Formation of Mima mounds: A seismic hypothesis

Andrew W. Berg*
U.S. Bureau of Mines, Western Field Operations Center, Spokane, Washington 99202

ABSTRACT

Mima mounds approximately 2.5 to 15 m in diameter and up to 3 m high occur on the ground surfaces at Mima Prairie, south of Olympia, Washington, in the Channeled Scabland of eastern Washington, and at many other locations in the United States and around the world. Small-scale Mima mounds can be produced experimentally by subjecting a plywood board covered with a thin veneer of loess to impacts that produce vibrations in the board. Experimentally produced mounds have characteristics that are nearly identical to those found in the field. This suggests that most Mima mounds formed as the result of seismic activity in conjunction with unconsolidated fine sediments on a relatively rigid planar substratum.

INTRODUCTION

Ground surfaces at Mima Prairie south of Olympia, Washington, and in the Channeled Scabland of eastern Washington are covered with thousands of mounds, the genesis of which remains unclear. The mounds are smooth, hemispherical to ellipsoidal forms protruding from the ground. They are variously called Mima mounds, prairie mounds, pimple mounds, or, simply, mounds. In this paper all mounds are called Mima mounds, after the type locality at Mima Prairie.

Mima mounds are also found in other areas of the Puget Trough and Columbia plateaus, Basin and Range province, Central Valley of California, Pacific Border terraces, southern Rocky Mountains, river terraces of the Great Plains, Central Lowlands, Ozark-Ouachita region, and the Gulf Coastal Plain (Knechtel, 1952) (Fig. 1). Mounds are also found in Africa and South America (Cox, 1984; Cox and Roig, 1986) and are no doubt present in many other parts of the world.

Mounds at Mima Prairie are 2.5 to 15 m in diameter and up to 2.4 m high. Many intermound areas contain a pavement of cobbles up to 0.2 m in diameter. These mounds are composed of "soft black prairie silt" resting on well-bedded gravel (Scheffer, 1947). They were described by Washburn (1988) as being composed of "black non-bedded sandy loam overlying bedded Vashon outwash"; Washburn also suggested that some of the silt fraction may be loess.

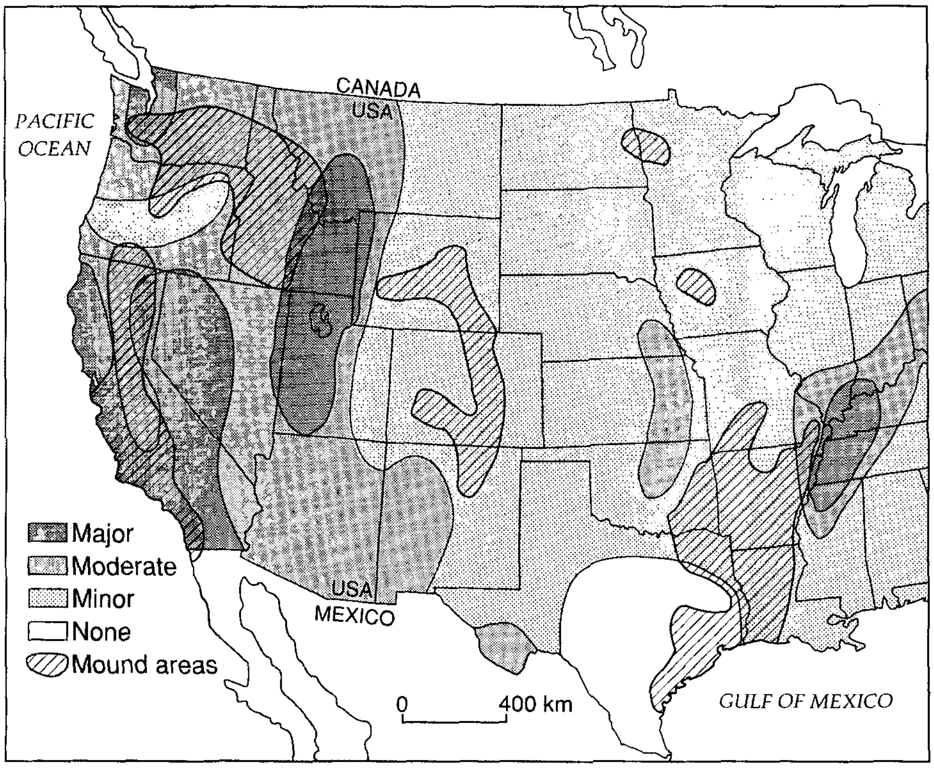

Figure 1. Mima mound distribution and seismic risk zones in United States. Modified from Algermissen (1969) and Washburn (1988).

In the Cheney quadrangle of the Channeled Scabland, the mounds are generally 10 to 15 m in diameter and 1 to 3 m high (Tallyn, 1980), and cobbles are usually present in intermound areas (Fig. 2). These mounds are composed of 55% sand, 40% silt and clay, and 5% gravel-sized and larger material. The sand, silt, and clay are eolian. The gravel-sized and larger material is composed of basalt rubble from the planar substratum of basalt on which they usually form.

Mima mounds form where a shallow mantle of loess or other fine unconsolidated sediment lies on a relatively rigid planar substratum. The substratum can be hardpan, bedded gravel, or any bedrock type that forms a relatively planar substratum. The fine unconsolidated sediments forming the mounds typically are not stratified.

Four common modes of occurrence are illustrated in Figure 2. Figure 2A is a cross-section view of mound occurrence on bedded gravel, typical of the mounds at Mima Prairie and of some locations in the Channeled Scabland. Figure 2B shows the usual mode of formation in the Channeled Scabland. Here mounds typically formed on Columbia River basalts, which were denuded of their loess cover by late Pleistocene flooding from glacial Lake Missoula. Sedimentation resumed and mounds formed, commonly with cobble rings surrounding them. In California, clay hardpan is the usual subsurface material (Fig. 2C). On sloping surfaces ellipsoidal shapes are common in all known mound areas, and steep upslope ends are mentioned by most authors. The dashed outline in

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*This paper is based on independent study, and reflects only my personal views.

Figure 2D represents the morphology expected on a horizontal surface. If the seismic hypothesis explains their genesis, then it is easy to see how the shape indicated by the solid outline could be produced by seismic wave motion on sloping surfaces.

PROPOSED HYPOTHESES FOR MIMA MOUND FORMATION

The hypotheses proposed previously to explain the genesis of Mima mounds may be grouped into four main categories: depositional, erosional, periglacial, and biological. Some explanations rely on a combination of several categories (Washburn, 1988).

One depositional hypothesis proposes that vegetation develops, attracts, and holds more soil, while soil is removed from intermound areas. Another proposes that loess settles in water-filled depressions, which become vegetated and attract more soil, resulting in mound growth. Erosional hypotheses suggest that mounds result from the removal of the soil mantle in intermound areas by wind or water, leaving the mounds as topographic highs. Periglacial hypotheses propose that geomorphic processes, which are enhanced in a periglacial environment, produce mounds. Most biological hypotheses suggest that the mounds were formed by burrowing animals, usually gophers. A comprehensive review of the various Mima mound hypotheses, with special reference to the Puget Lowland, contains 159 bibliographic citations (Washburn, 1988).

PROPOSED SEISMIC HYPOTHESIS

My interest in the possibility of a seismic origin for Mima mounds began when I observed the behavior of a thin layer of loess on a rigid surface subjected to impact-induced vibrations. The vibrations reformed the unconsolidated material into perfect microreplicas of mounds I had seen in the field, including the cobble rings that commonly surround them (Berg, 1989).

To understand how unconsolidated fine sediments on a relatively rigid planar substratum might form Mima mounds, consider the case of propagating wave patterns and their reflected analogs, in which the coincidences of wave peak to wave peak and wave peak to wave trough occur at some angle relative to one another. This results in points where energy delivered to the surface material is accentuated. Where wave peaks and wave troughs coincide, the wave energies are canceled, resulting in no force being delivered to the surface at that point. Figure 3, a plan view of hypothetical interference patterns between propagating and reflective waves, illustrates the pattern of canceling and reinforcing points that can be produced by propagating and reflective wave interference.

Where propagating and reflective wave peaks coincide, maximum displacement occurs. At points where wave peaks and troughs coincide, no displacement takes place. Particles will move away from points of maximum displacement and tend to collect at points of no displacement, because there is no force at these points to move material. Simply speaking, material is bounced from points where wave peaks coincide to points where wave peaks and troughs cancel each other.

Richter (1958, p. 129) made the following comment on visible waves.

> Whatever the facts, observations manifestly cannot refer to the seismic waves recorded by instruments; these travel at speeds measurable in miles per second and cannot possibly be followed by an observer's eye. Waves actually seen would have to be of another physical type with much lower velocities. They might, however, be a modification of standing waves; that is, an interference pattern of nodes and loops may be set up which shifts over the ground as the exciting disturbance changes. A high school instructor described to the author what he saw in the streets of Long Beach in 1933 during an earthquake; it could easily be such a pattern of nodes and loops. There was no suggestion of large motion of the surface of the ground, but the loops

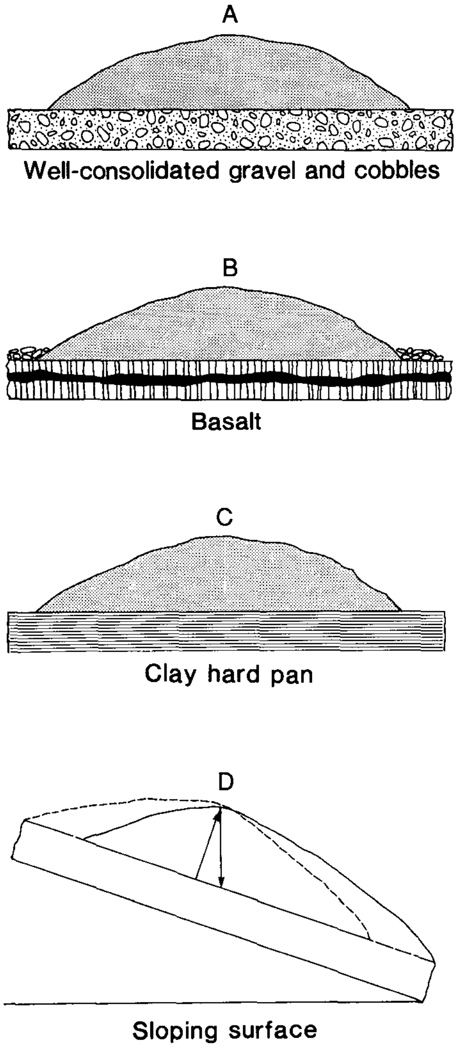

Figure 2. Cross-section views of Mima mounds formed on various surfaces.

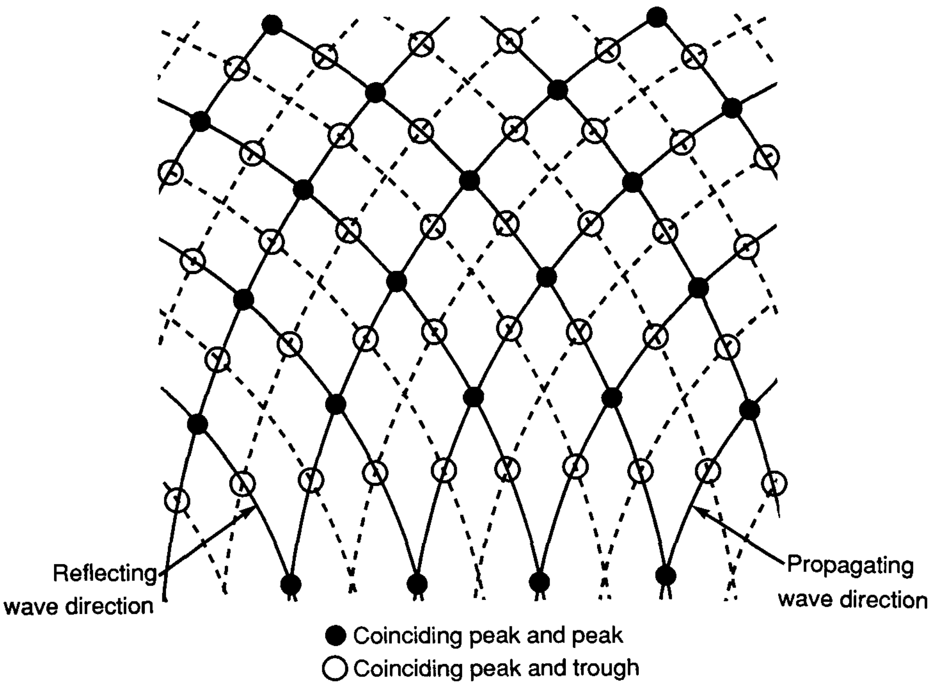

Figure 3. Coincidence of wave peak to peak, wave peak to trough, and resultant interference patterns.

> or antinodes were put in evidence by dust thrown into the air, while the nodes appeared quiet.

A similar observation was reported to me by a colleague who observed the same phenomena during a seismic event in Tacoma, Washington, in 1949 (R. Van Noy, 1987, personal commun.).

EXPERIMENTAL EVIDENCE

Experiments to illustrate certain geologic phenomena can be informative, with the caveat that they are usually not proofs, but demonstrations that sometimes serve the useful function of guiding thought processes to possible insights.

The simple experiment described here demonstrates that when vibrations are produced on a rigid planar surface covered with a thin layer of unconsolidated fine sediments, mounds are formed. The similarity between these experimentally produced mounds and those observed in the field is striking.

The micromounds were produced experimentally using a 60 × 46 × 1.9 cm plywood sheet for the substratum. A veneer of loess 2 to 3 mm thick was sprinkled evenly on the plywood sheet. Four or five moderate blows from a hammer were directed to the center of the plywood sheet from the bottom side. The result was the field of micromound forms shown in Figure 4. Note how the coarser material forms rings around the experimentally produced mounds, similar to those features observed in the field.

Subjecting these formed micromound fields to further tremors demonstrates a fact of fundamental importance: the mounds, once formed, apparently represent a state of "morphologic equilibrium" in regard to subsequent vibrations of similar magnitude in the subsurface. In this connection it may be worth noting that a mound 10 m in diameter and 1.5 m high would contain about 85 Mt of material.

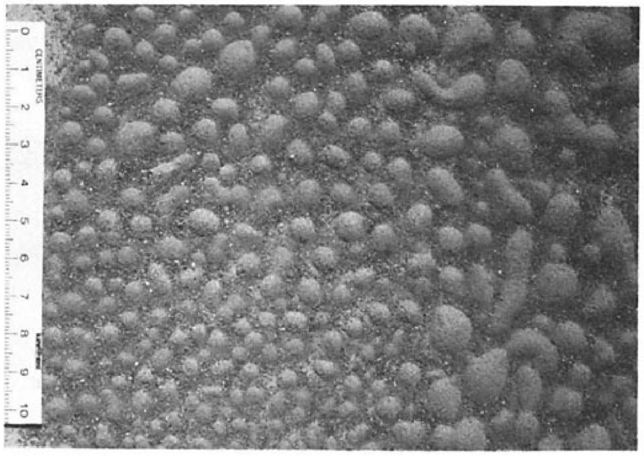

Figure 4. Experimentally produced mounds showing coarse material surrounding mounds and in intermound areas. (Photograph by Jack J. Satkoski.)

FIELD OBSERVATIONS

Mounds at Mima Prairie and in the Channeled Scabland are fairly young features. At Mima Prairie they postdate the Vashon Stade of Fraser glaciation, which culminated at about 14 ka (Washburn, 1988). In the Cheney quadrangle of the Channeled Scabland they postdate the late Pleistocene floods from glacial Lake Missoula (15.3 to 12.7 ka) (Waitt, 1985) and pre-

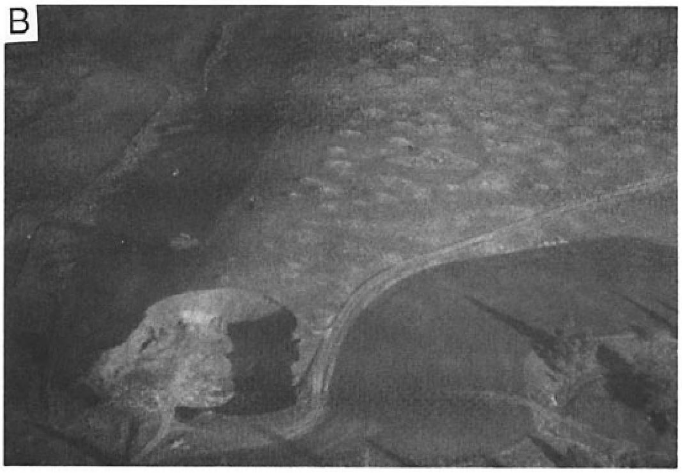

Figure 5. Mima mounds near Rock Lake, Washington. A: Mima mounds formed on planar surfaces of Columbia River basalts. B: Mima mounds formed on bedded gravel deposit. C: Mima mounds on basalts and subfluvial island on which they are absent. (Photographs by Jack J. Satkoski.)

date a Mazama ash fall dated at 7 ka that is situated stratigraphically above the mounds.

The formation of Mima mounds appears to depend on the coincidence of a not-too-thick (less than 1.8 m in the Channeled Scabland) veneer of unconsolidated fine sediment, a relatively rigid planar substratum, and seismic tremors. The Channeled Scabland, where the mounds are numerous, met these criteria perfectly. Late Pleistocene flooding from glacial Lake Missoula created the Channeled Scabland. After the last episode of flooding, loess accumulation began anew on the planar surfaces of the exhumed basalts. Between 12.7 and 7 ka, eolian sediment accumulated on the exhumed basalts of the Channeled Scabland to depths sufficient for mound formation.

At other locations in the United States and elsewhere, the mounds could be older, because their formation depends on a relatively thin unconsolidated sediment mantle, which in some cases could develop over considerable time because of low sediment-accumulation rates.

It seems noteworthy that in the Channeled Scabland and at Mima Prairie, mounds occur on surfaces on which the cycle of sedimentation was disrupted and then reinitiated. In the Channeled Scabland, deeper deposits of loess adjacent to and within the path of the floodwaters remain formed into linear ridges of the rich Palouse soil of the region, which is present in thicknesses exceeding 30 m. The basal parts of these deep accumulations may contain relict evidence of mounds created in the past when these sediments were of an appropriate thickness. The mounds probably represent an early stage in development of the soil mantle (Olmsted, 1963).

Figure 5A shows mounds formed on surfaces of Columbia River Basalt near Rock Lake, Washington. The basalt was denuded of its loess cover by late Pleistocene flooding from glacial Lake Missoula. Coulees were formed by floodwaters plucking columnar and other zones of structurally weakened basalt. Eolian sedimentation resumed after the last episode of flooding, developing thicknesses necessary to produce mounds. Mounds are generally 10 to 15 m in diameter and 1 to 3 m high. Figure 5B shows a mound field developed on a bedded gravel bar in the Rock Lake, Washington area. This setting is analogous, in the subsurface material on which the mounds have formed, to the Mima Prairie location. In Figure 5C, an uncultivated Palouse island surrounded by mounds is shown. Cultivated land can be seen at the top of the photograph. The streamlined shape of the island suggests that it was subfluvially eroded (Baker, 1978). Note that it contains no mound forms, whereas the surrounding terrain has them in abundance. They are probably absent from the island because greater thicknesses of fine sediments dissipated the seismic energy that otherwise would have produced mounds.

SEISMIC CONNECTION

Corbel (1954a, 1954b) suggested that patterned ground is produced by seismicity. At Spitsbergen, Svalbard Islands, Norway, zones with the most abundant stone polygons (patterned ground) were in areas of maximum seismicity. Less active seismic zones were reported to have fewer stone polygons, and stable terranes had none. Corbel also suggested that areas like Spitsbergen the world over, where deglaciation had taken place, would have been areas of moderate but repeated seismic activity, from isostatic adjustment to crustal unloading from deglaciation. Corbel's work strongly suggests that seismicity has much to do with the formation of some patterned ground, which could explain mound formation in which fine sediments are lacking or are so minimal that only the stone rings form, little material being available for interior mound formation.

Most known mound areas in the United States are near or in areas of past moderate to high seismicity (Fig. 1). Mounds in Kenya, Africa (Cox, 1984), and in Argentina near the eastern foothills of the Andes (Cox and Roig, 1986) are in areas of high seismicity, as are mounds at Mima Prairie and the California trough, where they are almost indistinguishable from one another.

CONCLUSIONS

Most Mima mounds form from seismic activity in conjunction with relatively thin depths of fine unconsolidated sediment resting on a rigid planar substratum. They are, therefore, surface expressions of past seismic activity. This hypothesis accounts for their existence in a wide variety of geomorphic and climatic provinces and allows prediction of their existence wherever these conditions have coexisted.

A substantial amount of further work is indicated to verify the seismic hypothesis, but I believe it points the way to the solution of a geologic enigma that has been with us for more than 100 years.

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Reviewers' comments

Concerns a mystery that has been discussed for over 150 years and that may have generated a greater variety of hypotheses than any other geologic feature. You editors will have to fight off a host of those who want to be heard! It may be the most talked-about paper you'll ever publish.

Charles Higgins

Very interesting hypothesis. It makes a lot of sense—a real "eye-opener."

Edward Keller
