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SOILS AND GEOMORPHIC SURFACES IN ANTARCTICA **

Abstract

Comparison of soils and soil morphology from coastal Enderby Land with soils of the ice-free areas (oases) of Victoria Land and Queen Maud Land revealed that soil development has progressed much further in Enderby Land. Relatively deep, highly colored, moist soil profiles with easily identifiable particle reorientations are formed in friable materials in Enderby Land. No other reports of such well developed soils on the continent have been made. Evidence is presented to show that the present climate is the major factor controlling pedogenesis. Chronological dating of surfaces may be valid if the climatic parameters are comparable.

In general, the weathering and soil-formational processes of the Antarctic continent, especially the local and regional variations in rates, are imperfectly known. That soil morphological properties may be a measure of the relative age of geomorphic surfaces in the ice--free portions of the continent has been suggested (Ugolini and Bull, 1965). This report describes the soils of the coastal region of Enderby Land, indicates the variations in these soils and soil materials from the modal concepts developed in other sectors, and presents data indicating regional environmental properties (climate) may be dominate in the conditioning of the geomorphic surface. No previous pedological observations had been made in this region.

As polar pedology is only of recent vintage and the literature not readily available in many locations, a review of the results of

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other workers is in order. Pedogenetic studies have been conducted by many workers in recent years in the ice-free portions of Victoria Land (Claridge, 1965; McCraw, 1960, 1967; Tedrow and Ugolini, 1966; Ugolini, 1963, 1964, 1967; Ugolini and Bull, 1965). Supporting data on soil temperatures, depths of thaw, surface microenvironments, chemical compositions of soluble salts, soil moisture contents and dynamics, and exchangeable ion contents from this portion of the continent are available from numerous sources (inc. Angino, Armitage, and Tash 1962; Ball and Nichols, 1960; Black and Berg, 1963, 1966; Blakemore and Swindale, 1958; Boyd and Boyd, 1963; Boyd, Staley and Boyd, 1966; Claridge, 1961, 1965; Flint and Stout, 1960; Gibson, 1962; Gressitt, 1962, 1965; Gressitt, Leech, and Wise, 1963; Janetschek, 1963, 1963b; Jensen, 1916).

A single study of chemical and mineralogical weathering of bedrock has been reported from Victoria Land (Kelly and Zumberge, 1961), although the majority of workers have assumed the predominance of physical degradation processes over chemical processes. Landform relief, macro and micro, has been reported to be mainly the result of physical actions (Nichols, 1966; Péwé, 1960), although degree of weathering has been used to establish the chronology of glacial deposits (Calkin and Cailleux, 1962; Nichols, 1961; Péwé, 1962; Ugolini, 1964; Ugolini and Bull, 1965).

With few exceptions, all workers have reported alkaline soil reactions, high contents of soluble salts, particle size distributions dominated by the coarse fractions, weakly developed profile differentiations, lack of structure, low to very low soil moisture contents, and lack of appreciable humic contents to be the characteristics of the mineral soils of Victoria Land. It will be shown that this is not the situation in Enderby Land.

From samples collected during the first Soviet Antarctic Expedition by K. K. Markov, Glazovskaia (1958) has described the chemical and mineralogical alterations that constitute primary soil formational processes on the Queen Mary Coast. The extent and relative stage of the chemical and mineralogical alterations reported are, in general, greater than those recognized in Victoria Land. That similarities do exist has been demonstrated (Ugolini, 1964), although these may be, in part, paleoclimatic. As in the case of Victoria Land, other workers have reported fragmental data on depths of thaw, soil surface temperatures, examples of physical degradation, soluble salt presences and compositions, etc., throughout the coastal sector of East Antarctica. All of these data indicate general alkaline soil conditions, high soluble salt concentrations in surface layers, and low moisture contents (Avsiuk, Markov and Shumskiy, 1956a, 1956b; Grigoriev, 1959, 1962; Markov, 1956; Markov, Bardin and Orlov, 1962; Skeib, 1964; Voronov, 1961). A series of reports describing the exchangeable ions, extractable salts, exchange capacities, free iron and aluminium oxides, and salt compositions from 46 samples of soil materials from the coastal region of East Antarctica, exclusive of Enderby Land, has been published by the Soviet workers. However, unfortunately, these data do not include such data as color, depth of sampling, particle size distribution, profile differentiation, or mineralogical composition for the majority of the samples (Voronov, 1961; Voronov and Spiro, 1963, 1964, 1965). The lack of adequate descriptions, especially the depth of sampling, seriously weakens the validity of the conclusions made by these authors. This author's studies, as well as those of workers in Victoria Land, have repeatedly shown sharp gradients with depth in all physical and chemical parameters; and in Enderby Land, the inflection points within the gradients generally are accompanied by changes in profile morphology.

Japanese scientists have reported on soils and weathering products associated with ecological studies on the Prince Harald Coast (Meguro, 1962; Matsuda, 1964). The conditions are similar to those reported from the previously mentioned regions, although the percentage of moss-lichen colonized soil surfaces is greater than that of Victoria Land. Personal communications with membres of the 8th Japanese Antarctic Expedition indicate that alkaline and saline soils predominate in the region surrounding the Japanese station, Syowa.

Mainly as a result of the pedogenetic researches carried on in the 'dry valley' areas of Victoria Land, but also with considerable review of the literature, the soils of the antarctic continent have been classified as "soils of the cold desert" (Tedrow and Ugolini, 1966). This grouping, apparently equivalent to a 'Suborder', has been further divided into the apparent equivalents of 'Great Soil Groups' (Thorp and Smith, 1949). These subdivisions are as follows: Ahumic Soils; Evaporite Soils; Protoranker Soils; Ornithogenic Soils; Regosols; and Lithosols.

Briefly, these Great Soil Groups are characterized as follows: (1) Ahumic Soils are those soils which form the major portion of the cover of the valley floors and lower slopes in the 'dry valley' region. They are associated with a continuous open-fabric desert pavement of varying thickness, have surface horizon colors of yellowish brown, brown, or gray, and underlying horizons of lighter colors. Soluble salt contents and pH values are high throughout the profiles. Layers of lime or gypsum may be present. Predominant particle size distributions are gravelly sands, gravelly loamy sands, and gravelly sandy loams. The soils are structureless. As the name implies, there is no organic horizon. The presence and preservation of high soluble salt contents and layers of lime and gypsum testify to the maintenance of low moisture contents within the soil profile.

(2) Evaporite Soils are those soil conditions associated with basin topography. They exhibit concentrations and efflorescences of soluble salts, some of which may be deliquescent, at the soil surface. Essentially these soils are saline soils formed either as a result of periodic inflows of salt-charged melt waters or the evaporation of brackish lakes. The salts may be derived from atmospheric precipitation, relict marine waters, and/or contemporaneous weathering. The problem of the origin of the salts is presently being discussed in the literature (Black and Berg, 1963; Gibson, 1962; Nichols, 1963; Tedrow, Ugolini, and Janetschek, 1963; Ugolini, 1964). No modal soil profile can be described for such conditions.

(3) Protoranker Soils are those soil conditions associated with moss and moss-lichen communities in the Antarctic. Tedrow and Ugolini (1966) did not described a modal profile for these soils, although creating a place for them within their classification system, as they were not found well developed in the 'dry valley' region of Victoria Land where these workers formulated their concepts. Based upon my observations in Enderby Land, where these soil conditions are very common, the modal solum consists of a thin, up to 3 cm. thick, dark reddish brown high organic sandy loam or loam horizon which is transitional from the living moss or moss-lichen community to a second horizon, 5 to 7 centimeters thick, of light reddish brown to reddish brown sandy loam or loamy sand. This horizon often has weak fine granular structure and partial infusion with roots, both living and dead. The next underlying horizon, equivalent to a C horizon, is variable from site to site, and in some cases is absent and replaced by bedrock. Soil moisture contents in these soils are variable throughout the course of the summer season, but tend to be 2—5% higher than adjacent mineral soils at the time of

maximum desiccation. Soil moisture contents of the mineral horizon ranged from 4 to 46% by weight in 1967-68 during the periods when active infiltration of melt or drainage waters was not occurring. These soils are usually found in wind-protected sites, hence they are, to some extent, associated with snow and detritus accumulations.

(4) The Ornithogenic Soils are the low-grade guano deposits associated with antarctic rookeries.

(5) The Regosols, of course, have no modal profiles; however, they were described as being saline soils in their occurrences in Victoria Land. In Enderby Land, all of the regosolic soil conditions are not saline, although saline varieties have been recognized in basin positions. Profile defferentiation, as evidenced by grain coatings, horizonization, and color development, is lacking in the Regosols.

(6) The Lithosols consist of frost-shattered or intact bedrock conditions and are probably the most common of the antarctic soils.

ENDERBY LAND SOILS

The conceptual classification of antarctic soils, as suggested by Tedrow and Ugolini, must be considerably modified to be applicable within the coastal regions of Enderby Land. Analogues to all of the enumerated Great Soil Groups, with the notable exception of the Evaporite Soils, are found, but the chemical and moisture regimes, as well as the degree of profile development as indicated by fabric reorientations, structural element developments, color strengths, and profile depths, differ in measurable and significant quantities from the Victoria Land mode. At present, based upon extensive field observations, it seems that most of the differences can be attributed to the effects of a more moderate climate; a longer period of thaw and abundances of melt water.

The typical Protoranker Soil of the Molodezhnaya region has been described in a previous section of this report. It has been indicated that this soil is lacking in the 'dry valley' region of Victoria Land because of the paucity of available water to support the plant community.

Microbiologists and ecologists have repeatedly indicated that the principal limiting factor to the development of extensive plant and animal communities in Victoria Land is the availability of moisture (Boyd, Staley, and Boyd, 1966; Gressitt, 1965; Janetschek, 1963; Rudolph, 1966). Ugolini (Ugolini, 1963; Ugolini and Bull, 1965) has demonstrated the diurnal ascension-descension of moisture during the summer season in the 'dry valley' region of Victoria Land. Essential to the development of this phenomenon is the existence of a 'wet' permafrost condition at the base of the active layer. Throughout much of ice-free parts of Enderby Land, the underlying strata is 'dry' permafrost [1]. A net general movement of solutions from depths to the surface has been reported on a variety of materials over the whole continent, always as a result of the development of strong temperature gradients (Black and Berg, 1963, 1966; Glazovskaia, 1958; Markov, 1956). Indeed the preservation of the surface efflorescences and subsurface layers of the highly soluble salts found in Victoria Land and other parts of the continent, if not their actual formation, must be correlated with a net upwards movement of water.

Field investigations, which included the monitoring of soil moisture contents throughout the whole of an annual cycle, as well as the properties of the soil profiles themselves, indicate that in Enderby Land there is considerable transport of water down through the soil profile to the top of the perennially frozen ground. That no large ice masses or bodies are located at the interface between the active layer and the perennially frozen ground, with the exception of basin and lower slope sites, strongly suggests that there is a balance between ascending, lateral, and descending water movements.

Infiltration into the soil profiles as water films has resulted in the formation of illuviation cutans. Concentrations of the mobile fractions of the soil materials, the plasma, (which under the influence of cryogenic processes includes particles of sizes up to and including coarse silt, and is not restricted to colloidal-sized particles as originally defined by Brewer, 1964), indicate that the net transfer of plasma is downwards. Infiltration occurs both at the initiation of the summer season with its melting of the snow accumulations, and at the beginning of the autumnal period when infrequent snows and rains occur and the soil materials are thawed. Reverse movements, as water films at depth in the profile, but in the vapor phase in the upper parts of the profile, occur in mid and late summer.

[1] The diurnal ascension-descension of moisture within the coastal oases of Enderby Land is only evidenced early and late in the season when the lower parts of the active layer have become frozen in states of supersaturation. This subject will be discussed at some length in a forthcoming report on the dynamics of soil moisture within the coastal oases.

That the balance is delicate is demonstrated by the fact that the net movements in rock exposures and shallow soil materials on windswept sites is to the surface. This is manifested in the development of desert varnishes and minor salt efflorescences. The near-constant sweeping of the surface by relatively dry winds, as well as the excessive temperature gradients that exist at rock-air interfaces, cause the net movements to be to the surface. Neither the

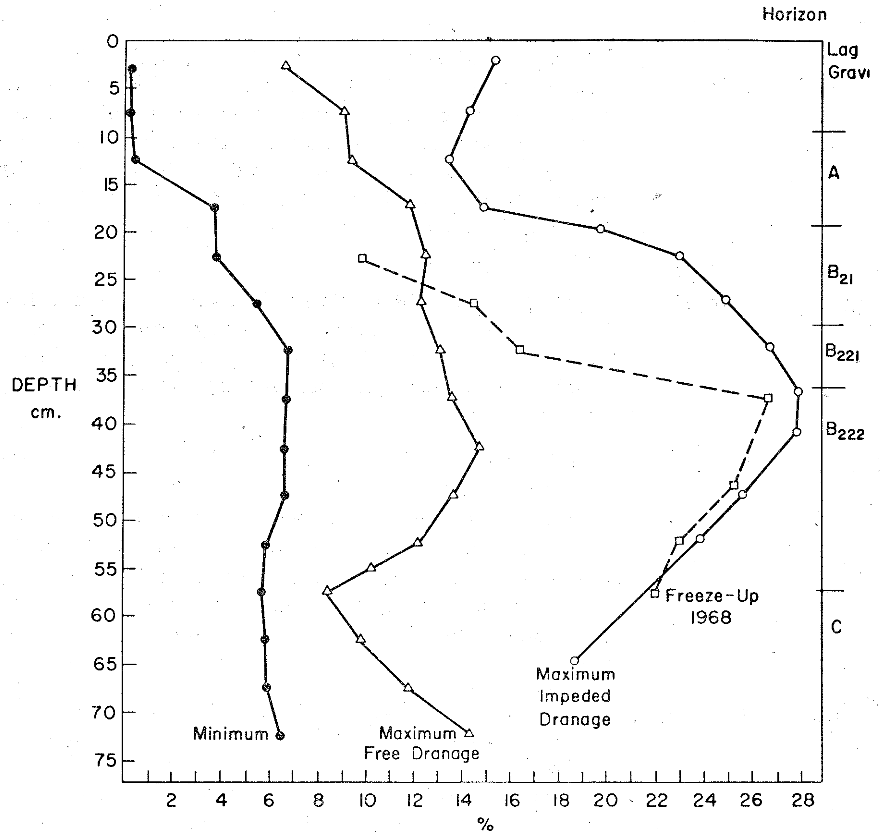

Fig. 1. Moisture dynamics, Red Ahumisol. Molodezhnaya, Antarctica; 1967—68

excessive humidity gradients nor the large temperature gradients are developed on normal sites because of the lag gravel covering which acts as a mulch and functions as the microclimatic active surface.

The analogues to the Ahumic Soils, which for the purposes of this report, in order to differentiate them from the dry soil con-

Table I

Morphology of a Red Ahumisol from Enderby Land, Antarctica

Site: Flat topped windswept ridge-bench, 40 meters above sea level
Parent Rock: Frost-shattered migmatized fine granular Pre-Cambrian gneiss with cross-cutting veins of coarse to fine pegmatite
Date: 15.3.67; 29.9.67; 1.2.68 (Explosives)

Horizon	Thickness cm.	Description [1]
Lag gravel	3 to 11	Lag gravel of 75 to 85% by volume angular fine gravels of parent rock; few erratic cobbles and boulders; poorly developed moss-lichen community covers 1-2% of surface; granular fabric of angular very coarse and coarse yellow (10YR 7/8D) * 75-85% by weight sand, apedal; random large irregular intrapedal simple packing voids; lower boundary gradual and smooth.
1 (A)	9 to 12	Light brown (7.5YR 6/6M) sandy loam; agglomeroplasmic fabric; fine gravel 35-50% by weight; apedal; single-grained; loose; random large irregular intrapedal simple packing orthovoids; lower boundary abrupt and irregular.
2 (B_{21})	6 to 12	Reddish yellow (5YR 6/6M) sandy loam; porphyroskelic fabric; fine gravel is 10-15% by weight of compound gneiss grains and pegmatite; parts of overall fabric are intertextic; sesquans and ferri-argillans (?) as free grain cutans; much firmer than overlying horizons; random and clustered intrapedal smoothed metavoids (vesicles); lower boundary abrupt and wavy.
3 (B_{221})	12 to 16	Red (10YR 4/8-4/10M) loam; porphyroskelic-intertextic fabric; fine gravel of partially disaggregated, but hard, gneiss is 5-15% by weight; sesquans and ferri-argillans as free grain cutans, embedded grain cutans, and vesicle cutans; strongly adhesive and strongly separated; firm; large clustered subcutanic intrapedal smoothed metavoids (vesicles); lower boundary gradual and wavy.
4 (B_{222})	18 to 30	Brown (10YR 5/3M) to light yellowish brown (10YR 6/4M) sandy loam; porphyroskelic-intertextic fabric; gravels and cobbles of partially disaggregated, soft,

1 Void and cutan terminology follows Brewer (1964).
* Color notations are in reference to Munsell System (Munsell Color Company, Baltimore, Md.).

Horizon	Thickness cm.	Description [1]
		uncemented, gneiss are up to 30% by weight, sesquans and ferri-argillans as free grain cutans, embedded grain cutans, and vesicle cutans, strongly adhesive and strongly separated; firm; large clustered subcutanic intrapedal smoothed metavoids (vesicles) with orientation to surfaces of skeletal cobbles and gravels; few arcuate voids of transient nature filled by small ice lenses observed in winter; lower boundary diffuse and wavy.
5 (C)	40 to ?	Yellow (2.5Y 7/8M) and reddish-yellow (7.5YR 6/6M) disaggregated gneiss; thin sesquans continue in fractures; frozen; hard

ditions of Victoria Land, will be referred to as the Ahumisols, are characterized by cutans that are ferriargillans and sesquans, strongly separated and strongly adhesive [2]. Flow-forms and zonation are infrequently noted, indicating that the cutans are illuvial in origin. Subcutanic segregations of soil materials by particle size are present in the lower parts of the solum in most profiles, and are the result of sorting by cryogenic processes, movements in front of the freeze zone (Corte, 1963). Vesicles, equant smoothed vughs, are associated with the subcutanic segregations. Vesicle frequency and size is at a maximum in the layers between 40 and 55 centimeters depth. The vesicles have apparently been formed as a result of the release of gases during the freezing processes, and have been preserved from year to year because of particle reorientations in response to the exerted pressures. Weak fine platy structural elements are often seen in the upper parts of the solum (20-35 centimeter depths), indicating that other types of particle reorientations, probably as a result of small ice lens formation and its associated directional pressures, occur during pedogenesis.

Reactions, as determined on 1 : 1, soil to water, extracts over a great number of sites in widely separated geographical areas vary from pH 5.70 to 6.05 at the surface. Reaction usually increases about 1 pH unit in the lower horizons (B_2, B_3). Soluble salt quantities are usually highest in the A horizon, immediately under the lag gravel, and sharply decrease in the B horizons. Isolated profiles, usually associated with the presence of calcitans, were slightly alkaline

[2] The terminology follows that of Brewer (1964).

Table II

Morphology of a Brown Ahumisol from Enderby Land, Antarctica

Site: (No 5); South-facing 3-6% slope from secondary bench; 35-40 meters above sea level

Parent Rock: Jointed, weakly frost-cracked migmatized olive-brown, coarse grained Pre-Cambrian gneiss; surficial additions of ground moraine and locally derived aeolian materials

Date: 4/67 and 11/68

Horizon	Thickness cm.	Description
Lag gravel	4 to 7	Lag gravel of 70-90% by volume medium, fine, and very fine gravels of local gneiss with 3-8% gravels of pegmatite and other erratics; moss communities have less than 2% cover; granular fabric of dark yellowish brown (10YR 4/6-4/8D) and dark grey brown to olive brown (2.5Y 4/2-4/4D-M) very coarse, coarse, and medium sands; apedal; random large irregular intrapedal simple packing voids except where moss communities cover the surface; where moss communities are the voids are smaller and the surface 1-2 cm. and agglomeroblastic fabrics are found; lower boundary gradual and smooth.
1 (A)	9 to 14	Olive yellow (2.5Y 6/6M) to dark grey brown (2.5Y 4/2M) sandy loam and loamy sand; agglomeroblastic fabric; gravels of fragments of gneiss are 30-50% by weight; apedal; single-grained; loose to firm; random large, medium, and small irregular intrapedal simple packing orthovoids; few fine acicular voids attributed to small ice lenses; lower boundary distinct and wavy.
2 (B_{21})	17 to 24	Olive brown to light olive brown (2.5Y 4/6-5/6M) sandy loam with subcutanic segregations of brownish yellow silt loam; porphyroskelic-intertextic fabric; floaters of bedrock up to 30% by volume; (10YR 6/6M) thin to thick cutans, free-grain and vesicle types present; cutans strongly separated and strongly adhesive; firmer than overlying horizon; large (to 3 mm. diameter) clustered subcutanic intrapedal vesicles (smoothed metavoids); fine to coarse irregular simple packing voids in skeletal fabric; cutans and subcutanic segregations have reference to bedrock orientation; lower boundary diffuse and wavy.
3 (B_{22})	7 to 10	Olive brown to light olive brown (2.5Y 4/5-5/6M) sandy loam with thick (to 3 cm.) subcutanic segregations of brownish yellow (10YR 6/6M) loam and silt loam; porphyroskelic-intertextic fabric; jointed bed-

Horizon	Thickness cm.	Description
		rock is up to 85% by volume; cutans on vertical faces of bedrock, free grain cutans present, vesicle cutans well developed; all cutans are strongly adhesive and strongly separated; many assorted size clustered subcutanic intrapedal vesicles; lower boundary abrupt and wavy.
4 (B_3)	15 to ?	Olive brown (2.5Y 4/4-4/5M) sandy loam; intertextic fabric; in joint planes of bedrock; few free grain cutans, strongly adhesive and strongly separated; bedrock is up to 95% by volume.

(pH 7.2-7.7) at depth. These zones often exhibited a secondary maxima of soluble salt concentration. Data concerning the annual salt cycle in the soil profiles is presently being refined and will be reported on at a later date.

Tables I and II present the soil morphologies of two typical Ahumisols from the coastal oases of Enderby Land. Figures 1 and 2 depict the moisture dynamics at these sites, determined weekly throughout the 1967-68 polar summer and at intermittent times in the 1967 winter. Moisture was determined gravimetrically at 105°C. The term *free drainage* refers to measurements made when the underlying layer (usually a 5 cm. thickness) was not frozen or above saturation; conversely, the term *impeded drainage* refers to measurements made when the underlying layer was either frozen or above saturation. The *impeded drainage* state corresponds to the initial spring melt of the zone. For comparison purposes the soil moisture contents at the time of freeze-up in 1968 (mid-February) are indicated.

Regosolic conditions in Enderby Land are restricted to youthful land forms and unstable soil materials such as deltas, aeolian deposits, moraines, fine-grained talus, outwashes, beaches, terraces, and materials on solifluction slopes. The colors of the soil materials show little change from that of parent material. No horizon differentiation exists within the profile. Cutans, grain coatings, grain bridgings, and other structural elements are uniformly absent. Reaction is variable from acid to alkaline. Particle size distributions are dominated by the coarser fractions, resulting in a low moisture holding capacity. The aridity limits the expression of the soil-formational processes.

Figure 3 is a plot of weekly average soil temperatures at selected depths, as calculated from the author's microclimatic study. Soil temperatures for each layer were determined by thermocouple instrumentation. Recording was visual on an 8 times per day, every 3 hour, basis, from a remote transistorized amplifying tele-thermo-

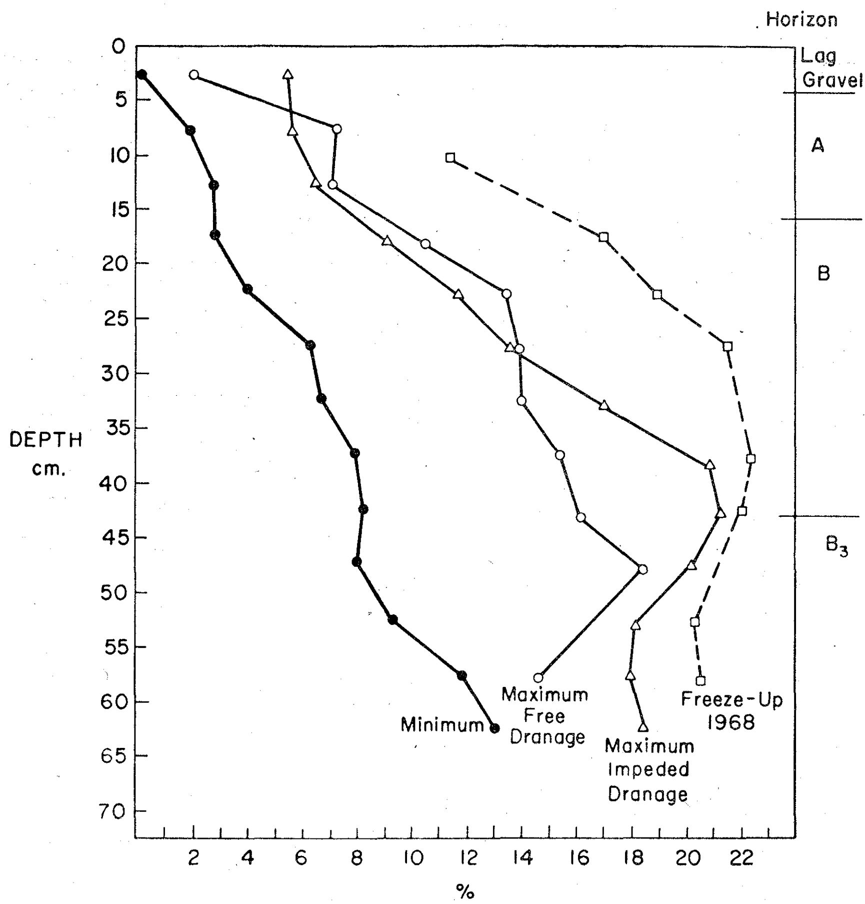

Fig. 2. Moisture dynamics, Brown Ahumisol. Molodezhnaya, Antarctica; 1967-68

meter. The length of the thawed period, of course, decreases with depth, but is considerably greater than that of the 'dry valley' region of Victoria Land.

DISCUSSION

The lack of appreciable soluble salt concentrations, the slightly acid reactions, the moisture dynamics within the soil profile, the degree of profile development, and the type and distribution of void space within the profile are all criteria by which the soils of the Enderby Land coastal oases differ from those of the ice-free areas

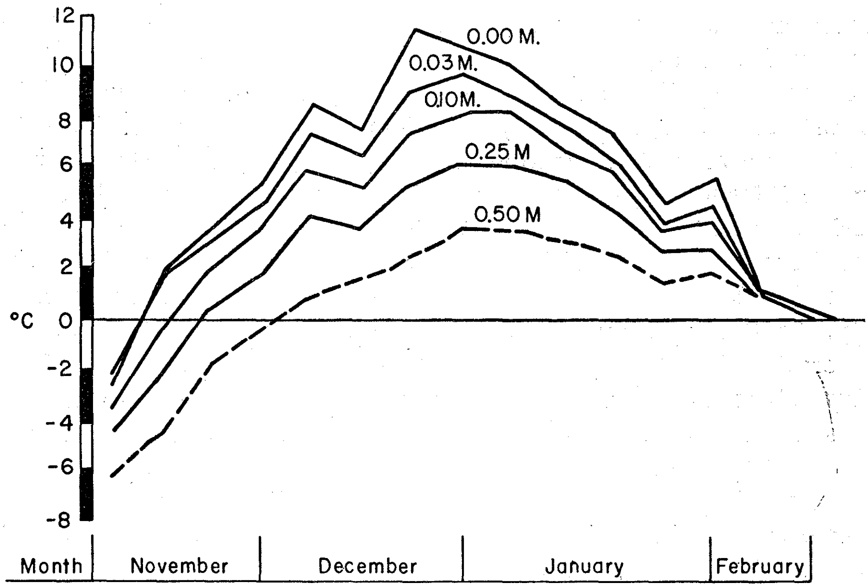

Fig. 3. Average soil temperatures at indicated depths, 1967-68. Molodezhnaya. Antarctica

of Victoria Land. At this stage of investigation it seems that all of the soil divergencies from modal concepts developed in other sectors of the continent can be explained by the differences in the macro- and microclimates of the two areas, or more specifically, by the microenvironment of weathering created within the soil materials. The concordance of active layer thickness and manifestation of pedogenetic processes shows that soil development is not paleoclimatic, but is a present day process.

The coarseness of the surface mantle, a lag gravel that at times approaches a desert pavement, is mainly the result of eolization of the surface. Minor eluviation may also have occurred, by cryogenic processes as well as by normal processes of water ingress. The present water balance is achieved because of the combination of the mulching effect of the lag gravel and the distribution and properties of the void types within the soil profile. It is probable that the lag gravel must be developed prior to the acceleration of profile differentiation and chemical-mineralogical transformations within the soil volume.

The zone of maximum weathering and finest particle size is characterized by vesicles which are interconnected by microscopic pores. These narrow passages restrict the removal of moisture to higher tension levels than would be expected from pore space volume measurements. The overlying horizons, as well as the surficial lag gravel mantle, have relatively open fabrics with interconnected voids that do not restrict infiltration of water when it is available via melt or the infrequent summer storms. During much of the early spring period, when the B horizons with their higher moisture contents are yet frozen, nightly additions of drifting snow, which melt on the following day, fill the A horizons to above their free drainage capacity. As thaw continues these melt waters descend in the profile, supersaturating the zone immediately above the descending frost. Upwards transport later in the summer is restricted by the narrowness of the connecting pores between vesicles and by the decrease in temperature gradient that is related to the looseness of the upper horizons. A limited amount of capillary movement to the surface does occur in mid- and late summer, but the greatest water removals during this period are in the vapor phase, for soluble salt concentrations do not appreciably change. Because the ascension is weak and for the most part in the vapor phase, the eluviation that occurs during the descension of the supersaturated zone in the spring is non--reversible. This non-reversibility is partially responsible for the finer texture of the B horizon. Weathering proceeds at a faster rate in the moist horizon and is also partially responsible for the increase in the finer size fractions. Cryogenic processes cause particle reorientations and construction of the large smoothed vesicles by release of gases from the freezing liquid and by the volume change associated with the change in state. Apparently, because the cryogenetic processing results in an increase in water holding capacity and the development of the manifestations of the cryogenetic processes are themselves a function of water content, the processes are self-sustaining.

The overall climate of the Enderby Land coast is far more moderate than that of Victoria Land. Table III presents the approximate

Table III

Approximate Mean Monthly Temperatures (°C)

	McMurdo Sound (77°40′S., 166°30′E)	Hallett Station (72°13′S., 170°19′E)	Molodezhnaya (67°40′S., 45°51′E)
January	−4	−2	−1
February	−9	−3	−4
March	−19	−11	−9
April	−21	−17	−11
May	−23	−23	−14
June	−24	−23	−17
July	−27	−27	−19
August	−29	−28	−18
September	−24	−24	−17
October	−20	−20	−15
November	−9	−9	−7
December	−4	−3	−1
Average	−18	−15.5	−11.5

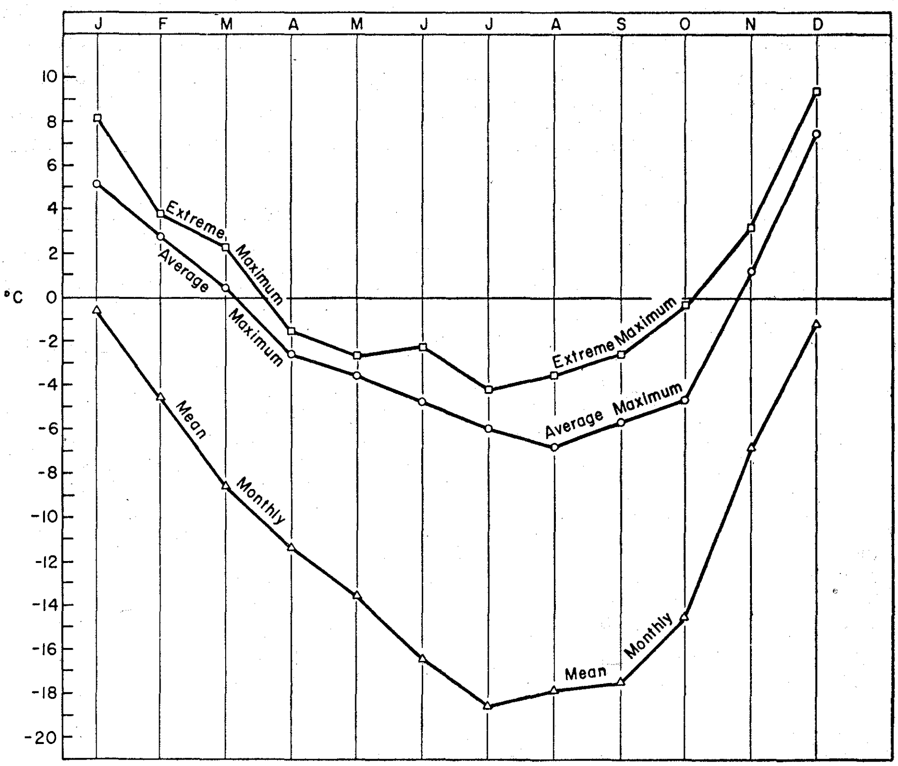

Fig. 4. Monthly air temperatures, Molodezhnaya, Antarctica

mean monthly temperatures of Molodezhnaya, McMurdo, the station nearest the 'dry valleys', and Hallett, a coastal station occupying a latitudinal position between the first two. The significance of latitudinal position is clearly seen. The quantity of solar radiation reaching the soil surface, based on theoretical considerations, is nearly two times larger at Molodezhnaya than in the 'dry valley' region. As all chemical transformations are related to available energy, it is not surprising that soil-formational processes are more active in the more northerly area. Table IV presents other selected climatic data for the coastal oasis in Enderby Land, Molodezhnaya. As can be seen, the calmest periods are in the summer season. Although this is also the period of maximum thermal gradient, the reduction in wind velocity, and hence turbulent transport, reduces evaporation below that suggested from the climatic data. At various times during the summer season the author measured relative and absolute humidities at micro-levels. In all cases the absolute humidity was greater near the soil, but often, especially in mid-day, the relative humidity was less than that at the standard level because of the intense heating of the soil surface. At nights during the summer season, although calms are less frequent at night because of the drainage winds, relative humidity at the micro-level would reach the dew (frost) point and frost would form in the lag gravel and upper 1-2 cm. of the A horizon.

Consideration of the average maximum, extreme maximum, and average air temperatures, figure 4, shows that melting is very rapid at times. Figure 5 shows daily maximum, minimum, and average

Table IV

Mean Monthly Climatic Parameters, Molodezhnaya, Antarctica
(Station Records 1963—1967)

	Windspeed m/sec	Precipitation mm.	Relative Humidity %	Air Temperature °C
January	5.5	13.0	65	−0.6
February	7.3	12.3	60	−4.5
March	12.0	40.1	66	−8.5
April	14.6	88.8	73	−11.4
May	13.7	60.8	70	−13.4
June	13.5	66.4	68	−16.2
July	11.0	57.1	66	−18.6
August	11.2	104.9	68	−17.9
September	9.9	64.7	67	−17.4
October	8.2	46.5	64	−14.5
November	8.0	40.3	64	−6.9
December	6.5	3.7	64	−1.1

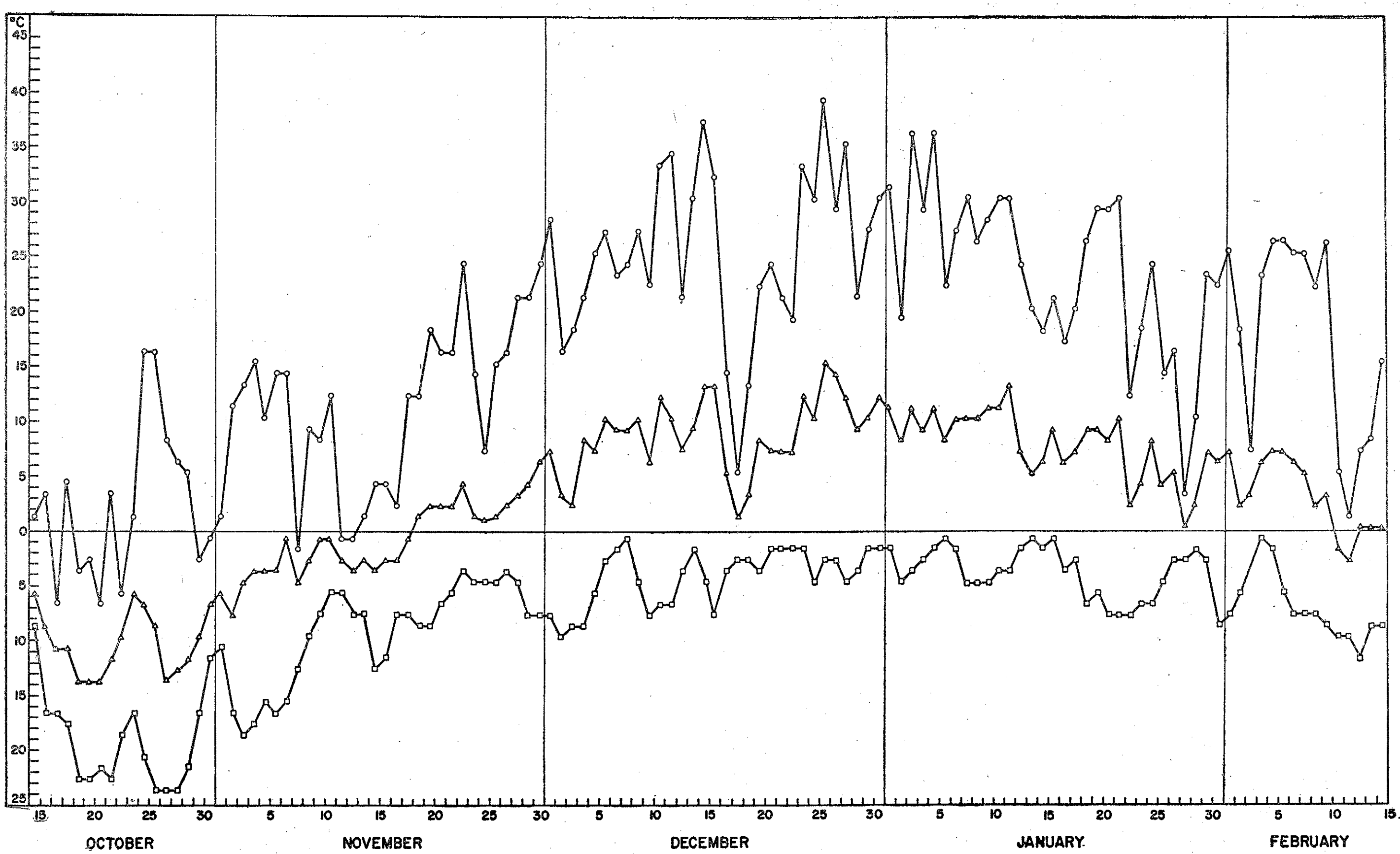

Fig. 5. Daily maximum, average, and minimum soil surface temperatures.
Molodezhnaya. Antarctica, 1967-68

soil surface temperatures for the 1967-68 spring, summer, and fall periods. Generally maximum air temperatures coincide with maximum soil surface temperatures and with periods of calm. It is at these times that maximum summer infiltration occurs because the melting rate far exceeds the evaporation rate. These intermittent recharges of the upper parts of the solum nearly balance the potential withdrawals from the lower parts of the solum and by such compensations create the quasi-stabilized water regime.

Comparative data from the 'dry valley' region, although far less complete, show very low relative humidities during the summer months, and even more importantly, it has been indicated that there is little or no snow accumulation to furnish abundances of melt waters (Ugolini and Bull, 1965). The snow that occurs in the winter months is said to be removed by drifting and sublimation (Mc Craw, 1960, 1967). Wind velocity remains high throughout the year (Tedrow and Ugolini, 1966; Ugolini nad Bull, 1965). The microenvironment of weathering created is much more conducive to pedogenetic processes in the coastal oases of Enderby Land than in the 'dry valley' region of Victoria Land.

During the austral autumn of 1968 a brief study of the soils and soil conditions of the Schirmakher Oasis, Queen Maud Land (vicinity of Novalazuruskaya Station, USSR, 70°46′S; 11°50′E) was conducted. The general climate of the area closely approximates that of the areas investigated in Enderby Land, as shown in Table V.

Soil profile development, however, in the Schirmakher Oasis is nearly non-existent. Undifferentiated soil materials exhibiting alkal-

Table V

Mean Monthly Climatic Parameters, Novalazuruskaya, Antarctica (1962 Data)

	Windspeed m/sec	Relative Humidity %	Air Temperature °C
January	7.2	49	−2.0
February	8.9	50	−2.4
March	9.2	46	−9.1
April	10.0	56	−13.6
May	9.9	62	−13.6
June	13.3	51	−14.4
July	9.4	50	−19.0
August	12.6	58	−16.6
September	11.2	68	−14.9
October	12.4	64	−11.0
November	12.8	54	−5.5
December	8.1	54	−2.7

ine reactions underlie open fabric desert pavements. Soluble salt contents are high with efflorescences present in many sites. No structural elements were recognized. In essence the soil conditions are nearly identical with those described, previously cited, in the interior oases in Victoria Land.

These observations strongly suggest that the Schirmakher Oasis, and possibly the inland oases of Victoria Land, are not only relatively younger but possibly chronologically younger than the coastal oasis near Molodezhnaya in Enderby Land. Detailed studies of mineralogical alteration are planned in order to validate this hypothesis.

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