Comment and Reply on "Formation of Mima mounds: A seismic hypothesis"

COMMENT

G. W. Cox, *Department of Biology, San Diego State University, San Diego, California 92182*

Berg's (1990) suggestion that seismic activity has resulted in the formation of Mima mounds from unconsolidated fine sediments lying on rigid, planar substrates is fraught with difficulties.

First, his Figure 1 (Berg, 1990, p. 281) shows no clear correspondence of mound regions to regions of moderate to major seismic activity, as claimed (p. 284). Most of the extensive areas of mounded topography in the Rocky Mountain, Ozark-Ouachita, and Gulf Coastal Plain regions experience only minor seismic activity, and along the Texas Gulf Coast, where the largest Mima mounds in North America are (W. A. Price, personal commun.), seismic activity is negligible. Mima mounds are absent from most of the areas in the United States that have major seismic activity. In addition, the Argentinian mounds of Cox and Roig (1986) are not in the eastern foothills of the Andes, as stated (p. 284), but in the central pampean region, about 500 km to the east.

Second, Berg's Figure 2 (p. 282) inaccurately portrays several mound features important to the hypothesis. Figure 2A does not show that mounds in stony soils contain a substantial content of small stones, up to about 50–60 mm in diameter, and that the concentration of such stones is commonly greater in the mound soil than in the adjacent intermound soil (Cox, 1984; Cox and Gakahu, 1986; Cox et al., 1987). Figure 2B implies that cobble-sized stones occur only in a narrow zone at the edge of mounds on basaltic substrates. In reality, these stones are part of a continuous basal layer of such elements in the mound and intermound soils, and are simply exposed near mound edges (and frequently elsewhere in the intermound zone) by removal of soil due to the tunneling of pocket gophers (Cox and Allen, 1987). Figure 2, A, B, and C also imply incorrectly that the intermounds lack any soil of the type forming the mound.

Third, results of the plywood-soil-hammer experiment, as described, cannot realistically be extended to Mima mound landscapes. No evidence is provided that blows by a hammer to the underside of a plywood sheet qualitatively simulate seismic activity. Neither is it shown that the force of these blows is comparable, at the scale of the experimental model, to seismic forces that occur in nature. The micromound forms created in the experiment do not correspond in scale to Mima mounds. The 2–3 mm depth of experimental soil yielded micromounds that seem to be about 3–10 mm in diameter, suggesting that a 2–3 m depth of parent material in nature would be needed to produce mounds 3–10 m in diameter. Mima mounds, which at full size range from 10 to 50 m in diameter, are absent from soils of such depth. The experimental soil (described as loess, but apparently containing particles up to about 1 mm in diameter), apparently consisted of dry, loose sediment sprinkled on a rigid surface, and it had no macrostructure. This does not realistically simulate the wide variety of parent materials of mounds in nature. These include residual soils derived by weathering of bedrock, alluvial materials of varied textures, lacustrine deposits, and eolian material. The formation or deposition of almost all of these materials is gradual, and pedogenic processes operate continually to produce some degree of macrostructure, which can make the stratum more resistant to seismic deformation. Also, contrary to Berg's statement (1990, p. 282), it is not easy to see how seismic activity can produce the modification of form (Fig. 2D) seen on slopes; solifluction or gelifluction of soils on slopes typically creates mounds with a steep downslope side (Daubenmire, 1981, Fig. 2; Washburn, 1980, Fig. 6.13).

Fourth, no field evidence is offered for the hypothesized mechanism. Do mounds occur in areas of recent volcanic activity (e.g., Mount St. Helens) with conditions of frequent seismic shocks and fresh, unconsolidated ash deposits on much more rigid substrates? If not, this suggests that seismic activity in nature is qualitatively or quantitatively incapable of forming mounds.

Fossorial rodents (such as pocket gophers, Family Geomyidae) are necessary and sufficient agents of Mima mound formation in North America. They mine and translocate large volumes of soil in the manner required to produce mounds (Cox, 1990a) and adjust their activities on slopes in a manner that accounts for the observed change in mound form (Cox, 1990b).

REPLY

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

Paleoseismology is providing dramatic insights regarding paleoseismic events, their distribution, and their effects. Quaternary seismic activity was more widespread and intense than previously believed. I did not claim that my Figure 1 (Berg, 1990) showed a "clear" association of mounds and seismic activity, as purported by Cox, but only a general association, which may become clearer as the distribution of paleoseismicity is revealed. Terms such as "minor" or "negligible" seismicity should be used with great care.

The three New Madrid earthquakes of 1811–1812 were rated at *M* 8.1, 8.2, and 8.3, and are the largest "stable continent" earthquakes reported anywhere in the world (Johnston and Kanter, 1990). Damage was reported 1600 km away, on the U.S. East Coast. The New Madrid meizoseismal zone extends into the Ozark-Ouachita highlands to the southwest. Whereas New Madrid–type earthquakes are infrequent, episodes of similar magnitude or greater could have occurred farther back in the Quaternary, affecting areas without historical seismicity. It is likely that earlier occurrences were centered at other locations along the northeast-southwest inferred rift zone where the New Madrid events took place.

Fault systems in the Rocky Mountain mounds area, east of the zone of high seismic risk (Berg, 1990) are sites of frequent *M* 4 earthquakes; there are occasional events of *M* 5 and *M* 6. Holocene earthquakes of *M* 7 or greater are possibilities that cannot be ruled out (Scott, 1970).

Geologic evidence of recurrent rapid coastal subsidence off the coast of Washington documents six such events over the past 7 ka. Sheets of sand atop at least three of these buried lowlands provide evidence that tsunamis resulted from the events causing the subsidence. These may have been great earthquakes (*M* 8 or more) from the subduction zone between the Juan de Fuca and North America plates (Atwater, 1987). Any of these events could have produced seismic shaking of the prairies near Puget Sound, which are covered with mounds.

The relation between mounds and seismicity in California is surely too obvious to require elaboration. The Carrizo plains, astride the San Andreas fault, are peppered with mounds.

In my paper I said "near the eastern foothills of the Andes," not "in the eastern foothills of the Andes," as stated by Cox. Cox and Roig (1986) reported that "Branner (1905) stated that mounds similar to Mima mounds were common in areas along *the eastern base of the Andes* in Argentina, but did not give specific localities. . . . Oliver P. Pearson recently told us of possible Mima-type mounds in southern Cordoba Province, Argentina. This observation, together with Branner's (1905) early account, led us to undertake a search for Mima mounds in the region from *the western edge of the pampas to the base of the Andes* in central Argentina. This study was conducted from 8 to 20 January, 1985" (emphasis added).

The distance of 500 km cited by Cox lies east of the eastern boundary of their map (Cox and Roig, 1986). Mounds reported by them are located no more than 300 km east of the foothills; there are mound fields 200, 150, and 100 km east. My statement that they are situated "near" the eastern foothills of the Andes in a highly seismic area is accurate (Berg, 1990).

The "inaccurate portrayal of mound features" mentioned by Cox is an inaccurate description. The purpose of Figure 2, A–D, was to show graphically a variety of planar substrate types. I was concerned with only two features—a planar substrate and fine unconsolidated sediments. Small stones and cobbles in some mounds are of no consequence to the seismic hypothesis (Corliss, 1983). Cobble rings around many Channeled Scabland mounds are well-documented features (Tallyn, 1980).

The plywood-soil-hammer experiment demonstrates that micromounds are produced by a simple physical process. Their similarity to mounds seen in the field is striking. The question is: Are there processes operating in the geologic environment which could produce such forces? The answer is yes, and one such process is seismicity. The obvious variables involved in mound formation by seismicity make a linear relation between experimentally produced mounds and field mounds unlikely.

Solifluction or gelifluction are possible explanations for the mound form shown in my Figure 2D, but so is seismic activity, during which sediments are propelled upward normal to planar substrates, and return to those surfaces by gravity, producing ellipsoidal shapes with steep uphill slopes (Berg, 1990). Macrostructures developed by slow pedogenic processes would be mitigated by "seismoturbation" of the soils, and if they did develop, they would pose no obstacle to an earth-shaking event.

Regarding the Mount St. Helens example cited by Cox: earthquake activity associated with volcanoes of the Cascade Range is persistent but rarely comparable to historical regional earthquakes. More important, planar substrates are not present in the Mount St. Helens area. The surficial deposits are thick sequences of poorly consolidated volcaniclastic detritus, pyroclastic debris, and tephras, commonly preserved on valley-side slopes (K. Scott, 1990, personal commun.). Volcanic terrains are clearly among the least likely to experience mound formation of seismic origin.

The seismic hypothesis requires three conditions: (1) planar substrate, (2) fine unconsolidated sediments, and (3) seismic activity. Requirements 2 and 3 are variables within which mounds can form; requirement 1 is invariable. Thin covers of sediment with minimal shaking could form small mounds, which are present in many areas. Thicker covers and maximum shaking could form large mounds, which are present in some areas. I do not imply that seismicity = mounds; clearly, all three conditions are required. The interaction of conditions 2 and 3 explains concordant mound summits seen in most mound areas.

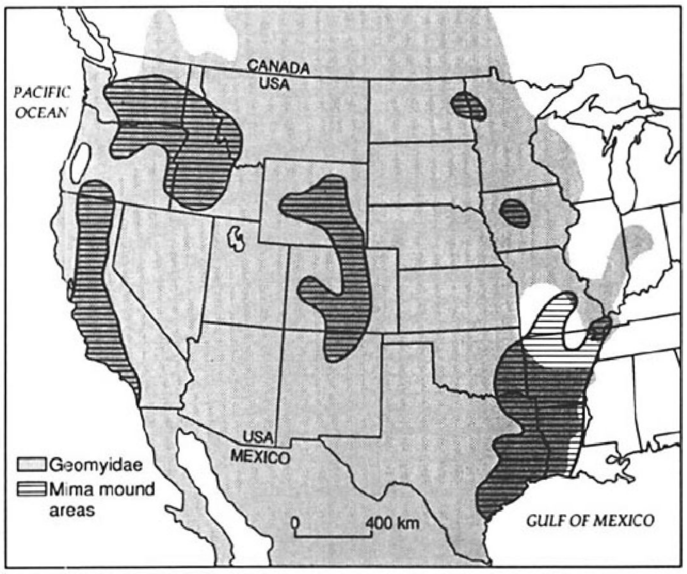

Figure 1. Combined ranges of 11 species of Geomyidae (pocket gophers) and Mima mound locations in United States (after S. Cassell, 1990, personal commun.).

Figure 1 here shows the range of the pocket gopher and mound areas. Gophers are widely distributed, but mounds are not. Gophers are absent without trace from many mounds; where present, they exact a destructive effect on mound integrity (Tallyn, 1980). Gophers and other small mammals invariably occupy the best habitat available, which in some areas includes mounds. That gophers inhabit mounds says no more about their role in mound development than to suggest that caves are constructed by the bats who inhabit them. The existence of mound areas proximal to zones of moderate to high seismic risk in the United States (Berg, 1990) is in sharp contrast to sporadic mound occurrences within vast areas of gopher habitation (Fig. 1). Further support of the seismic relation to mounds is provided by the Argentina and Kenya examples.

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