400,000	30,000	2,800,000
	Cape Royds, Ross Island							
11-29-61	Volcanic ash	+8	4.3	0	0	0	0	0
11-29-61	Volcanic ash, rookery	+1	6.8	0	45,000	5,200	0	73
	McMurdo Sound, Ross Island							
12-15-61	Volcanic ash, lichen growth	+1	6.6	0	270,000	1,100	3,100	34,000
12-9-61	Volcanic ash, sewage contamination	+4	7.3	390	84,000,000	49,000,000	1,100	25,000,000
	Taylor Dry Valley, Victoria Land							
1-16-63	Gravel, no visible plant growth	+2	1.0	0	0	0	0	0
1-18-63	Gravel, *Nostoc commune* present	+1	9.8	0	7,300	86	7	1,400

* Per gram of dry soil.

Table 2. Chemical composition (in p.p.m.) of representative polar soils.*

Date	Location	pH	Phosphorus	Potassium	Calcium	Magnesium	Nitrate	Ammonia	Sulfate	Chloride
	Barrow									
11-24-63	Peat	5.8	20	840	400	200	0	120	0	2,400
11-27-62	Arctic brown	4.8	110	240	12,000	0	0	220	80	80
	Inuvik, N. W. T., Canada									
7-27-64	Loam	4.8	5	100	2,000	125	0	25	0	0
7-27-64	Loam (cultivated)	6.8	200	360	2,000	800	1	25	0	0
	Cape Royds, Ross Island									
11-29-61	Volcanic ash	8.3	180	1,300	3,800	600	0	0	11,000	22,000
11-29-61	Volcanic ash, rookery	7.0	2,400	280	200	80	0	6,000	5,600	1,800
	McMurdo Sound, Ross Island									
12-15-61	Volcanic ash, lichen growth	8.0	100	320	3,200	1,800	0	60	0	20
12-9-61	Volcanic ash, sewage contamination	8.1	300	320	2,400	280	0	160	20	800
	Taylor Valley, Victora Land									
1-16-63	Gravel, no visible plant growth	8.1	120	100	2,400	1,200	6	10	0	4,800
1-18-64	Gravel, *Nostoc commune* present	8.0	90	660	2,200	120	1	12	10	400

* Hellige-Truog Soil Tester.

take place. Despite the fact that molds can grow at low pH ranges, there will be little physiological activity because they are predominantly aerobic and cannot grow in the limited amount of available oxygen. The least developed soil (peat), is found in wet areas (moisture content up to 90.4%), while the best developed soils, the arctic brown soils, are found on beach ridges which are well drained. However, even here oxygen content is limited, and pH is low. Nitrification is at a minimum, and ammonification is a result primarily of the anaerobic deamination of aspartic acid, serine, and threonine; some urease activity also takes place. This low microbial activity is also responsible for slow plant growth, since the temperature in the summer seldom gets above 20°C at the surface. The overall factors which may limit growth and physiological activity, therefore, are temperature, high moisture, low pH, and low oxidation-reduction potential.

Turning to Antarctica, permafrost is present although there is better drainage along the coastal areas where soil is exposed. A high degree of evaporation takes place due to wind activity. Antarctic soil differs from arctic varieties in that low moisture is present. This has the indirect effect of raising the osmotic pressure which slows down or inhibits bacteria growth but has a lesser effect on the growth of yeasts and molds. It is interesting to note that on Ross Island osmotic pressure is high, while in the rookery there is penguin guano with a very high concentration of ammonia and phosphorus. In those areas where there is no growth, soluble ions are high, particularly chloride and sulfate as shown in soils from Taylor Valley and Cape Royds. In dry valleys where there is melt water, blue-green algae, *Nostoc commune*, can initiate growth. The water serves as a necessary nutrient in hydrolytic enzyme reactions and as a solvent for other nutrients and dilutes any toxic ions which might be present. The blue-green algae are autotrophic and capable of fixing nitrogen and, given water and a few soluble trace elements, they can synthesize organic matter which can be utilized directly or indirectly by other autotrophic and heterotrophic members of the flora and fauna. Therefore, whenever moisture is available, visible colonies of *Nostoc commune* can be observed, and along with them can be seen bacteria, diatoms, green algae, protozoa and tardigrades, and rotifers. Molds are not found as a rule, and this may be one reason why the valleys lack *Collembola*, which has been postulated to feed on spores and mycelial elements of molds (GRESSETT, 1962).

Since a microflora can be demonstrated in both polar regions, it might be expected to find groups of microorganisms differing in their physiology and metabolism because of the selective action of the different habitats. An enrichment series was set up to detect the presence or absence of different physiological groups to assay the physiological potentiality of each soil (Table 3) as described by BOYD, STALEY and BOYD (1966). Absent from all soils were acidophilic sulfur oxidizers, methane producers, and photosynthetic sulfur bacteria. Iron oxidizers were found in arctic soils but not in antarctic soils. *Chromatium minutissimum* was found in only one case, Skua Pond, at Cape Evans on Ross Island. This pond is inhabited by skua, which supply organic matter in their excrement. This serves as food for heterotrophic microorganisms which possess the

Table 3. Survey of physiological types of microorganisms in polar regions.

Physiological type	Area					
	Alaska		Canada		Antarctica	
	soil	water	soil	water	soil	water
Iron oxidizers	Bact.	0	0	Bact.	0	Bact.
Acidophilic sulfur oxidizers	0	0	0	0	0	0
Photosynthetic nitrogen fixers	Blue-green algae	Blue-green algae	0	0	0	Blue-green algae
Heterotrophic nitrogen fixers	Bact.	Bact.	Bact.	Bact.	Bact.	Bact.
Ammonia oxidizers	Bact.	Bact.	Bact.	Bact.	Bact.	0
Photosynthetic microorganisms	Algae	Algae	Algae	Algae	0	Algae
Photosynthetic nonsulfur bacteria	0	0	Bact.	Bact.	0	Bact.
Methane producers	0	0	0	0	0	0
Sulfate reducers	Bact.	Bact.	Bact.	Bact.	Bact.	Bact.
Lactate fermenters	Bact.	Bact.	Bact.	Bact.	Bact.	Bact.
Photosynthetic sulfur bacteria	0	0	0	0	0	Bact.

enzyme (cysteine sulfhydrate) which catalyzes the breakdown of cysteine or its oxidized product, cystine, to pyruvic acid, ammonia, and hydrogen sulfide. The H_2S is utilized as the oxidant in photosynthesis by *C. minutissimum* which reduces it to elemental sulfur which accumulates in the cell in the form of globules and gives the interior of the cell a beaded appearance. Nitrogen-fixing bacteria and blue-green algae are also present, but nitrogen-fixation has not been demonstrated *in situ*. Sulfate reducing bacteria are widely distributed as reported by BARGHORN and NICHOLS (1961).

Quantitative studies carried out on some of the reactions of the nitrogen cycle are given in Table 4 (BOYD, 1958; BOYD and BOYD, 1963). The rate of ammonification in all cases is low and when translated in terms of available plant nitrogen particularly in the antarctic soils, would be rather insignificant although it could be important for other members of the microflora. In those cases where activity was obtained, it was possible to increase the activity by raising the temperature, emphasizing the role the temperature plays in regulating the rate of metabolism. The rate of the reaction is also important in limiting the amount of NH_3-N which would be available to other forms as a nitrogen source. Under natural conditions, low amount of organic matter are found in soils of Antarctica except in rookeries, where it accumulates because of environmental factors. Out of the rookery, nitrogen-fixers are probably the most important producers of humus. This is why *Nostoc commune* is so important in the food chain of Antarctica. In the Arctic there is a significant amount of plant and animal debris accumu-

Table 4. Ammonification by polar soil.

Sample*	Incubation conditions**	Casein solution: Micrograms of NH_3-N produced by one gram (dry wt.) soil per 100 ml medium
Point Barrow		
Sandy-loam	22°C	9,000
	2°C	0
	outside	25
Arctic brown	22°C	19,500
	2°C	0
	outside	560
Peat	22°C	12,000
	2°C	650
	outside	400
Ross Island		
Volcanic ash	22°C	0
	2°C	0
	outside	0
Volcanic ash-rookery***	22°C	2,800
	2°C	1,600
	outside	120
Volcanic ash-lichens growing	22°C	250,000
	2°C	13,000
	outside	0

* Control values have been subtracted from all experimental values.

** Covered with soil to a depth of 6 cm and incubated for five weeks.

*** Soil control bottle contained 3,000 μg NH_3-N/100 ml.

lating because of low activity.

In penguin rookeries an interesting association has been observed (SIEBURTH, 1963). Phytoplankton, produce acrylic acid, a three-carbon unsaturated aliphatic acid. Apparently this substance remains stable when the phytoplankton (*Phaeocystis pouchetii*) are eaten by krill, *Euphasia superba* and when consumed by the penguin, it becomes concentrated in the intestinal tract but can be demonstrated in other body fluids such as blood serum. Antibiosis has been demonstrated in serum, in intestinal contents, and in soil from rookeries contaminated with penguin quano. The antibiotic has a broad spectrum, and will inhibit the growth of *Pasteurella multocida*, *Staphylococcus aureus*, and *Corynebacterium pseudodiphtheriticum* to the greatest extent, while *Torula lactosa* and *Aspergillus fumigatus* showed the least inhibition. *Escherichia coli* could not be detected on Ross Island but was isolated from rookeries in the south Shetland Islands by SIEBURTH (1963). Therefore, this antibiotic will have some effect on the quality and in some cases on the quantity of the microflora.

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