Patterned Ground in Central Washington: A Preliminary Report

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THIS PAPER is concerned primarily with the patterned ground which covers hundreds of square miles on Manastash Ridge and portions of the adjacent Kittitas Valley and Yakima County, in central Washington (Figs. 1 and 2). The countless mounds, which characterize much of the

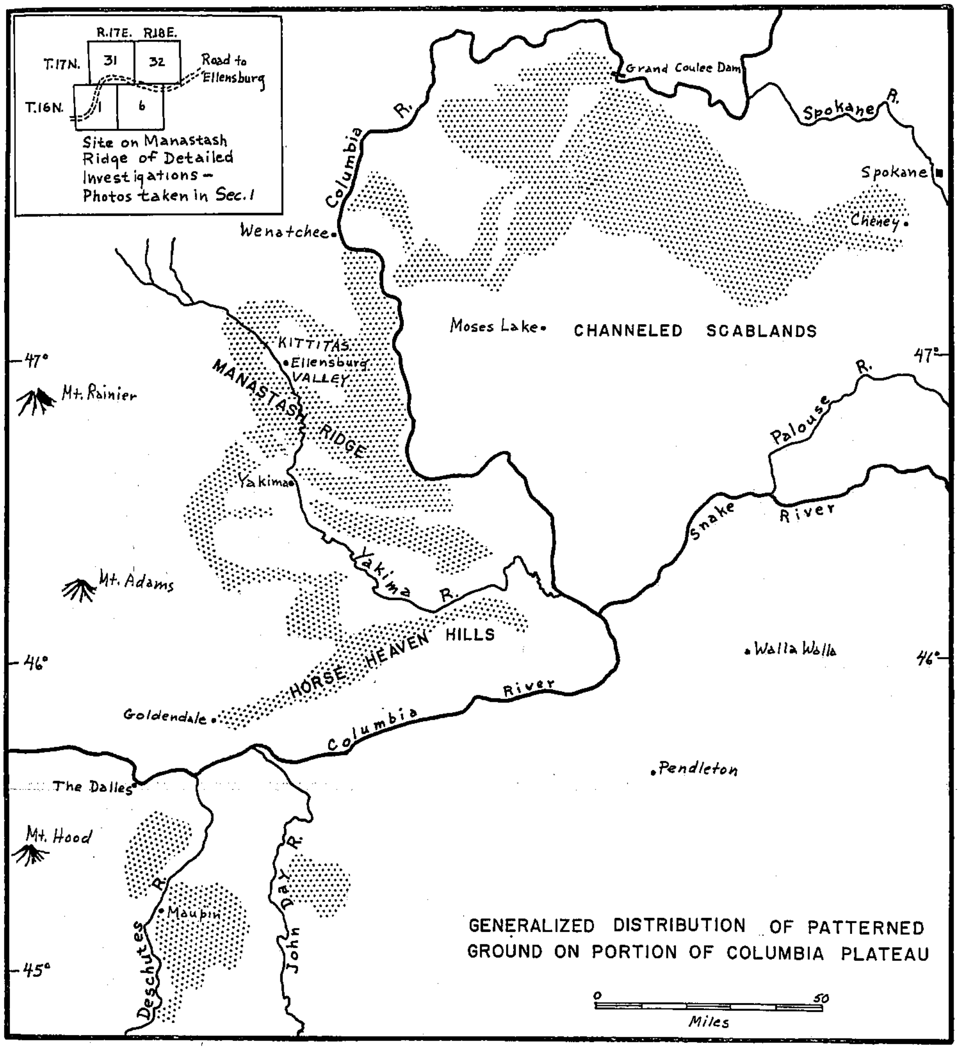

Figure 1. Distribution of patterned ground on portion of Columbia Plateau generalized from field observation, aerial photographs, and published literature.

patterned ground and constitute its most striking aspect, are referred to hereafter as the Manastash mounds.

"Patterned ground is a group term for the more or less symmetrical forms such as circles, polygons, nets, steps, [mounds], and stripes that are characteristic of, but not necessarily confined to, mantle subject to intensive frost action" (Washburn, 1956, p. 824). Found in various parts of the world, it has been the subject of much discussion and debate. We need only look to the Mima Mounds which have stirred up so much controversy, now perhaps at last laid to rest by Newcomb (1952) and Ritchie (1953). Patterned ground on the Columbia Plateau of Washington and Oregon, in many ways similar to that in the Mima region, has been the subject of study starting with Le Conte (1874), and continuing with Piper (1905), Freeman (1926 and 1932), Waters and Flagler (1929), and Larrison (1942). In addition, Knechtel (1952), writing about patterned ground elsewhere in the United States, discusses its occurrence on the Columbia Plateau. In all of these, attention has been focused on mounds. The major theories of mound, or patterned-ground, formation emerging from these studies on the Columbia Plateau are: (1) they are the result of normal water erosion, (2) they are the product of burrowing animals, and (3) they reflect the jointing pattern in the basalt bedrock. To these I wish to add the theory that the majority of the mounds and associated patterned-ground features are primarily the consequence of intensive frost action under a periglacial climate.[1]

The full extent of patterned ground in the Pacific Northwest remains yet to be determined. There seems to be a marked coincidence between the occurrence of mounds in Washington, Oregon, and Idaho and the distribution of shallow eolian deposits. The latter are shown on the map edited by Thorp and Smith (1952). The sorted stone features not only seem to be associated with the above but also with the recent lava flows in these states plus northern California.

In central Washington the gentle south slope of Manastash Ridge southwest of Ellensburg and west of the Yakima River exhibits excellent examples of patterned ground in the form of mounds, sorted stone nets and polygons, and sorted stripes. Although all of these phenomena are related, they are not everywhere found in association. Their distribution varies with slope, mantle, depth to bedrock, and drainage. One or more of these patterned-ground features have been observed in Kittitas County on each of the following: (1) basalt bedrock, (2) the sedimentary conglomerates and sandstones

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[1] Masson (1949) describes mounds and stone nets in California near the western base of Mt. Shasta that are almost identical in all their features to those of central Washington. He concludes that they are the result of intensive frost action.

of the Ellensburg Formation, especially where exposed in dissected pediments, and (3) on the thin moraine of the valley glacier which extended farthest east into Kittitas Valley. The most ubiquitous distribution of the patterned ground, however, is over the folded basalt bedrock of Kittitas and Yakima counties.

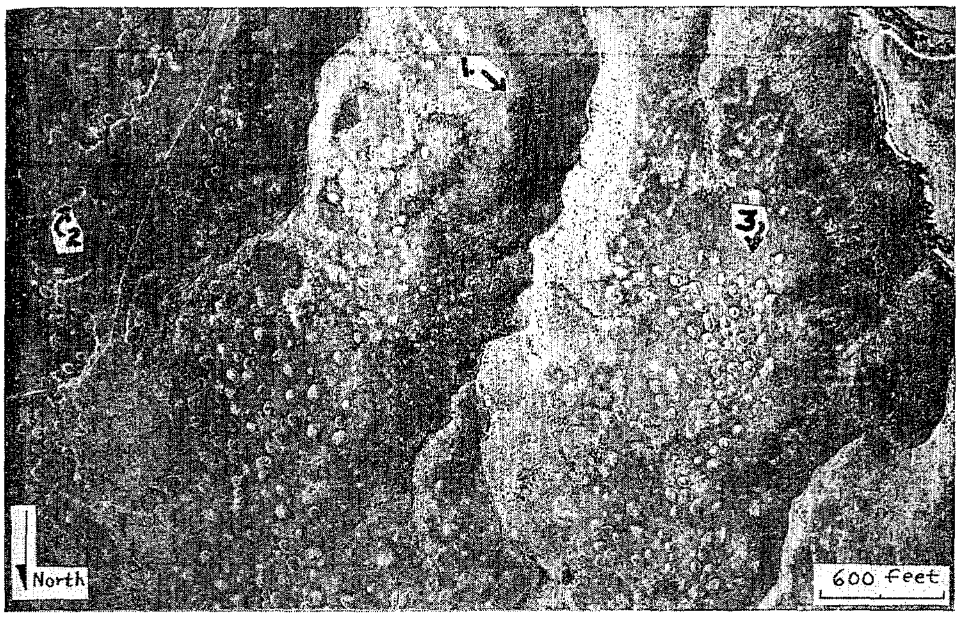

Figure 2. Aerial photo of variety of patterned ground on portion of south slope of Manastash Ridge in central Washington (T 16N, R 18E, Sec. 6 and T 16N, R 17E, Sec. 1). C.S.S. Photo NL-5F-07, 6-30-49. No. 1, sorted polygons and stripes shown in ground view Figure 4c; No. 2, thaw depression; No. 3, typical mound swarm.

Let us begin with a description of the mounds since they are the most obvious of the patterned-ground phenomena. The Manastash mounds vary in plan, from circular to oval; in long diameter, from about 20 to 130 feet; and in height, from about one to five feet. They are flat topped and in most instances rise abruptly from the intermound surface. The weathered basalt bedrock on which the mounds rest weathers "too slowly under a semiarid climate to keep pace with erosion, so that normal soil profiles do not form from the residual materials" (Smith, 1945, p. 65). The mound soils and the associated deep unmounded mantle usually are, or are akin to, Renslow and Ritzville silt loams developed from loess. They are permeable and well-drained soils, yet their texture is favorable for retaining the available water during the dry season. Occasionally small, subangular basalt pebbles,

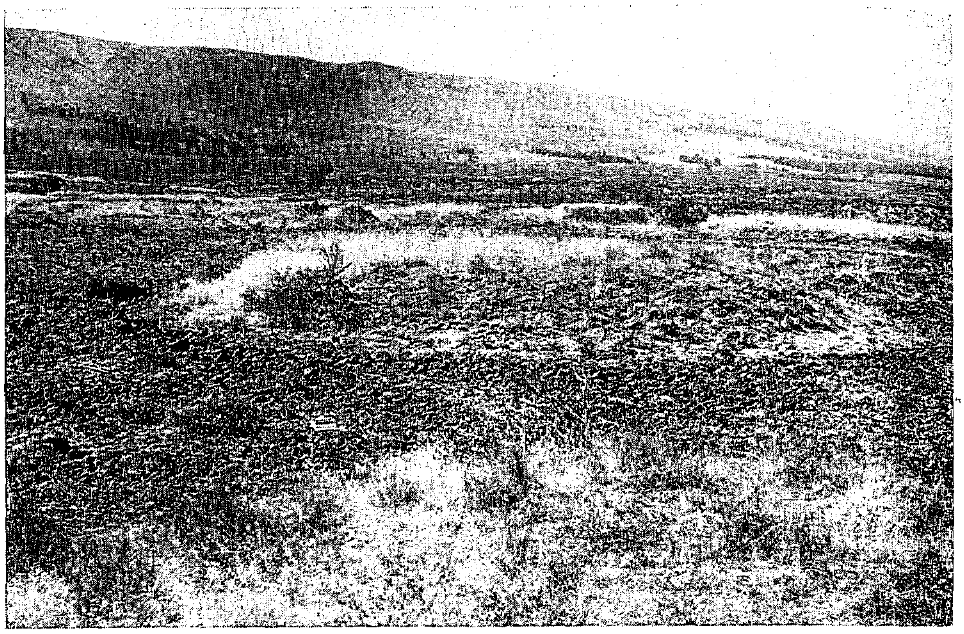

Figure 3. A typical mound together with sorted nets and polygons. Photograph taken from nearby mound whose surface comprises the foreground. Note clipboard in middle foreground for scale.

about one inch in diameter, are encountered scattered at variable depths in the mounds. In some areas the mounds are more pebbly than in others.

A typical mound would be an ellipsoid 40 by 56 feet, elongated downslope, with a flat summit about three feet high merging imperceptibly into the sides (Fig. 3). The north faces of the mounds tend to be steeper than those on the south. They occupy one- to seven-degree slopes, but reach their most perfect development on slopes of less than three degrees (Fig. 2). The Manastash mounds occur in interrupted groups covering 10 to 20 acres. The summits of all the mounds within a group are generally accordant (Fig. 4a). Densities of three to four mounds per acre are common. Although the spacing in each group is variable, slightly curving strings of mounds spread out in a narrow fan shape are a common arrangement. The distance between individual mounds is also highly irregular. In some instances they are isolated with less than one mound per acre, while in others they appear amoebalike in various stages of detachment from one another, or from the unmounded soil mantle. Every conceivable intermediate stage in spacing may be encountered. Mounds usually do not occur where the soil mantle is more than six feet deep over the weathered basalt bedrock.

In the relatively barren ground between the mounds are the sorted stone nets and polygons (Figs. 3 and 4b). Most of the Manastash mounds regardless of size and shape are completely or partially ringed by stone nets composed of basalt blocks and rubble ranging up to about two and one-half feet in diameter. These blocks are subangular, and often lie with individual fragments fitting together as in a jigsaw puzzle. Where exposed to the surface the basalt is discolored by weathering and lichens. In some instances slab-shaped fragments a foot or more in diameter stand on edge. Individual stone nets may be over four feet wide. They end rather abruptly on their mound and intermound margins and are bordered by dominantly fine material; on, beneath, or projecting through the surface of this fine material are scattered large and small basalt fragments and blocks. Bedrock lies about 10 to 12 inches below. Clumps of grass and other plants grow amidst the finer material but are lacking in the sorted stone net. For many of the intermound areas this completes the picture, but in other intermound areas the girdling stone nets interlace with stone polygons which do not surround mounds (Figs. 3 and 4b). These polygons are about eight to nine feet across and border abruptly on dominantly fine material as do the stone nets which inclose mounds. A trench dug at right angles through a sorted net surrounding a mound reveals the following sequence: The top seven or eight inches consist of basalt blocks from six inches to over a foot in diameter,

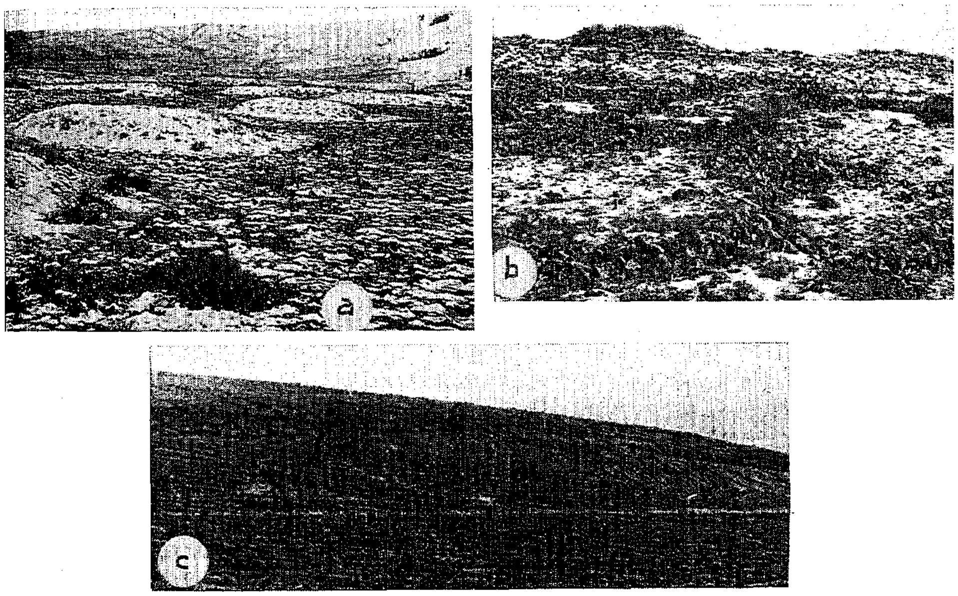

Figure 4. Variety of patterned ground on Manastash Ridge in central Washington. a. Typical mound grouping. Note their flat and accordant summits. b. Sorted stone polygons. c. Sorted stone nets and polygons merging into sorted stripes where slope steepens appreciably. Cf. Figure 2, arrow No. 1.

the size decreasing with depth. The spaces between the basalt are without any filling. The width of this zone decreases with depth. The next two or three inches contain small fragments, generally under three inches in diameter, with soil filling the interstices. This is followed by a zone of like depth which consists mostly of soil with scattered pebbles of basalt, underneath which lies the weathered basalt bedrock. Similar sequences are encountered when digging into stone nets and polygons which do not inclose mounds.

Where slopes are very steep the stone nets and polygons form sorted stripes (Fig. 4c). They are variable in length and width. The few that were dug into revealed profiles somewhat shallower but otherwise similar to profiles in the stone nets and polygons. A common sequence on many of the minor ridges consists of mounds on the gentle upper slopes, sorted stone polygons on the steeper intermediate slope, and sorted stripes on the steepest lower slope (Fig. 4c). Sorted stripes may also be found without any nets, polygons, or mounds associated with them.

A visit to the Manastash mounds at different seasons of the year is instructive. In early spring, to walk over the intermound surface means to wade to one's ankles in a sticky mass of clay and slippery rock fragments. A jeep will become mired. Water rests on the surface in areas of gentler gradient. In the summer, by contrast, the same surface assumes the character of a firm rocky roadbed, and dust replaces the muddy water of spring. The change is all but unbelievable to one who has not actually witnessed it. On the mounds themselves it is a very different story; here one finds firm ground at any season of the year. The ranchers in the area know this, and some build their corrals on the larger mound surfaces.

Some 75 per cent of the region's approximately 10-inch annual precipitation occurs between October and March. The degree of saturation in spring is influenced not only by whatever frost has persisted from the preceding winter but in addition by the distribution of annual precipitation, most of which falls in the form of snow. Frost penetration to depths of 30 inches and the occurrence of ice lenses at depths of 24 to 29 inches were recorded by the State Highway Department, at an elevation of about 2,640 feet, east of Ellensburg during the record-breaking cold of January, 1950 (Sibley and Krashevski, 1957, p. 6). This, of course, represented abnormal conditions, and records are lacking for general frost conditions in the Manastash region.

Let us examine the three major theories which propose to account for the patterned ground on the Columbia Plateau. Knechtel (1952) suggests that the mounds of the Columbia Plateau reflect, in part, the polygonal jointing in the bedrock and that the "intermound furrow systems" originated from such jointing. Without going into detail, this idea would seem to be weakened, if not refuted, by noting that the mounds and associated features occur also on the sedimentary Ellensburg formation, in which there certainly is no polygonal joint pattern.

Larrison (1942), studying a region several miles west of Manastash Ridge, concludes that pocket gophers are the agency responsible for the mounds. Newcomb (1952) has argued effectively against the gopher hypothesis for the Mima Mounds. Many of his excellent arguments are equally applicable to the Manastash mounds and will not be elaborated here. There is no shortage of evidence of gopher activity in the Manastash region, but, surprisingly, much if not most of it is concentrated in the intermound area. Upon saturation these intermound gopher burrows completely lose their original form and have the appearance of large earthen pancakes, a foot or so in diameter, spilled over the area.

Waters and Flagler's study of three separate areas on the Columbia Plateau in the late 'twenties is the most careful and comprehensive to date, and their conclusions have remained generally unchallenged anywhere in print. Although concentrating their attention on the region about Maupin in north-central Oregon, they also investigated the Horseheaven Hills near Goldendale, Washington, and the Cheney-Palouse scabland in eastern Washington (Fig. 1). They agree essentially with Le Conte (1874) and argue that the mounds are "wholly the result of surface erosion" by running water, resulting from the "greater moveableness of the surface soil" compared with the weathered basalt subsoil. Where the ashy surface soil is too deep over the less moveable basalt below or where "the surface is absolutely flat, mounds are not found." They describe the sorted stone nets as "erosion furrows" whose surface "matrix of ash has been removed by the surface run-off," and state that the ". . . areas between the mounds form a definitely integrated and minutely adjusted drainage system." Their petrographic study led them to conclude that the mounds are composed of deposits from volcanic explosions. They reject the idea of any climatic change being necessary, stating that the mounds were "carved from material that was deposited rapidly at the time of, or shortly following, a period of explosive volcanic activity." In further support of the dominance of water erosion they point out that as slopes become steeper more and more of the mound mantle is stripped off until only the underlying weathered basalt is left on the steepest slopes.

Let us consider these findings by Waters and Flagler (1929). Water erosion cannot by itself adequately explain the sorted stone nets, polygons, and stripes. These features do not occupy the lowest points between mounds; moreover, the stone polygons typically have more than one side extending at nearly right angles to the regional slope. The puddles of water standing in many of intermound areas following a thaw also would seem to cast doubt on the reality of an "integrated and minutely adjusted drainage system." Absolutely flat surfaces of any extent are relatively rare on the Columbia Plateau, but I suspect that mounds are less governed by flatness of surface than they are by conditions of mantle thickness and subdrainage. While it is true that the mounds do bear some relationship to slope, this relationship is more complex than the one suggested by Waters and Flagler. One of the peculiarities of the Manastash mounds is that, in many instances, on the gentler upper portion of a convex slope the surface may be segmented into mounds, while the steeper lower portion retains its soil mantle essentially intact. Also associated with the Manastash mounds are areas of concave slope with mounds at the gentle base but with the mantle intact on the steeper upper slope. This failure of the patterned ground to show a consistent relationship to slope is a phenomenon for which I have no ready explanation; at the same time it constitutes an important refutation of the dominance of water erosion as the causal agency for patterned ground on the Columbia Plateau.

If the heretofore proposed theories of patterned-ground formation on the Columbia Plateau are to be rejected or assigned a less important role in favor of frost action, what is the evidence? First, wherever mounds occur on the Columbia Plateau, there is the relationship which has been observed between the depth of the soil mantle and the location of mounds. The juxtaposition of mounds and unmounded mantle with common summit levels indicates that the mounds represent remnants of formerly uninterrupted deposits. These deposits, probably derived directly or indirectly from volcanic ash, were of variable thickness as a consequence of differences in exposure and the underlying surface configuration.

How did the mounds initially become detached? During the period of maximum glaciation in the Pacific Northwest, those areas not actually glaciated but fringing the glaciated countryside were subjected to a much colder climate than now prevails (Bryan, 1928, p. 163). Frozen ground extended to a greater depth and persisted for a longer period of the year than at present. Permafrost may have developed. If not, the relatively impermeable and ill-drained, weathered basalt bedrock has virtually the same effect that permafrost would have had in restricting subdrainage. Intensive frost action does not occur where good subdrainage extends below the frost line, but it is favored by water-saturated soil at or above the frost line (Siple, 1952, p. 173 and Hopkins, *et al.,* 1955, p. 142). Since the Manastash mounds fail to develop where the soil mantle is more than six feet deep, this depth is interpreted to represent the general level of frost penetration in the soil. Where the mantle was less than six feet deep, conditions were favorable for the development of ice-wedge polygons because the frost line extended into the easily saturated, weathered basalt surface beneath. With seasonal warming and long-range moderation of the climate, the soil above the wedges slumped into cavities left by the melting ice. This process is described in detail by Péwé (1954, p. 331), in his account of current mound formation near Fairbanks, Alaska, and also by Black (1952, p. 131). Solifluction, aided by snow melt and precipitation, carried away the slumped materials and gradually created a network of trenches which eventually segmented large areas into mounds. Concurrent with the above was the formation of thaw lakes and depressions similar to those which Hopkins (1949) describes in Alaska. Their mode of origin is summarized by Hopkins, *et al.* (1955, p. 140) as follows:

> Frozen fine-grained sediments generally contain a volume of ice in the form of clear ice lenses and masses greatly in excess of the porosity of the unfrozen material. Upon melting of the ice the ground subsides, and a basin is formed in which a thaw lake may accumulate. The lake increases in size by thawing and wave erosion of its banks and is eventually drained when the retreating banks intersect a stream valley or other low ground.

In Alaska these lakes rarely exceed 1,000 feet in diameter and 10 feet in depth. Banks are generally five to 10 feet high. Thaw depressions are smaller, ranging from 100 to 500 feet in diameter; they may never have contained water and are found as indentations on slopes of 2°-5° (Hopkins, 1949, p. 127).

The Manastash mounds occur mostly on surfaces with slopes of less than 5°. The occasional nearly closed depressions which are encountered at the edges of relatively large unmounded portions of the loessial mantle and the numerous embayments in the mantle offer the best evidence that thaw lakes and depressions are responsible for the numerous broad intermound areas, which are otherwise difficult to explain (Fig. 2). Too much time has elapsed since their formation for details such as former shorelines to persist.

What of the sorted nets, polygons, and stripes found in the denuded intermound areas (Figs. 2 and 4)? These, with their frostrived rubble, fit perfectly the descriptions of similar phenomena currently observed in arctic regions and alpine environments (Washburn, 1956); indeed, they defy any plausible alternative to frost action for their formation. Bedrock and rock debris are rapidly comminuted by water freezing and thawing in pores and fissures. Frequent alteration of freezing and thawing segregates the larger rock fragments from the finer materials, pushing out the former and contracting the latter which, because they are finer, can absorb more water. Given a sufficient period of time sorted patterns evolve.

The occurrence of sorted stone patterns only between the Manastash mounds, and not beneath them, indicates that they developed after the segmenting of the unmounded mantle. The peculiar manner in which the mounds themselves are so often surrounded by stone nets, which appear to have been shoved against them, also accents their postmound development (Fig. 3). Only after the mound mantle was removed could the weathered basalt beneath feel the full impact of frost action. The size and perfect development of the sorted stone patterns indicates that the intermound barren ground continued to be subjected to intensive frost action long after the mounds themselves were formed.

The sorted stone stripes found on the steeper slopes are a variation of the sorted polygons which probably continued to form after most of the other patterned ground ceased to be active (Fig. 4c). Their origin and relationship to solifluction and soil creep is discussed by Sharpe (1938, pp. 38-39), who describes stone stripes in central Washington. The problems associated with their origin are also discussed by Richmond (1949) and Washburn (1956).

That the various intermound sorted stone patterns are not active today is shown by their subangular, lichen-covered surfaces discolored from long exposure to the elements, in contrast with the clean faces of the rock beneath the outer layer. This also appears to be true of the stone stripes, which have not been studied in as much detail as the other phenomena. Sharpe (1938, p. 39) believes that the stripes may still be active.

Some frost action and solifluction is currently taking place, however, but on a much reduced scale from that responsible for the mounds and their associated features. For example, miniature, sorted stone polygons a few inches in diameter can be found near the 3,000-foot level on Manastash Ridge. Also, following a thaw the south- and southwest-facing sides of many of the mounds, where the vegetation has been disturbed, show miniature frost heaves and mudflows, which help to explain the lesser steepness of these sides.

To conclude, I have tried to demonstrate that intensive frost action during a periglacial climate has been more significant in the development of patterned ground in central Washington than hitherto has been recognized. While I cannot accept the gopher hypothesis (Larrison, 1942), I do not wish to conclude that running water has been without significance in shaping the patterned ground (Waters and Flagler, 1929), or that polygonal jointing in basalt is not important to the initiation of the pattern of stone nets in some situations (Knechtel, 1952). My argument is that these are of secondary importance when compared with frost action. I have focused attention on the evidence of frost action and offered a general, rather than a detailed, explanation for the various processes involved. The latter seems premature without further study. The many conflicting theories regarding the mechanism of frost action, permafrost, and solifluction in patterned-ground formation are excellently discussed and summarized by Washburn (1956).

For central Washington, many questions remain unanswered. Was the loesslike mantle formed before or during periglacial times, or perhaps both? What is the explanation of the numerous subangular basalt pebbles scattered in the otherwise loesslike soil of many of the mounds? Was the periglacial climate wetter, in addition to being colder, than now? Bretz, *et al.* (1956, p. 969), in a footnote, mention a postglacial humid climate in central Washington. To what extent may the mounds be used as a datum since they postdate the channeled scablands in which they frequently occur? The variety of the patterned ground features and the sites they occupy will require further study before these and other questions can be answered satisfactorily.

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