sults which can be achieved through photo-interpretation. But, as a Secret Service man, I have a vital interest in another kind of photo-interpretation. Because of the nature of this work, it was with some misgivings that I asked Chief Baughman for permission to demonstrate this technique to you. But the Chief is photographically minded and deeply appreciative of the cooperation which this Service receives from organizations such as yours. I reminded him, too, that the principle involved was lifted bodily from your profession and if the author is present, he will recognize the following:

"To become a good interpreter of camouflaged objects or areas, one should gain familiarity with the practices employed by the camoufleur and tell what tell-tale signs to look for."*

POLYGONAL PATTERNS AND GROUND CONDITIONS FROM AERIAL PHOTOGRAPHS†

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Introduction

IN UTILIZATION of land for agriculture, engineering projects, or other purposes, it is often desirable or necessary to determine whether permafrost is present, whether seasonal frost is destructive, and whether detrimental swelling and shrinking will accompany wetting and drying of the surface. Commonly, published reports and evaluation by aerial photographic interpretation techniques can provide the answers to pertinent questions. The microrelief features, particularly polygons, should not be overlooked as an aid in such interpretative techniques. With a knowledge of them in mind, it may be possible to obtain more complete answers, or to obtain the necessary answers more quickly.

Purposes

The purposes of this paper are (a) to provide geographers with a bibliography of recent or comprehensive literature in which polygons are described and in which their significance in interpretation of their physical environment is appraised, and (b) to emphasize the widespread distribution of these features and their complexity. To emphasize their complexity and to interject a word of caution in their use, 1) the physical environments, multiplicity of forms in different environments, and their origins are pointed out, and 2) results of some recent research on ice-wedge polygons in northern Alaska are used to refute some statements occurring in the literature. The ice-wedge polygons are used as an example even though considered less complex than many other types. However, the differences of opinion prevalent in the literature about their origin and significance are typical. As polygons are easily recognized and their physical descriptions are recorded in the literature, only their origin and significance are treated.

Definitions

A polygon is defined in Webster's New International Dictionary as: "Geom. A figure, generally plane and closed, having many angles, and hence many sides, esp. one of more than four sides." Such a figure, by definition, should lie between a square and a circle, but should never become either. In nature a wide

* A movie film followed the reading of this paper—*Ed.*

† Publication authorized by the Director, U. S. Geological Survey. This paper was prepared to be a part of the Symposium on Air Photos in Geography and Soil Science. Most of the papers are in Vol. XVII, No. 5.

variety of microrelief figures ranging from quadrilaterals (quasi squares, rectangles, and parallelograms) to quasi circles and even semicircles have been or may be called polygons. They are found throughout the world, and vary in size from a few millimeters or centimeters to many tens of meters. Strictly speaking, few are planes although their relief generally is less than one meter and rarely more than 2 meters. Many other surface patterns, particularly those on slopes, are not polygonal yet are related in origin to polygons.

The usually descriptive terms employed for polygons and similar figures are multitudinous. For areas of moderately level ground, such terms include tundra polygons, Tetragonalböden, fissure polygons, Strukturböden, Texturböden, stone pits, stone-centered polygons, stone nets, stone rings, stone polygons, stone circles, soil circles, spot medallions, mud boils, Ostioles, cemetery hummocks, Mima mounds, hummocky ground, natural mounds, pimple mounds, prairie mounds, puffs, pimpled plains, lichen polygons, and vegetation nets. Many of these phenomena grade into related features in areas of sloping ground; and for those features different terms are employed, such as ribbed ground, stone stripes, striated land, soil stripes, earth stripes, terracettes, turf-banked terraces, earth waves, stone-banked terraces, stone streams, and solifluction stripes.

Very little information on these forms has appeared in the geologic textbooks commonly used in this country. Much of the work on Arctic forms has been done in the Old World, and results are scattered widely through the literature of many countries. Perhaps because of a lack, until recently, of economic incentive, relatively few quantitative data are known about them. In spite of this, several hundred articles have been written about them, and the classifications that have been attempted are numerous and varied.

Review of Some Literature

Troll (1944) presents the most comprehensive summary of frost forms, many of which are polygons or related forms. His general group of Frostmusterböden (frost-patterned soil) includes structure soils (Strukturböden) where sorting of material according to size takes place, and texture soils (Texturböden) where no sorting takes place. The text with 72 figures and 16 1/2 pages of references cannot be ignored by any photo interpreter of natural conditions.

Troll (1944, p. 547) describes the disagreement of nomenclature of forms produced by frost and (p. 548) other features that commonly display definite patterns. These are associated with a plant cover or with Humusböden (humus soil) or Torfböden (peat soil) but the role of frost is not clear. Similar patterns in turf and peat soil (p. 549) have nothing to do with frost, but result from wind erosion, gullying, anthills, cow paths, plant tussocks, and hummocks. He emphasizes (p. 548) that stone nets with sorted materials are known from the Libyan Desert and presumably have formed during the formation of mud cracks by desiccation. Apparently crystallization and re-solution of salts play a similar role as does regelation by ground frost. (See also Hörner, 1950 in this regard.) Fossil frost forms (p. 550) are important paleoclimatic criteria; their use depends, however, upon exact correlation of modern climatic zones in relation to active forms occurring in them. Distinguishing active from past forms is in places very difficult. Yet misinterpretation, for example, can easily mislead the engineer in construction problems, the pedologist on soil-forming processes, or the geographer on climatic conditions and land utilization.

Troll also states (p. 550) that polar areas and high mountains of the tropics and temperate regions are fundamentally different climatic zones and have generally distinguishable frost forms; however, in the middle latitudes structure soils occur that are transitional. Furthermore, in high latitudes, oceanic and continental climates produce different forms, of which some are similar to those in the tropics. Although permafrost is present widely in the northern hemisphere Black, (1951), Troll (1944, p. 557) emphasized that neither permafrost nor humid climates are necessary for the production of structure soils even in high latitudes, and that snow cover is perhaps one of the most important factors in their origin. In contrast, structure soils commonly develop (p. 647) in regions of no annual freezes. Troll believes that great contrast of frost forms exists between individual climatic types in the subarctic zone.

The most recent paper, to the author's knowledge, is the noteworthy attempt of Washburn (1950) to condense many arctic and subarctic forms into a general term, "patterned ground." (See also Smith, 1949, for a historical review and summary of frost forms.) This term is further subdivided into classes containing sorted and nonsorted circles and polygons on horizontal ground, and sorted and nonsorted stripes on sloping ground. As in any gradational series, the distinction between circles and polygons is not always clear, and similarly some gradations exist between those forms where the degree of sorting is the distinguishing factor. Some are bedrock forms and not ground in the strict sense of the word. We can turn, in addition, to the brief reviews of Newcomb (ms.), Knetchtel (ms.), and Melton (1929) for a discussion of some similar features in temperate regions. Here possibly the variety is only slightly less than in arctic forms. Fewer classifications exist (although probably just as many suggested origins have been proposed as in the arctic forms), possibly because fewer workers have studied more than local forms of a few types.

Origin of Polygonal Patterns

Washburn (1950) discusses the following hypotheses for origin of some forms: 1. multigelation (repeated freezing and thawing); 2. expansion due to freezing or to colloidal absorption of water; 3. contraction due to drying, to low temperatures, and to thawing; 4. convection due to temperature-controlled density differences, to saturation-controlled density differences, and to ice thrusting; 5. weathering; 6. cryostatic processes, such as growth of ice crystals and hydrostatic pressure; 7. frost-wedging; 8. artesian processes; 9. rillwork; and 10. solifluction. Knetchtel (ms.) and Melton (1929) refer to literature in which the following processes have been suggested for origin of some of the forms in the United States. 1: erosion by networks of rivulets; 2. water and wind erosion and deposition; 3. hydrostatic pressure or gas pressure; 4. "concretionary action"; 5. processes associated with frozen ground; 6. construction by ants, fish, termites, rodents, or aborigines; 7. shrinkage or contraction due to low temperatures or drying; 8. uprooting of trees; 9. chemical solutions; 10. differences in settling; and 11. combinations of these and other processes. Rutten (1951) suggests that many stone nets in Iceland are secondary features resulting from deposition of stones around vegetation hummocks which are later destroyed by sheep and by wind erosion.

Washburn (1950, p. 55) clearly states the case when he says: "Not only are a number of different phenomena involved in the concept of patterned ground, but from the accumulated evidence it seems extremely probable that similar phenomena may be the result of different processes. . . . Many mysteries will remain until investigators can recognize more clearly the different types of patterned ground and the stage through which each type may pass. . . . Only then will it be possible to evaluate better the relative importance of the various formative processes." For frost forms in the restricted area of Wolf Creek, Sharp (1942, p. 300) corroborates Washburn by saying: "Intensity and frequency of

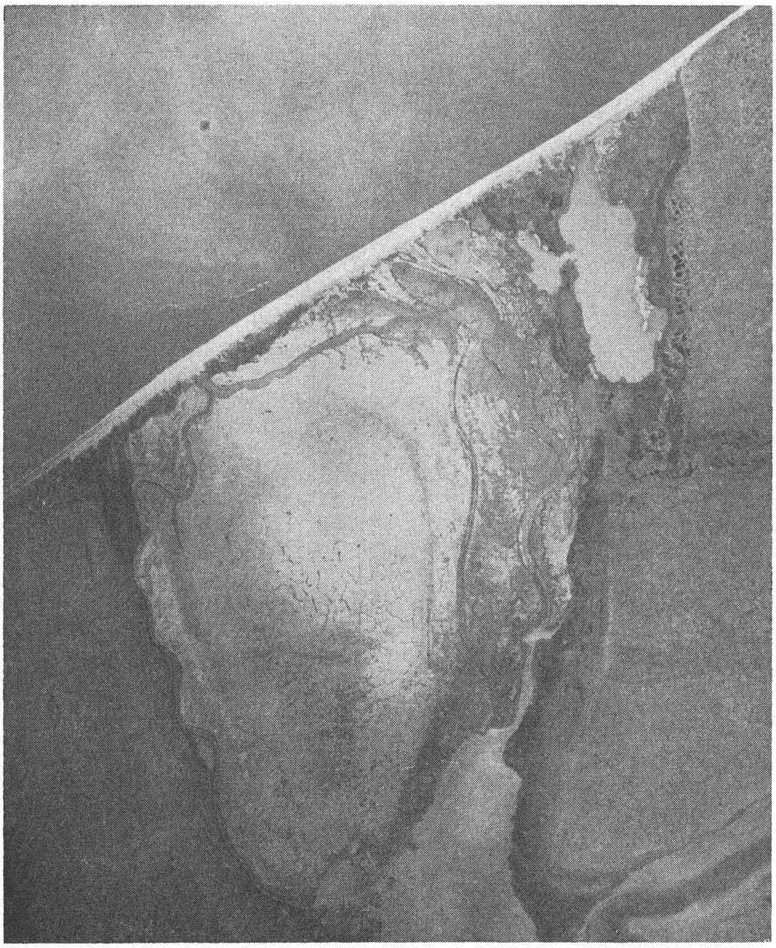

FIG. 1. Ice-wedge polygons in northern Alaska, about lat. 70°55′ N. and long. 153°20′ W. Contrast those in the bed of the recently drained lake with those in the surrounding tundra and with those in fig. 2. Photographed 1948 by the U. S. Navy.

freeze and thaw, constitution of surface debris, weathering and comminution, degree of slope, amount of water, drainage, height of water table, vegetation, and depth to perenially frozen ground are all recognized as contributing factors which must be evaluated for each particular locality." For forms in the temperate region, Melton (1929, p. 119) says ". . . these simple features can be formed in a variety of ways. . . . Though some of the contributors felt the sufficiency of, and so offered, just one hypothesis for the origin of the so-called 'natural mounds,' most investigators realized that in different places they must be of different origin."

Misconceptions and Significance of Some Polygons

It thus behooves us to look more closely into these features if we are to avoid loose thinking and overgeneralizations. Most of these forms have considerable present or past climatologic and geologic significance; yet it is easy to be misled by them. For example, a recent classified publication, in reference to polygons in the arctic and subarctic, states that polygons everywhere indicate permafrost; that the number of sides in a polygon suggests the climate (marine or continental) and the general latitude; that the size of the polygon suggests type of climate:

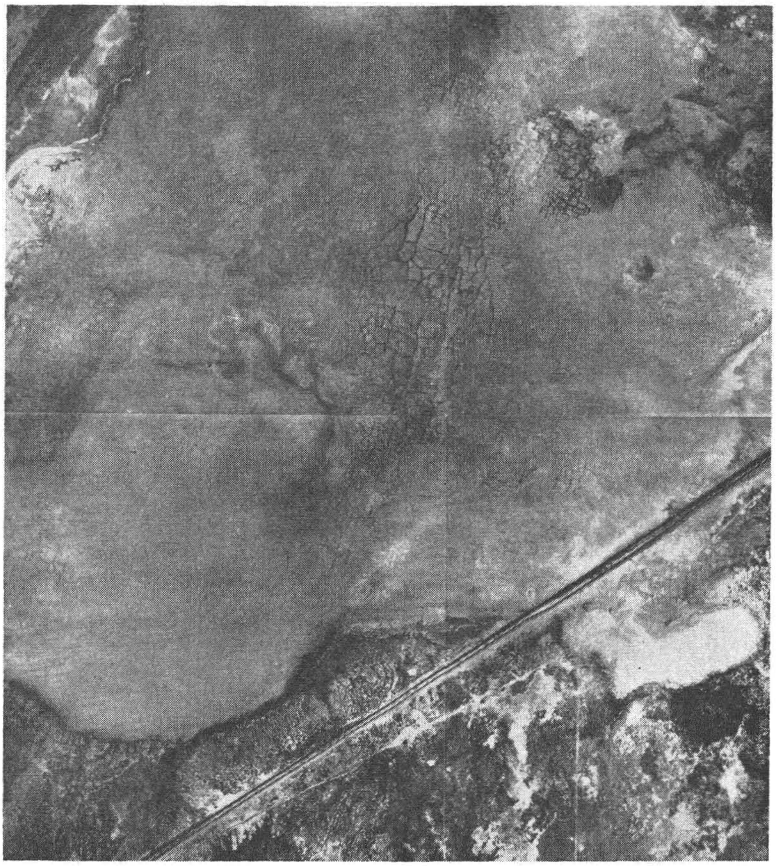

FIG. 2. Desiccation (?) and seasonal-frost (?) polygons in and adjacent to Playa de los Pinos, Conrad Siding, Southern Pacific Railroad, 11 miles southwest of Lordsburg, N. Mex. Elevation is about 4,150 feet above sea level. Photographed 1935 by Fairchild Aerial Surveys, Inc., for the Department of Interior. Compare with fig. 1.

that the mere presence of polygons indicates the vegetal types, the groundwater table, soil depth—and a detrimental permafrost; that any polygonal type indicates a low, wet muskeg or tundra area supporting a dense mat of low vegetation; that the channel [high-centered] polygon often indicates a fine-grained soil underlain by a somewhat coarser material; and that the depressed-center [low-centered] polygon has a center usually of ice-peat underlain with massive layer ice. Frost (1951, p. 28) says "Soil polygons are one of the chief identifying surface features of permanently frozen ground. In arctic and subarctic regions, polygons indicate detrimentally frozen ground with one exception being a particular type found in a gravel-soil outwash area," and (p. 32) that "A layer of ice, often several feet thick, forms the bottom of the 'pan' of low-centered polygons." Woods et al. (1948, p. 498) write "In each instance the presence of these polygons indicates that detrimental permafrost exists" and (p. 499) that "Polygons in the interior of Alaska are associated with the severest form of permafrost since massive ice wedges of clear ice are found frequently in the substratum of the polygon trenches."

Such statements as these tend to be misleading, or are erroneous, yet many similar statements are being made in our scientific journals, e.g., Cabot (1947, pp. 640 and 644) and Sager (1951, pp. 554–562). As pointed out earlier in this

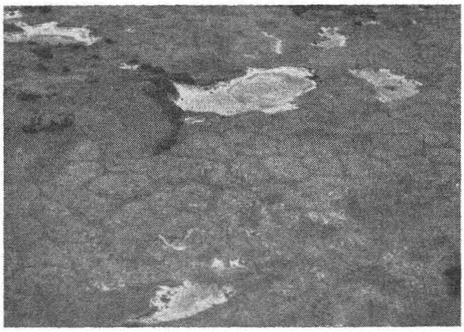

FIG. 3. Seasonal-frost (?) polygons in medium to coarse sand about 20 miles north of Ugashik, Bristol Bay, Alaska. Permafrost, if ever present, is now absent under such polygons in this area. (Oral communication from Ernest H. Muller.) Compare with fig. 4. Photographed Aug. 19, 1949, by the writer.

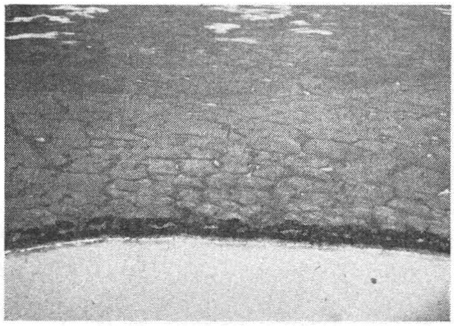

FIG. 4. Ice-wedge polygons of northern Alaska, about lat. 70°52′ N. and long. 153°30′ W. Tops of ice wedges are less than 2 feet from the surface in medium to coarse sand. Bank is 10 to 15 feet high. Compare with fig. 3. Photographed Aug. 28, 1947, by the writer.

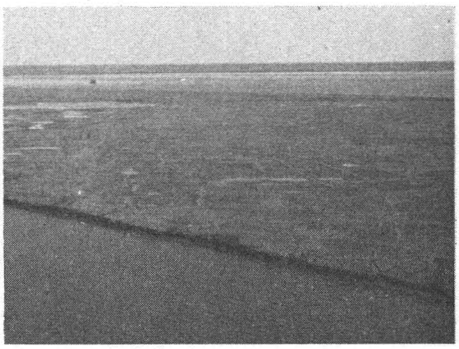

FIG. 5. Ice-wedge polygons in silt and fine sand in a recently drained lake in northern Alaska, about lat. 70°50′ N. and long. 159°00′ W. Compare with fig. 6. Photographed Aug. 25, 1947, by the writer.

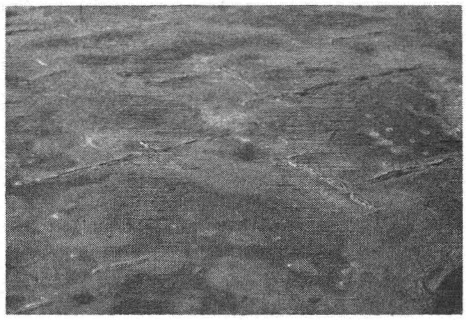

FIG. 6. Seasonal-frost wedges in bedrock joints in vicinity of Cape Hearne, mainland north of Coppermine, North West Territories. (Reprinted from Washburn, 1950, pl. 14, fig. 1, p. 48.) Compare with fig. 5.

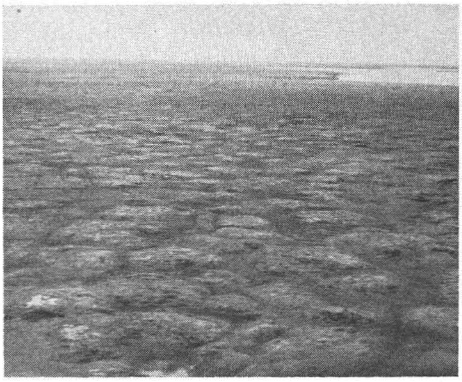

FIG. 7. Ice-wedge polygons under natural conditions, about 15 miles southwest of Barrow, Alaska. Permafrost is 6 to 15 inches from the surface. Ice wedges are as much as 25 feet wide. Compare with figs. 8 and 9. Photographed July 20, 1947, by the writer.

FIG. 8. Ice-wedge polygons about 3 miles west of Fairbanks, Alaska. Relief developed by thaw of permafrost after the vegetation was cleared for farming. Compare with figs. 7 and 9. Photographed Sept. 19, 1948, by the writer.

paper polygons do not indicate that permafrost is present or even that it ever was present. Except for Rutton's theory polygons generally indicate that certain disturbing forces are or have been operating in the soil or bedrock. Some polygons result from forces that are very complex and not clearly understood. This is particularly true of polygons in which material has been sorted according to size. Polygons in which no sorting takes place are simpler. Yet the ice-wedge or tundra polygons (see Figures 1, 4, 5, 7, 8, and 10), for example, are not completely understood, and numerous theories have been proposed for their origin and the conditions under which they can form. They are summarized by Leffingwell (1919, pp. 179–243) and Taber (1943, pp. 1510–1528). Furthermore, ice-wedge polygons also can be confused with polygons of different origin in the Subarctic, outside the zone of permafrost, in temperate latitudes, and even in the tropics, particularly if inactive forms are present. (See Figures 2, 3, 6, and 9.)

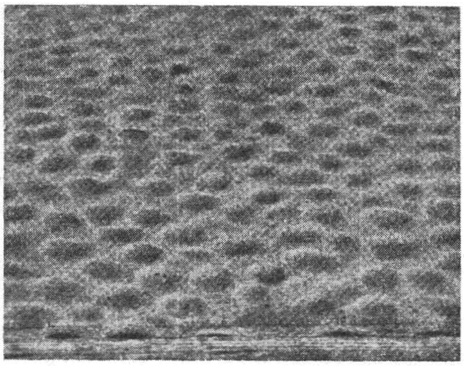

FIG. 9. Typical Mima mounds 2 miles southwest of Tenina, Wash. (Reprinted from Dalquest and Scheffer, 1942, fig. 1, p. 70.) Compare with figs. 7 and 8.

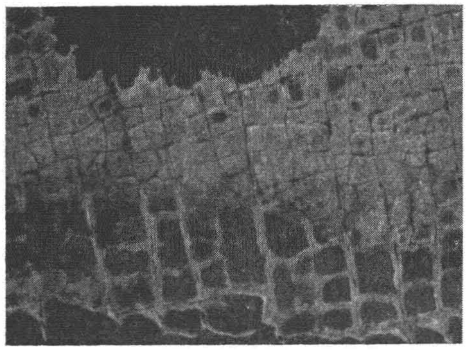

FIG. 10. Tetragonal ice-wedge polygons in northern Alaska, about 10 miles north of Alaktak. The initial large, low-centered polygons at the bottom are subdividing and becoming high-centered as those at the top. Photographed July 17, 1947, by the U. S. Coast and Geodetic Survey.

ICE WEDGE POLYGONS

The writer found in his studies (Black, ms.) that Leffingwell's contraction hypothesis for origin of ice wedges is largely correct. In the winter of 1949 and 1950, temperatures of $-15°$ to $-25°$C. were recorded in the upper few feet of permafrost near Barrow, Alaska. The coefficient of thermal expansion of ice is about 50×10^{-6} per degree C., and much of the tundra soil, according to the writer's measurements of contraction and moisture content, reacts like pure ice to temperature changes. Thus a block 20 meters long contracts about 20 mm. after a temperature drop of 20°C. Obviously this results in intense stresses. They are relieved generally by formation of open cracks, horizontally and vertically. Depth hoar and seedling ice crystals grow in those openings by sublimation from overlying snow and water flows into some and freezes during spring breakup. By summer about one-quarter to one-half the void is filled with ice, and a new ice wedge has started or an older one has grown.

The configuration assumed by these cracks bears no direct relation to the climate or the latitude but is dependent upon the nature of the material and the amount and direction of the stresses. The cracks usually have the same configuration in marine, continental, or alpine climates. In uniform material one notes a tendency for the theoretically simplest form—a hexagon—to predominate. Contractual stress from a point is relieved most easily by three radial cracks, 120° from each other. A group of points with cracks results in hexagons like those formed in cooling lava. On slopes where the effect of gravity is important or in drained lakes and in abandoned stream channels where older zones of different characteristics about the newly exposed ground, tetragonal forms are produced. Here stress is most easily relieved by cracking parallel or normal to the slope or to the boundary of the different zone. Because of slight irregularities in slope and invariability of material, tetragonal forms are perhaps most common in northern Alaska. (See Figure 10.)

Throughout permafrost areas, it is believed that initial ice-wedge polygons bear no direct relationship to climate. They are determined by ground temperatures. The largest and most irregular cracks or complete polygons form in areas of lowest moisture content in the ground, and hence lowest coefficient of thermal expansion, or wherever the ground is well insulated, particularly with snow. They occur in silt, sand, gravel, or even bedrock and may or may not be covered with vegetation. Such vegetation includes many species of lichens, mosses, sedges, grasses, shrubs, and trees and is conspicuously different from place to place. Polygons in gravel with low moisture content are in places incomplete or generally more than 50 meters in diameter. In contrast, polygons in old areas of fine-grained silt with much ice may be less than 1 meter. As polygons age, the initial polygons may split up into secondary and tertiary polygons. This may occur at any time, whether the polygon is in a low- or high-centered stage. Such splitting depends upon the material, the surface configuration of the polygons, and the insulating effects of snow cover, ice, and vegetation. A particular ice wedge may crack each year for several years, lie dormant, or crack at irregular intervals. Materials, moisture, insulation, vegetation, and other factors vary so much from place to place that it is difficult to quote sizes of polygons without being misleading or erroneous. However, in the silt and sand in the vicinity of Barrow, tertiary polygons in older areas of high-centered types may be 1 to 3 meters in diameter; secondary polygons may be 4 to 8 meters; and initial polygons may be 10 to 100 meters, or rarely larger. Splitting generally is by halves, thirds, or quarters. The depth of seasonal thaw varies from place to place, from less than one foot to more than 6 feet.

Leffingwell (1919, pp. 205–211) clearly described the surface expression of the two main extremes—high-centered and low-centered polygons. It should be pointed out that gradations exist between them, that are the result of many factors, including primarily surface erosion by water, wind, and mass wasting processes, vegetation, type of material, water content, rapidity of thaw and growth of ice wedges, and age. By knowing the relationships of these various factors, it is possible from an interpretation of aerial photos to predict in places with fair reliability the depth and width of ice wedges and the total amount of ice in the ground.

In northern Alaska all ice wedges initially are reflected at the surface by minute cracks where the active layer was split. These can be seen only by ground inspection or excavation. As the ice wedge grows, the surface may or may not reflect the presence of the wedge. On steep slopes, vegetation, creep and other mass wasting processes within the active layer commonly obscure the wedge completely so that it can not be detected by surface observation. On slopes of a few degrees, because of mass wasting, thaw, and surface erosion, only high-centered polygons form. In the flat, wetter places where surface drainage is poor or non-existent, low-centered polygons form. Shearing and flow within the wedges force organic and mineral material to the surface along the sides of the wedge, producing ridges. These aided by preferential growth of vegetation further impede surface drainage, and small ponds are formed. Vegetation accumulates in some ponds to depths of 4 feet; and some of this accumulation contains interbedded layers of ice. These layers are only a few millimeters or centimeters thick. Massive ice is rarely, if ever, present. The low-centered polygons eventually attain a stage in which lateral growth of ice wedges, mass wasting processes, thaw, or surface drainage working headward along polygon troughs convert them into high-centered polygons. In the later stages of surface erosion, it commonly is very difficult, if at all possible, to determine the amount of ice left in the ground by a study of surface features. For example, roots of ice wedges in places are widening rapidly with addition of ice in contraction cracks, but rapid surface thaw and erosion cut off the tops and prevent them from extending to great depths as in normal wedges of similar surface expression.

The construction and destruction of ice-wedge polygons is visualized as a continuously fluctuating process. Construction takes place by addition of ice within wedges, uplift of material along the sides of the wedges, preferential accumulation of ice, vegetation, and wind-blown silt within polygon ponds or on tops of ridges, and accumulation of droppings of birds and rodents on tops of high-centered polygons. These elevate the surface of the tundra. Destruction takes place through erosion by water, wind, and mass wasting processes, and thaw of ice. These lower the surface of the tundra. No two years can be expected to produce identical results, although certain trends from year to year may be noted. Effects of all climatic factors, vegetation, and cycles of rodents and other animals on the local geologic conditions must be considered.

Value of Ice Wedge Polygons

In air-photo interpretation in the Arctic, the practical application of intimate knowledge of ice-wedge polygons, for example, is readily apparent. The size of polygons correlated with air temperatures and snow cover (or ground temperatures) predicates a certain coefficient of thermal expansion of the ground. Knowledge of ice-wedge polygon growth and arctic geomorphology enables the interpreter to obtain data on such items as size-grade distribution of material, depth of seasonal thaw, and moisture content in the active layer and in permafrost. The information is required in most construction problems and particularly in construction of pipe lines, sewerage lines, utilidors, and hard-surfaced roads and airfields. The stage of polygon development and surface expression of the polygon can be correlated with the amount of ice in the ground and depth of seasonal thaw. Hence the amount of slumping that will take place if the ice is melted, for example, in agricultural use, and the trafficability problems for cross-country military use can be approximated.

Polygons Similar to Ice Wedge Polygons

In places in the Subarctic, outside the zone of permafrost, practically identical polygons (from surface expression but lacking ice wedges) (Paterson, 1940, pp. 100–105) develop in the zone of seasonal freeze and thaw. (See Figures 3 and 6.) The mechanics of their formation is not clearly understood; permafrost is not now present. Perhaps in moist areas, contraction in the freezing ground is comparable to that in the Arctic, and frost cracks in polygonal outline can be expected. Like contraction cracks in the Arctic, these collect depth hoar and snow. Slumping into the open crack lowers the surface. During spring when the ground is warming up slowly, it expands. The extra material in the cracks suggests that crushing and shearing possibly take place, so that over a period of many years the material in and adjacent to the zone of cracking becomes foliated vertically and a small furrow or depression marks the zone. Small ridges may or may not be present adjacent to the crack, depending on surface erosion, climate, vegetation, and the material involved. Although vegetation commonly is different, such frost-formed cracks can not always be distinguished even on the ground from fossil ice wedges. Similarly, in playa lakes and in deserts, shrinkage cracks commonly produce polygons of similar size and surface configuration. (See Figure 2.) Of course, their location is generally sufficient to warrant the assumption that permafrost was never present during their formation. However, seasonal frost at least in some places can not be overlooked. If the forms are no longer active, it may be difficult in the light of present knowledge to determine the exact significance of the cracks.

Conclusion

In conclusion, it can be said that considerable caution must be exercised to avoid overgeneralizations in interpreting polygons. Only when their origin is clearly understood in any particular localtiy can they be useful in correctly interpreting present and past earth conditions and in properly evaluating land for agriculture, engineering projects, and other purposes.

ACKNOWLEDGMENT

The writer is grateful to the Office of Naval Research for making available to him the facilities of the Arctic Research Laboratory near Barrow, Alaska during part of his research on ice-wedge polygons.

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THE O'NEILL-NAGEL LIGHT-TABLE (A MULTIPURPOSE LIGHT-TABLE) ITS USES IN PHOTO-INTERPRETATION OF COLOR AND OTHER PHOTOGRAPHY*

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A NEW TYPE OF LIGHT-TABLE

IN INTERPRETING aerial photography especially color-transparencies, it was soon realized that the recognition of minute objects, especially colored objects, could be facilitated by using a light-table where light of any color could be easily obtained and where illumination could be varied in insensible gradations from very bright (e.g. 400 to 500 on the scale of a Weston light meter) to very dim (less than 5 on the Weston scale). To meet this need this new type of light-table was designed and built (Figure 1). It is primarily made for use in studying color-photography; but because of the high degree of illumination and the very great variability of the intensity of this illumination, this instrument is also useful in studying black and white photography. Furthermore, this light-table has applications in any industry where an inexpensive source of transmitted light of many (thousands) commercial colors can be used, since this apparatus can be very simply and quickly made to serve as a source of light of any color or of any six or twelve colors, side by side in the same field on the viewing screen. When lights of various colors are shown on the viewing screen, it is possible to determine readily what color can best be used to restore the color balance of an under-exposed or over-exposed color-picture by placing the transparency in the successive areas of the differently colored light.

Some of the Notable Features

Color

1. Provision is made for obtaining, conveniently and cheaply, light of any of the thousands of kinds of color transmitted by commercial dyes, pigments, paints, inks, pure chemicals, stained glass, colored fabrics, paper, plastics, photographic filters, etc. This colored light will be available for studying and interpreting color-photography or any translucent or transparent object. Certain studies of opaque colored objects can also be made by allowing the various colored lights to impinge on such objects directly from the light-table or transferred by mirrors. The "thousands" of different kinds of colored light are obtained by interposing in the filter chamber of the light-table, i.e. the space between the fluorescent tubes and the viewing screen (accessible when the

* Invented incidentally to a contract between the Amphibious Branch, Office of Naval Research, Department of the Navy and the Arctic Institute of the Catholic University.