THE EROSIONAL ORIGIN OF THE MIMA MOUNDS OF SOUTHWEST WASHINGTON[1]

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ABSTRACT

The Mima Mounds of southwestern Washington are from 10 to 70 feet in diameter and range from barely perceptible forms to 7 feet in height. The mounds are round or oval in plan and in cross-section commonly resemble a segment of a circle. They lie upon glacial outwash gravels and are composed of a structureless dark pebbly-sand and silt; many contain ice-rafted erratics. The mounds are restricted to the outwash valleys of the Vashon glacial stage, and in this region nearly all the outwash valleys bear mounds. The mounds probably were formed from a partially thawed pebbly-silt mantle, possessing a polygonal-fissure ice network, and by running water, which removed the thawed material from around the hemispheroidal frozen cores of each polygon. Afterward, the frozen cores thawed in place and formed the Mima Mounds.

A mainly hexagonal pattern of fissure ice in a pebbly-silt mantle determined the mound spacing and is represented by most of the intermound spaces and by the remains of branching trenches in unmounded prairies. The mounds have strong curved alignment, rather regular spacing, and a common maximum height in any one mound field. Evidence for the erosion of a polygonal-fissure ice network in a pebbly-silt mantle consists essentially of low mounds with wide intermound areas, mounds that lie upon pedestals of submound gravel, intermound cobbles that have been uncovered, parallel asymmetrical development of the mound surface with the steep side up-gradient, and parallel elongation of oval mounds. Many of the lowest prairie channels are lacking in mounds but possess, instead, a few widely separated bars of mound material.

INTRODUCTION

The Mima Mounds of southwestern Washington were first reported by Charles Wilkes (1845) over a century ago. Since that time the origin of the mounds has been a topic of considerable discussion, for the mounds are one of the best-known minor physiographic features of the region. The name "Mima Mounds" was first given to them by Bretz (1913). A clear-cut concept for the origin of the mounds has been elusive, because only in recent years has a knowledge of arctic processes been acquired and distributed.

Because the Mima Mound problem was an embarrassment to geological science and because all early hypotheses fail under field tests, mound formation was attributed to gophers (Dalquest and Sheffer, 1942). This novel idea left the geologist in a position of arguing on what a gopher might or might not do.

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DISTRIBUTION OF MOUNDS AND CHANNELS

Figure 1 shows the relationship of the major gravel-filled outwash valleys of the southern Puget Sound region near the terminus of the last continental ice sheet. These channels were active intermittently at the various stages of advance and retreat of the Vashon ice (Bretz, 1913). Well-developed mounds are found within and restricted to these outwash valleys, though not all the outwash valleys bear mounds, nor are those with mounds completely covered by them.

The mounds occur in the southwestward-trending valleys as far east as the town of Rainier and as far west as the vicinity of Gate, a distance of over 20 miles. The mounds are also found as far north as Offut Lake and as far south as Grand Mound. Mounds are absent from the upper Skookumchuck drainage and from the Bucoda-Centralia valleys, which carried only meltwater during the advanced stage of the ice. During the re-

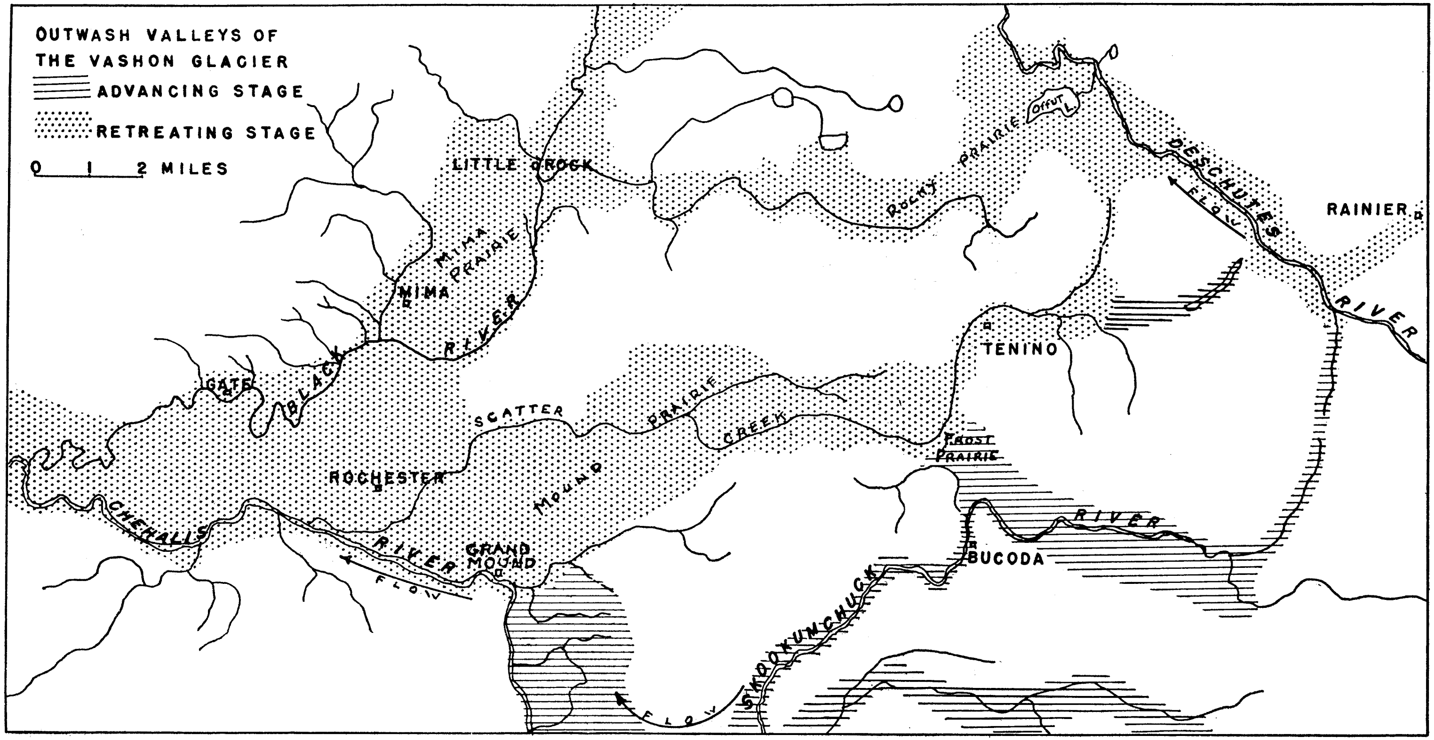

FIG. 1.—Outline map of southern Puget Sound region, showing relationship of the major gravel-filled outwash valleys near the terminus of the last continental ice sheet.

treat stage, water flowed in the lower channels to the west, and it is only in these channels that mounds are present.

The mounds occur within a pebbly-silt mantle that once buried the channeled surface of the outwash gravel terraces. Postmound erosion and reshaping have been negligible, as most of the precipitation sinks into the ground and runs off internally. Almost all the present prairie channels have been essentially nonfunctional since the formation of the mounds.

MATERIALS

SUBMOUND MATERIAL

The submound material consists of sand and gravel in various proportions, with cobbles and erratic boulders. The gravels are mostly light in color, well bedded, with the major bedding, which is essentially the slope of the surface of the terraces, dipping downstream toward the Chehalis Valley at about 10 feet per mile.

Many state highway and railroad gravel pits have been opened into the stratified submound gravels within the mound country. One state pit, J-35, is located near the center of Mound Prairie. An analysis of these gravels shows 41 per cent, by weight, of the aggregate larger than 2 inches in diameter. In a mounded area, 3 miles west of the town of Rainier, submound material is characterized by cobbles and boulders up to 4 feet in diameter. On Frost Prairie and on Mima Prairie, the submound gravel is much finer, commonly containing more than 85 per cent smaller than 2 inches in diameter. There is, therefore, a great range in the percentages and size of the submound material.

As the Puget Sound lobe of the Vashon ice retreated from the region, part of the gravel terraces that had been constructed were dissected by the later meltwater, leaving stepdown terraces, erosional remnants, and an intricate channel pattern on the surface of the prairies before they were covered by a pebbly-silt mantle. In most places this dissected surface is characterized by a cover of lag stones, commonly ranging from 4 to 12 inches in diameter and almost everywhere devoid of 2–3-inch material. These lag stones form a cobble stratum that underlies the mounds and constitutes the cobble-covered surface between the mounds, where the stratum has been re-exposed by erosion. Test pits expose this same cobble zone at the base of the pebbly-silt mantle in unmounded terraces.

MOUND MATERIAL

The mound materials, as well as the unmounded mantle on outwash gravels, are composed of structureless black silt, sand, and pebbly gravel. After diligent search, more than fifty larger stones, ranging from 4 to 20 inches in diameter, have been found inside the mounds well above their base, and their presence, the writer believes, has not been previously reported. The mound materials are exceedingly variable in the ratio of silt to sand and pebbles but are everywhere unconsolidated and lacking in clay constituents. The black material is apparently a very stable decomposed organic product, which imparts a dark color to the mineral material and gives a false impression of a very high organic content. Bretz (1913, p. 84) states:

> A sample of it [the mound material] was ignited to determine the organic content. Almost no loss of weight resulted, the material simply losing its dark color and becoming a fine gritty clay. The organic content thus is very small. Black silt, unmingled with gravel and sand taken from Chambers' Prairie, a moundless outwash area, gave the same evidence of slight organic content.

In some places the organic material has stained the submound gravels, and this downward staining imparts, in cross-section, a pseudo-biconvex shape to the mounds. Because the organic content is roughly uniform for the full 7-foot height of the mounds or depth of the prairie mantle, the writer believes that the organic material was added during the time that the pebbly-silt mantle was deposited over the submound surface and that this dark organic material is decomposed arctic vegetation rather than, as Nikiforoff (1937) thought, due to disintegration of the common vegetation that the prairie now supports.

The enigmatic origin of the Mima Mounds has puzzled geologists for many years. One of the most difficult questions has been the origin of the mound material itself. The common maximum diameter of the pebbles in the mounds, $1\frac{1}{2}$ inches, and the complete lack of structure in a thick pebbly-silt mantle do not conform to common transported deposits. Perhaps these materials were carried into an impounded region on the underside of floating ice that had been frozen to the ground of a floodplain area during the winter months. The source for the mound material, thus, would be an area where the rivers had a chance to segregate the material. This suggested hypothesis for the origin of the mound material would explain its wide distribution as a uniquely sized, structureless, erratic-bearing material which lies as a mantle on all irregularities of the dissected outwash gravel surface.

DESCRIPTION OF MOUNDS

SIZE AND SHAPE

In general, the mounds vary from 10 to 70 feet in diameter and from nearly nothing to 7 feet in height. The mature, perfect, or typical mound is usually circular or oval in horizontal dimensions and flatly hemispheroidal in the vertical. The mounds are commonly asymmetric, with a steeper side facing up-gradient or, if in proximity to a prairie channel, facing that channel, in the latter case the steep face of the mound meets the submound material abruptly. Where the mounds show a pronounced elongation, they are parallel to one another, regardless of the minor topographic differences on which they occur. The mounds are mostly single, but double- and triple-tied mounds are common. In any one area most of the mounds rise to one common height. The spacing of the mounds might be said to be regular but this must be qualified by the degree of erosion that has shaped them. In general, the higher the mound, the more abruptly its slopes meet the submound gravel floor, and the wider the intermound area, the smaller the mounds.

RELATION TO TOPOGRAPHY

The highest and most easterly mound field lies west of the town of Rainier on a terrace at an elevation of about 450 feet. The mounds are poorly developed and are barely recognizable. Just south of

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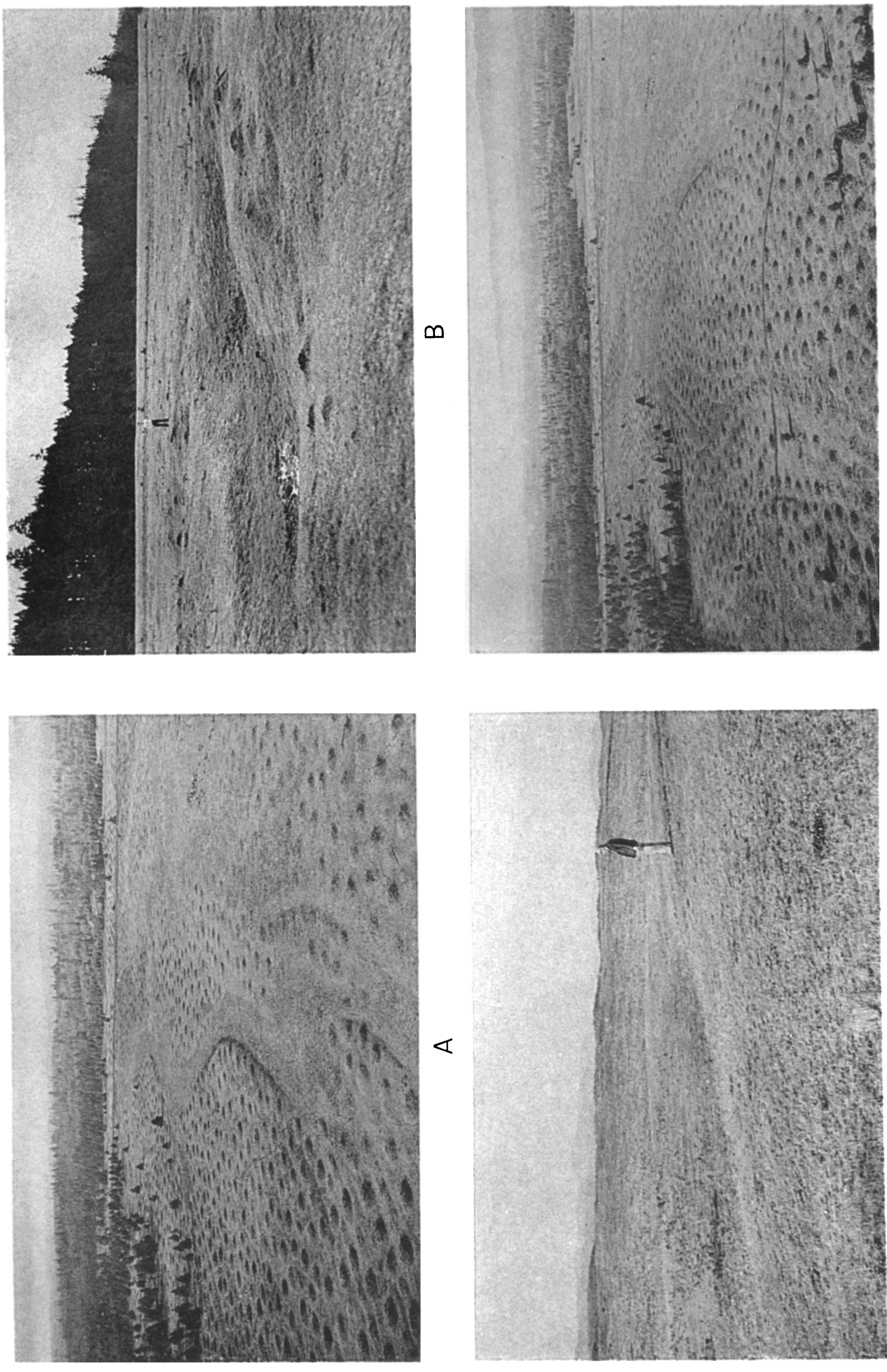
PLATE 1

A, Rocky Prairie, the left foreground showing pedestaled, elongated, and parallel mounds.

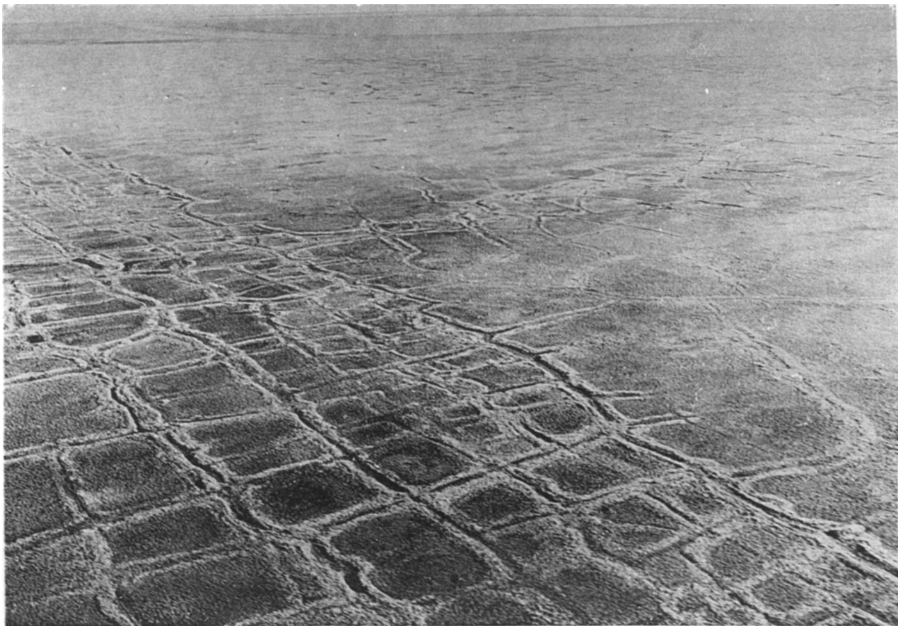
B, A branching trench left by the melting of fissure ice in a pebbly-silt mantle on Frost Prairie.

C, The man is standing on a crescent-shaped knoll of submound gravel which was exposed by the flood river. Part of the silt mantle is preserved on the down-gradient side of the knoll, which is the man's foreground. These features are the result of differential erosion of the mantle and submound materials while they were both yet frozen.

D, Rocky Prairie, west of Offut Lake. Regularity of mound spacing and strong carved alignment are evident.



Features of the Mima Mound area



A

B

Alaskan polygonal networks

Rainier the mounds begin on a terrace at an elevation of 340 feet and extend down the valley of the DesChutes River to the vicinity of Offut Lake. The glacial outwash channel coincides with the present DesChutes drainage until it reaches a point west of Offut Lake, where the outwash channel turns southwest, away from the river, and forms Rocky Prairie (pl. 1, *A*). Here the mounds leave the DesChutes drainage, which now flows northwestward into Puget Sound, and follows the old outwash channel. Where the DesChutes Valley and the mound fields coincide, step-down terraces approach the river from the north. The terraces support a light mantle of mound material, but only the lower terraces are mounded. Southwest of Offut Lake the region affords excellent mounds, and all degrees of mound development are represented (pl. 1, *D*). Mounds occur in kettles and in prairie channels, on flat terraces, or on the brink of terraces and on the steep slopes that join adjacent terraces. Newcomb (1949) considered the mounds in kettles to have ridden down with the surface of the gravel as the buried ice melted out. He stated: "It was the writer's observation that the mounds which occur within definite kettle depressions are so poorly formed they could have reasonably gone through the settling incident to the formation of the kettle." The writer is in agreement with this interpretation.

ORIGIN

INTERPRETATION

The mounds were formed by running water that flowed across partially thawed, polygonally fissured ice fields (see pls. 2, 3). The water, in cleaning and widening the polygonal trenches, re-exposed the submound surface, which, in many instances, was the lag cobble surface developed during the dissection of the outwash gravel terraces. Where the erosion was more vigorous, the intermound areas were scoured below the lag cobble surface, giving the mounds a pedestal base of submound gravel. Conversely, where the erosion was slight, the mounds are close set and may be nearly connected on all sides by part of the original pebbly-silt mantle. The size of the intermound areas is a function of the degree of erosion that formed the mounds. In some places erosion was very slight or lacking, and here a continuous silt-gravel mantle is preserved to a depth comparable to the height of the neighboring mounds. If polygonal-fissure ice did not form in the mantle, then the mantle was eroded uniformly from the top down, the net effect being a reduction in the thickness of the mantle.

The existence of cobbles and small boulders within the mounds seems to require that the area be submerged during the time of the pebbly-silt deposition. After such deposition, the area was subjected to a periglacial climate, during

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PLATE 2

A, Polygons of 200–300 feet in diameter in a rectilinear pattern of fissure ice found in silts north of the Brooks Range, Alaska. The ditchlike areas are caused by the lateral growth of fissure ice. Photograph compliments of K. B. Woods, Purdue University.

B, Polygons of 75-foot diameter in a hexagonal pattern of fissure ice found north of Brooks Range, Alaska. This pattern is thought to be the dominant type for the development of the branching trenches and the control for mound spacing in southwestern Washington. Photograph compliments of K. B. Woods, Purdue University.

which polygonal-fissure ice formed in the pebbly silts. The growth of ice wedges continued until a period of thawing was initiated, during which the ice melted in the fissures and some thawing occurred in the pebbly silts. The thawing of the ice wedges, or fissure ice, progressed more rapidly than the thawing of the patches of earth enclosed by the wedges, because of the insulation effect of the thawed silts upon the still frozen cores of each polygon. The thawing of the polygons progressed in such a way that the corners of the interwedge silt blocks melted more rapidly than the sides, and the frozen core of each polygon thus approached a mound shape. This thawing was analogous to the thawing of an ice cube and somewhat analogous to the spheroidal weathering of granite blocks. While the cores of the polygons were still frozen, the region was briefly subjected to erosion by running water. The erosional hypothesis requires a large amount of water or a quantity of water sufficiently retarded by ice in the restricted area near Little Rock to raise the level of the river high enough to cover the maximum relief of the mound fields, which is about 100 feet on Mima Prairie. It is known (Bretz, 1913; Mackin, 1941) from the history of the Vashon glaciation that marginal lakes existed and drained southward across the outwash prairies during the retreat of the ice. Such discharge is considered the source of the water that flowed down the outwash channels over the half-thawed polygons and stripped from around the frozen cores that material which was thawed.

The mounds, therefore, are probably the result of erosion by an ice-choked flood river of short duration in which the thawed ground was removed from the polygonal trenches and from the hemispheriodally shaped frozen cores of each polygon. When the flood abated, the water was drawn off through the last and lowest channels of each prairie. As the water flowed in the lowest prairie channels longer than in other areas, the frozen cores of the polygons in the channels were thawed excessively and removed proportionally to the degree of thawing and erosion. The frozen cores left after the water subsided formed the Mima Mounds.

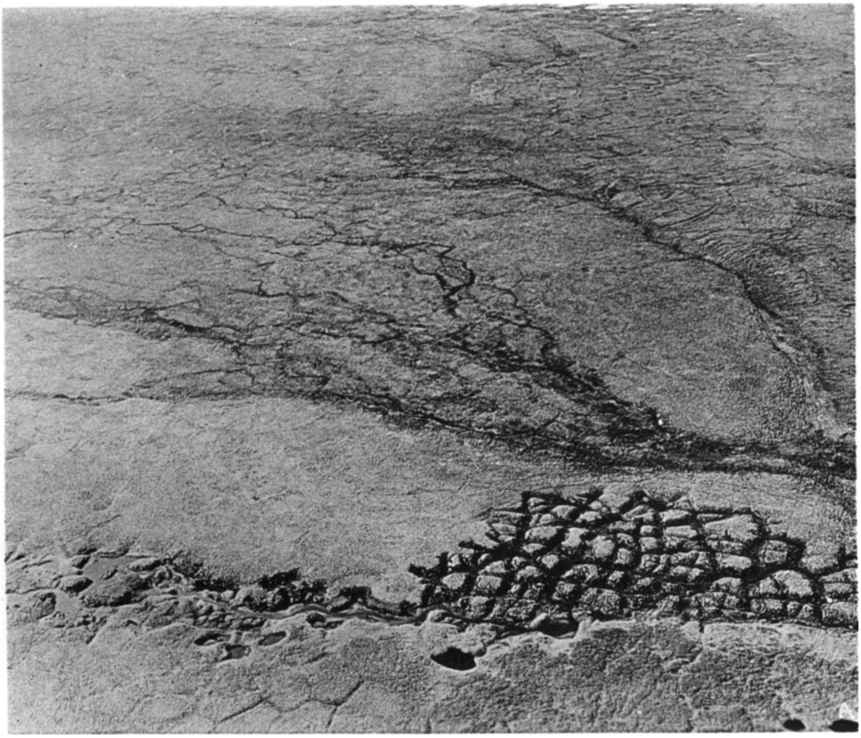
EVIDENCE

If the mounds originated through erosion of a silt mantle that was crisscrossed by a network of ice wedges, it is logical to suppose that some remnant of an undissected silt mantle, showing trenches or depressions corresponding to melted ice wedges, would be preserved near the mound area. The pebbly black silt characteristic of the mounds is present as a continuous mantle to a depth comparable to the mound height in several areas, but the surface features are generally obscured by cultivation. However, on Frost Prairie, 2 miles north of Bucoda, an area that lies between the nonmounded Skookumchuck Valley and the mounded Scatter Creek drainage, *but which did not receive meltwater after the ice had retreated considerably*, branching depressions up to 4 feet deep occur in little-dissected mound material (pl. 2, *B*).

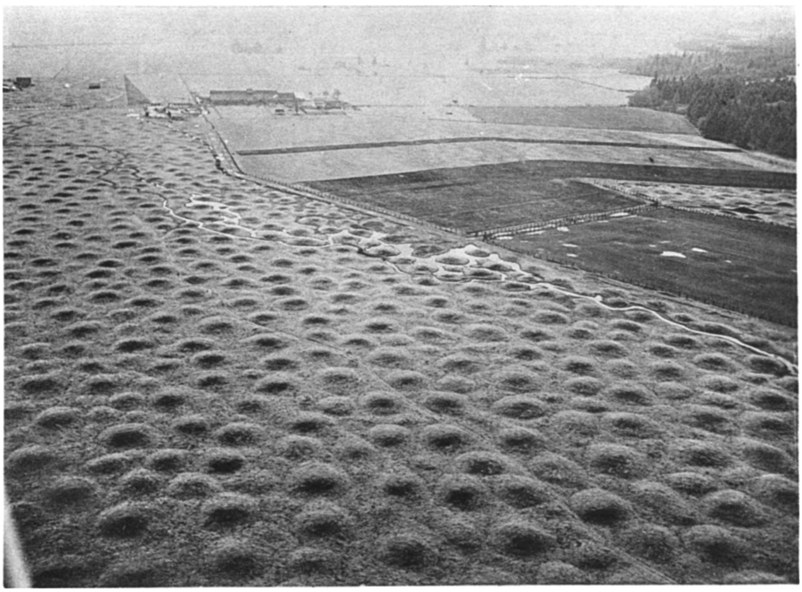
PLATE 3

A, Stream erosion of partially thawed polygons. Uneroded polygons about 75 feet across. North of Brooks Range, Alaska. Photograph compliments of K. B. Woods, Purdue University.

B, After a rainstorm, looking down gradient along a small perched stream on Mima Prairie.



A



B

Streams in polygonal network and in Mima Mounds

Some trenches reach to the submound material surface, exposing small cobbles. The depressions or trenches are triangular shaped in ground plan, with the depth of the trenches progressively less toward the points until they reach the prairie surface or join a branch from a neighboring hollow. In plan, they make a hexagonal network in the pebbly-silt terrace. The writer saw no discrete mounds, but what might be called mounds had low protuberances suggestive of incipient mound development from a flat top which coincides with the prairie surface. Stereoscopic study of air photos and subsequent field checks show that the depressions lie along an old submound channel, faintly showing in the prairie surface. Outside the channel the depressions are less in depth and less perfect in pattern, gradually dying out in an uninterrupted prairie surface. The writer attributes the localization of the branching trenches along this channel to the concentration of ground water on top of the submound surface. This concentration of water could feed and enhance the growth of polygonal-fissure ice in the overlying pebbly-silt mantle and, later on, by melting of the fissure ice, leave the branching trenches. If floodwater could have reached this area, the branching trenches would have been enlarged and mounds would have been formed.

Further evidence for the erosional origin of the mounds is found in the mounds themselves.

1. The Mima-type mound is restricted to the outwash valleys of the Vashon glacier but is limited to those valleys that could receive floodwater from the north.

2. Well-developed mounds occur in topographic positions where they could have been eroded by a flood river. Although high-level terraces adjacent to the outwash valleys have a mantle of pebbly-silt material, they are unmounded.

3. Terzaghi and Peck (1948, p. 133) state:

> The tendency of the ice layers to develop and grow increases rapidly with decreasing grain size. On the other hand, the rate at which the water flows in an open system toward the zone of freezing decreases with decreasing grain size. Hence it is reasonable to expect that the worst frost-heave conditions would be encountered in soils having an intermediate grain size. As a matter of fact, experience has shown that the greatest difficulties with frost heave occur in fine silts and sand-silt mixtures. . . .

Because polygonal ground ice is restricted to fine sediments or material having a high percentage of fine sediments, it is natural to find that the mounds occur only within the pebbly-silt mantle of the region and not in the glacial outwash gravel lacking this silt. Taber (1943, p. 1525) makes the following statement:

> Segregated ice forms when growing ice crystals exclude soil particles with which they are in contact instead of growing around them. An ice crystal can grow and displace an adjacent soil particle so long as they are separated by a thin film of water which transmits pressure and into which water molecules can be pulled to attach themselves to the growing crystal. If the soil particle is very small, the molecules have to travel only a short distance through the film to reach the points where they are attached to the growing crystal; but if the particle is large, it takes longer for the molecules to reach their points of attachment, and meanwhile, freezing may extend downward around the particle, thus gradually enclosing it.

It is obvious, therefore, that, upon freezing of the submound material of sand and gravel, segregated ice would not form. Instead, the ground would simply become frozen, while the overlying pebbly silts might develop segregated ice masses or wedges.

4. Mounds occur on topographic fea-

tures comparable to those where polygonal ground ice is forming today.

5. Mounds in any one area have a uniform maximum height, indicating that they were carved from a common mantle locally of a uniform thickness.

6. The mounds have pronounced curved down-gradient alignment and are rather uniformly spaced. These features require a mechanical control such as polygonal-fissure ice to form them. However, much of the alignment is due to the eroding effect of the water, which tended to flow in direct courses and thus to cause increased erosion on the pebbly silt in the path of a stream.

7. Some intermound areas were swept clean of all mound material, leaving a clean cobble surface. Other areas were eroded below the cobble surface, which is the base of the mounds, thus leaving a pedestal of submound gravel beneath the mounds. In other areas, where erosion was slight, intermound areas still carry some mound material.

8. Where mounds are widely spaced, there is evidence of extensive erosion, such as low and subdued mounds compared to their neighbors, as well as "blanks" in the regularity of spacing of the mounds.

9. The double or triple-tied mounds are evidence of the imperfect development of fissure ice in the pebbly-silt mantle.

10. Mounds are commonly absent in the lowest prairie channels, but in their place occur a few bars of segregated mound material. This indicates the actual removal and redeposition of mound material by running water.

11. Mounds locally show one asymmetrically developed steep side and a pronounced parallel elongation to one another, regardless of minor topographic differences in occurrence. The one steep side of the mounds faces up-gradient, a feature common to other material similarly eroded. To expect a perfectly spaced hexagonal pattern in fissure ice is unreasonable. The long axis of a thawing core of earth within a polygon should coincide with the long axis of the polygon. This might lie at some angle to the direction of the current and, therefore, produce a mound with its long axis not parallel to the direction of the current. But where mounds have been heavily eroded, as on Rocky Prairie, erosion has dominated over polygonal elongation, and the mounds have their long axes parallel and the upstream side of the mound steeper than the downstream side.

12. Cobbles and small boulders exist between and on the mounds. Most of them are found on the steep up-gradient side, as if floating ice containing erratics lodged against the mounds and dropped their load on that side. Some of the intermound erratics are as large as 5 feet in diameter.

13. Erosion of a frozen mantle unaffected by polygonal-fissure ice but surrounded by mound fields seems recorded by the differential stripping of this mantle from a knoll of frozen submound gravel. Such a knoll lies near the center of a prairie channel, 30 feet above the channel floor (see pl. 1, C).

EVALUATION OF SOME PREVIOUS THEORIES OF ORIGIN

No serious study based on examination of the mounds was made until Bretz (1913) suggested tentatively that mound material may have been washed into pits on the surface of ice and that this debris might have melted its way down and subsequently become mounds. Bretz made a list of conditions to which any serious attempt to explain the origin of the mounds must conform. The present erosional hypothesis fits these conditions rather well. Eakin (1932) considered the mounds and intermound cobbles to be the result of the segregation of gravel and soil of the mound region as a phenomenon of subarctic frost rearrangement of mixed alluvial materials.

Newcomb (1940) through published and unpublished work first presented the evidence of polygonal-fissure ice in the Mima Mound region. He believed that the material enclosed by ice wedges was forced toward the center of the polygon as the ice wedges grew. When the ice melted out, the interice earth blocks slumped down into mounds. Subsequent unpublished work (1949) takes to task a paper by Dalquest and Scheffer (1942), who deduced that the Mima Mounds were formed by the localized activities of pocket gophers (*Thomomys talpoides*) over thousands of years. Péwé (1948) attributed the origin of the mounds to the slumping of polygonal patches of earth into the ditches left by thawed polygonal-fissure ice. Although never having seen the Mima Mounds, Péwé considered the mounds to be of similar development as those he observed near Fairbanks, Alaska. He stated: "The Alaska mounds are in silt and fine sand. They vary in diameter from 10 to 30 feet and are from 1 to 8 feet high." The Fairbanks mounds ". . . are the result of the melting of a network of ice wedges. . . . Drilling into the low areas between the mounds has revealed the presence of clear ice." He illustrated a field of disconnected branching trenches that were formed when the ice masses melted out.

In general, Newcomb and Péwé propose the same origin for the mounds. The present writer is in hearty agreement with this hypothesis for the origin of some of the mounds in the Mima region, particularly where mounds are very closely set or in areas where there are branching trenches and immature mounds. Their hypotheses, however, do not explain the wide intermound areas or the anomaly in the relationship between wide intermound areas and the small amount of material in some mounds. Their hypotheses do not explain (1) the intermound cobbles stripped clean of all mound material, (2) an isolated mound surrounded by bare cobbles, (3) pedestals of submound material beneath the mounds, (4) the absence of mounds in prairie channels, (5) the steep sides of the mounds facing up-gradient, and (6) their enhanced alignment. These features can best be accounted for by erosion of an ice network after thawing.

Publication of the gopher hypothesis of Dalquest and Scheffer (1942) resulted in controversial discussions by Scheffer (1947, 1948), Grant (1948), Newcomb (1949), and many of us who were interested in the problem. These discussions, however, were largely concerned with what a gopher might or might not do. Scheffer (1948) states that "only a living, adaptable force, not a physical agency, could have produced the Mima-type mounds out of widely varying materials and in widely varying environments from Mexico to Puget Sound."

In view of the knowledge of periglacial geological processes now accumulated, it seems clear that the origin of the mounds is no longer a biological problem and therefore there is little need to continue to evaluate the engineering aptitude of the gopher.

AGE

The mounds were formed early in the recessional phase of the Vashon glacier, when the ice had retreated from the Tenino area but still occupied most of the Puget Sound basin. The mounds on

Rocky Prairie were formed when Offut Lake was still a block of ice. Wide, lightly mounded channels start at the west edge of the lake, 30 feet above the present level. These channels fed the floodwaters across the prairie during the short time in which the mounds were formed. The lake now drains from the east side by a meandering stream that joins the Des-Chutes River.

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REFERENCES CITED

BRETZ, J. H. (1913) Glaciation of the Puget Sound region: Washington Geol. Survey Bull. 8.

DALQUEST, W. W., and SCHEFFER, V. B. (1942) The origin of the Mima Mounds of western Washington: Jour. Geology, vol. 50, pp. 68–84.

EAKIN, H. M. (1932) Periglacial phenomena in the Puget Sound region: Science, new ser., vol. 75, p. 536.

GRANT, CHAPMAN (1948) Mima Mounds: Jour. Geology, vol. 56, pp. 229–231.

MACKIN, J. H. (1941) Glacial geology of the Snoqualmie-Cedar area, Washington: Jour. Geology, vol. 69, pp. 449–481.

NEWCOMB, R. C. (1940) Hypothesis for the periglacial "fissure polygon" origin of the Tenino Mounds, Thurston County, Washington (abstr.): Geol. Soc. of the Oregon Country, Geol. News Letter, vol. 6, p. 182.

——— (1952) Origin of the Mima Mounds, Thurston County region, Washington: Jour. Geology, vol. 60, pp. 461–472.

——— Refutation of the "gopher origin" for the Mima Mounds, Thurston County region, Washington (unpub. ms.).

NIKIFOROFF, C. C. (1937) The inversion of the great soil zones in western Washington: Geol. Rev., vol. 27, pp. 200–213.

PÉWÉ, T. L. (1948) Origin of the Mima Mounds: Sci. Monthly, vol. 66, pp. 293–296.

SCHEFFER, V. B. (1947) The mystery of the Mima Mounds: Sci. Monthly, vol. 65, pp. 283–294.

——— (1948) Mima Mounds: a reply: Jour. Geology, vol. 56, pp. 231–234.

TABER, STEPHEN (1943) Perennially frozen ground in Alaska: its origin and its history: Geol. Soc. America Bull., vol. 54, pp. 1433–1548.

TERZAGHI, KARL, and PECK, R. B. (1948) Soil mechanics in engineering practice, New York, John Wiley & Sons, Inc.