IV. Micromorphological properties of soils developed under different environmental conditions

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On the micromorphology of soils of the arctic of North Alaska

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The investigation of arctic soils in North Alaska has been made possible to me by an invitation of Dr. John C. F. Tedrow, one of the first international experts on polar soils, for a year of collaboration in the United States of America, and by the hospitality of the Arctic Research Laboratory, Point Barrow, in the summer, 1967. Under the guidance of Dr. Tedrow I was able as a guest investigator to perform excursions in the coastal plains near Point Barrow (71°20′ N., 158° 46′ W.), in the hill region of the outpost Umiat (69° 23′ N., 152° 10′ W.) and on the limestone ridge Crowbill Point near the outpost Cape Thompson (67° N., 166° 30′ W.). The climate of this region is characterized by low temperatures, sparce precipitation and strong winds. Temperatures above 0° occur only during the months of June, July, and August, partly in September. As to the precipitations, the climate could be designated as semihumid, but this effects soil formation only in areas with good drainage and corresponding deep lying frozen horizon. The very wet tundra plains are dominated by semi-terrestric soils. Since during the summer months the soils stay frozen below 20-50 cm depth, the rain and melting waters become stagnated and partly accumulate above the soil surfaces. This results in a general tendency to gley, pseudogley, and vast tundra peat formations. The humidity of the air in summer raises to mediums of 80 and 85% and may attain values of 95%.

General landscape views of the investigated area with one of the tundra peat profile near Point Barrow are shown in Plate 1.

Polar soils show in many cases a striking micromorphology. I intend with this contribution primarily to demonstrate that by showing the details with the aid of color slides prepared from soil thin sections, since it is very difficult to bring them by mere descriptions. Therefore in this publication only the main items can be brought in the text.

Like in general so also with polar soils micromorphology shows a great variety. However, the variety of forms shows a definite order, since it changes between definite poles of development. They are once closer

1. Aerial view of the patterned peat tundra of the coastal area near Point Barrow, summer aspect. The polygons vary in diameter of about 3 to 12 m. The frost cracks and the smaller depressions are in summer water-filled. The cracks have a diameter of about 30 cm.

2. Profile of a tundra peat near Point Barrow. The peat layer, in the first place colo-

once further away from these but show all intermediate stages in the direction to them. Therefore, we cannot confine ourselves with our investigations to arbitrary profiles or samples, we have to search for the poles (or the types in the sense of biologic morphology) and determine the position of our examples between them. This is the reason for my demonstrating here, not only soils taken from North Alaska but also from other parts of the Artic and Antarctic. The possibility for this was greatly given to me by the permission to investigate soils of other colleagues taken during their excursions, primarily to use the rich collection of J. C. F. Tedrow at Rutgers University for this purpose.

TERRESTRIC SOIL DEVELOPMENT ON LIMESTONE

In regard to terrestric soil development the most striking differences in micromorphology occur on hard limestone. On the limestone ridge Crowbill Point near the outpost Cape Thompson soil development on hard Lisburn limestone of the Upper Missisipian resembles in its initial stages those of the Proto-Rendzinas and Pitch-Rendzinas of the northern limestone Alps. Beginning with blackish cushion formations finally more or less continuous deeply blackish soil covers of greater thickness mainly under dense soils of *Dryas octopetala* are formed. However, the great contrast between arctic and alpine Rendzinas becomes surprisingly evident by the thin section analysis. While the alpine Proto-Rendzina represents a loose mixture of plant residues, blackish colored, and well humified animal droppings and fragments of clastic calcite, the arctic Proto-Rendzinas shows in spite of the high calcite content dazzling red to bright yellow (only in thick layers blackish-colored) nonhumified plant remnants, containing high amounts of red lignin derivates of unknown composition and red phlobaphenes. All this characterizes high dystrophic conditions and scarce development of bacterial and animal life. But even

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nized and formed by *Eriophorum scheuchzeri* and *Carex aquatilis* is in summer ice-free down to a depth of 20-50 cm. The frozen tjäle layer is visible by is greater density and its lighter color in the lower half of the picture. Also the upper part of the tjäle layer consists of peat and may reach down to a depth of 80 cm. It is underlain by gley horizons produced from silty to fine sandy sediments of the Pleistocene Gubik formation.

3. Nonsorted Patterned Frost Boil Soil. Foot of the Red Hill, Umiat region. The soil is formed from a calcareous bentonite clay of Createous origin. In the upper part of the picture between the colonized frost cracks polygons are formed, and stripes in the lower slope.

4. Magnified section from the center of the picture No. 3. The frost boils are free from vegetation, the frost cracks are colonized by *Arctostaphylos alpina, Betula glandulosa, Empetrum nigrum* and *Vaccinium vitis idea.* Under the plant cover a humus layer of dystrophic moder is formed. The tjäle layer in summer is reached in about 70 cm.

Descriptions of colour photographs

Left Row:

1. *Alpine Proto-Rendzina,* Kalbling, northern Limestone Alps. Completely loose mixture of undecomposed plant residues, blackish droppings of small arthropodes and clastic calcite grains.

2. *Arctic Proto-Rendzina* on Lisburne Limestone, Crowbill Point, Cape Thompson, Northern Alaska. As in No. 1 a mixture of undecomposed plant residues, droppings of animals and clastic calcite grains. However, the blackish color of the organic constituents, observed with naked eye, changes in the thin section only in thick-layers to a blackish dark red, but becomes in thin layers bright red and in very thin layers to bright yellow, produced by undecomposed phlobaphenes or red colored lignin derivates. The contrast against the alpine Proto-Rendzina of No. 1 is primarily given by the highly developed dystrophic character and the lower degree of humification of this soil.

3. *Alpine Pitch-Rendzina,* Dachstein, northern Limestone Alps. This humusform is developed from stages corresponding to the character of No. 1. With advanced development the content of animal droppings of blackish color is much increased while the undecomposed plant remnants have almost completely disappeared. The same happened to the calcite grains which had been removed by the very active solution weathering. Some grains left show rounded forms with removed corners and edges. All constituents form a coherent fabric which produces shrinking cracks by decreasing water content. In wet state the soil mass shows a pitch-like appearence.

4. *Arctic Rendzina.* Crowbill Point, Northern Alaska. This soil gives macroscopically the impression of a blackish Pitch-Rendzina with dense fabric and a thicker humus horizon (up to 20 cm). However in the thin section it shows the same dystrophic character and low degree of humification like the humus form of No. 2. The undecomposed plant residues become even more visible. The fragments of calcite show almost no signs of solution weathering.

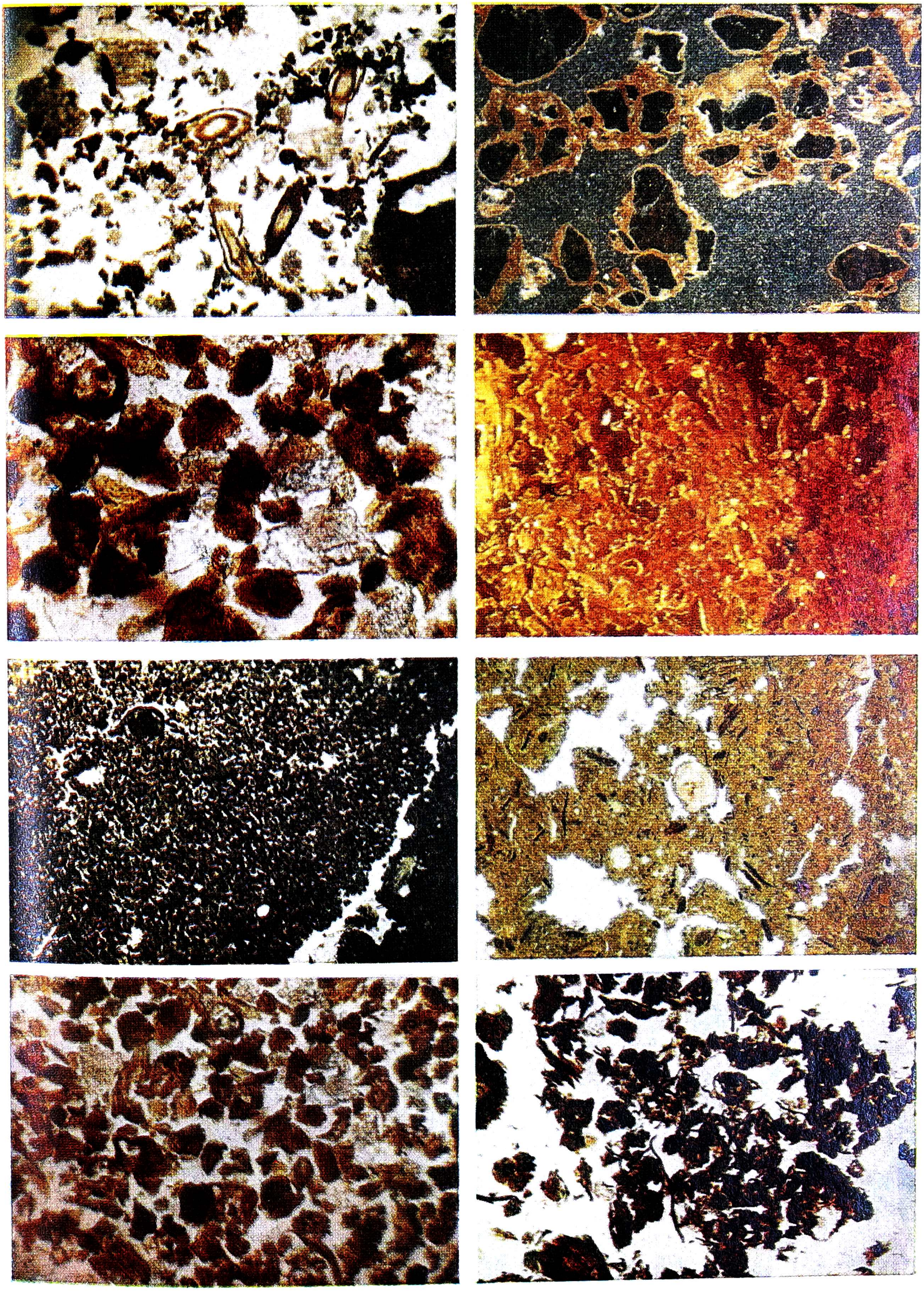
Right Row:

5. *Coated Råmark* (polar desert soil with mud coatings), Inglefield Land, Northwest Greenland. The coatings are formed by muddy melt water. Seen with incident light they are originally yellow in color and change to red by pseudogleyization.

6. *Eriophorum-Tundra-Peat,* Barrow, Northern Alaska. The plant remnants are coated after penetration of muddy melt water into the peat layer. This indicates that the coatings are not produced by the weathering of some mineral grains in situ but have been transported and deposited by the muddy melt water in spring time. The originally yellow color of the mud deposits (see left margin of the picture) is changed into red by pseudogleyization.

7. *Patterned Frost Boil Soil,* Red Hill, Umiat, Northern Alaska. The frost boils, which show no vegetation, are parts of a patterned soil and occur between frost cracks, which are overgrown by dwarf shrubs. The parent material of the soil are Createous montmorillonitic sediments of the Seabec Formation showing braunlehm fabric. In the frost boils the braunlehm fabric is completely preserved, while in arctic Braunerde the micromorphology gets transformed into braunerde fabric. This is produced because the freezing in the frost boils is at the same time a kind of drying. The water is moved to the frost cracks and is concentrated there during the winter in the form of ice which melts during the summer period. The frost boils also during the summer show little humidity.

8. *Patterned Frost Boil Soil of No. 7, Humus formation of the Frost Cracks.* While the dry frost boils are completely free of vegetation, the surrounding cracks, which get all humidity during the winter period, have in summer not only a dense growth



the more developed arctic Pitch-Rendzinas show a similar dystrophic character and the almost complete absence of humic substances, domination of red phlobaphenes and red lignin derivates, a high developed fungas flora with brown colored myceliae and the complete lack of the well humified animal droppings of the alpine Pitch-Rendzinas. The comparative investigations indicated that the dystrophic character is primarily due to the great differences in the climatic conditions. However, if we compare the monthly mean temperatures of the air of Cape Lisburn and the Alpine weather station Hafelekar (2,262 m) of the Austrian Limestone Alps we obtain the following data during the course of the year (in centigrades).

Cape	Jan.	Febr.	March.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Lisburn	-19.7	-23.8	-20.8	-11.9	-2.8	3.4	6.9	6.6	2.9	-4.2	-14.7	-21.8
Hafelekar	-8.0	-7.4	-5.7	-2.5	1.8	4.7	7.0	7.2	5.1	0.9	-3.4	-9.9

We see that the winter temperatures at the arctic station are considerably lower, like −23.8° in February against −7.4° in the alpine station, but during the decisive summer month of June, July and August the mean temperatures are almost the same. However, during our field work at Crowbill Point in the August sun we and our attending eskimo boy kept our winter clothes and our gloves while my students during our excursion in the alpine altitudes went with shorts and open shirts with tucked-up sleeves. We know that the great difference is produced by the high radiation intensity of the sun in the Alps. In addition to the high radiation intensity of the sun, the early breaking-in of the arctic winter seems to be of importance. While in the arctic with the beginning of September a continuation of our field work became impossible because of the early snowfall, our excursions in the alps in sunny periods had been agreeable even in November when the mean temperature in Cape Lisburn reached −14.7°.

The dystrophic character is even more pronounced in the rendzinas of the mountains near the Anaktuvuk Pass (altitude 1400 m) of the Brook Range of North Alaska (collected by Dr. Tedrow). Here the prevailing element of the red phlobaphenes and red lignin-deviates of the dwarf shrub vegetation are absent, the remaining have only the completely undecomposed remnants of *Cariaceae*, highly interspersed by deep brown myceltiae, dense root mantles, and numerous sclerotiae of fungi. Droppings of arthropodes are completely absent. Thus it seems that rigoreous climates are more effective in polar soil development on hard limestone rocks than on silicate rocks.

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of dwarf shrubs, but show underneath a humus layer of well developed moder. Although of dystrophic character, indicated by the reddish plant remnants and the abundant growth of brown colored fungus mycelium, the humus formation is more intense than in the case of the humus layers on limestone of No. 2 and 4.

POLYGENETIC DEVELOPMENT OF TERRESTRIAL SOILS ON SILICATE ROCKS

With silicate rocks the dystrophy was clearly less pronounced but still noticeable. It is of particular importance that the soil formation shows predominantly polygenetic character. The influence of secondary parent materials on the soil is therefore almost throughout deciding in the area, particularly with the soils of higher development stages, as belonging to the climax formation of arctic Braunerde (Arctic Brown J. C. F. Tedrow). In Petsamo, on the arctic coast of Northern Europe, where remnants of former soils were lacking, I found on unweathered Plutonics and Metamorphics only Dystrophic Ranker.

Also the semiterrestric mineral soils or soil horizons which in addition to the abundant arctic peat formations dominate in the arctic coastal plains of North Alaska show this great influence of weathering residues of former geological periods. This fact influenced already greatly the micromorphology of the polar raw soils (polar Råmark). The enormous masses of melting snow water, which in spring stream, loaded with sand and silt masses, cover the land surfaces and accumulate greatly in certain areas of the polar deserts, may contain great amounts of these highly decomposed fine constituents of former soils and become highly muddy by this. When evaporating, the mud content of these waters accumulates in the form of dense coatings around the mineral grains of the soils. We obtain by this process in the polar desert two different kinds of polar raw soils, the Noncoated and the Coated Polar Råmark; i.e., the raw soil characterized by mineral grains with mud coatings. These coatings are dark brown in the thin section when investigated with transmitted light, but might be yellowish when seen with vertical light, or may have more frequently bright red colors, as a result of intensive pseudogleyization. The coatings are originally dense, showing smooth surfaces. But under the influence of the polar climate they become loose and earthy and finally are separated from the grain surfaces and are found as completely loose material in the intergranular spaces. Both forms of raw soils; i.e., also the coated one, show frequently almost no chemical weathering in their sand skeleton. That the material of the coatings derives from the mud contained in the melting snow waters and not from the decomposition of the soil itself can be seen from the frequent coatings produced on the surface of the plant residues in flooded peat areas. Also these coatings show considerable pseudogleyization and appear, as a rule, bright red colored when investigated with vertical light. In the plains outside the polar desert regions we find a variety of arctic or polar Braunerde (Arctic Brown) which shows a similar fabric in the (B) horizon as a coated Råmark but somewhat transformed by flocculation and earthening of the coating. This variety of Arctic Braunerde developed from gley or Pseudogley on soil sediments of general originally braunlehm character.

The above cited variety of the Arctic Braunerde is different in its micromorphology from the variety formed directly from the parent material as it can be found in the hills of Umiat. The Umiat variety (Arctic Brown shallow phase after Hill and Tedrow) consists of typical braunerde aggregates formed directly from calcarious clay schists of cretaceous origin. But this soil is also of polygenetic nature since the parent material has to a great deal braunlehm character.

The investigated areas of Northern Alaska Lack parent materials of hard silicate rocks which are fresh enough to be able to develop monogenetic terrestrial AC-soils like the rendzinas on hard limestone. This is a very characteristic feature. On the coast of the Arctic Sea of northern Europe in the district of Petsamo about 70° N., which I could visit in 1939, as parent rocks prevailed unweathered gneis varieties. Here I found only AC-soils mostly dystrophic tundra-Rankers under dense plant covers of dwarf shrubs, in the first place of *Empetrum nigrum* and *Loiseleuria procumbens.*

A considerably higher influence of dwarf shrubs on the terrestrial humus formation could be observed on the hills of Umiat in northern Alaska (69° 23′ N.) mainly from covers of *Arctostaphylos alpina, Empetrum nigrum* and *Betula glandulosa.* Here the mean precipations have been only 152 mm, the mean monthly temperature during the summer months reached here 9°. The highest hill, the Mount Umiat, has an altitude of 280 m. Primarily arctic Braunerde could be found in altitudes from 100 to 180 m.

In addition to the arctic Braunerde a number of other soils of lower grades of development are typical for this hill area. On a mountain ridge open to strong winds in an altitude of 100 m, below the summit of Red Hill, a large plain completely free of vegetation can be found. In the surface soil aggregates smaller than millimeter size are formed. With depth the density of the grey colored soil is increasing. The soil surface is covered by flat stones frozen out of the interior soil like the desert pavement of some polar Råmark varieties. The stones are predominantely chalky clay shales which, like the whole soil mass, a clayey sediment containing montmorillonite as the leading clay mineral, are of *Cretaceous* age. The platy stones on the soil surface show crusts of travertine on their bottom side similar to those Dr. Tedrow found on arctic desert soils in northern Greenland, in Alaska more impregnated by mud and allochthonous minerals.

According to its micromorphology this soil represents a Gley variety but the gley character is already inherited from the *Cretaceous* clay (bentonite) sediment. The present soil condition could not change the Gley character. Since as a result of heavy frost-action no plant cover and no humus horizon was formed on the soil surface, it represent a Raw Gley; considering its particular genesis and morphology it can be called a Non-

Patterned Frost-Gley. The aggregate formation in the surface layer is partly produced by frost-action, but partly also by animal activity during the arctic summer, consisting of animal droppings (evidently *enchytreae*) combined to a slightly coherent sponge fabric. The same sponge fabric of animal droppings can be observed in the micromorphology of the frost boils of the following patterened soil of the same region. This soil, which we call a *Patterened Frost-Boil Soil,* can be found at the foot of the Red Hill in the Umiat region. Its development is also closely influenced by its parent material, the same chalky bentonite clay of Cretaceous origin, but here without interspersion of hard calcareous clay shales. The boils produced in it by frost action are therefore not surrounded by stone rings, but of stone-free frost-clefts which are colonized by a dense vegetation of dwarf shrubs, primarily of *Arctostaphylos alpina, Betula glandulosa, Vaccinium vitis idea* and *Ledum palustre.* The vegetation forms a humus layer of a well developed but more or less dystrophic moder. The profile corresponds thus to a Proto-Ranker. The boils surrounded by these clefts, have a diameter of about 70 cm, are vaulted upwards in its center and completely free of vegetation. They have raw soil character with no humus horizon. Like the Non-Patterened Frost-Gley they show in the upper 25 cm a well developed aggregate formation. The aggregates are partly produced by frost action (showing angular delimitations) but partly, and much more frequent than in the Frost-Gley, multiformous, knobby to kidney-shaped formed aggregates produced by animal activity, probably of *enchytreae.* They are combined to a coherent spongly fabric and are conspicuously interspersed with fine dark brown coloured plant splinters. These aggregates are not gray in colour but light yellow, produced by peptized ferric hydroxide. Their matrix shows thus a braunlehm-fabric, inherited from the *Cretaceous* parent material.

THE SEMITERRESTRIC SOILS OF THE ARCTIC COASTAL PLAINS

The great impermeability of the soils of the coastal and the adjoining areas to the south results that semiterrestric tundra soils predominate with tjäle layers at 20-50 cm depth. They are interspersed by open water basins and lakes. The latter are mainly colonized by fairly open communities *Dupontia fischeri.* Since this sedge does not form peats subaquatic peats seem to be completely missing. There must be widespread Dy formations on the bottom of the water basins but no samples could be taken for micromorphologic investigations. The great areas of peat formation set in under the influence of the dense plant cover mainly of *Eriophorum scheuchzeri* and *Carex aquatilis* on the marginal areas of the lakes and smaller water basins. The peat covers reach a depth of 20 to 80 cm and are underlain by gley horizons produced from mostly silty to fine sandy sediments of the Pleistocene Gubic formation. In some parts the gley horizons extend to the surface and give rise to the formation of humic gleys (with dystrophic anmoor), dystrophic Ranker and in drier areas the secondary Arctic Brown. The vast tundra peat areas are almost everywhere segmented into polygons of about 10 m in diameter, and separated by ditches to 30-70 cm in width. If the latter are water filled, they might be colonized by *Dupontia Fischeri.* If the peats get to dryer conditions they are transformed in the surface to raw humus or coarse moder. Under wet conditions they might be transformed to a dystrophic anmoor and greatly colonized by *enchytreae* and a gray form of *colembola.* Since *Sphagnum* species are missing as peat formers in the Point Barrow area a further development to *Sphagnum* peats, as it can be partly observed on the banks of the Colville River near Umiat, does not take place. The transformation of the peats into raw humus and coarse moder is favored by some growth of dwarf shrubs and herbs in the plant cover, primarily of *Arctostaphylos verticillata, Empetrum nigrum, Vaccinium uliginosum, Salix rotundifolia, Draba fladnicensis* and others.

SUMMARY

There have been carried out investigations on Arctic Point Barrow soil of Northern Alaska. Those were rather difficult for the climatic conditions. Such soils on the very wet tundra plains being dominated by semiterrestric ones. The soil being even in summer deeply frozen the precipitation stagnate and accumulate above the soil resulting glay and pseudogley formation. However the Arctic Rendzina soils are of more dystrophic character than the alpine ones. The Alpine Proto-Rendzina represents a picture of loose plant residues, blackish colour and well humified animal droppings and fragments of clastic calcite, the Arctic Proto-Rendzina showing, in spite of high calcite content, dazzling red to bright yellow-humified plant remnants, impregnated by red lignin derivities of unknown composition and red phlobaphenes. The dystrophic character is due to climatic differences, mainly the different arctic sun radiation. Similar dystrophic humus formations can be found on silicate parent material. Even the humus horizon of the Arctic Braunerde of Northern Alaska show scarcely humified moderforms. On the Point Barrow peats no more peat varieties were found, only on semi-terrestric were cottongrass sedge peats developed under *Eriophorum scheucheri.* Sand grains show the typical polar mud coatings. In some hilly regions on *Cretaceous* sediments a.o. frostboil-polygon soils were observed.