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Ground Patterns as Keys to Photointerpretation of Arctic Terrain

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area, and the normal gentle southwesterly dip of the strata is once again observed.

Conclusion

Faults and folds are not unusual in Iowa geology, but the folds are generally not as steep as those observed in this area, and the rocks are almost always covered with drift and not readily studied.

Ground Patterns as Keys to Photointerpretation of Arctic Terrain

Keith M. Hussey[1]

Abstract. Data based on field observations made during the summers of 1955-61 substantiate the belief that angle of slope is the most significant factor in determining the type of ground pattern which regionally or locally features arctic terrain.

The factors of influence in any arctic terrain ground pattern are texture of regolith, type and thickness of vegetation mat, amount of surface and subsurface water, thickness of active layer, and angle of slope of the ground surface.

The angle of slope and texture of regolith determine surface and subsurface drainage to a large extent, and thus control the water loss from the area. The amount of water in the ground, in turn, plays a large role in determining the type and amount of vegetation that can grow in the area and, hence, the thickness of the vegetation mat. The vegetation mat, in turn, pretty well determines the thickness of the active layer. It is most thick (deep) where the mat is very thin, or absent.

It was determined that equidimensional ground patterns, circular frost scars, hummocks, ice-wedge polygons, and sorted stone nets develop on slopes of less than two degrees. With increase in slope to four degrees, these patterns become elongated, but not aligned nor continuous, i.e.—not stripes. Further increase in slope to six degrees is featured by such linear features as stripes (both sorted and non-sorted), and by development of steps. Steps become much more pronounced on steeper slopes, and solifluction lobes characterize slopes in excess of eight degrees.

Some changes in slope are very common and very local, so that a regional pattern peculiar to a slope of two to four degrees will be modified by a pattern of the locally developed steeper slope.

Once one knows the significance of the different types of ground patterns, he can do an excellent job of determining terrain conditions of an unknown area from good air photos of that area.

Introduction

Anyone who has flown over Arctic Coastal plain terrain, or

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who has studied aerial photos of the area, cannot help but be impressed by the variety of ground patterns expressed by minor relief features. These features – which include polygons, frost scars, steps, stripes, nets, solifluction lobes, tussocks, and ridges—have been very well described and/or explained by a number of well qualified people. The following listed papers are among some of the more recent and/or climatologicallye, more closely associated discussions of these land forms (Black, in manuscript; Hopkins and Sigafoos, 1951; Hopkins, 1954; Muller, 1947; Taber, 1943; Washburn, 1956; Leffingwell, 1915; Troll, 1958; Pewe, 1954)--therefore, no attempt will be made herein to give detailed descriptions of the forms, or to discuss the causes of their origin. Koranda's (Koranda, 1960) unpublished manuscript contains an excellent treatment of plant-slope-soil relationships, as well as some outstanding photos of the Franklin Bluffs area. The reader is referred to Washburn's paper for an excellent bibliography on ground patterns.

Observations made in the Franklin Bluffs and Barrow areas during the summer field seasons of 1956-1961 have served to determine the close relationship between the type of ground pattern and such surface factors as angle of slope, degree of drainage, thickness of vegetative tundra mat, and character of the regolith. Of these, the most effective is angle of slope. The other factors serve to control the range of slope in which a particular pattern will develop. For instance, terracettes (steps) will form on lesser slopes in non-vegetated, or sparsely vegetated, loose gravels than on slopes blanketed by a heavy vegetative mat developed on fine-grained regolith (mantle rock).

The importance of the slope angle lies in its close association with drainage. The Arctic Coastal Plain lies entirely within the zone of continuous permafrost (Pewe, 1954). Therefore, there can be no great downward movement of water. Rain water, water from melting of snow, and thaw of the seasonal frost zone (active layer) must either run off over the surface or near surface (few inches to few feet), or evaporate, or stand on the surface in pools of all sizes (from puddles to large lakes), or remain in the active layer. Angle of slope is the greatest factor in determining the extent of drainage of the surface and active layer. The extent of subsurface drainage, i.e.-the amount of water in the active layer, is one of the controlling factors in determining the type of ground pattern. It plays an important role in controlling, to a large extent, the development of the vegetative mat, both of which are factors in determination of the minor relief ground pattern.

Therefore, since the product of these interrelated factors is the variety of minor relief ground patterns, one should be able to make a fairly accurate estimate of terrain conditions in an unknown area by comparing the ground patterns as revealed on aerial photos with those of a similar area for which properly annotated photos are available.

Statement of the Problem

It is widely recognized that patterned ground landforms are the product of the interaction of a relatively small number of processes, and that the extent to which one of the processes is dominant depends on the factors mentioned in the introduction. The processes are gravity, freezing and thawing of surface and near-surface water, the relative quantity and movement of underground water, and plant growth. It stands to reason that each distinctive type of patterned ground can be produced only by a certain association of factors and processes and, further, that it should be possible to determine terrain conditions from a study of the ground pattern once their significance is understood.

The problem, then, is to select an area in which as wide a variety as possible of patterned ground features, which are peculiar to the region, are well developed to study the association of factors for each pattern; and, to determine the cause and effect relationships. The area selected for the study of patterned ground on the Arctic Coastal Plain of Alaska is that known as the Franklin Bluffs. The site was selected because of the high range of slopes, from near horizontal to almost vertical; the relatively great amount of relief, in excess of three hundred feet; and the variety and range in size of materials in the regolith.

Location and Description of the Area

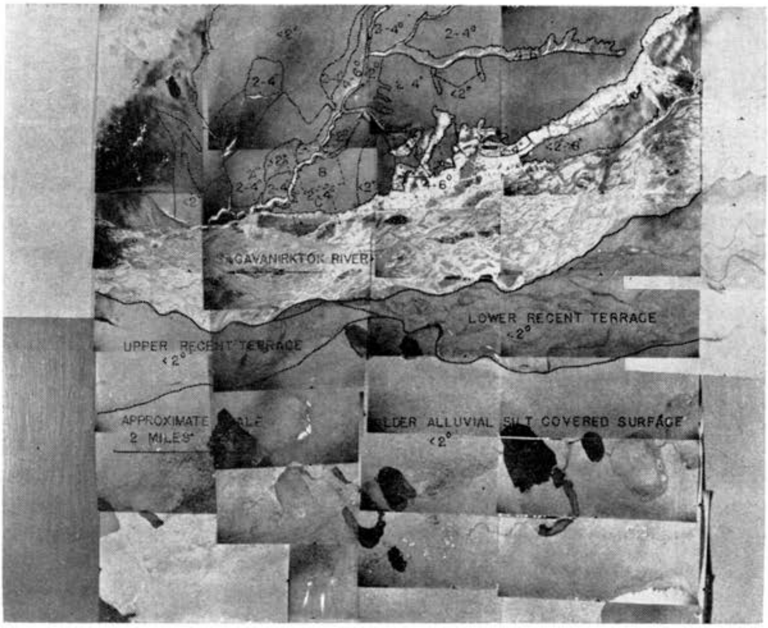
That portion of the Franklin Bluffs area entailed in this study is located immediately east of a stretch of the highly braided Sagavanirktok River, which extends for about four miles north from the USGA Bruce Benchmark (latitude 69° 45' N, longitude 148° 38' W). In this portion of its course, the river is against the eastern side of its broad valley. The valley wall is featured by a highly dissected scarp, ranging up to better than two hundred feet in height. Deep ravines have been cut into the scarp by meltwater streams, and by thaw of ice-wedges and other ground ice. The streams have formed alluvial fans along the base of the bluffs, which show all stages of development, and reveal the fact that the river has shifted to, and away from, the bluffs' base several times in the recent past. The material exposed in the bluffs' face is that of the Sagavanirktok formation. The formation dips to the north and east. Therefore, the more southern bluffs expose lower Sagavanirktok lignitic silts, which outcrop along the base of the bluffs. In the same area, the sand section, middle of the formation, is buried by mass movement. This sand section is well exposed in the lower part of the bluffs, about midway along their length. The northern one-third of these bluffs is underlain primarily by interbedded gravels and sands. The upland area, east of the bluffs, is regionally a surface of relatively low relief. Locally, along the drainage-ways, slopes are steep. Much of the upland surface is underlain by a thick vegetation mat consisting of mosses, grasses, and some variety of other small plants (Dryas, Cassiope, lichens, willows, are common). Locally, the mat is thin. There are many frost scars where the mat has been split and the soil surface is bare. The wind has scoured away the fine particles in many of the scars, leaving a cover of small pebbles, which resembles a desert pavement.

Types of Patterned Ground in the Area

The types of patterned ground found in the area are those produced by the interplay of cryostatic, colluvial, and alluvial processes on the variety of slopes extant, with the differing types of vegetative cover and the variation of materials in the regolith. There are circular, irregularly-shaped, and linear frost scars; sorted and non-sorted nets, garlands, stripes, and steps (terracettes); features emphasized by vegetative growth, such as the cotton-grass tussocks and the ridges around some frost scars; vegetated and non-vegetated steps (terracettes) and stripes, solifluction lobes, irregular (mixed pattern) surfaces, and frozen ground polygons (Washburn, 1956).

Factors in Control of Ground Pattern

A study of the photos (Plates I and II) will reveal that similar types of ground patterns are found in areas having similar ranges in slope. Also, that there is some variety of pattern found within each slope range. Therefore, slope is not the only factor in control of the ground pattern. It is undoubtedly the most important factor, however, because of the extent to which it controls drainage and its close tie-in with the work of gravity. Next to slope angle, drainage is probably the most important factor in control of ground patterns. The degree of drainage is reflected in the type of vegetation, the thickness of the vegetative mat, and the amount of water in the regolith available as an aid to downslope movement. The physical nature of the regolith, i.e.—particle size and degree of sorting, also plays an important role in determining its relative permeability and hence controls its viscosity. A highly permeable material will not accumulate water to any extent, so will not be as easy to move on a given slope as a less permeable material. Gravels, for instance, will not "flow" down a slope of as low an agle as will very fine sand or silt. Particle size of the regolith, and type and thickness of the



The area to the west of the Sagavanirktok River (bottom of the photo) is all very flat and very poorly drained. On the "older alluvial silt-covered surface", the ground pattern of ice-wedge polygons is almost completely masked by cotton-grass tussocks and circular frost scars. The two terraces show excellent examples of the ice-wedge polygons. The lower one is about seven feet above low-river-stage, and should possibly more properly be called "floodplain" as it is subject to being flooded by extreme high water. The higher terrace is about sixteen feet above low-river-stage, and shows little trace of old channel scars. All three surfaces are covered by a layer of silt several feet thick.

The bluffs, which show up white on the photo, are developed in the upper (gravel) member of the Sagavanirktok (Tertiary) formation. Toward the southern end, where the bluffs are made up of two scarps separated by a broad solifluction slope ($< 2°$ to $> 8°$), the upper (eastern) unit rises to 510 feet below low-river-stage. The bluffs are featured by sorted stone stripes, solifluction steps and lobes. None of these features show up on the small-scale mosaic.

The upland, lying to the east of the bluffs (top of the photo), has enough variation in slope to be featured by some variation in ground pattern. It thus serves to illustrate the effect of slope on ground pattern. Only the more gross slopes have been outlined, because only their patterns show up on the small-scale photo.

vegetation mat also are of importance in determining the thickness of the active layer, i.e.—depth to permafrost. It will be thickest in gravels, considerably thinner in fine sands and silts, and thinnest under a heavy, peaty vegetation mat. The range in thickness for a given day in late summer was: over four feet in coarse gravel; just under two feet in a mixture of small gravel (in minor amounts), and fine sand and silt; and only eight inches under a heavy moss-peat mat (the vegetative mat was thicker than the active layer). When the permafrost table is close to the surface, or if its surface is very uneven, drainage will be inhibited and thus effect the ground pattern of that area. The intertwining of the fibers, roots and stems which make up the vegetative mat, give it sufficient strength to resist gravitative pull downslope until the stress becomes great enough to rupture the

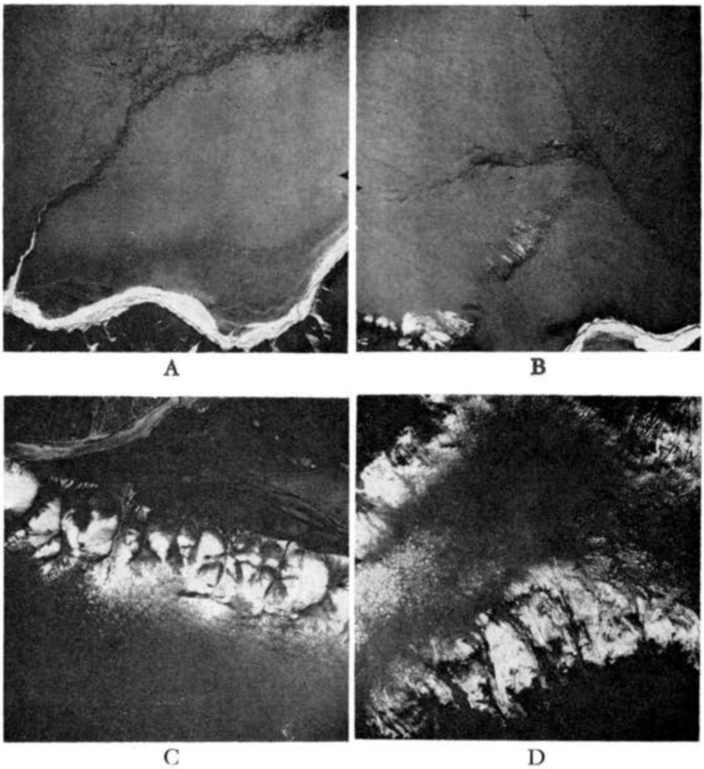


FIGURE A

This is an excellent photo to illustrate the effect of slight changes in slope on the ground pattern. Adjacent to Hawk Creek, bottom of photo, are two terrace remnants; to the east of these, the slope rises at about 3° and the ground pattern is somewhat linear. Where the pronounced linear pattern extends across the photo, the slope increases to between 4° – 6°. Still further east, the slope decreases to about 2° and the surface is featured by cotton-grass tussocks and circular frost scars. On to the east, the surface slopes down to the area featured by ice-wedge polygons where the slope is less than on degree.

FIGURE B

The slope of the area covered by this photo is generally between 2°–4°. However, each local variation can be detected by the local change in ground pattern. This is strikingly shown by the pattern on the solifluction lobes, and that above and below the lobes, as compared with that in the southwest quadrant of the photo.

FIGURE C

This photo shows the excellent alluvial fan development along the base of the bluffs, the sorted stone stripe pattern on the bluff face, the very excellent development of stone steps on the bluff shoulder and the gradational change to a random pattern of frost scars on the less than 2° slope of the upland.

FIGURE D

A close study of this photo will find most of the features associated with a gravelly-sandy-silty regolith where the slopes vary from less than two degrees to over twelve degrees. The "fingerprint pattern" just to the east (above, on the photo) of the north-pointing area, is developed on a rounded knob with a slope of about two degrees. The slope decreases *all* around the knob (site of USGS Greta Benchmark) and it is featured by a random pattern of well-developed frost scars in a fairly thick vegetation mat. The slopes in the obviously bare gravel (very light) areas range from as little as four degrees to better than twelve. On the more gentle slopes, the linear pattern of sorted stone stripes is most strikingly developed. On slopes between six and ten degrees, the linear pattern is broken by rather large steps. The treads, some covered by a heavy vegetation mat, are several tens of feet wide and some have pools of water on them. The risers are as much as six feet high with the typical solifluction-produced, arcuate down-slope form (north-central part of photo). In this area, as in the others, change in slope is most directly responsible for change in ground pattern.

mat. Therefore, the thickness of the mat also effects the local ground pattern, in that the thicker mat with its included regolith will rupture only on fairly steep slopes, greater than 12°; whereas, the thin mats will rupture on much lesser slopes, four to six degrees. Some ground patterns are produced by rupture of the vegetation mat by cryostatic pressures. This produces frost scars, which frequently are "healed" by the movement of fine-grained materials into the rupture during the freeze-thaw cycles (Hopkins and Sigafoos). Many of the resultant scars are composed of bare, fine "soil", some of a scattering of gravel in a matrix of fines, others are "paved" with gravel as a result of wind scouring the "fines" away, still others were obviously bare, fine soil in the past and are now completely revegetated.

Solifluction lobes occur on slopes in excess of 6°, if the vegetation mat is sufficiently thick and strong to resist rupture. If not, then some variety of stripe or step, or combination of the two, will form. A solifluction feature, somewhat similar to the terracette, or step, in that it develops approximately perpendicular to the direction of slope, forms on well-vegetated, very poorly drained slopes of 2° to 4°. They are ridges which range from a few inches to nearly two feet high. They are subparallel, frequently zig-zag, spaced from a few feet to several yards apart. Some are continuous for over a quarter of a mile.

Relationship of Slope to Ground Pattern

Inasmuch as slope seems to be the most critical factor in determining the type of ground pattern found in any given area, either through its effect on drainage, and thus on vegetation, or its effect on distribution of effective gravitational stress, it was decided to map the slope angles of the area in as much detail as was practical. It was found that the relationship of slope to ground pattern was so fine that many local patterns, too small to be shown on small-scale photos, were quite obvious in the field. Therefore, it was decided that only the more regional slopes would be indicated on the small-scale mosaic (Plate I), and the smaller areas illustrated by low altitude (large scale) photos (Plate II, figs. A-D).

It can be noted on the small-scale mosaic (Plate I) that the slopes of less than two degrees show little, if any, pattern. This is also true on the large-scale photos in poorly-drained areas where cottongrass tussocks mask the ground pattern. Where the pattern is visible on the photos, it consists of an equidimensional pattern of round frost scars (boils) or ice-wedge polygons. In areas of fine-grained, poorly-drained regolith, the polygons are non-sorted and appear relatively dark on the photos. If the regolith is gravelly and relatively well-drained, the polygons are of the sorted variety, and show up light on the photos.

The small-scale photos (Plate I) show some type of linear pattern where the slopes range between two and four degrees. In areas where the regolith is fine-grained to somewhat gravelly, rather poorly-drained, and with a loose vegetation mat of not more than four to six inches, the pattern ranges from randomly scattered, slightly elongated frost scars, through more elongated and somewhat aligned but discontinuous frost scars, to those that are elongated, interconnected into continuous, bare soil, non-sorted stripes which show up relatively dark on the photos. If the regolith is quite gravelly and well-drained, the same sequence occurs. However, here it consists of sorted polygons, sorted garlands, and sorted stone stripes; and it is modified by the development of steps (terracettes) which form at right-angles to the stripes. Locally, along the shoulder of the bluffs, where subsidence has accompanied removal of ground ice by deep thaw of the gravels, steps (terracettes) have developed. This pattern shows up very well in area C (Plate II, fig. C). On rounded, gravelly ridges or knobs, with two to four degree slopes, a somewhat reticulate pattern is found. It is comprised of a combination of sorted stripes and steps, giving rise to what is herein termed a fingerprint pattern (Plate II, fig. D.) Solifluction ridges also develop on slopes of this magnitude where the vegetation mat is tight and more than eight inches thick, and the regolith is fine-grained to gravelly and poorly drained. They form at right-angles to the direction of slope, and appear as sinuous to zig-zag ridges from a few inches to more than two feet high. These features show up very faintly in area B on the mosaic (Plate I), but are quite striking in other places on the Arctic Coastal Plain.

The features on slopes of four to six degrees are pronouncedly linear. Where the regolith is fine-grained to somewhat gravelly, and the vegetation mat is only a few inches thick, the stripes are non-sorted. Their appearance on the photos is due to the difference in type of plant that grows on the ridges, as compared with that which grows in the troughs. Even though the relief between ridge and trough is only a few inches, the difference in moisture content sets up a difference in micro-environment and, hence, a difference in types of plants (Koranda, 1960). Where the regolith is composed of gravel, the stripes are sorted and show up very strikingly on the air photos. The gravel stripes are very light, and the vegetation stripes quite dark. The sorted stripes are commonly modified by steps (terracettes) which produce an interference pattern (Plate II, fig. D).

The slopes in excess of six degrees are featured by steps with arcuate (downslope) "risers" and solifluction lobes in areas where the regolith is fine-grained to gravelly, and the vegetation mat is tight and in excess of eight inches thick. The uneven surface is poorly drained, and frequently has pools of water on the "treads". Where the regolith is composed of gravel, sorted stone stripes are outstandingly developed. These features do not show up very well on the mosaic, but are quite striking on the large-scale photos of areas B and D (Plate II, figs. B, D).

Conclusion

The generally flat, regionally undulate, locally uneven surface of the Arctic Coastal Plain is featured by cold climate ground patterns which are associated with specific terrain conditions. These patterns are produced by the varying reaction of the regolith to the processes of gravity, freeze-thaw, and movement of water on and beneath the surface. The factors which control the reaction are: depth to permafrost, angle of slope, degree of drainage, thickness of the vegetation mat, and the character of the regolith. Since the controlling factors are all observable and capable of being measured, it is possible to determine their relative importance in the total picture. Field observations have established that changing angle of slope is more closely associated with change in ground pattern than any of the other factors. Once the relationship between ground patterns and controlling factors is understood, one can determine the terrain conditions of an unknown area from a study of the ground patterns observable on aerial photos of the area.

The Arctic Coastal Plain lies within the zone of continuous perma-frost and, therefore, is characteristically poorly-drained. However, lack of any ground pattern, or a random pattern of circular frost scars, or a pattern of low-centered ice-wedge polygons are indicative of particularly poorly-drained, relatively slopeless area; whereas, well-developed linear patterns relatively uninterrupted by a cross-pattern of steps indicative of relatively well-drained, gently-sloping areas. Slopes featured by solifluction lobes, large, arcuate steps, or a combination of stone stripes interrupted by steps, will be quite steep and, because of the thinness of the active layer, are quite apt to be poorly drained.

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Unusual Exposure of Silurian-Devonian Unconformity in Loomis Quarry Near Denver, Iowa[1]

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Abstract. In the Loomis quarry, located in the NW¼ sec. 29 T. 91N., R. 13W., Bremer County, Iowa, there is an unusual exposure of an unconformity between the Silurian and the Devonian sediments.

Several Niagaran hummocks rise approximately 30 feet above the general Silurian level with Devonian sediments (Cedar Valley and Wapsipinicon) desposited against the flanks of the Niagaran remnants.

A basal Wapsipinicon breccia is exposed in this section. Chert from the Silurian forms an important part of the breccia.

INTRODUCTION

A most remarkable exposure of an irregular Silurian surface with Devonian sediments deposited along the eroded flanks can be seen in the Charles Loomis quarry located in the NW¼ sec. 29, T. 91N., R. 13W., Bremer County, Iowa. This quarry is generally known as the Denver Quarry. The location of the quarry and the routes leading to it from either Waverly or Denver are shown in figure 1.

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