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SOME ENVIRONMENTAL FEATURES OF HALLETT STATION, ANTARCTICA, WITH SPECIAL REFERENCE TO SOIL ARTHROPODS[1]

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Abstract: This paper discusses the environment and ecology of soil arthropods at Hallett Station, northern Victoria Land. Four species each of Acarina and Collembola, and one or more species of Tardigrada were found. The collembolan *Isotoma klovstadi* Carpenter is treated in detail. Large numbers live in the substrate near areas inhabited by birds, and feed on moss and lichens in warm humid weather. Low temperatures can be tolerated (experimentally as low as -50°C), but desiccation is a serious adverse factor and humidity is very low in sunny weather. Hibernation is in egg and adult stages, but particularly in the egg stage.

1. INTRODUCTION

Since Cook's voyage of 1772–1775, numerous expeditions, nationally and independently supported, have explored coastal and inland areas of Antarctica. The primary purpose of most early scientific expeditions was directed toward a study of the physical nature of the continent. In most instances, biologists were not included as expedition personnel and a large portion of the information concerning the flora and fauna of the continent has been contributed by investigators trained in a variety of scientific disciplines. Very few systematic investigations of land flora and soil fauna have been made. In spite of the obvious inadequacy of such investigations, a considerable number of arthropod species have been reported from various parts of Antarctica.

Very few groups of terrestrial arthropods are represented in the fauna of continental Antarctica. When the subantarctic islands are recognized in a larger complex, an increase in both number of groups and species is evident. Acarina, Collembola, Anoplura, Mallophaga, and Diptera have been found on the continent. The order Mallophaga is represented by 15 species which have been taken from sea birds found in many coastal areas. Acarina, the second largest group, is represented by 13 species which have been extracted from mosses, lichens, and soil. Eight species of Collembola have been reported from various areas on the continent. Six species of Anoplura have been taken from seals and two species of Ixodidae have been reported from host penguins. One species of Diptera, *Belgica antarctica* Jacobs, a wingless chironomid fly, has been reported from melt pools in

1. A thesis presented to the Graduate Council of the University of Tennessee in partial fulfillment of the requirements for the degree Doctor of Philosophy. The author was overwintering at Myrnyy while this paper was in press, and had no opportunity to see proofs. Proofs were kindly read by Drs. A C. Cole and G. A. Llano.
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the lower latitudes of Palmer Peninsula.

The terrestrial arthropod fauna of the subantarctic islands is quite similar to that of continental Antarctica with the exception of more diversity in groups represented in island populations. Diptera, Coleoptera, Lepidoptera, and Araneae are found on the subantarctic islands (Gressitt & Weber, 1959). Diversity is especially noticeable on those islands situated in the lower latitudes. More than 150 species of terrestrial arthopods have been reported from the Auckland Islands (about 51° S, 166° E) which are included in the subantarctic group.

Most of the species of terrestrial arthropods reported from continental Antarctica have been found on Palmer Peninsula. This mountainous peninsula extends southward and southwestward from 63° 15′ S, 56° 40′ W to approximately 73° S latitude. The northern extremity of the peninsula represents the most northerly point on the continent and is the closest to any other continental land mass. It is separated from South America by Drake Passage which is approximately 1000 km wide. Favorable ice conditions and a less rigorous climate have promoted exploration in the area and many stations were established on the peninsula during the rise of the sealing industry in the early part of the 19th century. Continued research has made it the best known and most thoroughly investigated area in Antarctica.

The first Acarina found on the continent were collected on Palmer Peninsula by the Belgian Antarctic Expedition of 1897–1899. Two species, *Notaspis antarctica* and *Notaspis belgicae*, were described by Michael in 1903. From 1903 to 1908, 11 species of Acarina were collected by various expeditions working in the peninsular area. Only two other species, collected on opposite sides of the continent, have been described from areas away from the Palmer Peninsula. One of these was collected at Cape Adare (71° 14′ S, 170° 15′ E) and described by Trouessart in 1903. The other species was collected by the Norwegian-British-Swedish Expedition to the Antarctic 1949–1952 at two locations in Western Dronning Maud Land; at Passat (72° 17′ S, 4° 3′ W), and Ekberget (72° 17′ S, 0° 21′ W). This species, *Maudheimia wilsoni*, was described in 1958 by Dalenius.

Of the eight species of Collembola recorded from continental Antarctica, six were found on Palmer Peninsula. The first species to be described, *Isotoma klovstadi* Carpenter, was collected in 1898–1900 by members of the Southern Cross Expedition at Robertson Bay (71° 40′ S, 169° 50′ E) in northern Victoria Land. In 1902, Carpenter indicated that the species was taxonomically allied with a species from Tierra del Fuego. Carpenter (1908) also described a species of Poduridae from Granite Harbor (76° 55′ S, 163° 0′ E), which is across McMurdo Sound from Ross Island. With the exception of the subantarctic islands, collembolans have been described only from these three widely separated areas (Gressitt & Weber, 1959). These data should not be interpreted as being indicative of unusual distributional patterns, for intensive surveys have been few in number and restricted to very small areas in isolated regions of coastal Antarctica. It is very probable that a circumpolar distribution for higher taxa will be discovered through continuing research. The study presented in the following pages is an attempt to supply data which will aid in verifying such a premise.

Three objectives were maintained in the planning and carrying out of the problem; first, and of major importance, to investigate environmental factors associated with the Hallett Station area and second, to determine what species of soil arthropods are present in the immediate vicinity of the station. A brief analysis of insect responses to changes in local summer environments is offered in a separate study. In view of the fact that the research program reported upon in this paper represents a first attempt to survey biologically a recently established station site, a rather comprehensive analysis of local climate and topography is presented. The first objective was somewhat limited by the number, and frequent malfunction, of available recording instruments. The second endeavour was limited only by the action of climate on area terrain and the consequent confinement to smaller survey sites. The amount of time available made it impossible to investigate thoroughly all the factors that bear to some degree upon the ecological problem.

For the purpose of maintaining continuity and clarification, it will be necessary to include brief discussions and explanatory remarks throughout the text of this paper.

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2. MATERIALS AND METHODS OF STUDY

During the antarctic summer of 1958–59, the writer spent two months collecting land invertebrates from various coastal areas in the Ross Dependency of Antarctica. At the end of this period, it was evident that a more successful summer program could be completed at Hallett Station in northern Victoria Land. In the winter months of 1959, a research program for the following summer was planned. Field work completed during the first summer season, and the subsequent study of material collected, facilitated the planning and execution of ecological investigations during the second summer.

The field work upon which the study is based was initiated during the first week of November, 1959 and was terminated on February 15, 1960. The first two weeks at Hallett Station were spent in reconnaissance and sampling the fauna and flora of the areas. Every environmental unit which appeared to be different with respect to soil, topography, vegetation, slope, exposure, and water relations was examined in an attempt to select favorable sites for continuous surveys and ecological studies.

Invertebrate collections: For the mass collecting of invertebrates, plant and soil samples were taken to the laboratory and immediately submerged in distilled water. The specimens were removed from the surface of the water with a small camels-hair brush. Persistently low humidity in the laboratory and consequent desiccation of specimens made the use of the Berlese method of extraction impractical. For surveys made in more remote areas, specimens were collected singly and transferred immediately to preserving media. Standard insect nets and "tanglefoot strips" were used in specific studies associated with passive dissemination by wind. Series of obviously different species, in varying stages of development, were mounted on slides for taxonomic studies. Reference collections were stored in 70% ethanol.

Plant collections: Plants collected in the field were marked for specific site identification, placed in plastic bags, and returned to the laboratory. Mosses were dried, wrapped in paper, and stored for future study. Intact lichens were wrapped in cotton batting and stored in individual containers. As a result of the difficulty associated with preserving and transporting algae, an attempt was made to classify these plants as new groups were found. Available descriptions were used in determining dominant plants found in the Hallett Station area. In most cases, plants recorded in this analysis have been identified only to genus.

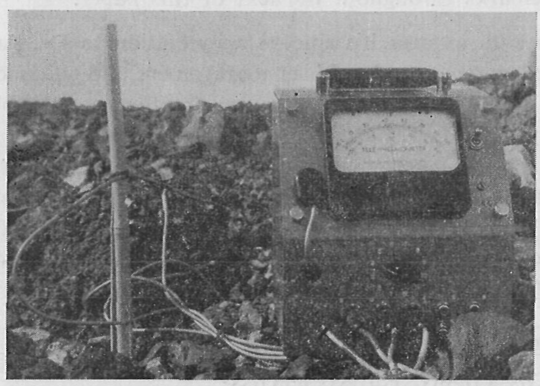

Fig. 1. Portable instrument used for recording soil and air temperature.

Fig. 3. Battery-powered psychrometer used for measuring relative humidity.

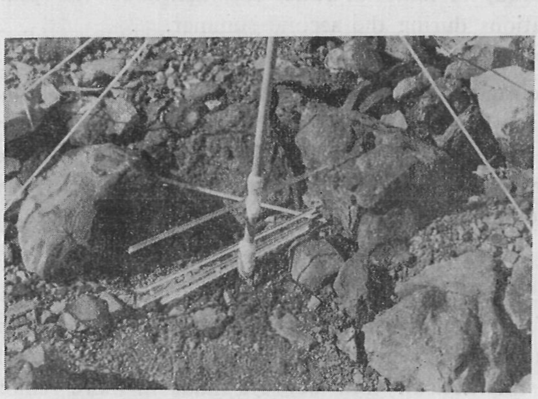

Fig. 2. Mercury-in-glass thermometers used for measuring temperatures at levels above the surface.

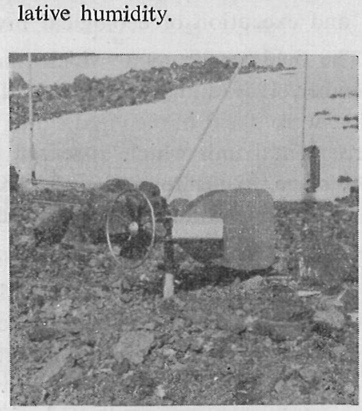

Fig. 4. Portable weather station used for measuring wind direction and velocity.

Measurements: The most reliable temperature observations were made with a battery-powered field instrument designed by the Yellow Springs Equipment Company, Inc. (fig. 1). Leads from plastic-covered thermistors were channelled into a switch-operated measuring circuit and rapid changes in temperature were recorded. A variety of probes designed for use with the "Tele-Thermometer" was utilized for air and sub-surface observations.

Weston dial-type metallic thermometers were also used in measuring soil temperature. A series of Weston thermometers was inserted in the soil at varying depths and maintained as a permanent recording station.

Mercury-in-glass laboratory thermometers were calibrated and fixed on bamboo poles for the purpose of measuring air temperature at various heights above the surface (fig. 2). Glass thermometers were used only when the area was in shadow.

Although most temperature records were obtained by personal observation, U. S. Weather Bureau-type maximum and minimum thermometers were used in some remote areas. These instruments were exposed in pairs in an aluminium shield designed after one developed by Thornthwaite and described by Baum in 1949.

Atmospheric moisture content was determined at various levels from the surface to a height of 2 m. Measurements were made with a small battery-powered psychrometer developed for the Bureau of Aeronautics, U. S. Navy, by the Instrument Corporation, Baltimore, Maryland (fig. 3). A "Serdex" laboratory hygrometer was used for measuring relative humidity in specific situations.

Air movement was very accurately measured by a portable, propeller-type weather station (fig. 4). Wind speed and direction, as well as temperature and relative humidity, were measured with this instrument.

3. DESCRIPTION OF THE STUDY AREA

Hallett Station (72° 18′ 50″ S, 170° 12′ 30″E) is situated on a hooked bar-peninsula that extends 1 km W. from the base of Cape Hallett into Moubray Bay (fig. 5). Soundings made from a small boat indicate that the bar extends for at least 0.5 km under the surface of the water. The station, established in January 1957, is located on the west side of the bar which is referred to as Seabee Spit. The elevation of the spit ranges from sea level to a height of 5 m. Hummocks 2 m in height are scattered on the S. and SE sides of the hook. The elevation of the main spit, which forms the N. and NE boundaries of the bar, is consistently higher than the surrounding area. East of the spit, Willett Cove, which is approximately 250 m wide, separates the main hook from a slightly older beach area which is roughly triangular in shape.

Penguins (*Pygoscelis adeliae* Hombron & Jacquinot) occupy nesting sites on the hook and main spit. The Skua (*Catharacta maccormicki* Saunders) nesting area is confined to the older beach and higher elevations on the cape. The nesting area utilized by the penguins is covered with the bodies of dead birds in various stages of development, pebbles made smooth by erosion, and guano deposits of varying depths. The Skua rookery is generally flat and extends for a distance of approximately 100 m E. of Willett Cove. At this point the area gives way to sharp inclines of loose stone (talus) which border the proximal edge of the beach. The beach is traversed by shallow drainage ditches that carry melt-water from the steep cliffs to Willett Cove.

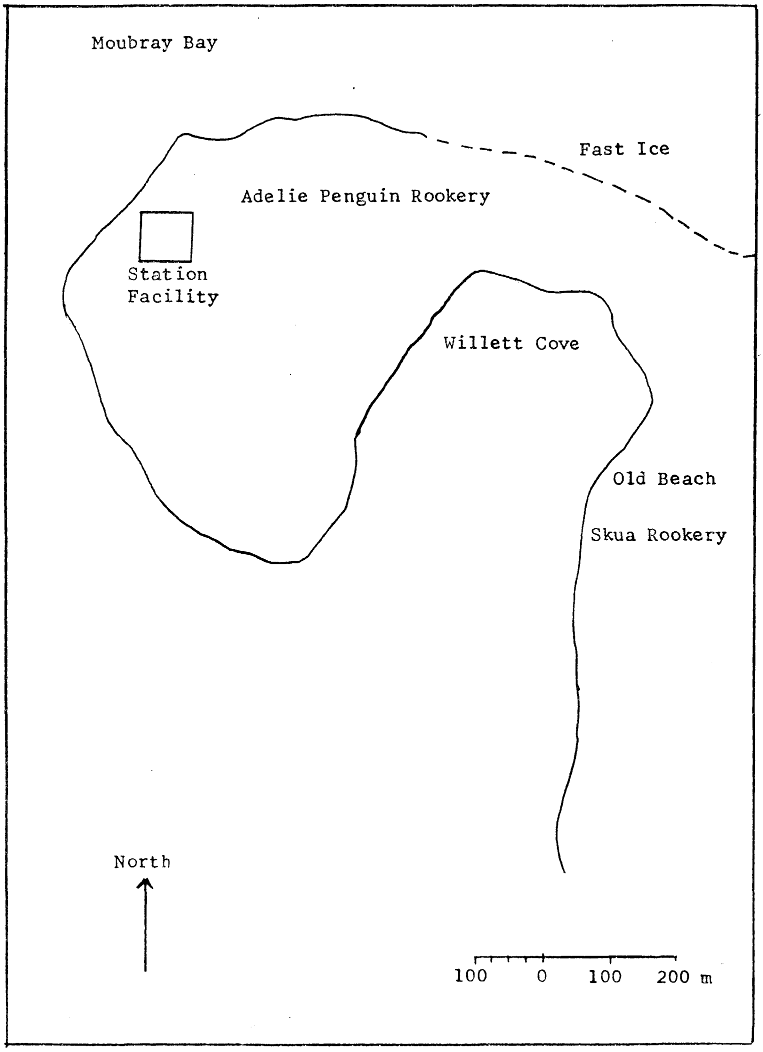

Fig. 5. Hallet Station, Antarctica. S Latitude 72° 18′ 50″ E Longitude 170° 12′ 30″. Talus slopes of Cape Hallett just east of old beach and Skua rookery areas.

Mosses and lichens are abundant on the talus slopes and algae grow profusely in the basins that trap melt-water. Guano deposits which are located on the north and north-west boundaries of the Skua area indicate that penguins have occupied portions of the older beach in past years. The area is presently dominated by the Skua and the cover of polished stones is in direct contrast with the guano cover of the penguin breeding sites.

In the austral summer, the sea ice surrounding the spit is usually broken and moves north and eastward with the prevailing ocean currents. From January to late April, the area may be surrounded by open water. The peninsula is free of snow during the summer season and surface thawing usually begins in early November.

4. ENVIRONMENTAL DATA

Geology and topography: Geological investigations in the antarctic are, for a large portion of the continent, still in the reconnaissance stage. Those areas which have been most thoroughly worked are the Palmer Peninsula, Marie Byrd Land, and Ross Dependency, which includes Victoria Land. Valuable information concerning the geology of the interior of the continent will be afforded by data gathered during the International Geophysical Year. Recent field work (1957–1958) by the New Zealand Geological Survey in northern Victoria Land, and specifically in the vicinity of Hallett Station, has provided pertinent information concerning the geology and topography of the area.

Cape Hallett is a 305 m cliff of basalt flows located in the Admiralty Range of northern Victoria Land, which lies on the western side of the Ross Sea (fig. 6). Victoria Land is an ice-covered plateau bounded on the west by a mountain range varying in width from 80 to 160 km and rising to elevations of approximately 3,500 m. Topographically, the coastal areas of this sector of Antarctica are characterized by precipitous cliffs and glacier systems which flow into the sea. Sparsely scattered embayments are encircled by narrow beaches which are only slightly higher than sea level. These beach sites are frequently free of ice and snow as a result of the action of high winds, but may be backed by ice falls.

Geological nomenclature for all antarctic rock formations has been very unstable and only recently has an attempt been made to establish a formal system for naming major regional units (Harrington, 1958). The proposed nomenclature will be used in this study.

Research by New Zealand geologists has shown that the Admiralty Mountains are composed largely of quartose greywacke and argillite, meta-greywacke and meta-argillite, schist, and some metamorphosed limestone. The new name of Moubray Group has been proposed for this assemblage (Harrington, 1958). The rocks are of Lower Paleozoic or Precambrian age and are, with all the rocks of Victoria Land, assigned to the Ross System with the type beds those of the Moubray Group. A study of the rocks of the Ross System occurring in Victoria Land suggests that these rocks are deposits in a major geosyncline. Deepwater sediments and a scarcity of carbonate rocks are characteristic of northern Victoria Land; carbonate rocks and shelf sediments were deposited further south in the McMurdo Sound area.

Hallett Peninsula is characterized by the presence of at least two volcanic cones and the precipitous talus slopes on the west side of the peninsula are composed primarily of younger volcanic rocks. Basalts, trachytes, and phonolytes comprise the major rock types. Scattered fragments of marble and quartz are present as erratics on terraces at varying elevations on the slopes. Occassional ash beds of the late Tertiary times are found at higher elevations on the cape. The flat terraces are adequately supplied with water during the period of thawing and may support a variety of moss and lichen species. These areas are fairly stable and provide the most desirable sites for ecological studies.

Soil: Any review associated with antarctic soils must be based upon the acceptance of the term "soil" in its broadest ecological interpretation. In this sense, any part of

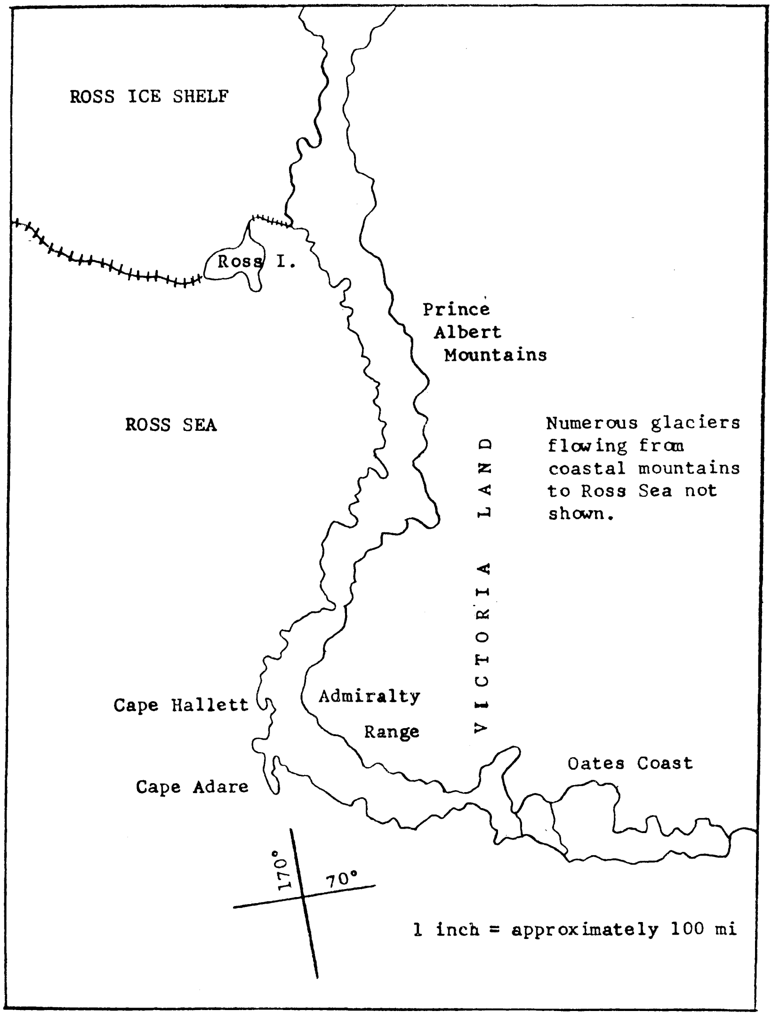

Fig. 6. General location of Cape Hallett, Antarctica.

the earth's crust in which plants are anchored may be referred to as soil (Daubenmire, 1947). Although this general description includes glacial deposits and bare rock surfaces that support the growth of certain bryophytes and thallophytes, it does not provide for the occurrence of sterile areas that are characteristic of certain wind-swept valley systems in Antarctica. An approximation of a soil profile can be distinguished in certain localized areas of these valley systems, although vegetative growth is not apparent. In this respect, these valley deposits approach the more modern Russian concept of soil composition which is based on the movement of water and profile formation.

A very small portion of Antarctica is ice-free and the exposed areas are present as mountains, nunataks, or coastlines. The initial phases of soil formation are obvious in certain coastal areas where residual and transported parent materials are found. In many areas, rock formations are exposed to intense weathering throughout the year and receive little seasonal protection. Diurnal fluctuations of climatic factors are magnified during the austral summer and responses to these rapid changes are readily discernible.

Scree, or talus, is the most obvious transported parent material in the vicinity of Hallett Station. Alluvial fans formed during the period of thawing are not stable. Coarse materials deposited by swift-flowing melt-water are dispersed by high winds during the winter. Hallett Station is built on glacial moraine; the obvious nature of this parent material being concealed by the accumulation of guano and wind-blown debris. Materials transported by wind are very unstable and gross changes in localized topography can be recognized following violent wind storms.

Although temperature and moisture are the most significant factors determining soil development and type, it is very probable that the action of high winds is one of the factors controlling soil development in the Hallett Station area. As the parent material matures, certain stages become more susceptible to the moving forces of winds. The prevailing wind at Hallett Station approaches from glacier and snow-covered areas and continues across the station toward the sea. Observations made on the sea ice, on the leeward side of the station, indicated that a considerable amount of geological debris was transported from the land area. On the talus slopes, an obvious difference was noticed in the texture of soils from windward and leeward areas. In the absence of erect plants, minor topographic variations produced major differences in soil texture and rate of accumulation.

Generally, the soils of Victoria Land are alkaline as a result of the accumulation of salts, carbonates, and zeolites, and the absence of organic acids. Shallow profile trenches excavated at various sites in the Hallett Station area revealed a distinct accumulation of calcium carbonate at two levels in the soil profile. In the mountain valleys SW of the station, and at specific sites on the original beach, the carbonate was deposited as a compact surface crust varying in thickness from 2 to 5 cm. Such a stratification is typical of semi-arid regions in which high evaporation brings the alkali salts to the surface. The salts remain at the surface when precipitation is insufficient to such a degree that redistribution is inhibited. In northern Victoria Land these conditions prevailed in level areas which were snow-free for a large part of the year and received little drainage-water during the season of thawing. The position of calcium carbonate in the soil profile was quite different in moist areas. In excavations made on moist slopes, the carbonate accumulation appeared deeper in the profile and formed a distinctly compact pan 8 to 10 cm below the surface of the soil. Similar results were obtained in level areas that received abundant melt-water. Soil profiles identical to these were found at higher latitudes in the vicinity of McMurdo Sound (McCraw, personal correspondence, 1960).

Soils in close proximity to bird rookeries were much more difficult to classify. Some areas receiving the direct drainage from guano-covered mounds were more alkaline and appeared to be quite sterile. Such a condition existed on a black-sand beach north of the station. Nitrates formed a surface crust in areas near the guano mounds, but appeared deeper in the profile at sites nearer the water. Those areas which received melt-water from the talus slopes and drainage from guano mounds by a more circuitous route, were frequently acidic and supported a lush growth of algae.

Soils associated with well established moss beds were quite unique. At least one such deposit occurred in the vicinity of Hallett Station. A thick layer of peat-like material extended into the substratum from the surface to the permafrost. The soil was black and greasy and had a texture similar to that of a moor. Organic debris, such as feathers and broken egg shells, was often combined with plant roots in various stages of decomposition. The soil was frequently acidic in the center of the moss bed and more alkaline on the periphery. Experimentally, at least one generation of selected higher plants have been grown in this soil.

Pedological research has not attained any degree of refinement in Antarctica and previous references to soil types have been primarily expressed in geological terms. It is apparent that soil research will become more important as continuing investigations associated with plant and animal ecology are intensified.

Land flora: In contrast to arctic regions, the south polar continent is characterized by a paucity of vegetation. A low mean temperature is probably the major factor controlling the development of a land flora. Near sterile conditions are maintained as a result of aridity, high winds, and a shallow permafrost table. Vegetation is found only in local areas where these factors are minimized or absent. Inside the Antarctic Circle, plant growth is restricted to ice-free coastal areas, mountains, nunataks, and protected valleys. Distribution patterns are more variable in the less rigorous climate of Palmer Peninsula.

Two flowering plants have been reported from isolated areas in lower latitudes outside the Antarctic Circle. A grass, *Deschampsia antarctica* E. Dev., and a pink, *Colobanthus crassifolius* Hook, have been described from certain localities on the west coast of Palmer Peninsula.

Lichens are the predominant terrestrial plants in Antarctica. At least 441 species, representing 151 genera and 87 families, have been reported from various sites on the continent (Llano, 1961). Approximately 50% of the recorded species have been reported from Palmer Peninsula. To the present time, 36 species have been found in South Victoria Land.

A maximum of 72 moss species has been reported from antarctic climates (Steere, 1961). A small number of mosses is endemic and a large percentage is widely distributed, especially in the northern hemisphere (Du Rietz, 1940). Luxuriant growth occurs only in favored localities where moisture and nitrogenous materials are readily available. *Grimmia antarctica* Cardot appears to be the dominant continental species. *Bryum antarcticum* Hook is abundant in South Victoria Land.

Fresh-water algae, other than diatoms, from antarctic and subantarctic regions are represented by 160 taxa (Wille, 1928). Wille placed most of the plants in Myxophyceae and Chlorophyceae. Available samples have been collected randomly from widely separated areas and detailed surveys have not been made. Drouet (1961) indicates that a thorough knowledge of antarctic flora is dependent upon a careful revision of the classification of all groups of fresh water algae.

Only one species of fungus has been reported from the continent. *Sclerotium antarcticum* Bomm. & Rous. (1905) has been found on grass on the Danco Coast of Palmer Peninsula. Two species have been described from Deception Island (Llano, 1961).

Bacteria inhabit soils, sediments, and fresh-water lakes. They are abundant in the vicinity of bird rookeries. To the present time, research has been primarily concerned with marine bacteria and more detailed studies associated with the microflora of endemic animals. Burkholder (1961) has reviewed the present state of bacteriological research in Antarctica and has suggested programs designed for terrestrial investigations.

Although a survey of local flora was beyond the scope of the research program at Hallett Station, certain groups were conspicuous as a result of their abundance. Determinations of taxa recorded in this paper have been based on descriptions provided by earlier expedition reports.

The emerald green alga, *Prasiola crispa* Lightf., was found in moist areas on the west side of Cape Hallett and occurred abundantly on sites adjacent to the penguin rookery. Species of *Chlamydomonas* flourished in melt-water ponds at the base of the cape. Smaller melt-pools on the beach contained species of *Navicula.*

Lichens were abundant on the talus slopes east of the station. Orange-colored species of *Placodium* were most obvious, but species of *Neuropogon* and *Lecanora* were also found on slope sites.

Mosses were restricted primarily to moist areas near the base of the cape, but sparse deposits were found at various elevations on the talus slopes. *Bryum argenteum* Hedwig and *Grimmia antarctica* Cardot were the most obvious species in the immediate station area.

Land fauna: Birds are the most conspicuous and, in many respects, the best documented of all antarctic fauna. Four species occupy characteristic nesting sites in the immediate vicinity of Hallett Station. From late October until early April, a large portion of the peninsula is occupied by 100,000 nesting penguins (*Pygoscelis adeliae*). Over 200 pairs of skuas (*Catharacta maccormicki*) occupy nesting sites on the original beach at the base of the cape and at higher elevations on the talus slopes east of the station. The Snow Petrel (*Pagodroma nivea* Forster) is usually found in rock crevices at high elevations, but in some instances is found at lower elevations. At Cape Cristie, 7.5 km W. of Hallett Station, this species nests in easily accessible areas approximately 20 m above the surface of the sea ice. The Wilson Petrel (*Oceanites oceanicus* Kuhl) utilizes smaller crevices in those areas where the Snow Petrel is found. Wandering Emperor Penguins (*Aptenodytes fosteri* G. R. Gray) are frequently seen in the area, but rarely come ashore.

At least six species of ectoparasites are associated with the bird population of Hallett Station. These species belong to the order Mallophaga; the suborder Ischnocera; and the family Philopteridae. Two species of Ixodidae have been reported as being parasitic on penguins from the Palmer Peninsula (Johnston, 1937), but representatives of this group were not collected at Hallett Station.

In addition to mites and collembolans, other soil-inhabiting invertebrates are present in the station area. Large numbers of tardigrades, ciliates, and rotifers were found in association with mosses and algal ponds. Nematodes occupied a variety of habitats ranging from beach areas frequently inundated by sea-water to guano deposits on the border of the penguin rookery. Research associated with these latter groups has not been initated at Hallett Station; however, they have been surveyed superficially at various other sites on the continent.

5. MACROCLIMATE

Hallett Station was established in January 1957 as a meteorological facility for the International Geophysical Year; consequently, long-term meteorological summaries for the area are not available. The data used in this analysis are based on U. S. Weather Bureau measurements made during the period from January 1957 to January 1960. Recording instruments were housed in a standard Weather Bureau screen located on the northwest side of Seabee Hook.

Air temperature: The warmest month isotherm of 0° C. encloses all of continental Antarctica except for certain areas in the northern part of Palmer Peninsula. In 1959 the average monthly temperature at Hallett Station was well within this isothermal limit. A low temperature of −47.8° C was recorded on August 21, and the high, +8.3 on January 8. In view of the scope of the present analysis, data concerning the number of days per month when the maximum temperature was equal to or greater than 0° C, and the number of days when the minimum temperature was less than 0° C, have greater significance than monthly averages. These data indicate that maximum temperatures of 0° or higher occurred only during the summer months. Temperatures above freezing were recorded on one day in late November; on 22 days in December; on 28 days in January; and on 7 days in February. Minimum temperatures of 0° or less were recorded every day of the year. Effectively, the summer season of 1950 was condensed into a two-month period. Similar temperature distribution were recorded for the years 1957 and 1958. Average maximum and minimum temperatures for 1959 are summarized in Table 1.

These temperature data are perhaps typical of Hallett Station proper, but do not reflect variations that exist in the general area. Synchronous recordings made on a talus slope 0.4 km W. of Seabee Hook differed from station weather observations. On calm days, extreme values for the two areas were closer together, but daily maxima appeared to be consistently higher on the slope. Minimum temperatures were lower at station level (fig. 7). On days characterized by medium and variable winds, extreme values were more widely separated and daily minima, as well as maxima, were more pronounced on the slightly higher talus slope (fig. 8).

Table 1. Average monthly maximum and minimum temperatures for 1959 (°C.).

Month	High Maximum	Low Minimum	Average Maximum	Average Minimum
January	+ 8.3	− 8.3	+ 2.4	− 4.8
February	+ 2.2	− 6.7	− 1.6	− 5.4
March	− 2.2	−17.8	− 7.6	−11.2
April	− 5.6	−28.9	−14.7	−19.7
May	− 6.7	−36.1	−19.9	−26.1
June	−11.7	−34.4	−20.0	−26.1
July	− 4.4	−39.4	−19.1	−27.2
August	−17.8	−47.8	−26.4	−35.8
September	−14.4	−36.7	−20.0	−31.5
October	−10.0	−38.3	−17.9	−28.7
November	+ 1.1	−21.7	− 7.9	−14.5
December	+ 6.7	−11.7	+ 1.3	− 4.8

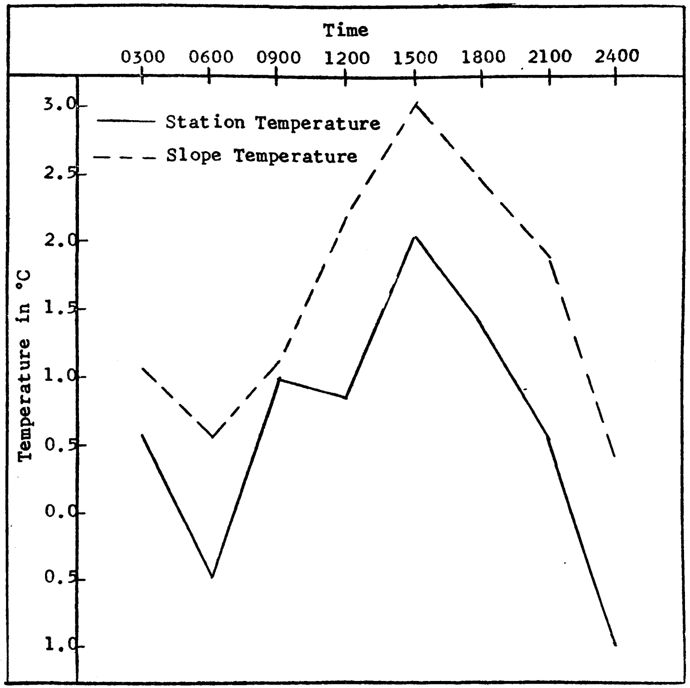

Fig. 7. Comparison of air temperatures recorded at Hallett Station and on basalt slope 0.4 km E. of station. Measurements made 2 m above surface during calm period; 22 Dec. 1959.

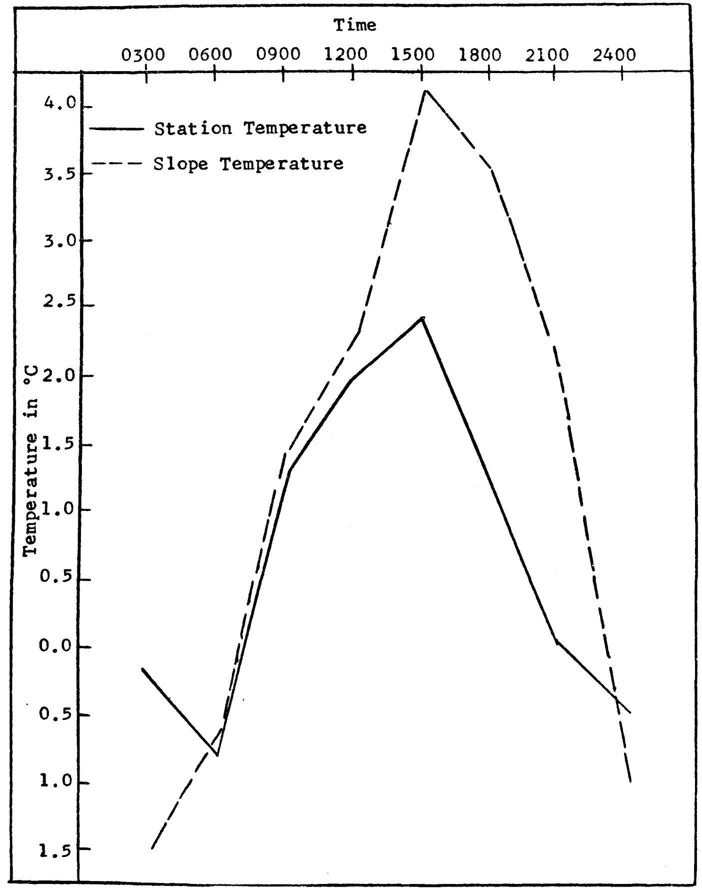

Fig. 8. Comparison of air temperatures recorded at Hallett Station and on basalt slope 0.4 km E. of Station. Measurements made 2 m above surface during period of light and variable winds; 23 Dec. 1959.

Soil temperature: Although soil temperature records were not maintained as an integral part of the station meteorological program, sporadic measurements made during the summer seasons of 1958 and 1959 provide data from which certain inferences can be drawn. These data have been augmented by subsurface measurements recorded daily from October 1959 to November 1960. Surface temperatures will be discussed in a later section concerned with microclimate. Daily and seasonal fluctuations in subsurface temperatures will be considered here.

Persistent subfreezing temperatures of great intensity during most of the year and extremely low mean summer temperatures account for the presence of a permafrost table at

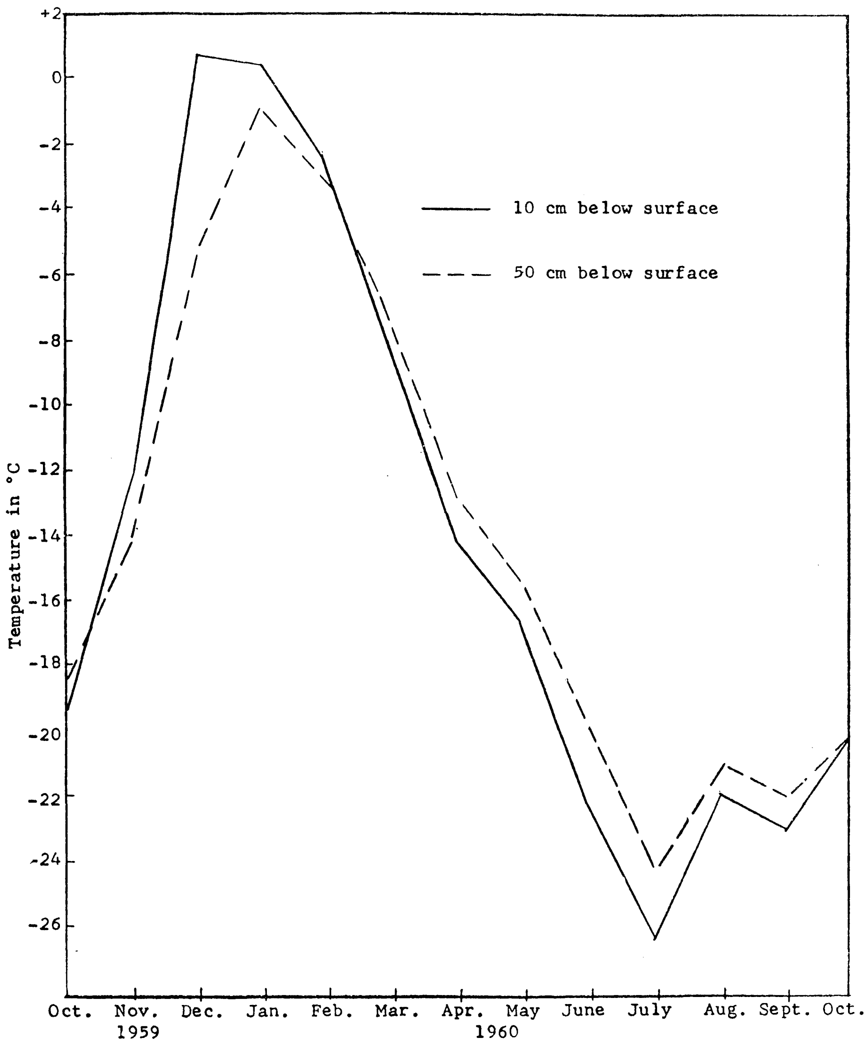

Fig. 9. Annual change in mean monthly temperatures at two levels in the soil. Hallett Station, Antarctica; 1959-1960.

depths of 15 to 20 cm even during the season of maximum thawing. On selected sites, the thin mantle above the permafrost table supports plant and animal life during a short summer season. The upper boundary of frozen ground varies daily and monthly during warm periods.

Thermocouple measurements recorded from a depth of 10 cm show a temperature increase of approximately 20° during the two-month periord preceding mid-summer. At this depth the ground is unfrozen for varying lengths of time on most days in December and January. At 50 cm the temperature approaches 0° in December, but thawing is not evident (fig. 9). Reversed summer and winter gradients are apparent even at these depths, and a lag of approximately one month is noted at the 50 cm level. Daily fluctuations in the temperature at 10 cm are evident during the coldest and warmest months. These changes are felt at a depth of 50 cm and responses can be charted (fig. 10).

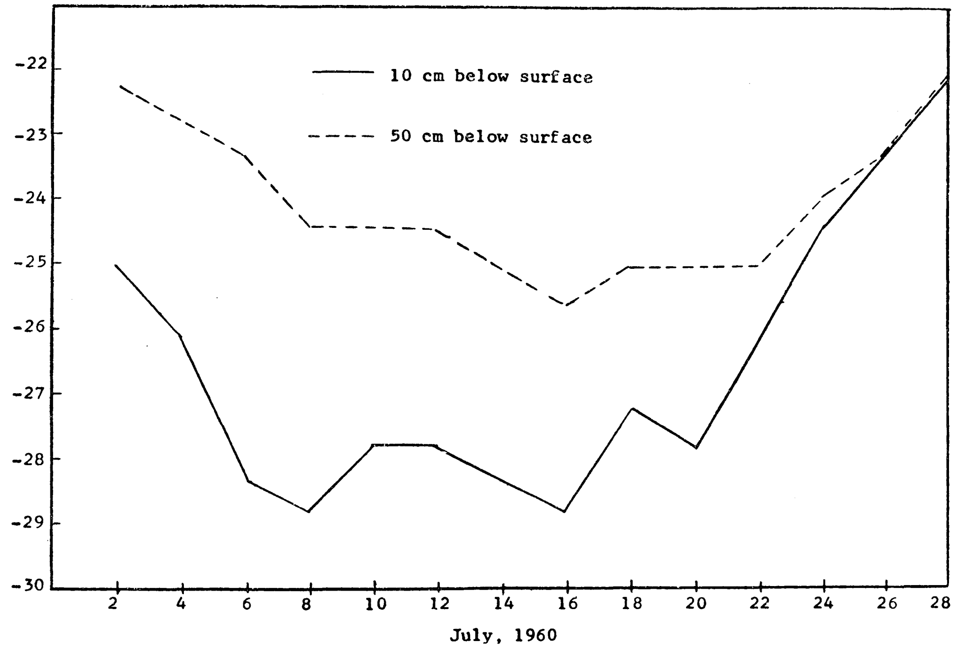

Fig. 10. Daily thermocouple measurements made at two levels in the soil during the coldest month of 1960. Hallet Station, Antarctica.

Precipitation: Except for some areas in the northern part, and along the west coast, of Palmer Peninsula where seasonal rains occur, precipitation in continental Antarctica is almost always in the form of snow or hoarfrost. Various estimates have been made concerning annual precipitation for local areas as well as the continent. Meinardus (1938) has estimated a net accumulation of 4 cm for all of Antarctica. A total continental precipitation figure of less than 9 cm has been offered by Kidson (1946). Estimates for local areas in the Ross Dependency for different years are: Cape Adare (71° 18′ S, 170° 09′ E) 36 cm; Cape Royds (77° 33′ S, 166° 07′ E) 23 cm; and Cape Evans (77° 38′ S, 166° 24′ E) 41 cm. More recent measurements made at Little America show a net accumulation of

30 cm of water during a period of 11.5 months.

As a result of high surface winds, it is most difficult, and in some areas impossible, to accurately measure precipitation as it falls. Diverse methods employing snow gauges and accumulation stakes have been used to determine local precipitation. The accumulation for a year can be determined by measuring daily changes in height of a snow surface, using a graduated stake which is securely embedded in the snow. Pairs of widely separated stakes established in four directions provide data from which total accretion, deflation, and ablation can be determined. This method is widely accepted and appears to supply the most accurate measurements.

Precipitation measurements for Hallett Station have been based on data gathered from snow gauges and the accuracy of those measurements made during periods of blowing-snow are doubtful. Although restricted in accuracy, these are the only data currently available and are used in station precipitation analyses.

In 1959 an annual net accumulation of 24.3 cm of water was recorded. Of this total, 20.5 cm fell during March, May, July, August, and September. In the summer months of November and December, a low net accumulation of .05 cm was recorded. These data compare favorably with measurements made at other coastal sites in the Ross Dependency, but are accurate only for the year 1959. Sufficient data to support characteristic precipitation figures for the station area are not yet available.

Soil moisture: The total effects of climate and topography on soil moisture are very evident in certain coastal area of Antarctica. In winter, soils may have a very low moisture content and for brief periods in summer they may be completely saturated. Exposed slopes are subjected to summer climatic conditions that favor successive periods of aridity and moistness. These periods may alternate daily before and after maximum thawing, or be of longer duration during the summer. Level areas and drainage basins are frequently flooded for varying lengths of time during the period of active snow melting. A high rate of runoff from talus slopes and the retention of flood-water in level areas are both greatly influenced by the shallow position of a summer permafrost table. The absence of vegetation and organic matter, combined with the action of persistently high winds, increases both the rates of evaporation and runoff.

In the Hallett Station area, snow melting occurred first on guano mounds. The process was accelerated by the constant movement of penguins. Snow remained on the old beach until mid-October. The position of polygons was evident under the snow cover and potential drainage areas were readily discernible (fig. 11). A thicker layer of snow persisted on the talus slopes until mid-November and terraced areas were the first to become snow-free (fig. 12). The period of active snow melting was accompanied by surface thawing and soils became saturated. Runoff was at a minimum and abundant moisture was available for local flora and fauna. In late December, glacier and fast-ice at the summit of the slope began to melt and a thin horizontal sheet of water moved down the incline under the loose talus and above the permafrost table. In localized areas, water was channeled into shallow ravines and cascaded down-slope with great force. Measurements made in one of these ravines on 25 Dec. 1939 indicated that water was moving at the rate of 5,000 gal./hr. through a channel 10 cm high and 25 cm wide. Level areas at the base of the cape became flooded and remained under water for as long as three weeks (fig. 13).

In 1959, snow began to recede on the slopes at the end of the second week in November. A gradual increase in surface water was noticeable until mid-December. During the last week of December, runoff reached a maximum and gradually decreased until mid-January of 1960. A large portion of standing water in low areas was removed by evaporation, but larger bodies of water remained as frozen ponds.

Fig. 11. The original beach (foreground) under snow cover in October 1959. Raised areas are polygons.

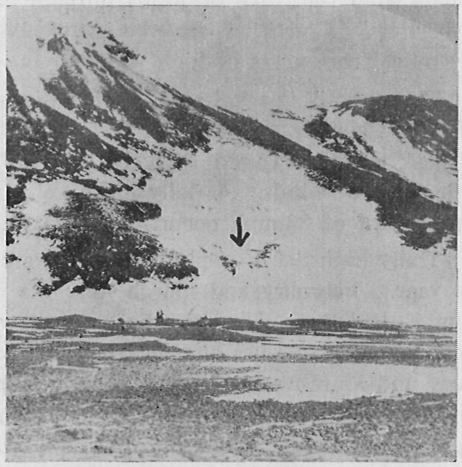

Fig. 12. Surface melting on talus slopes in November 1959. Arrow marks site of most ecological studies.

Fig. 13. The original beach during period of maximum thawing; 6 Jan. 1960.

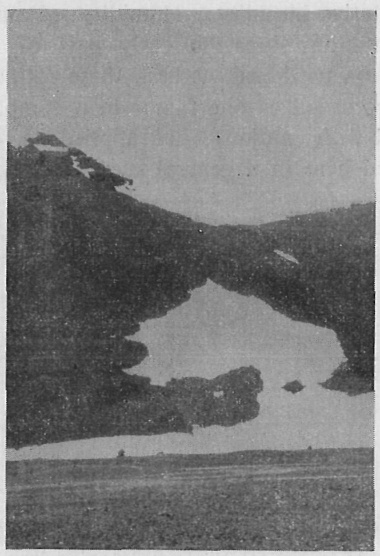

Fig. 14. Terraced area where microclimatic measurements were made in the austral summer of 1959–1960.

Wind: High winds are characteristic of most coastal areas in Antarctica, but variations in velocity and time of occurrence are quite common. The upper air that descends over the ice-cap is subjected to intense cooling and moves toward the coast in anticyclonic circulation patterns to low pressure areas over the sea. Air flowing down from the polar plateau may bring winds of hurricane force to coastal regions. Violent storms may be short in duration or prevail for many days. Mountain ranges, deep valleys, and glacier systems alter the force of winds through the formation of channels or transversely oriented barriers. Conditions may be extremely localized, with calm weather prevailing only a few miles from areas of high winds.

The prevailing wind at Hallett Station is from SW of S. Winds from the N. are of infrequent summer occurrences and appear to be less violent in their action. Data based on peak gusts measured daily in 1959 do not clearly indicate a seasonal distribution of high and low winds. A daily mean velocity of 26.5 mph was recorded for the year, with a peak gust of 88 mph occurring on 21 Feb. 1959.

Daily highs of 10 mph, or lower, were recorded on at least one day each month during the year. February and March were the windiest months with mean peak velocities of 37 mph, and December was the calmest with a mean peak velocity of 16 mph. Records show that these values change from year to year. In 1957, mean peak velocities for February and March were 26 and 29 mph respectively and the mean velocity for December approached the yearly mean of approximately 25 mph. Extremely high velocities were reported for 1957. A gust of 107 mph was recorded on 22 Oct. 1957 and was followed by a peak gust of 109 mph on 23 Oct. These data should not imply that the area is constantly swept by high winds, for short periods of calm weather occur in winter and summer, but are more characteristic of the latter.

Relative humidity: Humidity measurements have been made at most established antarctic stations since the early part of the 20th century. Various recording instruments have been used and, at best, these data are reliable only for limited areas. Relative humidity is recorded as one factor in a complex station meteorological program and must be utilized with caution when applied to other research projects. Recently recorded data are used here in a general survey of the macroclimate of Hallett Station.

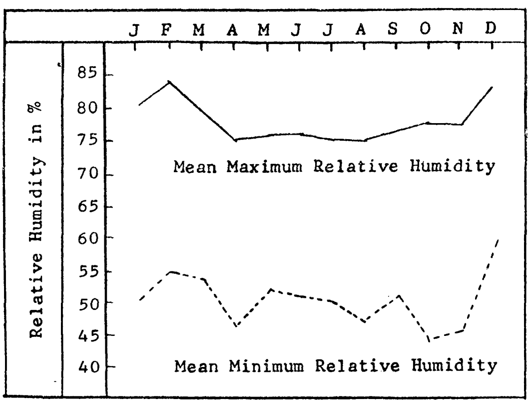

Fig. 15. Mean maximum and mean minimum relative humidity. Hallett Station; 1959.

In 1959, a maximum relative humidity of 97 % was recorded on two days in January and one day in February. A minimum of 10 % was recorded on one day in September. These figures represent extremes and do not occur often. A mean maximum of 77.8 % and a mean minimum of 50.7% were recorded for the year. Monthly fluctuations were more obvious in the mean minimum relative humidity and the mean maximum was characterized by winter stability (fig. 15). Synchronous measurements, made 2 m above a talus slope 0.4 km W. of the station, show considerable differences in relative

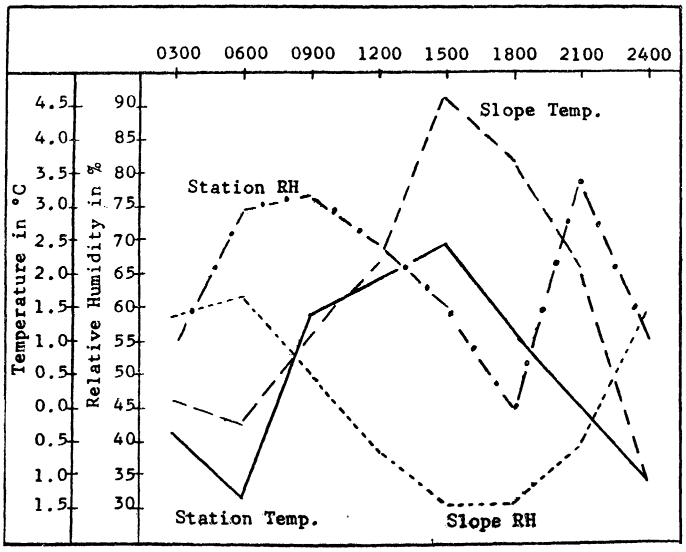

Fig. 16. Comparison of recorded temperature and relative humidity for station and slope sites. Hallett Station; 23 Dec. 1959.

humidity and temperature when compared with station data (fig. 16). A combination of factors control responses to climatic changes in the two areas. The exposed position of station instruments probably accounts for unusual variations in recorded humidity and temperature. Values are quite variable for both sites during the warmest hours of the day, but become more stable when both areas are in shadow.

Evaporation: Data concerning measurements of the evaporative power of the air are not available for most antarctic stations. Each of the two most widely used evaporimeters is limited in utility and cannot be maintained for long periods of time with any degree of accuracy. The open pan, which is a standard U. S. Weather Bureau instrument, has not been successfully used in antarctic meteorological research. The action of high winds, accumulation of debris, and interference by birds are the more obvious factors limiting the use of this type of evaporimeter. The Livingston porous-cup atmometer cannot be used at temperatures below freezing; consequently, this instrument is of value only during certain periods of the day in mid-summer.

Measurements made with a white-bulb Livingston porous-cup atmometer in December 1959 indicated a high rate of evaporation at selected sites in the station area. Data were collected 2 m above the surface of a west-facing slope which was exposed to direct sunlight for approximately 16 hours per day. During a period of 14 sun-hours, 64.2 ml of water were lost to the atmosphere through evaporative processes. Of this total, approximately 61 % was lost during a five-hour period near midday.

Many authors (*e.g.*, Shelford, Daubenmire, *et al.*) have elaborated upon the manner in which evaporation rates are influenced by relative humidity, wind, and temperature. An attempt to show the effects of these factors and responses to minor climatic changes

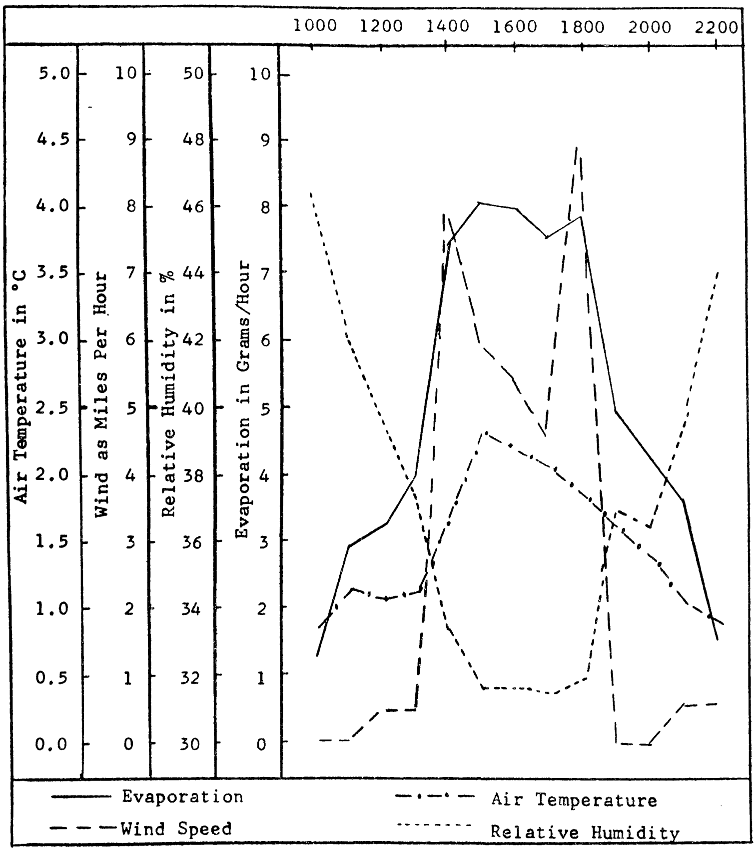

Fig. 17. The influence of air temperature, wind, and relative humidity on evaporation rates. Measurements made on a talus slope at Hallett Station, Antarctica; Dec. 1959.

in a specific area is summarized in Fig. 17.

6. MICROCLIMATE

A study of microclimate is essentially an investigation of temperature, moisture, and wind relationships in a layer of air extending from the surface of the earth to a height of approximately 2 m. The manner in which these factors are influenced by the surface makes it necessary to include this boundary, although it may be soil, snow, ice, or water.

Difficulties associated with research in this special climate are primarily those of data collection. Dependable field instruments necessary for precise measurements near the surface are not readily available and the use of modified macroclimatological devices often alters the environment being measured. These inadequacies are quite apparent at levels below 1 m and increase in intensity with successive measurements closer to the ground.

In this study, summer microclimatic observations were obtained from a series of stations established on terraced talus slopes on the west side of Cape Hallett. Station sites were carefully selected with respect to slope, exposure, drainage, vegetative cover, and surface geology. Each of these factors was represented by average conditions for the general area.

The atmosphere was sampled at 2 m for comparison with Hallett Station meteorological data and at 1 m for the purpose of establishing an accurate standard for the collecting area. Measurements were made at 50 cm, 20 cm, and at 10 cm in an attempt to obtain sufficient data for establishing vertical gradients. Mosses were the dominant plants in the area studied and the atmosphere was sampled at the 5 cm level to represent the bryophytic climate. The accuracy of measurements below 5 cm was limited instrumentally, but certain responses were obvious. Surface and subsurface measurements represent the lower limits of the microclimate.

At latitude 72° S, the antarctic summer is so short and daily climatic fluctuations are so great that it is often difficult to express faunal responses in terms of seasonal averages. Soil organisms may be subjected to both summer and winter conditions in the course of a day and they react accordingly. In view of immediate service, more emphasis has been placed on daily changes in the microclimate and seasonal averages are presented only when clarification is necessary. Investigations were made with respect to faunal responses to environmental changes. Data have been interpreted biologically from observed values and little attention has been given to true values necessary for meteorological analysis.

Surface properties: Since the microclimate is primarily controlled by the ground, a valid interpretation of data gathered in this stratum is dependent upon a working knowledge of surface features associated with the area measured. In the present research, soil and surface factors contributing to microclimatic variations are presented in summarized form and apply only to specific areas in the Cape Hallett region of Antarctica.

The study area was situated 12 m above sea level on a west-facing slope that rose abruptly at an angle of approximately 32° from a level beach 0.4 km W. of Hallett Station. Measurements were made on a terrace 10 m by 6 m which was surrounded on the W., S., and E. sides by fast-ice (fig. 14). The northern boundary of the study area was formed by a drainage ditch, which supported a lush growth of moss, and a slightly higher snow-free area occupied by nesting skuas. The terrace was exposed to the sun for approximately 16 hours per day in mid-summer and received abundant moisture from up-slope snow fields. The area was well drained and vegetation flourished in small depressions receiving melt-water. With reference to particle size, surface soil must be described as gravel with some dark colored deposits of finer particles which were restricted to well protected areas. Soils near the shallow permafrost had the texture of coarse sand. The terrace was underlaid by a permafrost table which remained stationary at 10–15 cm during the summers of 1958 and 1959.

Soil moisture: Soil moisture data were obtained by determining the water content of samples taken at two levels above the permafrost table. Surface samples, consisting primarily of gravel, were taken from the upper 5 cm of soil and subsurface samples of finer textured soil were extracted from a 5 cm stratum just above the permafrost. Samples of 100 cc were taken for each measurement and moisture content was expressed as per cent of total weight.

Observations made in early November 1959 indicated that soils were quite dry in early summer. Frozen samples taken from a surface under heavy snow cover had a mean moisture content of 6.5% with values ranging from 4.9 to 8.1 %. Finer textured soils below the surface had a mean moisture content of 8.2 % and a range of 6.4 to 9.8 %.

Measurements made on slopes during the period of early thawing showed a decrease in surface moisture at successive distances from an actively melting snow line. A decrease with distance was not characteristic of deeper soil near the permafrost. These relationships are summarized in Table 2. Continuing observations indicated that melt-water from the edge of the snow line percolated downward through the coarse surface gravel and flowed down-slope over the less-porous subsoil. During the period of maximum summer thawing, surface soils on slopes remained arid, except for those near the edge of the snow line. Level outcroppings became saturated and served as collecting basins for organic material and fine soil particles. Moisture lost from these terraces through evaporative processes was rapidly replaced by melt-water in mid-summer, but these areas were subjected to intense drying at the end of the melt season.

Table 2. Per cent moisture and range of values for soil measured at two depths and three distances from an actively melting snow line

Distance from Snow line	Per cent surface moisture 100 cc soil	Range in surface moisture	Per cent subsurface moisture 100 cc soil	Range in subsurface moisture
Snow line	10.3	6.2–19.7	16.7	15.9–18.1
15 cm	4.5	2.6–10.8	17.1	14.8–18.9
30 cm	1.8	0.7– 3.2	16.4	16.0–18.4

Daily, as well as seasonal, fluctuations in soil moisture content were characteristic of the area. Soils that were quite arid at midday were often moist when the area was in late evening shadow. The surface froze at temperatures just below 0°C and ice crystals formed in the interstitial spaces of the coarse soil. Moisture which accrued during the period of freezing was rapidly lost when the area was exposed to morning sun. Moisture content approached stability only during the seasons of continuous low temperatures and summer equivalents must be qualified with respect to specific time and location.

Soil temperature: Soil temperature was one of the most intensely studied micro-climatic factors associated with the survey at Hallett Station. An attempt to use continuous recording instruments was not successful and the data used in this analysis were obtained by personal maintenance and observation of field equipment. Investigations were primarily concerned with surface and subsurface temperatures in relation to microhabitats of soil fauna. Inversions and gradients associated with atmospheric temperature will be discussed in another section.

Subsurface temperatures were recorded from three depths in the soil. Thermistor probes, encased in glass tubing, were buried 2 cm in the permafrost, 2 cm above the permafrost, and 2 cm below the surface. Measurements from these depths, with surface observations, extended through a total vertical distance of approximately 12 cm. The elements were not removed from the soil and periodic observations were made throughout the summer.

A high surface temperature of +24°C was recorded on basalt ground in December

1959. Relatively low surface temperatures were recorded each day when the study area was in shadow. A low of –14°C was measured in the early morning hours on several occasions in late November and early December. In general, the surface reached its maximum temperature about 1500 each day and minima were usually recorded between 0300 and 0500. During a period of four clear days in December, an average surface temperature range of 27° was obtained.

Hourly measurements made in late November, prior to active thawing, indicated that surface and near-surface fluctuations were expressed at levels just above and in the per-

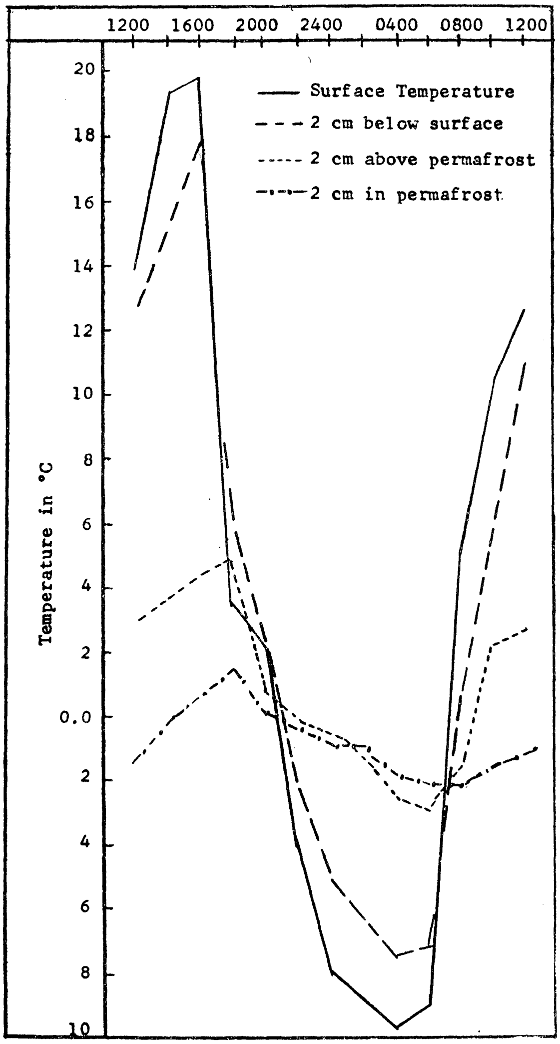

Fig. 18. Temperatures at four levels in soil prior to period of active thawing. Hallett Station, Antarctica; 30 Nov. – 1 Dec. 1959.

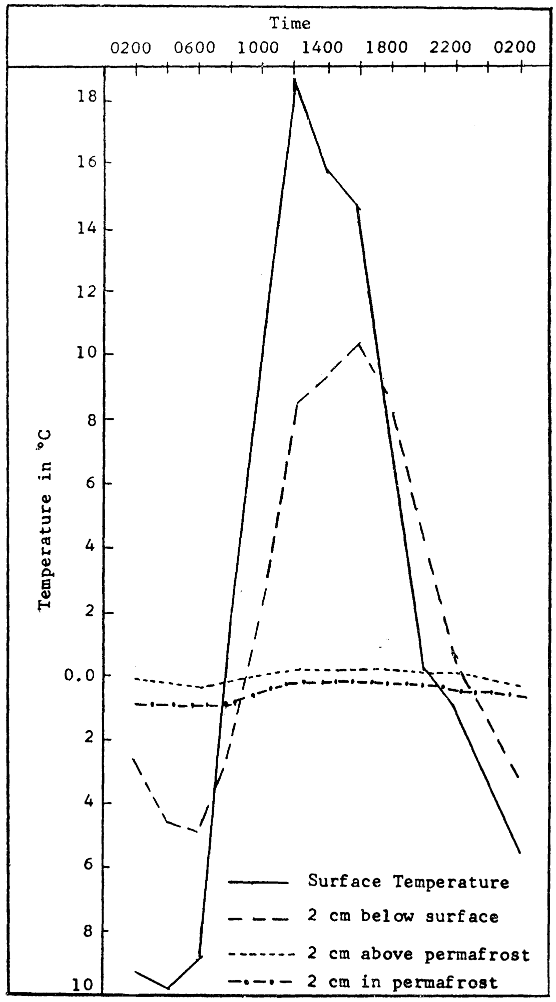

Fig. 19. Temperature at four levels in soil after beginning of active thawing. Hallett Station, Antarctica; 14 Dec. 1959.

mafrost. Surface temperatures responded rapidly to atmospheric changes and lag was most evident at the level just above the permafrost. Heat transfer at levels near the surface was apparent in the late afternoon hours. These relationships are summarized in fig. 18.

Observations made during the second week of December, just after the beginning of active thawing, showed that temperatures on the surface and at 2 cm below the surface were more widely separated and lag was more pronounced at the 2 cm level. The most obvious change from earlier distributions was found in the stability of permafrost and near-permafrost temperatures. At these levels, temperatures remained near 0° C and the daily range was less than 1° (fig. 19). It is quite possible that these responses resulted, either

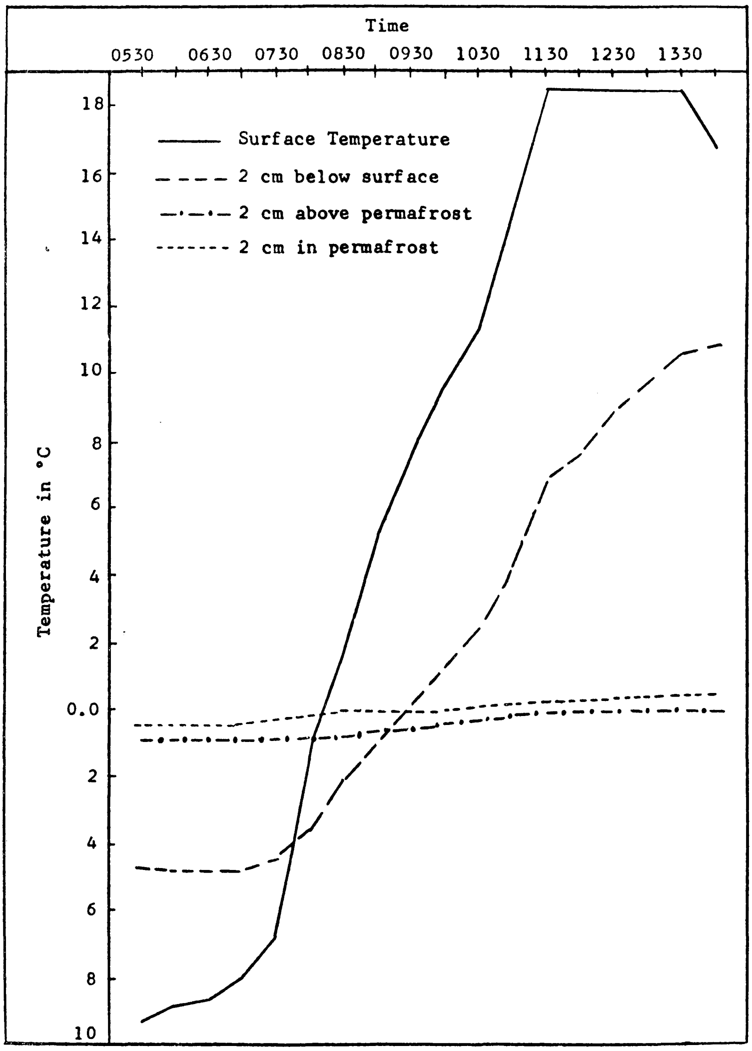

Fig. 20. Temperature responses in soil after exposure to morning sun. Hallet Station, Antarctica; 7 Dec. 1959.

directly or indirectly, from the vertical movement of melt-water. The immediate surface retained practically none of the water from melting snow, but less porous soils below the surface retained water in proportion to porosity. The movement of water through subsurface soil or responses associated with the processes of evaporation may have influenced the spread of temperatures near the surface. The remarkable temperature stability maintained at the two lower levels is more difficult to explain. If the soil above the permafrost table had remained intact and frozen, hourly fluctuations of temperatures at the two levels would be expected. More detailed analysis of temperatures in the level above the permafrost, combined with hourly sampling, indicated that soil at this level remained near saturation throughout the day and temperatures varied from just above to just below freezing. Moisture lost by evaporation was replaced by melt-water from soil levels above. It is probable that the thin layer above the permafrost served as an insulator and that constants were maintained at both levels. Although this response was frequently observed, variations in temperature at the two levels were noted. Measurements made at 1500 on 25 Dec. 1959 showed a temperature of +18° C at a depth of 12 cm (usual permafrost level) and the temperature at 8 cm below the surface was +4.2°. At the time of the measurement, surface temperature had been above 22° for at least four hours and unusually calm macroclimatic conditions prevailed.

On calm days, a slight rise in surface temperature was noted prior to the time of direct exposure to sunlight. Reflected light from snow and ice-covered mountains west of the station may have contributed to moderate increases. Temperatures at 2 cm below the surface did not show an immediate response to reflected light. The study area was exposed to direct sunlight at approximately 0715 and immediate increase in soil temperature were observed. On occasion, surface temperatures rose 25° between 0700 and 1100 (fig. 20).

Measurements made on 7 Dec. 1959 at five minute intervals, for one hour after the area was exposed to direct sunlight, showed an increase of 7.5° in surface temperature. Changes were evident at the level above the permafrost and a high rate of conduction was indicated as the surface began to thaw (fig. 21).

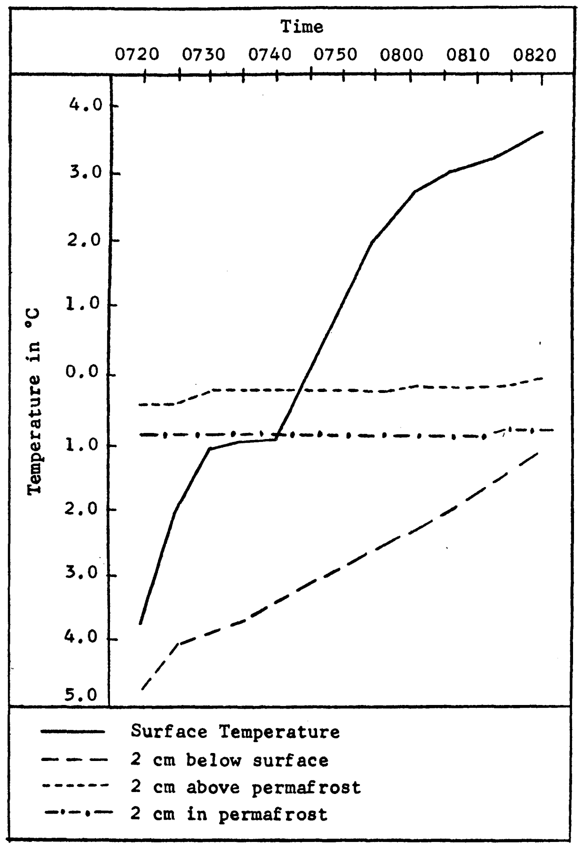

Fig. 21. Increase in soil temperature after exposure to direct sunlight. Hallett Station; 7 Dec. 1959.

Surface cooling occurred at a much slower rate, but decreases in temperature became more pronounced in the evening hours (fig. 22). The area was in shadow at 2000 on 8 Dec. 1959 and heat was retained in the surface layer for approximately two hours.

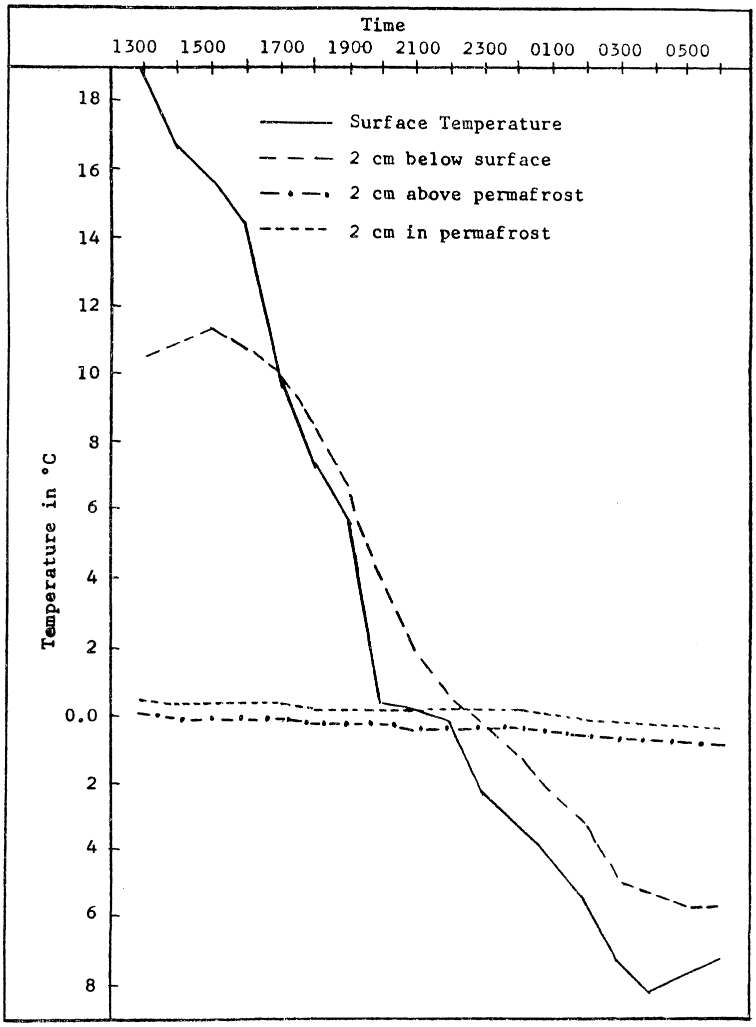

Fig. 22. Rate of surface cooling of talus slope. Hallett Station; 8–9 Dec. 1959.

A number of factors contribute to complications associated with any attempt to analyze antarctic soil temperatures. Under normal conditions, soils that are well aggregated show a rapid response to insolation. Dry soils respond slowly to incoming heat because poor thermal contacts between particles inhibit conduction (Daubenmire, 1947). Antarctic slope soils are not well aggregated, but in summer a near-constant source of moisture is maintained immediately below the surface. The soils are extremely shallow and the surface appears dry, but usually the upper levels have an intermediate moisture content which favors rapid response to insolution. Soil just above the permafrost remains wet throughout the period of thawing and specific heat rates are so high that temperatures in this stratum remain fairly constant.

Macroclimatic and topographic variations may present different summer temperature responses in slope soils from adjacent areas. It is obvious that different soil temperature relationships would be obtained from better aggregated, but drier, soils associated with continental valley systems.

Wind: The wind factor in microclimatic studies is primarily important as an agent affecting heat and water balance. Complete analysis of temperature and moisture interrelationships are dependent upon the accurate measurement of minute changes occurring in short time intervals. Single-factor responses can be best determined when surface air is quiet and even gross differences may be difficult to distinguish during storm periods.

Surface wind is an ever-present environmental factor in coastal Antarctica. Rapid changes in direction and velocity are characteristic of the area and extended periods of calm conditions are infrequent occurrences. Variations in velocity are influenced by diversity in surface features. Areas adjacent to snow fields are subjected to winds which have not been greatly impeded by surface friction. The rate of wind movement over rough terrain is often reduced as a result of surface drag.

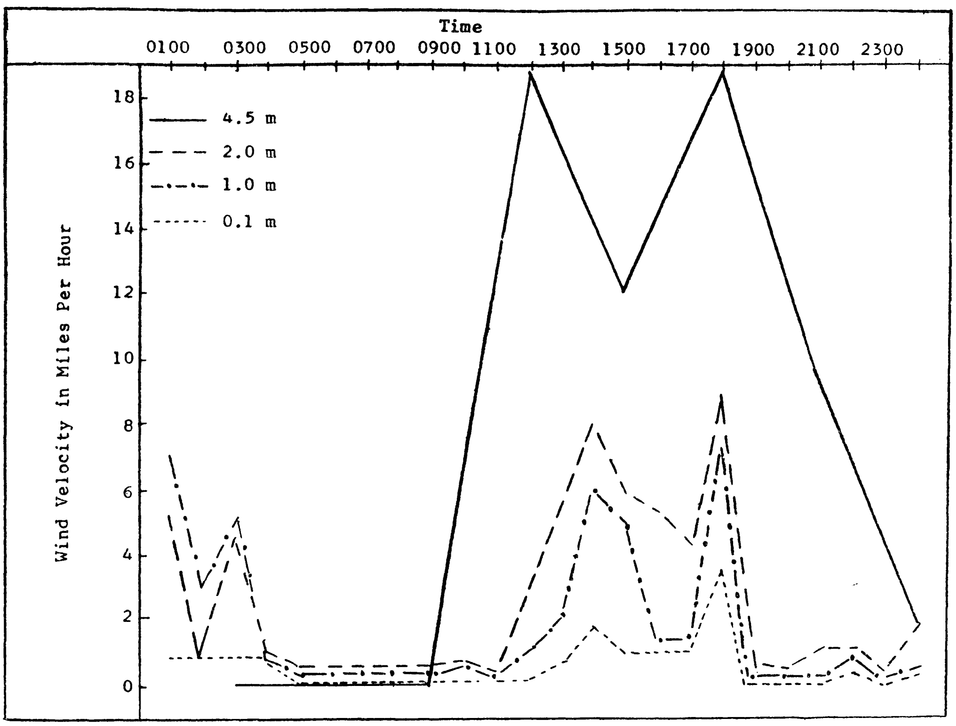

Fig. 23. Diurnal variation in wind velocity measured at four heights above talus slope located east of Hallett Station; 14 Dec. 1959.

The direction of prevailing winds is fairly constant in winter, but daily variations occur during the summer season. Coastal areas near open water often show a reversal of offshore and onshore winds. Winds moving across and up slopes from large bodies of water may have a marked effect on local microclimate.

Measurements of wind velocity and direction have been based on data gathered at three heights above the collecting area located W. of Hallett Station. Portable instruments were established at heights of 2 m, 1 m, and 10 cm above the surface and most observations were made at intervals of one hour. Data obtained from the collecting area were correlated with station meteorological measurements.

Velocities measured at heights of 2 m and below followed high and low trends recorded by station meteorologists. Successive decrease in wind speed at levels near the surface were apparent in all daily measurements. Greatest decreases in microclimatic wind velocities were recorded between 1 m and 10 cm. An inversion in velocities at 2 m and 1 m was noted in the early morning hours on calm days. Local surface wind moved down-slope with a velocity greater at the 1 m level than was recorded at 2 m. Although this east wind never reached speeds greater than 10 mph, it was measurable at 2 m, 1 m, and 10 cm (fig. 23). Wind velocities were frequently higher at midday during calm peri-

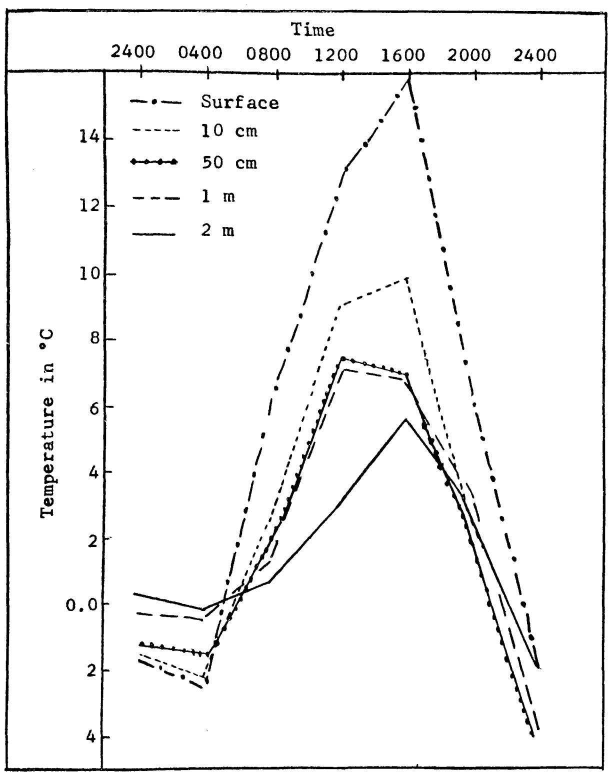

Fig. 24. Variations in air temperature in strata near the surface. Measurements made above talus slope at Hallett Station, Antarctica; 10 Dec. 1959.

ods, but wide variations in peak activity were recorded. The direction of prevailing winds was more variable in the early morning hours before the area was exposed to direct sunlight. Local winds from areas over open water, north and northeast of the station, were considerably warmer than those from the east. In the late morning and afternoon hours, prevailing winds were from the southwest and south.

Air temperature: Temperature characteristic of an area, and for specific time intervals, is usually approximated by the determination of mean values. Averages established for macroclimatic heat relationships are difficult to obtain in the microclimate. In areas subjected to an unequal distribution of daily and seasonal heat, mean values are often misleading and become less important as ecological indicators. In antarctic environmental studies, analyses are distorted by the use of means, and daily maximum and minimum values appear to be of greater ecological significance.

Midday surface temperatures near 20° C were frequently recorded on basalt slopes which were exposed to direct sunlight for approximately 16 hours each day. Minimum temperatures of 0° C or lower, were recorded each day when the area was in shadow. Microclimatic strata immediately above the surface were characterized by rapid responses to radiation, reradiation, conduction, and convection. The gross effects of surface heating and cooling were evident at a height of 10 cm, but responses became less obvious at the 50 cm

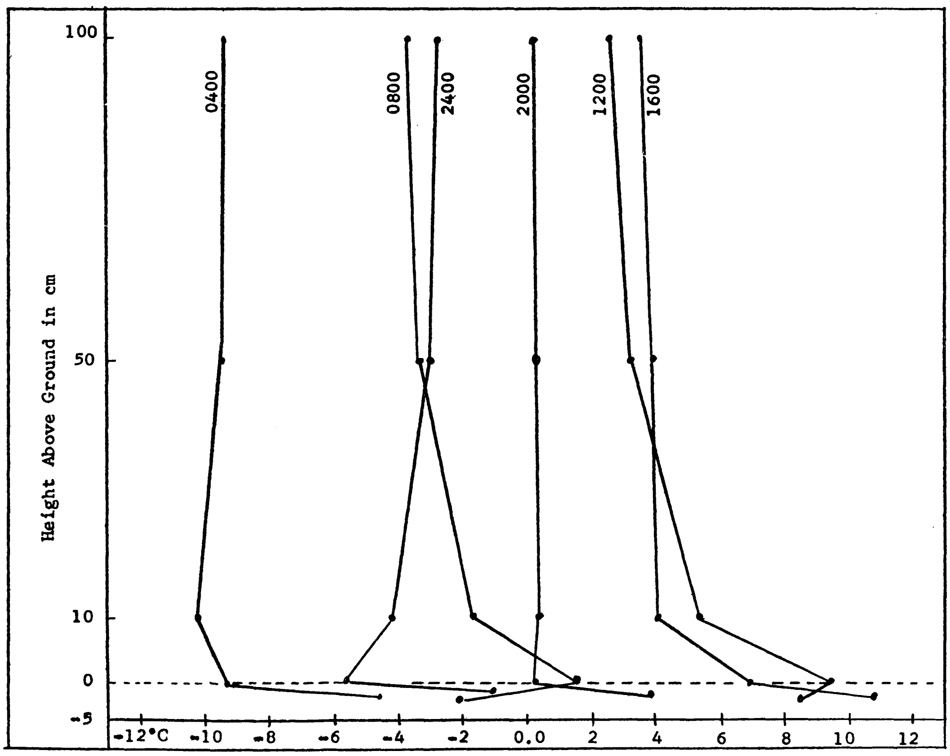

Fig. 25. Vertical gradients in air and soil temperatures for 24 hour period. Hallett Station, Antarctica; 7 Dec. 1959.

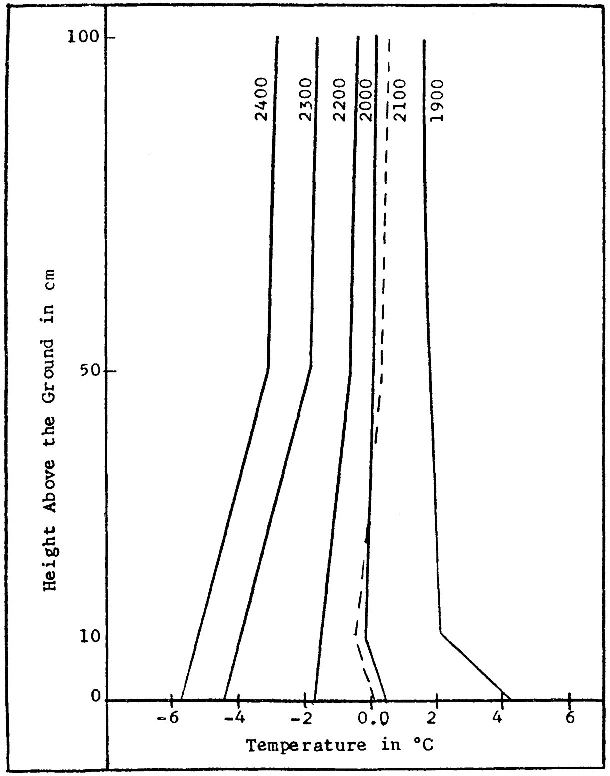

Fig. 26. Vertical gradients in air temperature showing change from incoming to outgoing-radiation type. Measurements made above talus slopes at Hallet Station; 30 Nov. 1959.

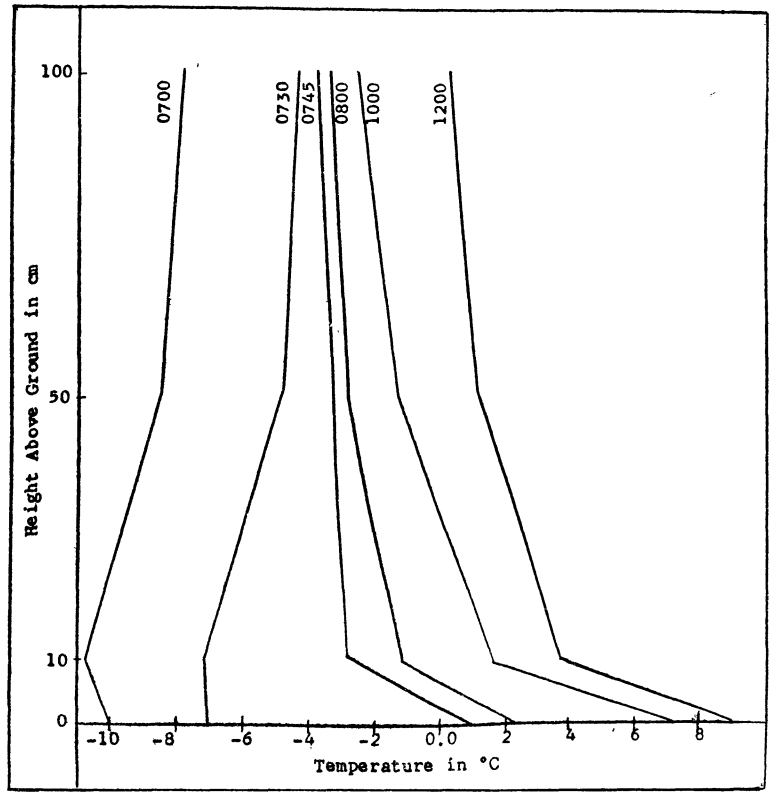

Fig. 27. Vertical gradients in air temperature showing rapid change from outgoing to incoming-radiation immediately after sunrise. Area was exposed to sun at 0738. Hallett Station; 30 Nov. 1959.

level. Rates and exchanges were greatly influenced by the absence of vegetation and the presence of water just below the surface.

On calm days, temperature nversions in layers near the surface were apparent during each 24 hour period. Minimum temperatures near 0° C were recorded at all levels in the early morning and late evening hours. As a result of strong insolation, greater temperature differences were noted in layers closer to the ground (fig. 24). Measurements made above 50 cm showed that temperature differences in the upper layers of the microclimate were consistently smaller. Frequently, maximum temperatures were reached at the 50 cm and 100 cm levels before surface and 10 cm peaks were recorded. Measurements made at 2 m indicated steady increases in temperature and maxima were recorded between 1500 and 1600 hours. Vertical temperature stratification was evident on cloudy days, but differences at all levels were reduced.

The magnitude of fluctuation near the surface was reflected by a decrease in temperature with altitude at noon and a corresponding increase with altitude during late evening hours. Measurements made at levels below 1 m on 7 Dec. 1959 showed that incoming-radiation was highest at 1200 and outgoing-radiation was highest at 2400. The vertical gradient at 0800 indicated a rapid response to surface heating. From 0800 to 1200, temperatures increased at all levels. Incoming-radiation was greatly reduced by 1600 and a midpoint between incoming and outgoing-radiation was most evident at 2000. These results are summarized in fig. 25.

Observations made on 30 Nov. 1959 showed that decrease in temperature with height continued until 1900, but gradients characteristic of outgoing-radiation were evident at 2000 (fig. 26). Vertical gradients for 2300 and 2400 differed by 1° at all levels. Increase in temperature with height (outgoing-radiation type) continued through the early morning hours and a sudden reversal of gradients was noted just after the area was exposed to sun (fig. 27).

Measurements made on 7 Dec. 1959, just after the area was exposed to the sun, showed an immediate increase in temperature at the 1 cm level (fig. 28). Successive observations showed that increases in temperature at 2 cm, 1 cm, and at the surface were much greater than those recorded at 10 cm.

The greatest changes in temperature were recorded just after exposure to sun. Rapid responses were observed in all strata from 10 cm above the surface to 2 cm below the surface. The area was exposed to sun at 0718 and an immediate response was noted at the 1 cm level. The initial increase at 1 cm was followed by rapid heating of the surface. A complete reversal in outgoing and incoming-radiation was observed between 0730 and 0745. With successive temperature increases at the surface, 1 cm, and 2 cm, gradients typical of outgoing-radiation were evident at levels between 2 and 10 cm. During a 35 minute interval after exposure to sun, surface temperature increased 7.5° and the temperature at 2 cm below the surface increased 1.5°. These responses are summarized in fig. 29.

Relative humidity: The amount of evaporation in the microclimate is primarily dependent upon the temperature of the underlying surface. The complexity of environmental factors associated with the surface made it difficult to measure values at that level, but temperature-evaporation data were readily obtained from strata above the surface. Observations made at the 10 cm level indicated that relative humidity fluctuated with major and

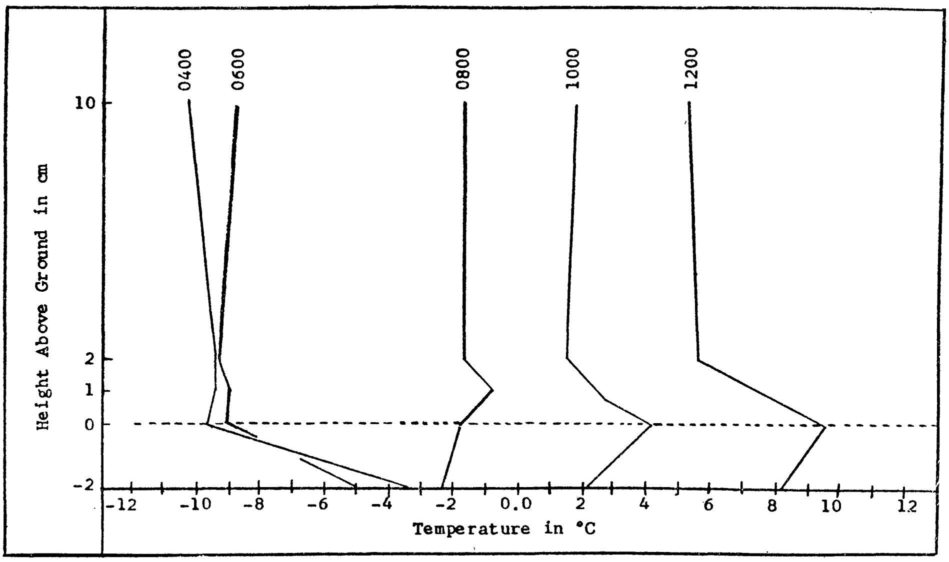

Fig. 28. Vertical gradients in air temperature at levels below 10 cm. Greatest differences noted at surface and 1 cm levels. Hallett Station; 7 Dec. 1959.

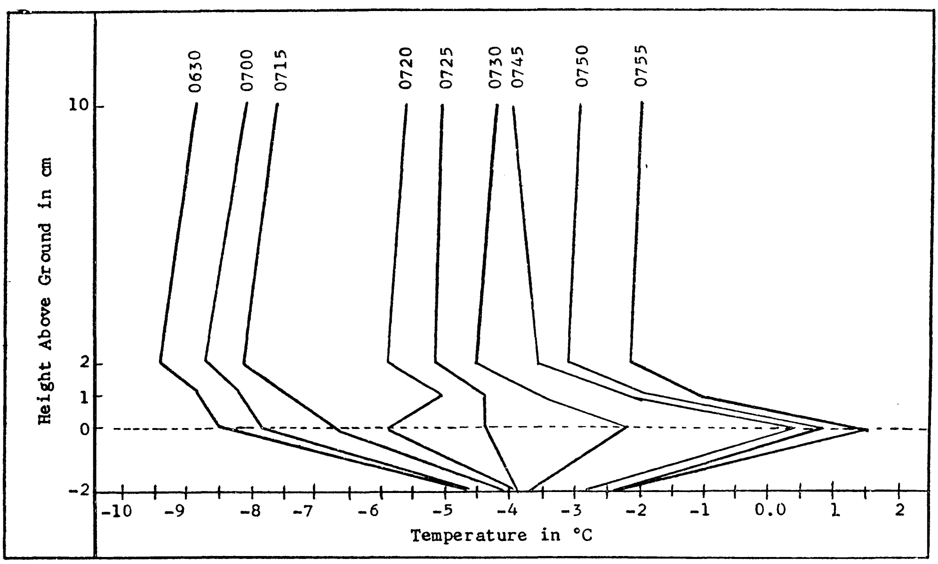

Fig. 29. Vertical gradients in air and soil temperatures showing responses to first appearance of sun on area. After obvious change to incoming-radiation curve at 0745, a return to an outgoing-radiation distribution is suggested at levels between 2 cm and 10 cm. Hallett Station, Antarctica; 7 Dec. 1959.

minor changes in temperature (fig. 30). A sharp decline in relative humidity was evident immediately after areas were exposed to morning sun. At midday, surfaces that had re-

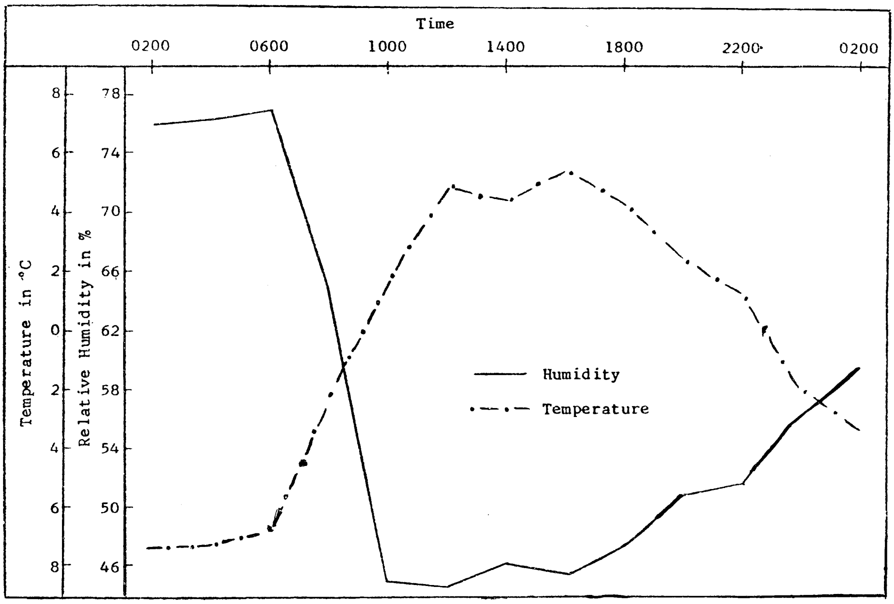

Fig. 30. Variation in per cent humidity with major changes in air temperature. Measurements made 10 cm above surface of talus slope. Hallett Station; 7 Dec. 1959.

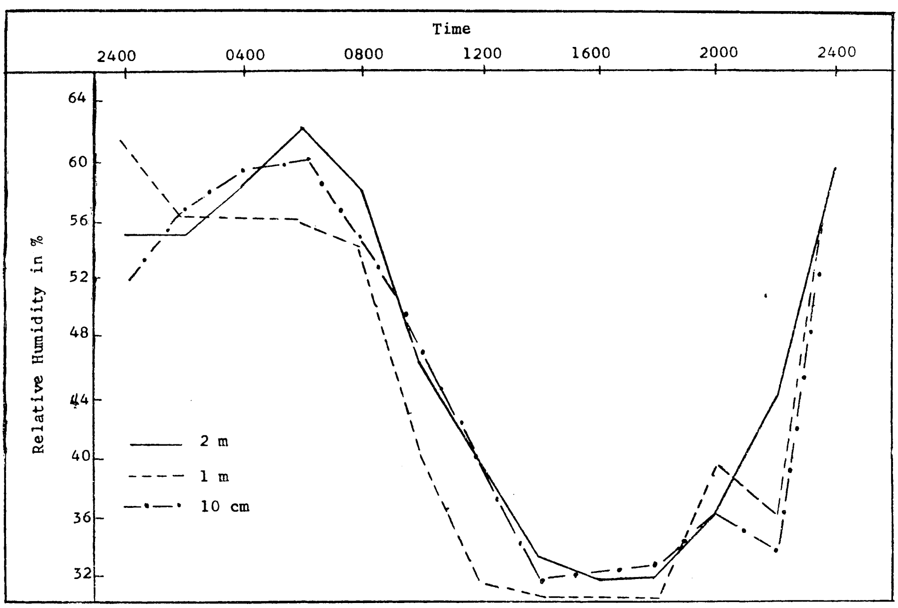

Fig. 31. Distribution of relative humidity at three levels in the microclimate. Measurements made above basalt talus slope at Hallett Station; 23 Dec. 1959.

mained moist through the morning hours were obviously very dry.

During the course of the study, it became apparent that humidity values at levels near the surface were frequently lower than those recorded at higher values (fig. 31). Geiger (1950) has referred to such a distribution of microclimatic humidity as being characteristic of a " dry climate type " and indicates that such a distribution has been observed only in southern India. Average values, based on 24 hourly measurements, for two summer days in 1959, clearly show that relative humidity increased with height from the surface to 2 m (fig. 32).

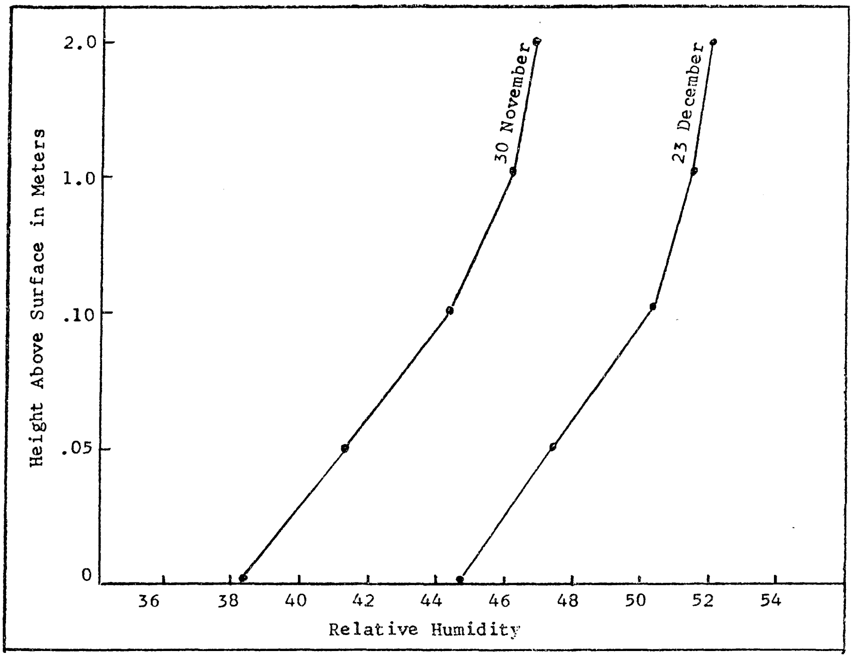

Fig. 32. Increase in relative humidity with height as shown by average values for two summer days. Measurements made above basalt talus slope at Hallett Station, Antarctica; 30 Nov. and 23 Dec. 1959.

Minimum values of 20 % or lower were frequently recorded in strata near the surface. A low relative humidity of 12 % was recorded at 4 cm above a talus slope on 1 Jan. 1960. Surface values near 90 % were recorded each day when the area was in shadow.

7. SURVEY RESULTS

The soil arthopod fauna of Hallett Station is represented by a very few species belonging to Insecta, Acarina, and Tardigrada. Although a paucity of species is characteristic of the area, individual populations are often quite large. As many as 59 specimens of Collembola have been extracted from a 10 cc soil sample taken at the edge of an actively melting snow line. Mild swarming was observed in early summer and the insects were often found in thick clusters during cold periods. The undersides of flat stones were frequently covered with mites. On at least one occasion, 263 mites, representing one species, were brushed from a stone with a surface area of approximately 100 sq cm. Tardigrades were found in great numbers in moist areas on talus slopes, but more frequently in association with mosses in wet areas near the base of Cape Hallett.

Insecta

All of the soil-inhabiting insects collected at Hallett Station belong to the order Collembola. A total of four species, three of which have been previously described, were found in the general area.

COLLEMBOLA

Family Isotomidae

Isotoma klovstadi Carpenter, 1902 (*I. besselsi* Enderlein, 1912)

The species has been found at one other location on the continent. It is also represented in the fauna of Tierra del Fuego and Macquarie Island. At Hallett Station, it occurred in great number in a great variety of habitats.

This species was selected for a more detailed ecological study which is reviewed in a later section of this paper.

Cryptopygus antarcticus Willem, 1902 (*C. crassus* Ewing, 1945)

The species has been found at one other location on the continent. It was originally described from collections made in a variety of habitats on Palmer Peninsula. On the Danco Coast of Palmer Peninsula, the species has been observed in association with mosses, algae, lichens, stones, and grass. At Hallett Station, it was frequently found under egg shells on talus slopes and closely associated with mosses in very moist areas.

Family Poduridae

Gomphiocephalus hodgsoni Carpenter, 1908

The species has been reported from one other site on the continent. The original description was made from specimens collected at Granite Harbor (76° 55′ S, 163° 0′ E) which is approximately 480 km S. of Cape Hallett. This collembolan was not as widely distributed in the area as was *I. klovstadi* or *C. antarcticus*. It was usually found in association with algal or moss deposits near the base of the cape. *G. hodgsoni* was not as active on the surface as were the other species.

A new species, which will be described at a later date, appears to belong to the subantarctic genus *Colonavis* which was established by Salmon in 1949. It will probably be necessary to expand the original conception of the genus before the new species can be included (Salmon, personal correspondence, 1961).

Salmon (1951) has indicated that the family Poduridae is represented by the single genus *Podura*. In his proposed system of nomenclature, *C. antarcticus* and *G. hodgsoni* belong to different subfamilies in the family Hypogastruridae.

Acarina

The four species of soil-inhabiting Acarina collected at Hallett Station represent two suborders and three families. All of the species have been previously described and a recent revision of antarctic Oribatei has been published by Dalenius and Wilson (1958).

TROMBIDIIFORMES

Family Eupodidae

Penthaleus belli Trouessart, 1903

The species has been found at one other site on the continent. The original description was made from specimens collected at Cape Adare (71° 17′ S, 170° 0′ E) which is just north of Cape Hallett. Specimens were frequently collected from frost fractures in large stones which were covered with species of the lichen genus *Placodium*. The species was largely restricted to drier habitats on talus slopes.

Penthalodidae

Stereotydeus (Tectopenthalodes) villosus (Trouessart), 1903 (*Penthaleus*)

The species has been previously reported from one other site on the continent. The original description was made from specimens collected in moss on the Palmer Peninsula between the latitudes of 65° and 68° S. At Hallett Station this species was taken in great numbers in dry habitats. Although it was found in a variety of habitats, it very rarely occurred in association with mosses.

SARCOPTIFORMES

ORIBATEI

Family Eremaeidae

Halozetes antarctica (Michael), 1903 (*Notaspis*)

The species has been found at various locations on Palmer Peninsula and is well represented on many of the subantarctic islands. It is the most widely distributed of the antarctic oribatids and has a circumpolar range. In the Hallett Station survey, it was found in mosses, lichens, and in depressions under stones. Southwest of the station it was frequently collected from the surface of melt pools and extracted from moist soil. These mites were definitely the most eurytopic of the species found in the general area. Specimens were frequently extracted from saturated soil below moss deposits.

Pertorgunia belgicae (Michael), 1903 (*Notaspis*)

With the exception of *H. antarctica*, this species is the most widely distributed of the antarctic mites. It has been found at various locations on Palmer Peninsula and is represented in the fauna of many subantarctic islands. Like *H. antarctica*, it occurs in a variety of habitats. In the Hallett Station area, the species was found under mosses, associated with lichens, and in moist depressions in the substratum. It appears to be able to survive in very moist and very dry habitats.

Tardigrada

Although specific determinations for this group have not been completed, specimens representing the genus *Macrobiotus* are found abundantly in association with mosses, algae, and fresh water pools in the vicinity of Hallett Station.

8. ECOLOGY OF ISOTOMA KLOVSTADI CARPENTER

Localities: *Isotoma klovstadi* Carpenter has been previously reported from three areas in the southern hemisphere (Gressitt and Weber, 1959). Specimens have been collected in Antarctica in the Robertson Bay area of north Victoria Land at 71° S, 169° E. The species has also been reported from Tierra del Fuego (54° S, 68° W), and from Macquarie Island (55° S, 159° E) which is just north of the Antarctic Convergence. The three localities are quite different in respect to biological components and geological formations. The less rigorous climate of the lower latitudes favors a more diversified flora and fauna. On the basis of present knowledge, the range of *I. klovstadi* extends through approximately 17 degrees of latitude and 135 degrees of longitude.

General habitats: *Isotoma klovstadi* was the most widely distributed of the insect species collected at Hallett Station. The insects were found on slopes of all directions, but less frequently on west-facing slopes exposed to the drying forces of winter winds. The species was observed at all elevations on Cape Hallett in areas which received moisture from melting snow. On the level beach at the base of the cape, it was restricted to moist areas bordering established drainage basins which received an annual supply of melt-water. Surveys made on the beach indicated that the species was not established on sites which were occasionally flooded for short periods of time in summer. Specimens representing small local populations from restricted areas were collected in major drainage channels on mountain slopes SW of the station. The insects were found infrequently in direct association with lichens, but occurred in great numbers in areas supporting the growth of mosses. Generally, mosses grew in small scattered patches on the talus slopes, but one deposit at the base of the cape covered an area of approximately 500 sq m. On this particular site, mosses had grown around flat stones and ideal conditions for successful habitats prevailed. The most typical habitats were those on terraced talus slopes where mosses and organic debris accumulated on the lee side of larger stones (fig. 33).

Microhabitats: Early descriptions of insects found on the continent usually included a general note concerning habitats utilized by various taxa. Mosses, lichens, algal ponds, stones, and penguin rookeries have been referred to as habitats in which collembolans have been found (Willem, 1901; Carpenter, 1902; *et al.*). Such references are vague, misleading, and accurate only in a very general sense. Closer observations indicated that habitats were more limited and adequate descriptions are dependent upon the qualifications of general terms.

I. klovstadi, and other collembolans, were rarely found in association with lichens. On occasion, insects were seen moving across lichen-covered stones, but collections made at temperatures near 0° C indicated that lichens were not used as established habitats by *I. klovstadi.*

Collembola were often found in specific habitats adjacent to penguin rookeries, but they were not collected from areas inside the rookery. Specimens transferred from slope sites did not survive in penguin rookeries, although a variety of experimental habitats was established.

The species was occasionally found on the surface of algal ponds, but such aquatic habitats were temporary. It is probable that the insects were accidentally transferred to these sites during the period of thawing and heavy runoff.

Insects were most often found in dry depressions on the undersides of flat pieces of rock. At temperatures below freezing, they were frequently found in compact clusters in frost fractures on stones of varying sizes. Large flat rocks, firmly anchored in the subsoil on the windward side, appeared to provide the most desirable habitats. Minor changes in the orientation of stones resulted in a shifting of position, or complete evacuation, by the inhabiting species. *I. klovstadi* was not found on the underside of all stones. It did not occupy all the surface area on stones where it did occur. Obviously, microclimatic variations associated with orientation, shape, color, and contact with the surface determine the effectiveness of certain stones, and specific areas on the underside of stones, as microhabitats for the species.

Microhabitats associated with mosses were more easily investigated. When surface temperature was high and relative humidity was low, the species moved downward from the surface of the moss to more humid and cooler areas. By vertically sectioning moss, collembolans were found in clusters in interstices of the upright branches of the gametophyte. Nematodes and protozoans were abundant in the decayed and matted portion of the branches near the soil surface. Collembola were invariably found at a higher level just above the partially decayed portion of the branches. Tardigrades were frequently found in association with collembolans, but mites were not seen in the sectioned moss. It is very probable that these microhabitats are used during long periods of intense cold. Cubes of frozen moss, 125 cc in size, were chiseled from a deposit near the base of the cape and horizontally sectioned for study. Adults, immatures, and eggs of *I. klovstadi* were found in pockets between the branches. Observations made on four different dates, when the moss was frozen, showed that eggs and immature collembolans were most abundant and adults were represented by only a few specimens.

Diverse media were intermittently used as microhabitats by the collembolans. *I. klovstadi* was occasionally found in feather boluses left near the snow line on talus slopes by skuas. The species was also found in association with egg shells and the skeletal remains of immature penguins. Wind-blown debris left by man was utilized as habitats in some remote areas.

Temperature: In the absence of vegetation, the influences of cloud cover and wind velocities on surface temperatures were intensified. On clear days with light and variable winds, insolation and out-going radiation attained higher values. Surface temperatures were unusually high (to $+24^\circ$ C) during midday and very low (to -20° C) when the area was in shadow. On overcast days with light winds, temperature extremes were not so widely separated. When exposed to persistently high winds, surface temperatures approximated those of the air which were usually below 0° C.

Temperature extremes characteristic of rock surfaces were not recorded in vegetative habitats. Temperatures measured in mosses at midday were frequentlly 11° lower than those recorded from adjacent areas on talus slopes. When the area was in shadow, temperatures in mosses were variable, but generally higher than those of exposed areas. Great differences were noted during periods of high winds.

I. klovstadi responded to temperature fluctuations at the surface by actively moving, either vertically or horizontally, to more favorable microhabitats. The species appeared on the surface shortly after the area was exposed to morning sun and consequent thawing. When the area was in shadow, movement from the surface was initiated by the onset of temperatures near freezing. The insects became quite immobile at temperatures just below freezing.

In addition to diurnal migrations to and from the surface, spontaneous movements were correlated with hourly temperature changes. On overcast days when the air temperature remained just below 0° C, the species responded to intermittent freezing and thawing of the surface which resulted from minor changes in wind velocity.

The insects were subjected to intense cold during the winter season. Although the opportunity to observe *I. klovstadi* closely during the winter was not afforded, laboratory experiments were made to investigate cold resistance and to determine the lethal cold temperature.

In the first experiment, the door from the freezing compartment of an electric refrigerator was removed and replaced with a fitted plexiglass window. Adult specimens (50) of *I. klovstadi* were placed in a glass tube which was suspended by wires from the top of the compartment. A second tube, immediately below the first, contained an alcohol thermometer for obtaining accurate measurements inside the freezing unit. Temperature was decreased from 0° C to –16° C in increments of one degree. Every second day the tube was removed, observed for activity, and replaced in the freezing unit at a successively lower temperature. At the end of one month, temperature had been decreased to –16° C (limit of the unit) and 8 specimens had died. The vial was returned to the freezing unit and left at –16° C for one month. At the end of this period, 13 more specimens had died, but the remaining 29 collembolans became quite active after thawing. Throughout the course of the experiment, it was obvious that the insects became quite inactive at temperatures near 0° C and activity was initiated by a temperature increase of 1.5° C. These experimental data corroborate observations made during summer field investigations.

In the second experiment, adult specimens of *I. klovstadi* were exposed to temperatures ranging from –20° C to –60° C in an attempt to determine the approximate lethal cold temperature. Low temperatures were obtained from a commercial deep-freeze unit. Stock specimens of collembolans were kept at 0° C.

A glass tube containing 50 specimens was exposed to a temperature of –20° C for three days and removed for observation. If most of the specimens were alive after thawing, another tube with 50 stock collembolans was exposed to a temperature of –30° C for the same length of time as the former and the process was repeated. Although none of the specimens survived a temperature of –60° C, 33 were alive after exposure to a temperature of –50° C. The lethal cold temperature after three days exposure for adult specimens of *I. klovstadi* falls between –50° C and –60° C. Similar results have been obtained for the adult stages of certain antarctic mites. Dalenius (1959) suggests a lethal cold temperature of –55° C for the oribatid mite, *Maudheimia wilsoni* Dalenius.

These data are offered as experimental evidence for an approximate lethal cold temperature for one species of collembolan. The effects were obtained in the laboratory by exposure to constant low temperatures, and cannot be compared with variable conditions occurring in the field.

Humidity: Respiration in the majority of Collembola is cutaneous. Some species of the suborder Symphypleona are tracheate, but the Arthropleona found in Antarctica depend solely upon cutaneous respiration. Surface moisture is necessary for the normal functioning of the insects.

I. klovstadi was active on the surface of mosses and stones during early morning and late afternoon hours when adequate moisture was available. Surface relative humidity at midday was frequently as low as 15 % and insects disappeared from the surface when this value was reached. The species remained inactive and confined to moist microhabitats until surface moisture was increased.

Immature stages appeared to be least resistant to desiccation. Eggs were most resistant, but were not viable after 24 hours exposure to relative humidities below 5 %. Adults died after being exposed for 15 minutes to relative humidities varying from 5 to 10 %.

During periods of flooding, adult and immature collembolans were frequently found on the surface of stones submerged in water. Experimentally, adults kept under water for five days were quite active when brought to the surface.

The förna, which serves as a buffer between wet and dry biotopes in temperate zones, is not found in antarctic faunal environments. Collembola are subjected to very high relative humidity in the shallow substratum or very low humidity on rock surfaces. Intermediate values are found only in specific areas which support the growth of moss or on sites characterized by fine-textured soils. The ability to move to more favorable microenvironments contributes greatly to the success of *I. klovstadi* in Antarctica.

Light: Light was one of the less important ecological factors associated with behavior of *I. klovstadi*. The species responded neither negatively or positively to direct light. Collembola were active on the surface as long as temperature and relative humidity values remained within tolerance limits. When surface temperature fell below 0° C the species retreated to crevices in soil or rocks. During the cold period, it did not respond to direct light which was offered in a variety of intensities.

The species showed a positive response to artificially created favorable temperatures and relative humidities, although it was subjected to total darkness. Squares of heavy black cloth, 1 sq m in size, were spread on the frozen ground and "hand-warmers" were placed on the cloth. The species appeared on the thawing surface, near the source of heat, shortly after application. When the cloth was removed, the insects retreated as surface temperatures approached 0° C. Repeated trials produced identical responses.

When stones were turned upside down during the warmer periods of the day, the species moved from the surface exposed to the sun toward the shaded side of the stone. One is tempted to accept the results of this simple study as being indicative of a photo-negative response, but it is very probable that movement toward the shaded area was initiated by temperature and humidity changes on the exposed surface.

Estivation: Most diurnal insects undergo a reduction or cessation of activities during the hottest part of the day. A negative response to intense surface heating is not only characteristic of insects inhabiting tropical and temperate zones, but also occurs in polar climates.

Although *I. klovstadi* was not restricted to diurnal activities, estivation was initiated by a combination of climatic factors characteristic of cloudless and calm days. The species retired to more favorable microenvironments when relative humidity values fell below 15 %. The collembolans remained inactive until surface humidity was increased. On overcast days, surfaces were not subjected to intense drying and the insects remained active until

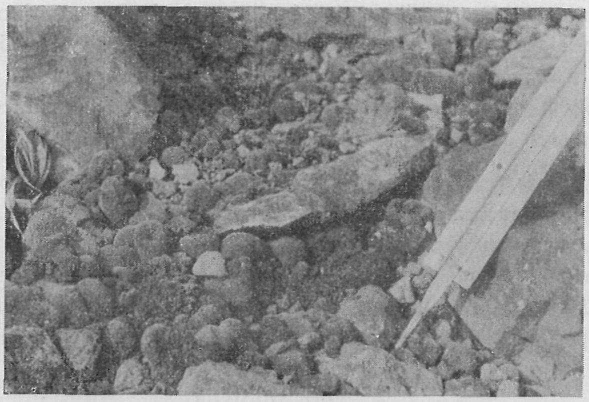

Fig. 33. Typical general habitat where *Isotoma klovstadi* Carpenter was found in abundance. Talus slope, Hallett Station, Antarctica; Dec. 1959.

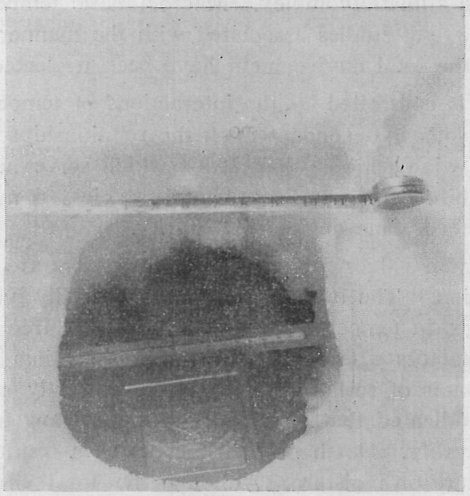

Fig. 34. Covered observation pit used for studying developmental stages of *I. klovstadi* Carpenter, Hallett Station, Antarctica; Nov. 1959.

Fig. 35. Organic residue left on surface of feeding area utilized by one pair of skuas, Hallett Station; Jan. 1960.

the surface became frozen.

Hibernation: *I. klovstadi* overwinters in both the adult and egg stages. Although the adult population is greatly reduced during the winter, this stage is of great interest in hibernation studies. Previous investigations have shown that the adult is resistant to extremely low temperatures. Apparently, large numbers die as a result of desiccation. The more resistant egg represents the major overwintering stage. Eggs were found singly, rarely in clusters, in mosses and soil.

In order to study developmental stages, observation pits were established on snow-covered talus slopes at Hallett Station in early November 1959. Overwintering stages of

I. klovstadi were collected from soil at the bottom of the excavation and the pit was covered with a plexiglass window (fig. 34). Immature forms were first observed in the study pit 28 hours after the surface had been exposed. Temperatures and relative humidities were extremely high in the enclosure and could not be correlated with natural conditions. Incubation periods may be of longer or shorter duration.

Food: *I. klovstadi* is primarily phytophagous, feeding extensively on mosses and algae. Frequently it was observed feeding in swarms on the surface of these plants. The moss pictured in the foreground of fig. 33 has been subjected to heavy surface feeding by large numbers of the species. Spores of algae and mosses were frequently found in the digestive tract of *I. klovstadi.* Occasionally they were found in great numbers feeding on the flesh of dead birds. Experimentally, the species was reared on lichens for short periods of time.

9. DISCUSSION

Climate: It cannot be denied that the rigorous climate of Antarctica is the major factor controlling the development of a land fauna, but too often generalities are based on the influences of a single component in the climatic complex. Macroclimatic temperature means for the continent are extremely low, but studies associated with the manner in which this most obvious single factor affects the total environment have been neglected.

The formation and development of soils is controlled by the interactions of temperature and moisture. The success of antarctic soils is dependent upon the relationships between these two factors in the presence of wind action. Vegetation which serves as a primary source of food and provides microhabitats for most continental species, is more abundant in those areas where soils have reached some degree of maturity.

In the microclimate, maximum and minimum values for most climatic factors are intensified as a result of the absence of vegetation. The fauna is subjected to daily variations which are equivalent to seasonal changes in temperate zones. Periods of freezing are frequently followed by a combination of factors which provide conditions similar to a "desert climate." The movements and responses of soil organisms are not directly controlled by temperature. Investigations have indicated that, for certain species, low temperature is not the direct cause of winter mortality. Death probably occurs as a result of desiccation through the influences of temperature on moisture. Although the total effects of temperature are more obvious near the surface, they must be carefully measured with respect to other environmental factors.

In a general sense, every climatic factor is influenced to some degree by the extremely low temperature characteristic of the area, but valid research associated with antarctic flora and fauna is dependent upon a thorough analysis of interrelationships existing between temperature and other components of the typical macroclimate and the more unique microclimate.

Productivity: It has been previously observed that those areas which harbor bird rookeries also have the richest plant cover (Siple, 1938). Perkins (1945) compared two mountains in Antarctica which were alike in respect to geology, amount of available moisture, exposure, and sunlight, but with a Snow Petrel (*Pagodroma nivea* Forster) rookery located on one mountain. The mountain with the bird rookery had a much heavier plant cover. Perkins indicates that it is very unlikely that the small amount of guano deposited by the birds accounted for the increase in vegetation.

Similar conditions were noted in the Hallett Station area where large numbers of penguins (*Pygoscelis adeliae* Hombron & Jacquinot) and skuas (*Catharacta maccormicki* Saunders) occupied nesting areas on the spit. Although vegetative growth was very sparse inside the confines of the penguin rookery, the areas utilized by skuas had a very rich plant cover. On these sites it was obvious that the occurrence of vegetation was not solely dependent upon the accumulation of guano. In the most productive areas, bones, feathers, egg shells, and the remains of dead birds (primarily immature penguins) were found on the surface (fig. 35). Analysis of finely textured soil, extracted from beneath mosses, showed that these same materials occurred in more advanced stages of decomposition in the substratum. A variety of food materials was carried to the talus slopes by skuas and the residue was distributed by wind and water and ultimately incorporated into the soil.

On isolated sites SW of Hallett Station, vegetative growth was very sparse, but even in those areas some organic debris was found. Similar associations were observed at various coastal locations in the Ross Dependency. Those sites harboring bird rookeries had the most extensive plant cover and near-sterile conditions existed in areas where birds were not found.

Obviously, areas characterized by a variety of plant species also supported a richer soil fauna. In terms of abundance and numbers of species, Hallett Station was the most productive area surveyed in the coastal regions of Victoria Land. Interrelationships of birds, plants, and soil fauna were always apparent, but vegetative productivity was not directly controlled by the abundance of guano. A comparison of microenvironments in adjacent areas should be made and local soils should be analyzed for organic content. The problem cannot be solved by the gross comparison of two adjacent mountains.

Distribution: On the basis of present knowledge, the Cape Hallett region is the most productive soil fauna area surveyed in Antarctica, with the exception of Palmer Peninsula. Although abundant, the regional fauna was not unique. Only one new species of Collembola was found, and approximately 90% of the taxa collected have been reported from at least one other area on the continent. Most of the Acarina and Collembola found at Hallett Station are also represented in the fauna of many subantarctic islands.

Although sufficient data to support theories concerning geographical distribution are not yet available, speculation based entirely on local observations may be of some value.

Dispersion by water, by winds, and by animals are the three factors which must be considered as agents influencing geographical distribution. It is possible that each of these factors plays some part in antarctic distribution, although the influence of any one may be more obvious in any particular area.

The direction of current-flow in the southern oceans does not favor water as a medium for transporting fauna to the polar continent, but it is very possible that movement between the subantarctic islands is affected by the east-flowing currents. The west-flowing current near the continent is a drift-current which moves in an opposite direction from those currents of the southern oceans. The movement of water near Antarctica may effect local continental distribution. At Hallett Station, the mite *Halozetes antarctica* was frequently found in rather saline habitats on the W. side of Willett Cove. The species has a circumpolar distribution and dispersal may have been influenced by ocean currents.

Strong winds which are characteristic of the higher latitudes have often been considered as a factor influencing distribution in Antarctica. Aerial surveys made in other parts of the world have shown that mites and collembolans are transported by air currents. Glick (1939), in one of the earlier aerial surveys made in the United States, collected mites from an altitude of 900 m. The success of such surveys made in temperate zones does not unconditionally validate the theory of air currents as a medium for transporting organisms to the south polar continent. It is very improbable that atracheate species of Collembola could survive the forces of desiccation encountered in movement over such great distances. Perhaps the more resistant egg is the stage involved in dispersal by air currents. If organisms are passively transported to Antarctica by wind action, they must be deposited in a very few favorable areas before successful populations can be established. Ecological investigations and aerial surveys are presently being made in Antarctica to determine the status of wind as an agent of long range dispersal.

Although there is much uncertainty associated with the methods of movement over long distances, the role of wind in local distribution is more apparent. On two occasions in December 1959, single specimens of *I. klovstadi* were collected in aerial nets established 10 m above the surface on the windward side of Hallett Station. Desiccated specimens of the same species were collected from the surface of sea ice 3 km SW of the station. Local distribution studies, made by stretching "tanglefoot strips" between bamboo poles, indicated that the majority of those organisms passively transported by wind remained near the surface. Many collembolans and a few mites were trapped at a height 15 cm above the surface. Collections made by suspending streamers of "tanglefoot" from higher elevations on the lee side of the cape, showed that a considerable number of Collembola were carried out to sea by the action of local winds.

Birds are the only animals potentially capable of transporting soil organisms to Antarctica. The circumpolar distribution of some species has made their position as disseminators quite convincing. Dalenius (1958) has suggested that the species of mite found at Passat and Ekberget in Dronning Maud Land was carried to Antarctica by either the Snow Petrel or the Wilson's Petrel. Although this association may be apparent at sites in Dronning Maud Land, such convincing evidence was not found at Hallett Station. In the general area of Cape Hallett, those areas occupied by nesting petrels (both species) were characterized by a paucity of flora and fauna which approached sterility. As previously stated, the most productive local areas were those frequented by skuas. Perhaps in the absence of one species of birds, dispersal is dependent upon the success of another bird species. Close examination of 21 skuas and 24 specimens of each of the two petrels indicated that these birds were not accidental carriers of free-living mites or collembolans. Although the number of specimens examined represented a small percentage of the local populations, it is important to note that the survey was made at a time when soil arthropod-activity was at a peak. It is possible that organisms are transported by birds in the less obvious egg stage.

Most theories concerning the geographical distribution and dispersal routes of antarctic species are based on the concept of movement from lower latitudes toward the polar region. The possibility that these forms are representatives of a relict fauna must be considered.

Evidence gained from fossil plants collected on the continent indicate that, during a large part of late Paleozoic and post-Paleozoic time, climate was much milder than it is at the present (Seward, 1914; Darrah, 1936). Coal deposits and fossil remains of the ancient *Glossopteris* flora have been found in various areas on the continent. It has even been hypothesized, on the basis of very incomplete data, that Antarctica may have served as a center of origin, or route of migration, for late Paleozoic, Mesozoic, or Cenozoic floras of South America and Australia (Barghoorn, 1961). More stable and modern relationships exist between present-day southern continents. The beech genus *Nothofagus*, which is represented by a fossil form in Antarctica, is an abundant forest tree in certain areas of the southern hemisphere.

Climatic data and vegetative affinities have been used extensively to support the theory of continental drift. Speculation concerning the probability of a more diversel and fauna rarely has been offered. It would seem likely that a climate favoring the development of a continental flora would also favor the development of a more abundant insect fauna. To the present time no fossil insects have been found in Antarctica and in the absence of fossil records, researchers are hesitant to speculate on the probability of an older and more complex insect fauna. It is important to note that intensive surveys associated with present-day fauna have been few in number and surveys specifically concerned with fossil forms have been non-existant.

The geographical distribution of antarctic species cannot be explained on the basis of any currently existing theory. Necessary data are so insufficient that even speculation is difficult. Floral and faunal surveys for most of Antarctica are still in the reconnaissance stage. An understanding of dispersal routes and distribution patterns can be obtained only after more immediate problems are solved.

10. SUMMARY

The major objective of this paper is to report the results of a soil arthropod survey conducted at Hallett Station, Antarctica in the austral summers of 1958–1959 and 1959–1960. Previous biological investigations have not been made in the immediate area and, in order to render the survey complete, it is necessary to analyze environmental factors characteristic of the region. General ecological studies associated with one of the more abundant species were made to show relationships existing between local fauna and environment.

Data were primarily obtained from direct field measurements, but some controlled laboratory experiments were made to determine faunal responses to extreme climatic variations.

Observations made in the macro- and microclimates show that effective summer conditions may prevail for as long as two months. Thermocouple measurements recorded from a depth of 10 cm indicate that the ground is unfrozen for brief periods on most days in December and January. At a depth of 50 cm, temperatures approach 0° C in December, but thawing is not evident. Although the surface was frozen for varying lengths of time each day during the summer season, temperatures near 20° C were frequently recorded at midday. In the macroclimate, a low temperature of –47.8° C was recorded on 21 Aug. 1959, and the high, +8.3 on 8 Jan.

Precipitation at Hallett Station is always in the form of snow or hoarfrost. In 1959

an annual net accumulation of 24.3 cm of water was recorded. Of this total, 20.5 cm fell during March, May, July, August, and September. In the summer months of November and December, a low net accumulation of .05 cm was recorded. During the summer season, water is abundant in localized areas which receive melt-water from snow fields and glaciers.

Wind velocities, measured on talus slopes at heights of 2 m and below, followed high and low trends recorded by station meteorologists. Successive decreases in wind speed at levels near the surface were apparent in all daily observations. Greatest decreases in microclimatic wind velocities were recorded between 1 m and 10 cm.

Relative humidity measurements made near the surface varied from 12% after long exposure to direct sunlight to 90% when the study area was in shadow. Humidity values at levels near the ground were frequently lower than those recorded at higher levels.

Survey results show that the soil arthropod fauna of Hallett Station is represented by at least nine species belonging to the groups Insecta, Acarina, and Tardigrada. All of the terrestrial insects found in the area belong to the order Collembola, which is represented by the four species: *Isotoma klovstadi* Carpenter, *Cryptopygus antarcticus* Willem, *Gomphiocephalus hodgsoni* Carpenter, and an undescribed species which probably belongs to the genus *Colonavis*. The four species of Acarina collected in the area are: *Penthaleus belli* Trouessart, *Tectopenthalodes villosus* Trouessart, *Halozetes antarctica* Michael, and *Pertorgunia belgicae* Michael. Tardigrada is represented by species of the genus *Macrobiotus*.

With the exception of the new species of Collembola, most of the other taxa are found in the fauna of other antarctic and subantarctic areas which have been surveyed.

Ecological studies associated with *Isotoma klovstadi* Carpenter indicate that the activities of the species are largely controlled by fluctuations in the amount of moisture available in local environments. Estivation appears to be initiated by relative humidity values below 15%. Winter mortality is probably a result of desiccation through the action of temperature on available moisture.

I. klovstadi is very resistant to low temperatures. Experimentally, adults have survived for a period of one month at a temperature of −16° C. The lethal cold temperature for adults falls between −50° and −60°C. These lower limits are not usually encountered in microhabitats. A minimum subsurface temperature of approximately −30° C was recorded at a depth of 10 cm in July of 1960.

I. klovstadi appears to be neither photopositive nor photonegative. Light responses are secondarily important in relation to temperature-moisture complexes. The insect overwinters in both the adult and egg stages, of which the latter is the more usual. The species is primarily phytophagous, feeding extensively on mosses and algae, but may feed on a variety of materials associated with particular habitats.

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