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PERIGLACIAL FROST FEATURES AND RELATED PHENOMENA IN THE UNITED STATES

Abstract

In areas within and beyond the border of the continental ice sheet in the United States, the following types of periglacial features have been found: stabilized talus, gliding blocks and block concentrations on low to moderate slopes, now immobile; boulder fields or block streams in valley bottoms; transverse boulder benches in valley bottoms; „rock cities" on the rims of uplands; involutions or „cryoturbations"; casts of ice wedges; and other features. Definite indicators of permafrost are few and far apart, and occur only within and very near to the glacial boundary.

In upland areas associated with alpine glaciation, various types of patterned ground, mostly relict, are common; other features include nivation hollows, boulder pavements, rock streams, and rubble sheets. Along the sides at the heads of glaciated valleys, talus, protalus ramparts, and rock glaciers are common, and in many places are relict features dating back to colder intervals of the Pleistocene.

Data on periglacial phenomena are very incomplete, and much work remains to be done.

INTRODUCTION

In North America, the concept of periglacial frost action is much older than the term itself. As early as 1881, Kerr recognized the anomalous characteristics of surficial deposits in the southern Appalachian region, and interpreted them as the result of frost action at a time when continental glaciation caused arctic climatic conditions to extend farther south. He stated that "these masses were earth glaciers, and these deposits may be denominated frost drift, as distinguished from proper glacial drift". Many years later, T. C. Chamberlin (1897) remarked, in an editorial footnote, that "It must be remembered that as a result of the excessive superficial thawing and freezing incident to glacial-border conditions, the facilities for landslides, bodily creeps, and similar modes of movement reached an extraordinary degree of development". These far-sighted observations, however, were almost entirely overlooked by subsequent investigators, and such progress as was made in the ensuing decades was largely in the study of modern frost phenomena, as represented by the work of Matthes (1900), in introducing the concept of nivation, the widely-quoted studies of Leffingwell (1915, 1919) on ground-ice

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wedges, and the observations of Eakin (1916), Capps (1919), and others on solifluction and related phenomena in Alaska.

In 1928, the concept of periglacial processes was reintroduced into North America from Europe by Kirk Bryan, in a review of Kessler's monograph on the topic. The time was then ripe for continued interest, and Bryan's inspiring leadership led to a long series of investigations by many workers in many places. By 1949, sufficient data were at hand to justify a brief regional review (Smith 1949), and in the same year a special issue of the *Journal of Geology* was devoted to cryopedologic phenomena, representing an important milestone in the progress of investigations. Since that time, interest has increased steadily, and numerous papers have contributed both to our knowledge of the nature and extent of periglacial features, and to our understanding of the processes involved.

In this review, it is intended to bring the record up to date, with emphasis on "fossil" or relict cryopedologic phenomena in the United States, exclusive of Alaska, and with reference to three broad geographic divisions: the New England-Appalachian region, the continental interior, and the western cordilleran region. It may be mentioned that studies in Alaska have been concerned primarily with existing permafrost and with currently active cryopedologic forms and processes, and contribute significantly to interpretation of comparable forms elsewhere in the inactive or relict condition; the works of Sharp (1942 a, 1942 b), Taber (1943), Wallace (1948), Hopkins (1949), Hopkins & Sigafoos (1950, 1954), Sigafoos (1951), Sigafoos & Hopkins (1952), Benninghoff (1952), Hopkins *et al.* (1955), Drury (1956), Wahrhaftig (1958, 1959), and Black (elsewhere in this symposium) are representative. The present status of periglacial studies in Canada has been reviewed recently by Cook (1959), and is not included here.

THE NEW ENGLAND-APPALACHIAN REGION

This region contains the mountains and plateaus of eastern North America. Continental glaciation extended south to approximately the 40°30′ parallel, and a few of the higher ranges at the north, reaching above 1500 meters, were subjected also to alpine glaciation, before and/or after being covered by the continental ice sheet. It is in the alpine zone of those higher mountains, notably Mt. Washington in New Hampshire, that cryopedologic features are best developed and were first recognized (Antevs 1932). The mountain reaches a height of some 1900 meters, and the summit area has a climate comparable to that of northern Sweden;

permafrost is reported to a depth of about 90 meters. Antevs described stone nets, stone stripes, turf-banked terraces, stone-banked terraces, and other less regular accumulations of frost-riven and frost-moved rubble. He distinguished between large-scale "fossil" stone nets and stripes, and their small-scale modern counterparts, but did not ascertain the extent to which the other types of features are now active. Additional observations on the above and related phenomena were presented by Goldthwait (1940) and Denny (1958), and the occurrence of modern stone nets on other mountains, down to elevations of some 320 meters in Maine, have been reported (Nichols, R. L. & Nichols, F. 1936; Denny 1940; Butler & Ray 1946). Modern stone-centered polygons have been reported also from western New York by Rozanski (1943).

In the lowland areas of southern New England, Bryan (1932) early recognized the anomalous nature of a disturbed soil layer containing numerous ventifacts, or sand-blasted stones, throughout a vertical interval up to 1,3 meters in thickness. This was interpreted as the result of intense frost heaving in a cold and windy periglacial environment associated with ice advance in the latter part of Wisconsin time. Similar features were found by Denny (1936, 1938) at other places, associated with periglacial involutions at one locality. Additional data on periglacial eolian phenomena are provided by the studies of Mather *et al.* (1942) on the ventifacts, by the discovery of eolian sands at depths down to 60 meters below present sea level (Stetson 1938), and by the occurrence of eolian silt in the profile of a bog (Ogden 1959). The convergence of evidence suggests a vigorous and extensive interval of periglacial wind action in late Wisconsin time, probably responsible also for one area of ancient, stabilized dunes (Smith & Messinger 1959); pollen studies by Ogden provide additional data on the sequence of climatic changes.

A need for caution in the interpretation of disturbed soils was noted by Lutz & Griswold (1939), who pointed out that the uprooting of trees by wind could produce some effects similar to those attributed to frost action. Additional observations on these effects were made by Goodlett (1954), but their applicability to supposedly frost-churned periglacial soils is yet to be adequately tested.

Another type of probable periglacial feature is represented by the network of clastic dikes described by Birman (1952) from Rhode Island, and interpreted as due to filling of fissures left by melting of ice veins originating under permafrost conditions.

All of the phenomena described above occur well within the border of the Wisconsin glaciation. Beyond that border, though in close proximity to it, periglacial phenomena are somewhat more impressive. Block and boulder fields and rubble deposits are characteristic, and have been described from various parts of Pennsylvania by Peltier (1945, 1949), Smith (1954) and Denny (1951, 1956). The features studied by Denny occur in the Appalachian Plateau of the north-central part of the state, at elevations of from about 550 to 750 meters, and are representative of their kind. Block fields, with closely-spaced blocks up to several meters in lenght, occur both on uplands and on slopes as low as 2°. They are now immobile and undergoing weathering and breakdown in place. The rubble deposits form a mantle of heterogeneous, unsorted detritus with rock fragments having a wide range in size; they have moved on slopes as low as 1° to 5°, but have long been static, and show a degree of weathering similar to that of the Wisconsin glacial deposits. Boulder rings and stripes are present locally. The above features are thickest and most extensive within about 15 kilometers of the glacial border, and become thinner and less continuous with increasing distance. Denny concludes that these features were formed by severe frost action under periglacial conditions, but doubts whether permafrost was present.

Of the various boulder fields in Pennsylvania, one in the east-central part of the state, very close to the glacial border, is exceptionally well developed, and may be considered as a type example of its kind (Smith 1953). It occurs in the plateau area, at an elevation of about 575 meters, along the bottom of a valley bordered by slopes of moderate steepness. It is approximately 550 meters long and 120 meters wide, somewhat irregular in outline. Its surface is a bare weathered expanse of unsorted, loosely-packed blocks and boulders up to about 6 meters in length. Despite minor irregularities due to jumbled and upended blocks, the general appearance is one of striking flatness, and the axial gradient is close to 1°. The blocks are believed to have been carried down from bordering valley sides by periglacial mass movement, involving solifluction and frost heaving, but details of the process are not clear, and close analogies from areas of intense modern frost action are lacking. In any event, influx of the blocks was such as to drastically interrupt the normal progress of stream erosion, choking the valley with material too coarse to be removed by running water until it is gradually reduced to smaller particles by weathering. The bareness of the present surface is attributed to secondary removal of original interstitial soil material by running water. A permafrost environment is postulated at the time of formation of the boulder field, but positive evidence is lacking.

In the coastal plain of New Jersey south of the Wisconsin glacial border, Wolfe (1953) has described an unusual and widespread occurrence of shallow, more or less rounded, inclosed basins. Depth is generally less than 6 meters, and area less than 2,5 square kilometers. Frost-wedge fillings, involutions, and related features are closely associated at many places, pointing to periglacial conditions. Wolfe postulates that the depressions were formed in the same way as the thaw basins developed at the present time in permafrost areas of Alaska. Farther south, in the coastal plain of Maryland, Nikiforoff (1955) has suggested that certain characteristics of soils may have been inherited from a time of periglacial conditions.

In one reentrant of the glacial border in western New York, the so-called "rock cities" are interpreted to represent a virtually unique type of periglacial phenomenon (Smith 1953). These features are developed in massive, flat-lying conglomerate at the edge of the plateau, bordering deep valleys. They consist of huge blocks, up to more than 20 meters long, separated by interconnecting passageways or fissures, up to more than one meter wide and more than 6 meters deep, opened along joint planes. Their walls are relatively straight and parallel, and follow a rectangular to angulate pattern. Except at the dropoff to the valleys below, the blocks show no variation from the bedrock either in dip or in level, but only in purely horizontal separation. The blocks are now immobile, and appear to be undergoing gradual disintegration in place. They obviously were moved to their present position by a force acting only in a horizontal direction, and the effects of frost or ice wedges under former periglacial conditions are believed to provide the only adequate explanation. It is hoped that this may be confirmed by the finding of similar features in other parts of the world, in areas of either present or past periglacial conditions.

Paleobotanical evidence relating to the periglacial zone described above is provided by studies of a marsh in southeastern Pennsylvania, some 85 kilometers south of the Wisconsin ice border (Martin 1958). The pollen record is interpreted to indicate taiga-tundra conditions at the time of the last Wisconsin glacial maximum.

At greater distances south from the glacial border, periglacial features are somewhat less common and less distinct. However, relict rock streams, boulder-choked valleys, transverse boulder benches, and overgrown, inactive talus slopes are observed at many places in the Blue Ridge area of Maryland, West Virginia, and Virginia, at elevations upwards of 300 meters (Smith, H. T. U. & Smith, A. P. 1945, and unpublished observations; Nickelsen 1956). Farther south, in the higher parts of the southern Appalachian mountains, block-strewn slopes and valley bottoms indicate movement of large masses of rock long distances by processes no longer in action, and are best explained by the agency of frost-induced transportation during more rigorous climatic conditions attending glaciation (King & Stupka 1950); it is suggested also that timber line was below the higher summits at that time. Another type of evidence relating to former climatic conditions in the Appalachian Highlands is the occurrence of striated cobbles and boulders in river terraces from Maryland to Tennessee (Wentworth 1928). These markings are attributed to the work of ice jams, such as occur today in arctic rivers, but are presently absent from the rivers along which the striated cobbles are found; it is inferred that ice jams must have been active during past intervals of more severe climate corresponding to glacial epochs farther north.

In the southern Appalachian Piedmont, extensive mass movement of soils, deeply burying vegetal material indicative of a cooler climate than that of the present, has been reported (Eargle 1940; Bryan 1940). Although detailed data have not yet been published, periglacial or semi--periglacial solifluction is suggested, but particularization is difficult.

It is tempting to speculate as to possible periglacial affinities of the Carolina „bays", distinctive oval depressions of concordant orientation which occur in great numbers in the southeastern Atlantic coastal plain. These highly controversial features have been variously attributed to meteor impact, artesian solution, and other processes. Superficial similarity to oriented lakes in the permafrost region of Alaska (Black & Barksdale 1949) might suggest the additional possibility that they were formed by processes associated with permafrost. The evidence of pollen analysis does indicate colder conditions during past time (Martin 1958), but no specific evidence whatever for periglacial processes has been found.

THE CONTINENTAL INTERIOR

In the broad plains and lowlands between the Appalachian Highlands and the western mountains, continental glaciation reached its southernmost extension (approximately to the 38° parallel) into the temperate zone. The Ohio River on the east and the Missouri River on the west, roughly mark the glacial border. Across this broad region, climate ranges from humid at the east to semiarid at the west. In the eastern part of the region, periglacial features appear to be rare. Goldthwait (1959) notes that of some 3000 exposures studied in western Ohio, "only one showed good possible convolutions (ice-twisted soil layers) and less than three had possible vague wedge structures. This indicates that permafrost was rare if it occurred at all." In Indiana, involutions of probable periglacial origin have been reported from a single locality, well back from the glacial border

(Gamble 1958). In Illinois, periglacial involutions, or "cryoturbations", were first recognized by Sharp (1942) in the northeastern part of the state, at a considerable distance from the Wisconsin glacial limit. They were believed to have been formed under permafrost conditions when the ice edge was 50 to 80 kilometers away. Farther west, but still within the area of Wisconsin glaciation, Horberg (1949) described a till-filled crack in loess, interpreted as an ice-wedge cast, indicative of frozen ground. More recently, Frye & Willman (1958) reported three occurrences of involutions a short distance beyond the Wisconsin glacial border, and one occurrence of an ice-wedge filling within the border. They suggested that "permafrost existed for a relatively short time, and perhaps locally, adjacent to the margins of Wisconsin glaciers in northern Illinois, but became ineffective in central Illinois. It is judged that an arctic climate was not prevalent at the Wisconsin glacier border in its southernmost extent".

In the Driftless Area of Wisconsin, somewhat farther to the north, topographic and geologic conditions were more favorable for the development and preservation of recognizable periglacial features. Blocks of resistant types of rock moved downslope to form talus, block streams, block fields, rubble zones, and dispersed rock masses, some on slopes as low as 4°. Locally, small valleys were choked by rubble, and at some places transverse block cascades or benches were produced — a type of feature noted also by the writer in the Appalachian area, but now known to have been described from any other part of the world. All of the above features are now immobile, and show the effects of long-continued weathering, stagnation, and decay. The evidence for periglacial origin of talus is particularly clear in this area, from a comparison of two localities having similar topography, lithology, and structure, and located about 13 kilometers apart, but on opposite sides of the glacial border; outside of the border, talus is very prominent, though now inactive, whereas talus is almost entirely absent inside the border, having been swept clear by glaciation, and having had no favorable conditions to develop under post-glacial climatic conditions. It seems probable that permafrost existed in the area, but no positive indicators have been found; certain features originally interpreted as ice-wedge casts were later shown to be soil tongues, formed by pedologic processes unrelated to frost (Yehle 1954).

On the western side of the Mississippi Valley, in east-central Iowa, the best example of ice-wedge polygons yet reported from the United States has been described by Wilson (1958). The fissures extend to a depth of nearly 4 meters in glacial clay of Iowan age, are up to nearly one meter in width, and are filled with sand. Together they form a polygonal pattern, with unit cells from about 1,3 meters to slightly more than 6 meters across, over an area about 1,6 kilometers long and 0,6 kilometer wide. The evidence of permafrost conditions of considerable duration and severity seems clear.

In Missouri, possible periglacial features have been noted by two investigators. Wentworth (1935) described striated rock surfaces along stream channels in the southeastern highland of the state, and suggested that they may have been produced by ice-jam action at a time of more rigorous climate. Peltier (1950) presented preliminary observations on boulder-strewn slopes, rubble deposits, poorly-developed block fields, and other seemingly relict features in the same general area, and considered them representative of relatively mild periglacial conditions; no detailed or definitive data have yet been published, however.

In northeastern Kansas, extensive searching by the writer revealed only one locality having features which might possibly be interpreted as periglacial. The features at that place consisted of limestone blocks which had been carried down slopes of moderate steepness into a stream valley, and then left stranded and immobile on the slopes over which they had been moving. The cessation of a process formerly active is indicated, and the finding of spruce of late Pleistocene age in a peat bog in the same general area (Horr 1955), some hundreds of kilometers from its present occurrence, suggests that a former cooler climate might have been related to the above phenomena.

In Nebraska, no periglacial frost phenomena have been recorded, although contrasting orientation of dunes of different ages suggests periglacial influence on the wind system during one interval (Smith 1955). In South Dakota, Flint (1955) reports that the search for frozen-ground phenomena was fruitless, and suggests that "Possibly in South Dakota the water table stood so low that despite rigorous climates, freezing and thawing of ground moisture failed to produce visible results". In North Dakota, on the floor of glacial Lake Agassiz, Horberg (1951) described a remarkable assemblage of intersecting minor ridges, with which are associated involuted structures and gravel and soil wedges. He postulated a permafrost environment at the time of formation, and concluded, tentatively, that the dominant features were best explained as fossil tundra ridges of unusual type. This, however, was questioned by Nikiforoff (1952), and the problem remains an intriguing one. Farther to the west, in central Montana, the evidence for permafrost conditions near the glacial border seems unequivocal, and consists of well-developed involutions and ice-wedge structures at several widely separated localities (Schafer 1949).

It may be mentioned that Łoziński (1933), from a study of the literature then available, concluded that some of the soil mounds of the Gulf Coast region are probably comparable to the palsen of periglacial areas in Poland, and mark the southern extension of the Pleistocene periglacial belt in North America. No definitive criteria were presented or applied, however, and in view of the long-standing controversy as to the origin of the mounds in question, Łoziński's interpretation must be regarded as an unsupported speculation. In one of the more recent studies on these features, in Oklahoma (Knechtel 1952), the hypothesis of frost--induced origin is considered but dismissed.

WESTERN CORDILLERAN REGION

Roughly the western third of the United States is a region of high mountains, plateaus, and intermont basins. Upland areas above 3000 meters are common, and many individual peaks and ridges exceed 4000 meters. During the Pleistocene, only the northernmost part of this area was covered by a continuous ice sheet, and the remainder of the region was marked by widely separated ice caps and velley glaciers on individual ranges, south as far as latitude 33°23′. During the last or Wisconsin glacial stage, valley glaciers predominated. At the present time, a few small valley glaciers are still found on some of the higher areas, mostly reformed since the "postglacial climatic optimum"; permafrost is reported locally at high altitudes in the northern part of the area, but available data are fragmentary and incomplete.

In this broad region, the first mention of phenomena which now would be termed periglacial was by Matthes, who in 1900 introduced the concept of nivation from studies in the Bighorn Mountains of Wyoming. Rock streams or rock glaciers have been known for a long time also (Howe 1909), but were originally attributed to landsliding, and the possibility of periglacial origin was not recognized until much later. Modern interpretation of alpine frost phenomena in the mountain region begins with the work of Russell (1933), who described nivation depressions, solifluction slopes, and altiplanation terraces, but failed to differentiate between relict forms and those now active — a distinction which, in some instances, requires considerable time and detailed work, and in many places is yet to be made. Following Russell's publication, scattered observations, mostly incidental to studies having other objectives, have been made by various workers at various places, and are represented in the discussion below. Systematic regional studies are yet to be carried out.

In rolling upland areas, mostly above the level of adjacent valley glaciers, rubble sheets, block fields, nivation depressions, earth hummocks, boulder pavements, one block stream, and various types of patterned ground, including stone nets and stripes, and stepped forms, have been reported in the Rocky Mountains of Colorado, Wyoming, and Montana (Ray 1940; Richmond 1949, 1953; Holmes & Moss 1955; and Smith 1950, and unpublished observations). Although some of these features show various degrees of activity at present, the major interval of development seems to have been in the past. Farther south, on San Francisco Mountain in Arizona, some of the above features occur on a minor scale (Sharp 1942). On the eastern side of the Colorado Rockies, a frost-churned soil containing ventifacts was noted by Bryan & Ray (1940) on a terrace considered to be of mid-Wisconsin age.

In one broad upland section of northern New Mexico, within the area of older Pleistocene glaciation but well south of the main area of Wisconsin glaciation, an unusual occurrence of periglacial landsliding on relatively low gradients has been reported (Smith 1936). The sliding occurred at two different times, correlated with glacial stages or substages.

On slopes too steep for the types of features discussed above, and particularly along the sides and heads of glaciated valleys, periglacial phenomena are mostly in the form of talus, protalus ramparts, and rock glaciers. Blackwelder (1935) early recognized that talus is an indicator of frost climate, and that inactive or wasting talus points to a former interval of more vigorous frost action. Later workers noted that old talus accumulations might represent the only effects of Wisconsin glacial climatic pulses at places where no actual glaciers were formed (Ray 1940; Holmes & Moss 1955; Richmond 1960). Where talus material accumulates at the edge of a persistent snowbank, a protalus rampart is formed (Bryan 1934), and where such a rampart occurs beyond the existing snowbank, and shows no evidence of recent addition of rock debris, it suggests a former more rigorous climate with more snow. This type of feature has been reported at several places as marking the last and weakest phase of Wisconsin glacial climate (Ray 1940; Sharp 1942; Eschman 1955; Richmond 1960). Rock glaciers represent another form in which talus material occurs, and extend outward from the base of the talus on lower gradients in glacier-like form; they are sometimes referred to ambigiously as rock streams. They occur most commonly in cirques, but are found also along linear cliffs (Smith 1951). Those studied in the active condition are found to move by reason of interstitial ice (Wahrhaftig 1959). Where found in stabilized or inactive condition, they are indicative of former near-glacial climate (Richmond 1952, 1960; Eschman 1955).

In the Puget Sount region of western Washington, Eakin recognized periglacial patterned ground as early as 1932. More recently, Péwé (1948), Newcomb (1952), and Ritchie (1953) have presented evidence for periglacial origin of the much-debated Mima mounds. In central Washington, preliminary results of studies on periglacial patterned ground have been reported by Kaatz (1959).

STUDIES OF TOPICAL CHARACTER

Although many of the papers referred to on preceding pages give valuable material on periglacial morphology, processes, and concepts, as well as on geographic distribution, there are some additional papers which fall largely or entirely within the former category, and should be included here. Bryan's treatment of classification and terminology (1946, 1948), although limited to rather broad, general categories, is particularly provocative, and has been very influential. The report of a National Research Council Committee on Pleistocene Research (Flint, *et al.* 1949) covered a wide range of topics, both physical and biological, relating to glacial and periglacial problems. Peltier, in 1950, presented a general discussion of periglacial phenomena in relation to climatic regions and to the erosion cycle. In 1956, Washburn provided a much-needed systematization of the classification and terminology of one category of periglacial phenomena — patterned ground — together with an extensive discussion on hypotheses of origin. In the same year, Dillon published an interesting reconstruction of Wisconsin climate on the basis of biogeographic data.

CONCLUSIONS

(1) Periglacial features of many types well known in Europe, together with some additional types, have been found in the United States, but known localities are rather widely separated and limited in number. This may be attributed in part to concealment by forest cover in some places, to the fortuitous occurrence and ephemeral nature of the exposures required for study of certain features, to the earlier workers' unawareness of the nature of periglacial forms and structures, and consequent mistaking of them for results of glacial push or other processes, and to the fact that active search for the features in question has been made by a very limited number of workers for a relatively short time. But it may be also that there are a limited number of occurrences to be found.

(2) In the area of continental glaciation, localities showing features diagnostic of or strongly suggestive of permafrost are particularly few and far apart, and are found only within or very close to the glacial border, especially along the more southerly extension of the latter. When it is considered that the continental ice reached much farther south in North America than in Europe — in fact, to the latitude of southern Spain — it is not surprising that the zone of more severe periglacial conditions should have been more restricted on the former continent than on the latter, with tighter squeezing of displaced climatic zones.

(3) Non-permafrost types of periglacial features seem to extend somewhat farther from the glacial border, particularly where distance is offset by increased elevation, but recognition and interpretation become more difficult southward.

(4) The distribution of periglacial features as outlined here is essentially consistent with Dillon's (1956) delineation of the Wisconsin tundra zone, on the basis of biogeographic data, but does not necessarily confirm the breadth or continuity of that zone as pictured by him.

(5) Aridity may have been an inhibiting factor on the development of periglacial frost phenomena in west-central United States.

(6) Periglacial features have played a significant role in the interpretation of late glacial history in the Rocky Mountain region, but thus far have been of minor importance in the unraveling of Pleistocene stratigraphy elsewhere in the United States, as compared with Europe.

(7) Present knowledge of the geographic and stratigraphic distribution of periglacial features in the United States is extremely inadequate, and much work remains to be done. Continued vigilance in finding and recording ephemeral exposures is needed, and collaboration of geomorphologists with soil scientists, construction engineers, archeologists, and others might be helpful.

(8) Definitive interpretation of many types of periglacial phenomena in terms of paleoclimatology requires more exact knowledge of their origin and criterion value. Detailed studies of forms, structures, processes, and rates, of development in modern periglacial environments, together with experimental studies both in the laboratory and under natural conditions, should contribute.

(9) The terminology for periglacial features, in general, is inexact and frequently misleading or confusing. Standardization of terminology,

preferably at an international level, with sharp distinction between genetic and descriptive terms, would contribute greatly to clarity in the communication of ideas. Washburn's work represents one step in this direction.

(10) Available data for North America are entirely inadequate for the mapping of periglacial climatic conditions. It is to be hoped that future studies will remedy this deficiency, and provide a basis for the type of mapping represented in European publications.

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Addendum

Since the original manuscript was prepared, the following additional data have come to the writer's attention, and are presented in the form of annotated references. All are in accord with conclusions already drawn.

Colton, R. B. 1955 — Geology of the Wolf Point quadrangle, Montana. *U. S. Geol. Surv. Map* GQ 67.

Describes sand and gravel wedges filling frost fissures up to more than 4 meters deep, in northeastern Montana, near the glacial border.

Eckhoff, O. B. 1962 — Hill slopes of the Piedmont of North Carolina. *Geol. Soc. Amer.*, Spec. Paper 68; p. 69.

Asymmetric valleys are interpreted to have been resulted from frost action at a time when the climate was colder than at present.

Flint, R. F. and Denny, C. S. 1958 — Quaternary geology of Boulder Mountain, Aquarius Plateau, Utah. *U. S. Geol. Surv. Bull.* 1061-D; p. 103—164.

Describes rock glaciers and stabilized talus which might be considered as periglacial, although the authors do not use that term. Also describes landsliding that may have been particularly active during times of glaciation, although frost action is dismissed as causative factor.

Hanley, J. B. 1959 — Surficial geology of the Poland quadrangle, Maine. *U. S. Geol. Surv. Map* GQ 120.

Reports talus and frost-churned soils developed immediately following deglaciation.

Hartshorn, J. H. 1960 — Geology of the Bridgewater quadrangle, Massachusetts. *U. S. Geol. Surv. Map* GQ 1127.

Describes periglacial congeliturbate in southeastern Massachusetts.

Kaye, C. A. 1960 — Surficial geology of the Kingston quadrangle, Rhode Island. *U. S. Geol. Surv. Bull.* 1071-I; p. 341—396.

Describes wedge structures and other features interpreted as evidence either of permafrost or of very deep annual freezing.

Philbrick, S. S. 1962 — Old landslides in the Upper Ohio Valley. *Geol. Soc. Amer.*, Spec. Paper 68; p. 69—70.

Notes old slide planes dates as aproximately 9000 to 9750 years B. P. The possibility of periglacial influences suggests itself.

Sharp, H. S. 1933 — The origin of Mountain Lake, Virginia. *Jour. Geol.*, vol. 41; p. 636—641.

The lake, at an elevation of about 1170 meters, is interpreted to have been dammed by large blocks of resistant sandstone which crept downslope from adjacent ledges. The occurrence is such as to suggest periglacial processes, although this possibility is overlooked by the author.

Sharpe, C. F. S. and Dosch, E. F. 1942 — Relation of soil-creep to earthflow in the Appalachian Plateaus. *Jour. of Geomorph.*, vol. 5; p. 312—324.

Earthflows are underlain by layers of clay, shale, and coal thinned and stretched out downslope from the outcrop by creep. The effects of creep are such that periglacial origin seems possible, although this is not considered by the authors.