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J. C. Chatters
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September 1991

Prepared for the U.S. Department of Energy
National Low-Level Waste Management Program
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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ARCHAEOLOGICAL MOUNDS AS ANALOGS OF ENGINEERED COVERS FOR WASTE DISPOSAL SITES: LITERATURE REVIEW AND PROGRESS REPORT

J. C. Chatters
H. A. Gard

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Prepared for the
United States Department of Energy
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

Closure caps for low-level radioactive waste disposal facilities are typically designed as layered earthen structures, the composition of which is intended to prevent the infiltration of water and the intrusion of the public into waste forms. Federal regulations require that closure caps perform these functions well enough that minimum exposure guidelines will be met for at least 500 years. Short-term experimentation cannot mimic the conditions that will affect closure caps on the scale of centuries, and therefore cannot provide data on the performance of cap designs over long periods of time. Archaeological mounds hundreds to thousands of years old which are closely analogous to closure caps in form, construction details, and intent can be studied to obtain the necessary understanding of design performance.

Pacific Northwest Laboratory conducted a review and analysis of archaeological literature on ancient human-made mounds to determine the quality and potential applicability of this information base to assessments of waste facility design performance. A bibliography of over 200 English-language references was assembled on mound structures from the Americas, Europe, and Asia. A sample of these texts was read for data on variables including environmental and geographic setting, condition, design features, construction, soil physics, age, and causes of degradation. Detailed information was obtained on all variables except those relating to physical and hydrological characteristics of the mound matrix , which few texts presented.

Comparisons of analysis of data on the design features of a sample of 44 mounds or mound groups showed that a mound's condition was related to its shape and was positively related to pre-construction surface preparation, the use of layered construction, presence of a revetment, presence of sheathing material on the mound surface, and the use of stone in general in the mound matrix. The most durable mound is conical, built in successive layers on a prepared surface during one or more closely spaced construction phases. It has a revetment around the base, preferably of stones, and a stone sheathing. The sheathing need not be continuous, but may be simply an admixture of stones with the mound matrix. Rectilinear designs built of homogeneous materials and lacking revetment or sheathing are not durable. Factors initially expected to be inversely related to mound durability, regardless of construction features, were age and the presence of a below-ground burial vault. The inverse relationship was not found; design characteristics appeared to be the controlling factors.

The factors contributing most severely to mound degradation are agricultural activity, slope wash, looting, vandalism, and borrowing for fill material. The existence of certain design features, particularly the use of stone in construction, controlled slope wash and the effects of agricultural activity, but had no effect on the frequency of borrowing or vandalism. Borrowing or vandalism and destruction by agricultural activity result, respectively, from the burial of valuable items beneath mounds and the raised relief of mounds in often-level areas. Vandalism, or more appropriately, looting, is exacerbated by the obviously man-made appearance of mounds, which identifies them as a potential source of objects or materials of value.

It is concluded that an extensive amount of literature and data are available on structures closely analogous to closure caps and that this information is a valuable source of data on the long-term performance of mounded structures. Additional study is recommended, including an expanded analysis of design features reported in the literature and field studies of the physical and hydraulic characteristics of different mound designs.

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INTRODUCTION

This report presents the results of a literature review of archaeological data on ancient human-made mounds conducted by Pacific Northwest Laboratory for the U. S. Department of Energy's (DOE's) National Low-Level Radioactive Waste Management Program. Under federal regulations, low-level radioactive waste disposal systems must be designed to minimize the probability of human intrusion for 500 years (10CFR61) and to indefinitely prevent infiltration to groundwater of radiation in excess of 4 mrem/yr (40CFR193). The preferred design for low-level waste (LLW) disposal facilities includes a mounded, layered closure cap consisting of gravel and/or sand placed around and immediately above the waste to promote drainage, an impermeable silt or clay cap, and a layer of topsoil (Nyhan and Barnes 1988). Similar designs are being developed or recommended for uranium mill tailings covers (e.g., Caldwell and Reith 1990) and for protective barriers to isolate low- and intermediate-level defense wastes (Wing 1989). The designs are intended to minimize water drainage through the waste and, in at least some cases, to impede hand excavation and thus reduce the potential for direct public exposure.

Effectiveness of the closure cap design for preventing the movement of water into and through the waste medium will depend in part on the durability of the cover. Erosion of outer mound layers, which are typically intended to shed water or support vegetation that transpires water collected in the cover, will reduce the cover's effectiveness. Modern engineering, with its understanding of the properties of various construction media and techniques, can predict with a high degree of certainty the short-term durability and performance of these layered, earthen covers. However, knowledge of the long-term performance of different cover designs cannot be extrapolated from this short-term knowledge within acceptable confidence limits, because experimental means for verifying predictions are lacking. Therein lies the problem of public credibility of all waste disposal mechanisms designed for the long-term. In solving the problem of public confidence lies the applicability of ancient engineering works to the waste management problem (see Winograd 1986; Chatters 1989).

Humankind has been constructing earthen mounds in a wide array of shapes and sizes throughout much of the world for more than 5000 years. Design characteristics of these mounds vary, as do the conditions they have existed under over many centuries (Lindsay et al. 1982). Some of these man-made deposits mimic proposed low-level waste disposal structures closely enough that careful study of them and reasoning by analogy can be used to refute or support the predictions of performance assessment models (Figure 1). Archaeologists have been excavating and reporting on mounded structures in varying degrees of detail for more than two centuries, so an extensive database exists.

The primary objective of the literature review was to determine 1) the breadth of information about engineering characteristics of mounded structures that can be derived from extant archaeological literature and 2) the types of information mounds may offer that is not currently being gathered by archaeologists. The secondary objective of this effort has been to conduct a detailed analysis of data on a sample of mounded structures from a variety of environments and of different ages to determine what design characteristics most often correlate with long-term stability of mounded structures.

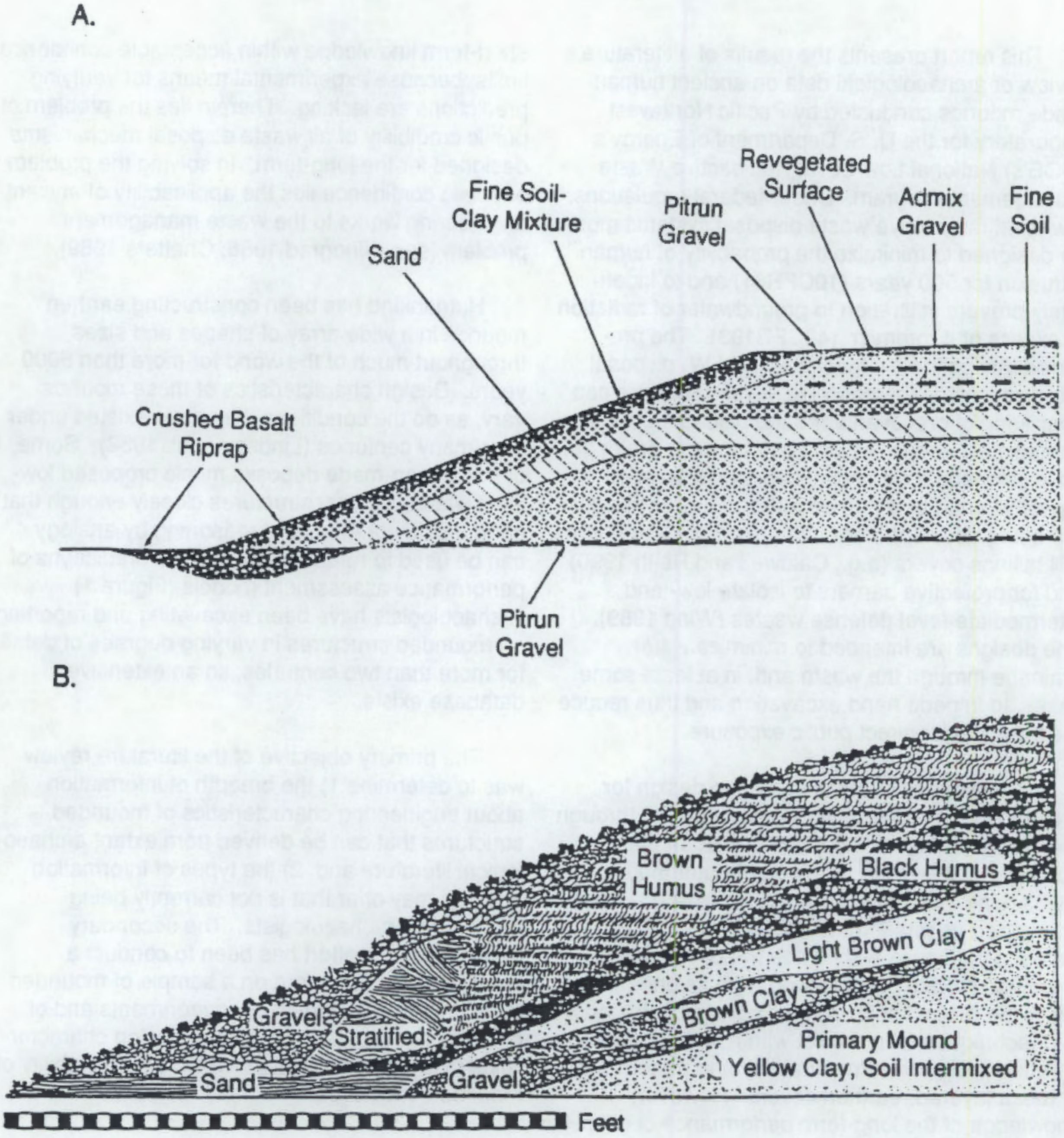

FIGURE 1. Cross-Sections of Portions of (A) Closure Cap Design (from Wing 1989) and (B) an Archaeological Mound (from Shetrone and Greenman 1931), Showing Similarities in Design

ARCHAEOLOGICAL MOUNDS AS ANALOGS FOR ENGINEERED WASTE COVERS

As commonly defined, an analog is that which corresponds to something else in construction, function, and qualities. Archaeological mounds are analogs of engineered waste covers in every aspect of this definition. Both mounds and covers are constructed by people, although the equipment used in construction today is larger and faster than that used in the past (i.e., heavy equipment versus strong backs). Both are made from naturally occurring earthen materials, and most waste covers and a large proportion of archaeological mounds consist of multiple layers of different-textured materials. The functions of the two types of structures are also similar, in that both are intended to bury and protect something. Waste covers protect dangerous materials from intrusion and water infiltration; archaeological mounds are typically (although not always) meant to bury, protect, and commemorate important persons and their grave offerings. The qualities of archaeological mounds are what we discuss in this report and by analogical reasoning extend to waste covers.

The similarity of archaeological mounds and waste covers, and the consequent potential of ancient structures to be a source of performance information for waste management, has been explored on at least three occasions. Two analyses have been conducted in the United States and one in Japan. [The Natural Analogs Working Group of the Commission of the European Countries has not discussed using analogs to assist with waste cover design (Come 1987).]

In the first U. S. study, Lindsay et al. (1982), in support of design studies for uranium mine-tailings impoundments, reviewed literature on mounded structures and conducted a workshop with experts on the archaeology of mounds. An impressionistic consideration of the literature led to the following five observations: 1) in regions supporting thick vegetation, rock riprap may not be needed unless flooding is a potential problem; 2) riprap is recommended for erosion protection where vegetation is sparse; 3) sideslopes should be kept under 3H:1V; 4) a dike should be constructed around the upper edge of side slopes using compacted layers of soil; and 5) brick-like construction materials should be avoided. A further observation made by Walters (1987) on the data of Lindsay et al (1982) was that riprap coverings were likely to collect water, counteracting the protection from water infiltration provided by a layered cover.

In Japan, Watanabe (1989), seeking conditions that would minimize corrosion of steel drums containing grouted waste, compared with mound design the degree of preservation of different grave-offering materials found in 1300- to 1500-year-old Japanese burial mounds. Using a factor analysis that related 18 structural, topographic, and hydrological characteristics to qualitative degrees of preservation for 7 different materials, Watanabe derived recommendations for the design of above-grade waste facilities. He concluded that the optimal design should include a clay cap to shed water, an intermediate layer of sand to drain away any water that penetrates the clay, and a thick inner layer of gravel surrounding the waste vault to drain away any water penetrating the outer systems.

The third use of mound analogs to support cover designs was the observation by O'Donnell et al. (1990) that Korean burial mounds resembled some of the covers being considered for low-level waste facilities. Like Watanabe, they noted that an outer clay covering over coarser textured fill tended to reduce water infiltration.

LITERATURE REVIEW

PNL staff conducted the review of archaeological literature between April and August 1990. The review consisted first of a library search and the acquisition of published material. A sample of this material was then reviewed for data on selected variables; the results were assessed to determine what kinds of questions about mound durability can be answered from literature alone and what questions can only be addressed with additional research.

THE SEARCH PROCESS

PNL contracted with the Battelle Human Affairs Research Center (HARC), Seattle, Washington, to identify and obtain references of potential use to this study. HARC began with an electronic search to identify the published literature and with calls to known experts on mound research to find gray literature or unpublished data. Two computerized data bases, DIALOG and the Western Library Network, were searched. References were sought first on mounds, tombs, and associated call words first in the engineering literature and then in the anthropological literature and in listings of recent Ph.D dissertations. While this method provided a quick listing of material, a major drawback was the inability of these systems to identify materials over 15 years old. A manual search of the card catalog at the University of Washington's Suzzalo Library demonstrated that the majority of published information on excavated mounds dates from the first half of this century.

Reference lists obtained were submitted to PNL, where we identified those texts that were pertinent to this study. HARC then proceeded to obtain copies of the requested literature and provide them to PNL staff.

This search was limited to the English-language literature, eliminating nearly all references available in Japanese, Chinese, Korean, Russian, and Northern European languages. Later searches will include literature in at least Japanese and German.

THE LITERATURE BASE ON ARCHAEOLOGICAL MOUNDS

Despite the language limitations of this study, over 200 references pertinent to the issue of mound construction and durability were obtained (Appendix A). Although most references addressed sites in North America and England, a small number of reports and articles described mound structures in Siberia, the Middle East, North Africa, Northern Europe, Central America, and the Far East. North American literature consisted almost exclusively of reports on mounds found east of the Continental Divide dating to the Mississippian and Woodland periods; little information could be found on the temple mounds of the Hohokam cultures of the Southwest. Detailed descriptions of mounds are rare in Middle Eastern reports, which focus on artifacts and historical associations, and are most common in reports on North American sites. Most of the mounds date from the period between 1500 A.D. and approximately 3000 B.C., though a few descriptions of older structures exist.

The majority of the detailed reports on mounds that contained the kind of engineering information we needed predate 1960. This surprising fact can be attributed to the development of the discipline of archaeology. Before 1960, the discipline was primarily concerned with data acquisition, rather than with interpretation or synthesis, as it is today (Willey and Sabloff 1980). In the majority of cases the earlier material has proven to be more useful to us than more recent studies, because more complete and more detailed descriptions of the excavated mounds were routinely provided. More recent, problem-oriented research focuses on specific information and often lacks descriptive detail we need.

Assessment of the Literature Base

Once literature had been collected, we proceeded with a thorough reading of available texts to ascertain what kinds of information were available. The data we sought, as partially illustrated in Figure 2, were the following:

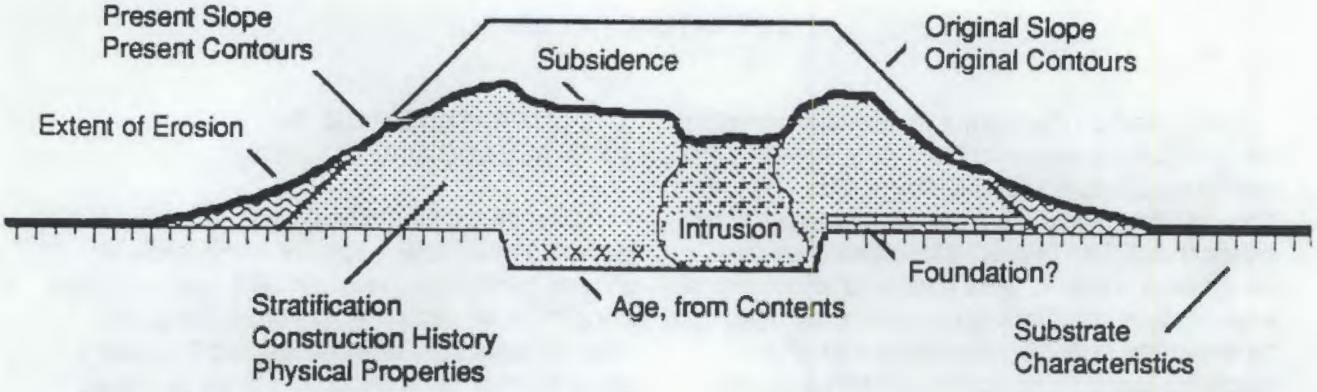

FIGURE 2. An Idealized Example of an Archaeological Mound, Illustrating Variables Studied During the Literature Review

- Geographic location
- Environmental setting
- Original contours and dimensions, as estimated from the remaining contours and the amounts of soil eroded from the mound
- Current contours and dimensions
- Age, either absolute age determined radiometrically or relative age determined from associated artifact styles
- Estimated extent of erosion and erosion type, including natural and anthropogenic erosion and intentional intrusion
- Construction history and design details, as inferred from stratigraphic characteristics
- Internal and substrate stratification
- Soil physical properties, including the texture, bulk density, percent compaction, and hydraulic conductivity of constituent materials
- Presence and type of foundation
- Additional characteristics, such as subsurface tombs, degree of preservation of contents, and other items not noted above

Because the amount of literature available on archaeological mounds in the English language alone is tremendous, it was necessary to concentrate on only a sample of the literature. Although a small number of sources from outside North America were used in this stage of analysis, we chose to concentrate on North American mounds, selecting approximately 25% of the references on that region. References that were used were those with the most descriptive detail (especially those including photographs and drawings), coming from a range of geographic settings, and including structures in varying states of degradation. Fifty-five cases were studied. These consisted of individual mounds where possible or mound groups where descriptions were presented in a generic fashion (Table 1).

For each case, data were recorded on forms designed for the purpose. Graphics presenting plans, profiles, and topographic maps of structures were appended to the backs of the forms. Appendix B presents an example of a completed data form from one of the best preserved and most thoroughly documented mounds.

Compilation of the data from case forms demonstrated that some kinds of information were consistently provided whereas other categories of data were rarely presented, if at all. The database included extensive information on geography, environment, engineering design characteristics, and the extent and causes of mound degradation, but, for all practical purposes, none on the physical properties of the mound matrix. All reports included descriptions or maps of the site's geographic location, and most addressed the environmental setting, although the degree of detail varied. Maps or drawings showing the mound's contours and dimensions at the time of the archaeological study were nearly always given, although again the quality of presentation varied from rough outline sketches to measured topographic maps. Less than half of the reports included drawings of the estimated original shape of mounds, although all described the original shape. In over 90% of the cases, age estimates, at least to cultural period, were either given or could be inferred from illustrated artifacts. Estimates of erosive agents and the extent of erosion either were described or could be derived from drawings for a similar proportion of the sample. Details of construction, internal stratification, and the existence of foundations were common to nearly all reports.

TABLE 1. Mounds and Mound Groups Analyzed for this Study

Case #	Name	State	County	Condition	Age	Reference (a)
#1	Monks mound, 11-Ms-38	Illinois	Madison	Good	A 900 to 1150	Reed et al 1968, Reed 1977, Fowler and Anderson 1975
#2	Sauls or Mound #9, Pinson Mound Site.	Tennessee	Madison/Chester	Fair /Poor	B 50 to A 200	Mainfort 1985, Morse 1963
#3	Ozier or Mound #5, Pinson Mound Site	Tennessee	Madison/Chester	Fair	A 30 to 90	Mainfort 1985
#4	Mound #31, Pinson Mound Site	Tennessee	Madison/Chester	Fair	A 380	Mainfort 1985
#5	Twin or Mound #6, Pinson Mound Site	Tennessee	Madison/Chester	Good	A 80 to 100	Mainfort 1985
#6	The Great Mound, Troyville Mound Group	Louisiana	Catahoula Parish	Good>Poor	A 900 to 1300	Walker 1936
#7	Crooks Site, Mound A	Louisiana	La Salle Parish	Fair /Poor	B 300 to A 700	Ford et al 1940
#8	Murad Mound, 46-Ka-30	W. Virginia	Kanawha	Ukwn	B 100	McMichael and Mairs 1969
#9	Mound #7, Harlan Site 34-Ck-6	Oklahoma	Cherokee	Good	A 950 TO 1250	Bell 1972
#10	Mounds #4 & 6, Harlan Site 34-Ck-6	Oklahoma	Cherokee	Good	A 950 TO 1250	Bell 1972
#11	The Pazyryk Barrows, Generalized Overview	Sibaria	Altai Mtn. Prov.	Good	B 1000	Rudenko 1970
#12	Norman Mound	Georgia	McIntosh	Fair	B 300 TO A 700	Larson 1957
#13	The Pate Mound, 40-MR-16	Tennessee	Monroe	Fair	A 1100	Chapman 1985
#14	The Rembert Mounds	Georgia	Elbert	Fair-Poor	A 1450 TO 1650	Caldwell 1953
#15	The Adena Mound, Scioto Valley, Ohio	Ohio	Chillicothe, City of	unk	B 1000 TO B 300	Mills 1902
#16	The Westenhaver Mound	Ohio	Pickaway	Good	B 1000 TO B 300	Mills 1917
#17	The Adena Mound, 46-Mr-2, Natrium, WV.	W. Virginia	Natrium	Fair/Poor	B 1000 TO B 300	Solecki 1952
#18	Huastec Mounds, Generalized Overview	V.C. & Ta, Mex	Tampico	Fair/Poor	Unknown	Muir 1926
#19	Irene Mound	Georgia	Chatham	Good	A 1200 TO 1700	Caldwell and McCann 1941, Moore 1898b
#20	The Seip or Mound #2 of the Seip Mound Group	Ohio	Ross	Excellent	B 300 TO A 700	Mills 1909, Shetrone and Greenman 1931
#21	The Pricer Mound #1, Seip Mound Group	Ohio	Ross	Excellent	B 300 TO A 700	Mills 1909, Shetrone and Greenman 1931
#22	Mound C, Helena Crossing Site, 14-N-6	Arkansas	Helena, City of	Good	B 50	Ford 1963
#23	The Toltec Mounds Site (3LN42), Generalized Overview	Arkansas	Lonoke	Poor	A 500 TO 900	Kaczor 1982, McCartney 1982, Rolingson 1982
#24	The Dorr Mound	Mississippi	Coahoma	Poor	A 700 TO 1200	Peabody 1904
#25	The Edwards Mound	Mississippi	Coahoma	Fair/Poor	A 1200 TO 1700	Peabody 1904
#26	The Split Rock Creek Mounds, #'s 1&2	S. Dakota	Minnehaha	Poor	Unknown	Over and Meleen 1941
#27	The Drake Mound, 16-Fa-11	Kentucky	Fayette	Poor	B 300 TO A 700	Webb 1941
#28	South End Mound I, 9-Li-3	Georgia	St. Catherines Is.	Poor	A 700 TO 1200?	Larsen and Thomas 1986, Moore 1897
#29	South End Mound II, 9-Li-273	Georgia	St. Catherines Is.	Unkwn	A 1000 TO 1300	Larsen and Thomas 1986
#30	Stubbs Mound	Georgia	Ocmulgee Nat. Mon.	Poor	A 1100 TO 1400	Williams 1976
#31	Avondale Mounds, 23-CL-23	Missouri	Clay	Unkwn	A 1400 TO 1600	Shippee 1951
#32	Toelner Mound, 33-FR-43	Ohio	Franklin	Unkwn	B 830 TO B 250	Norris 1985, Wetmore 1888
#33	The W. H. Browne Mound, 8-Du-62	Florida	Duval	Good	A 800 TO 1200	Sears 1959
#34	The MacKenzie Mound	Florida	Marion	Good	A 800 TO 1200	Sears 1959
#35	The Willow Island Mound, 46P13	W. Virginia	Pleasants	Good	B 500	Hemmings 1978
#36	Albany Mounds Site Overview	Illinois	Whiteside	Poor	B 300 TO A 400	Benchley et all 1977, Herold 1971
#37	Mound Co 114, Snyders Mound Group	Illinois	Calhoun	Unkwn	A 100 TO 200	Braun et al 1982
#38	Mound #2, Barry Mound Group	Illinois	Calhoun	Good	B 1000 TO B 300	Braun et al 1982, Thomas 1894
#39	Mound #1, Barry Mound Group	Illinois	Calhoun	Unkwn	B 1000 TO B 300	Thomas 1894
#40	European Earthen Long Barrows, Generalized Overview	N. Europe	N/A	Variable	B 4000 TO B 2000	Ashbee 1960, Marsden 1974, Midgley 1985
#41	The Carlson Annis Mound, 15-Bt-5	Kentucky	Rochester, City of	Good	B 5000 TO B 2000	Webb 1950
#42	The Ginther Mound	Ohio	Chillicothe, City of	Fair/Poor	A 1200 TO 1700	Shetrone 1925, Squier and Davis 1848
#43	The Miesse Mound	Ohio	Ross	Unkwn	B 1000 TO A 700	Shetrone 1925, Squier and Davis 1848

TABLE 1. (contd)

Case #	Name	State	County	Condition	Age	Reference
#44	Mound #2 at Marksville	Louisiana	Avoyelles Parish	Poor	B 3000 TO A 200	Vescelius 1957
#45	The Hollywood Mound, 9-Ri-1	Georgia	Richmond	Poor	A 1600 TO 1700	De Baillou 1965
#46	The North Benton Mound	Ohio	Mahoning	Good	B 300 TO A 300	Magrath 1945
#47	The Linn Mound	Pennsylvania	Washington	Good	B 1000 TO B 300	Dragoo 1955
#48	Mound #1, Group #1, Morse Site.	Illinois	Fulton	Fair	A 1400 TO 1600	Morse 1959
#49	McKees Rocks Mound	Pennsylvania	Allegheny	Good	B 1000 TO A 700	McMichael 1956
#50	Site 15 JO 2, at the C & O Mounds, Paintsville	Kentucky	Johnson	Poor	B 1000 TO A 300	Webb 1942
#51	Site 15 JO 9, at the C & O Mounds, Paintsville	Kentucky	Johnson	Gone	B 300 TO A 700	Webb 1942
#52	The platform Mound at the Beaverdam Creek Site, 9Eb85	Georgia	Russell Reservoir	Poor	A 1600 TO 1700	Rudolph 1984
#53	The Booger Bottom Mound, 9HL64	Georgia	Hall	Poor	B 1000 TO B 300	Caldwell 1952
#54	The Pharr Mounds, Generalized Overview	Mississippi	Prentiss/Itawamba	Variable	A 0 TO 200	Bohannon 1972
#55	The Bear Creek Mound	Mississippi	Tishomingo	Poor	A 1400 TO 1600	Bohannon 1972

(a) For complete reference see Appendix A

THE RELATIONSHIP OF DESIGN CHARACTERISTICS TO THE EXTENT OF MOUND DEGRADATION

The database derived from our literature search contained extensive information on the details of mound construction, the degree of mound degradation, and the causes of degradation. The following analysis uses these data to determine which design characteristics correlate most closely with the long-term retention of original mound contours and to identify the most common causes of degradation.

COMPARISON OF DESIGN COMPONENTS WITH MOUND CONDITION

This analysis uses occurrence frequencies to compare design components to the conditions of mounds at the time they were reported. Seven variables of design are reported frequently enough for quantitative analysis. These are mound shape, materials used in construction, the occurrence of layering, evidence for surface preparation prior to mound construction, the presence of a revetment around the mound base, the use of sheathing on the mound surface, and the construction sequence. Two additional variables, age and the occurrence of below-grade tombs under the mounds, were expected to have a negative influence on mound condition and were analyzed to determine the validity of this assumption. Finally, to investigate the influence of a confounding variable on the results of the analysis of design characteristics, we divided mounds into two environmental groups and compared the frequency of design characteristics against condition between the two. All data used in this analysis are presented in Appendix C. Forty-four cases could be used in this analysis; information for the remainder was inadequate for assessing mound condition.

Condition categorizes the degree of degradation a mound or mound group has undergone since its construction, and requires an estimate of the mound's original form and descriptions of its present form. Profiles were often used to estimate the amount of soil eroded from a mound's surface onto its toe slopes and the surrounding ground surface. Categories are good-to-excellent, fair, and poor (Figures 3, 4, and 5). Good-to-excellent means there is little or no evidence for erosion from the mound's surface, although small looter excavations may be present. Fair means the mound's original shape is still distinguishable at the surface but soil has eroded from the surface onto toe slopes and some gullying may be visible. Poor means the mound is still recognizable as a man-made eminence but its original shape and dimensions can only be estimated using stratigraphic data from excavations.

Definitions

Variables of mound design, age and environment are defined as follows:

Shape describes the overall contours of the structure and is analyzed in two categories, conical or pisiform and pyramidal. Conical and pisiform mounds (Figure 3) have round ground plans that may be tapering (conical), rounded (pisiform), or flattened (truncated conical) toward the top, but they lack angularity on their sides. Pyramids (Figure 4) have rectilinear ground plans, with distinct corners and flattened tops. Some may have conical eminences on the platforms.

Material refers to the textures of materials in layers composing the mound. Texts described materials as clay loam, heavy clay, sandy loam, sand, rock, and gravel. For our purposes, the texture of a mound layer is taken to be the finer composition of a layer. Thus, clay loam becomes clay, sandy loam is silt, and so on. Only where rock is included in a layer do we deviate and include the coarser constituent in the mound's characteristics.

Layering is the presence of distinct strata laid over all or a significant portion of what was the mound surface at the time of construction (Figures 1b, 6). Individual basket loads of earth, which are distinguishable in cross-section in many mounds, are not considered to be layers.

Surface preparation refers to physical evidence of ground preparation prior to the actual accumulation of mound material. It may range from simply clearing the ground surface down to subsoil and employing fill material to level the ground surface to the actual construction of a foundation feature utilizing rock, gravel, puddled clay, or shell. For example, the Natrium Mound, shown in Figure 6, had a surface preparation of humus removal and the emplacement of a sand floor, (Solecki 1952).

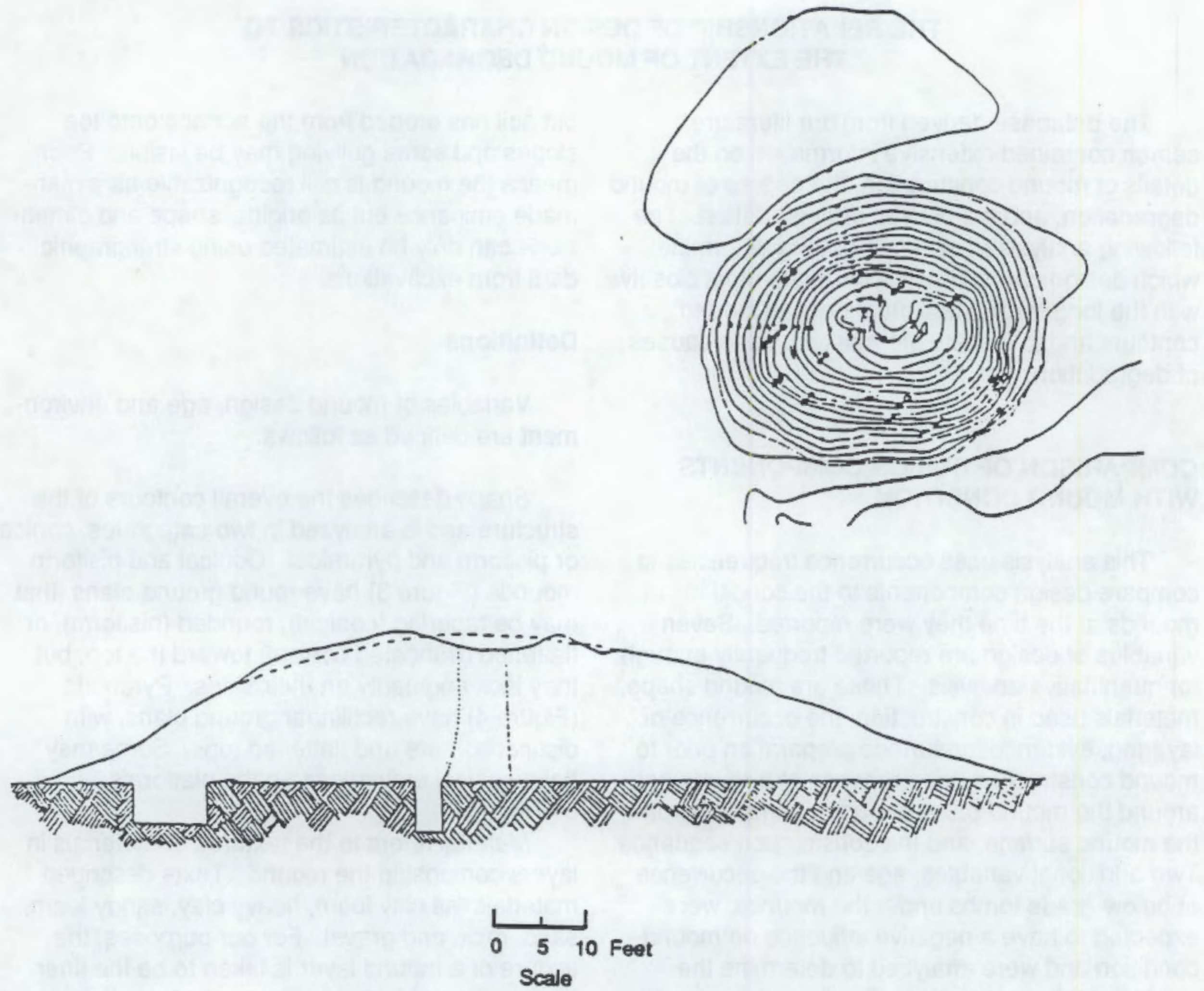

FIGURE 3. Profile and Topographic Map of the Westhaver Mound, Ohio, an Example of a Conical Mound in Good Condition. Note Looter Shaft in the Center of the mound. From Mills (1917).

A *revetment* is an engineering device designed to combat the natural tendency of walls, mounds, and other human-made structures to spread outward from the effects of gravity. These are typically confined to the lower edges of a mound, and may be an integral portion of a foundation structure. Rock is the most common material employed, though clay, shell, and gravel have also been used (Figure 7).

Sheathing, or surfacing, refers to a final/outer covering on a mound placed intentionally, presumably to impede water and/or wind-caused erosion or simply to effect a particular appearance. A material resistant to erosional forces is generally employed, such as fired clay, gravel, or shell. Sheathing may grade into a revetment, creating a complete erosion-prevention system, as in Figure 1b.

Construction sequence includes the categories single-event, phased, and staged construction. Staged construction refers to intentional, separate, coeval construction episodes (i.e., the building of a mound over a mound), whereas phased construction refers to construction events which have taken place on a single mound over a considerable time, (i.e., over several generations). This distinction is critical when evaluating the relative effectiveness of construction techniques. Staged construction is distinguished from phased construction by the lack of soil development on intermediate surfaces. Figure 8 shows a staged mound, Figure 6 a phased mound.

A *below-grade tomb* is a pit lined with logs, stones, fired clay or other material and containing human remains and grave offerings. The evidence for the in-filling of these tombs prior to mound

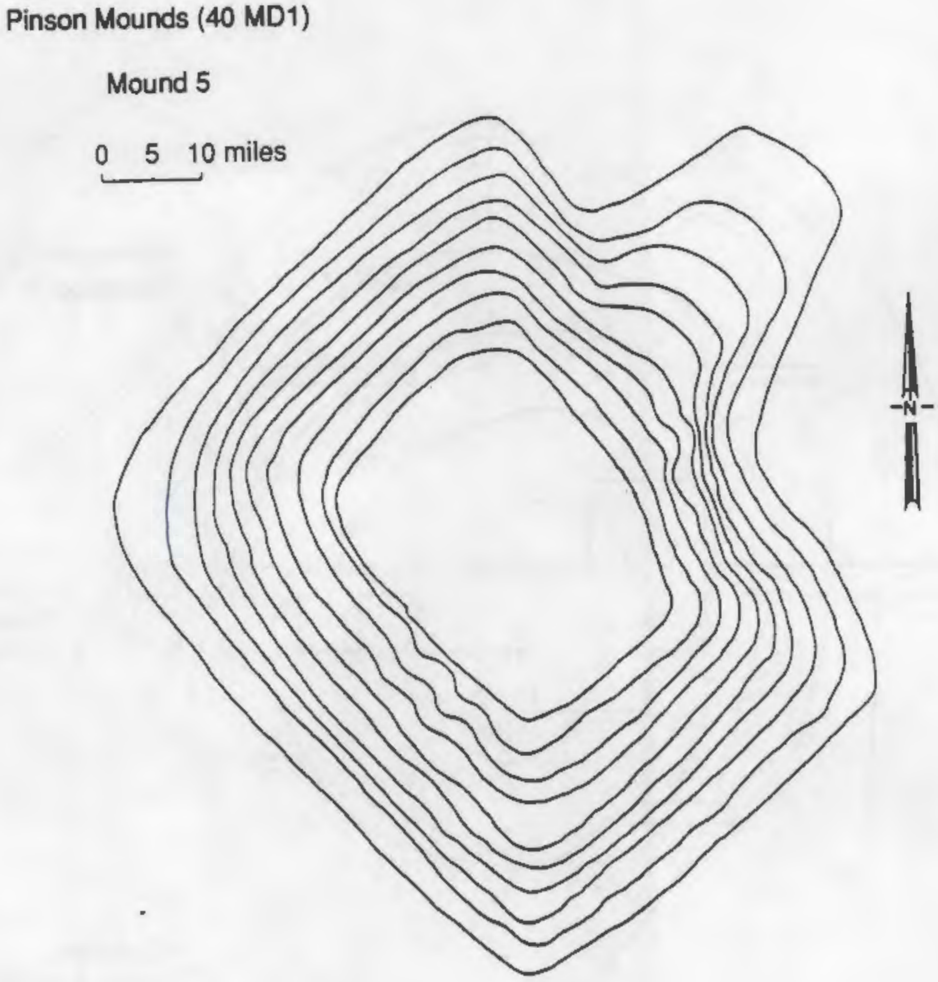

FIGURE 4. Topographic Map of Pinson Mound No. 5, a Pyramidal Mound in Fair Condition. From Mainfort (1985).

construction varies, but in no case was there evidence of subsidence of the outer mound surface above a tomb.

Age is considered in three chronological periods, because most dates given were ranges based on artifact style. The periods accommodating all dates presented are 1000 to 300 B.C., 300 B.C. to 700 A.D., and 700 to 1700 A.D.

Environmental regions were defined for mound sites in the United States only, and were based on the climatic regions defined in Barry and Chorley (1970). Sites in subtropical regions (Subtropical Interior and Subtropical Oceanic), with their relatively warmer temperatures and greater rainfall, form the *southern group* (Oklahoma, Louisiana, Mississippi, Georgia, Tennessee, Arkansas, Florida). Sites in the Ohio Transition, Interior, and Interior Complex climatic regions, which are relatively cooler and drier, form the *northern group* (North Dakota, Missouri, Illinois, Kentucky, West Virginia, Pennsylvania, Wisconsin, Minnesota). Climatic variation remains among sites in each group, including significant differences in the seasonality and amount of precipitation, but the samples are not large enough for further subdivision.

Relationship of Mound Shape to Condition

Of the 44 cases in this analysis, mound shape could be determined for 42 (Table 2). Pyramidal shape is negatively associated with condition. This may be due in part to the fact that two of the 13 conical cases in the good-excellent category are stone cairns. However, even when the cairns are removed from the analysis, percentages for conical and pyramidal mounds are 79% and 21% respectively, still significantly different from the fair and poor categories. The influence of shape on condition may be that the squared corners of pyramidal mounds are more vulnerable to erosion than are the rounded contours of the conical mounds.

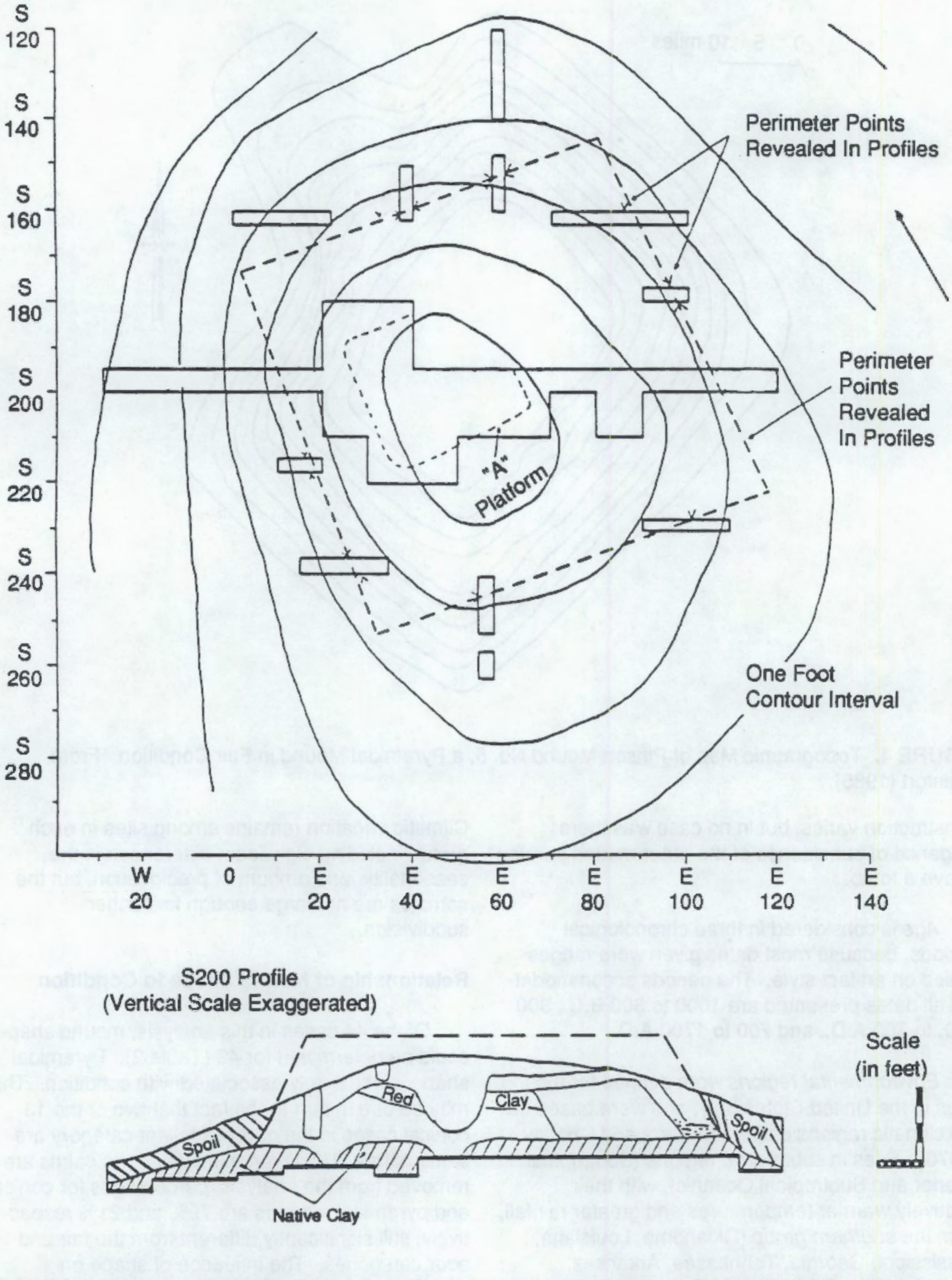

FIGURE 5. Plan and Cross-Section of Bear Creek Mound, Mississippi, an Example of a Pyramidal Mound Built in Stages that is now in Poor Condition From Bohannon (1972)

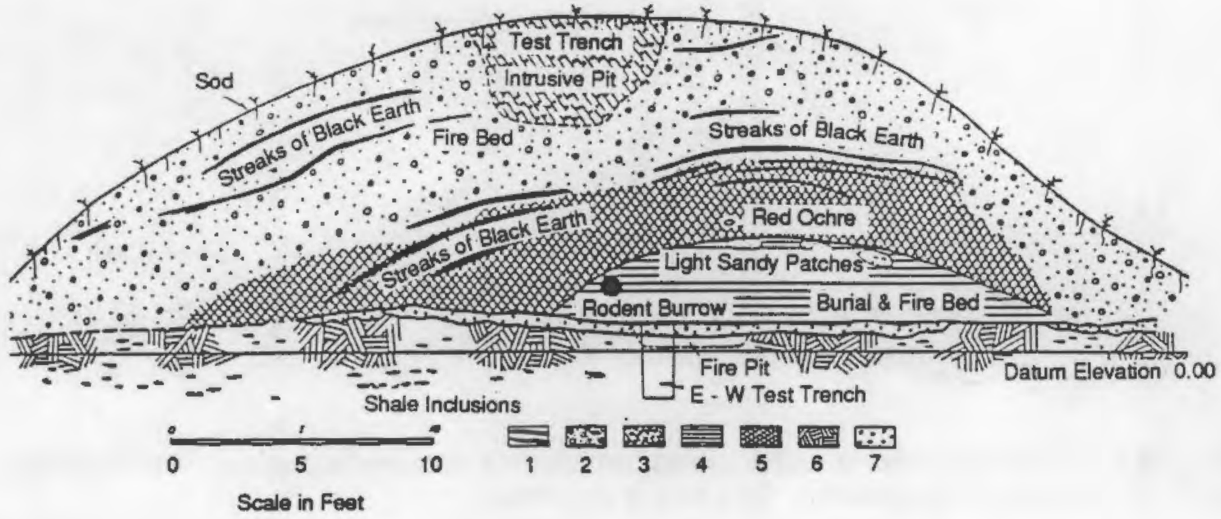

FIGURE 6. A Cross-Section of the Natrium Mound, Showing the Layering Characteristic of Many Archaeological Mounds. This mound was built in phases, and has subsequently been disturbed by borrowing activity (right side), and looting (top). Explanation of numbered symbols: 1, linear streaks of black earth stains; 2, earthy gravel; 3, mixture of light-colored gravelly soil; 4, dark mixed earth; 5, streaked earthy gravel mixed with charcoal; 6, sterile gravelly subsoil; 7, coarse yellow sandy loam (sterile). From Solecki (1952).

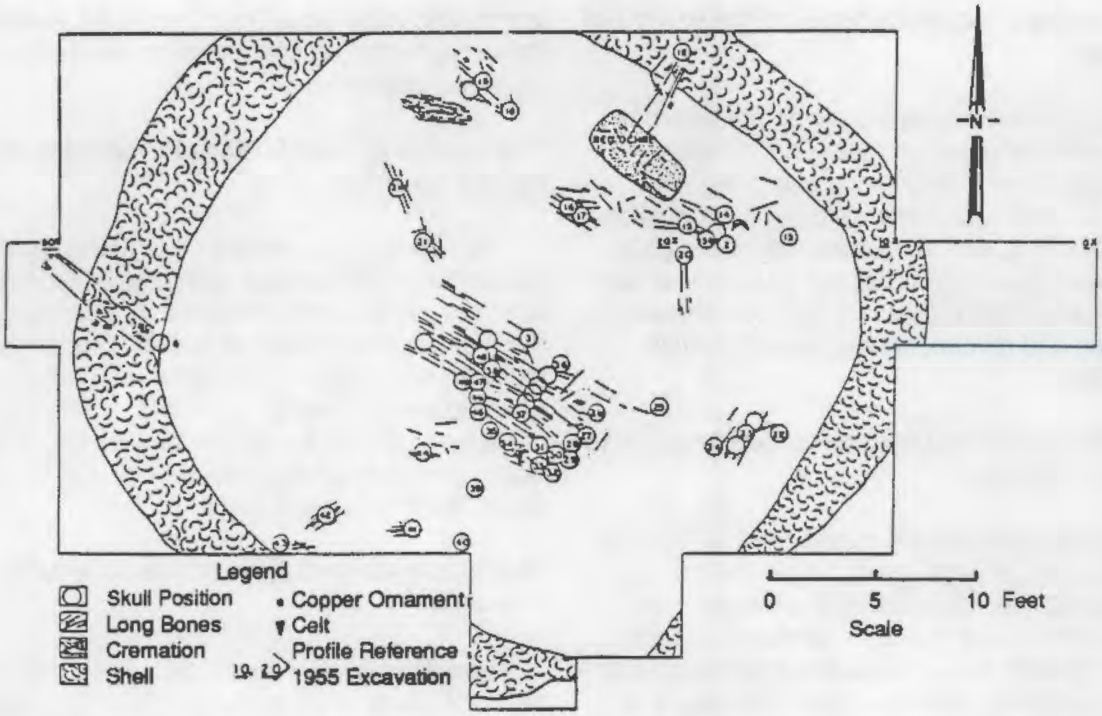

FIGURE 7. Plan of Bowne Burial Mound, Florida, Showing the Revetment of Shell around its Base. From Sears (1959).

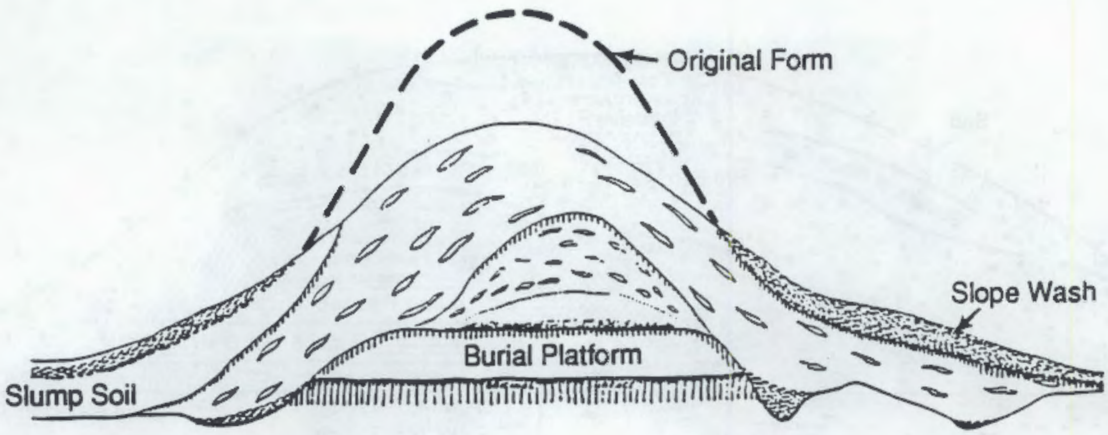

FIGURE 8. A Cross-Section of Mound A, Crooks Site Alabama, Showing Examples of Slope Wash and Mass-Wasting Types of Degradation. From Ford et al. (1940).

TABLE 2. Comparison of Mound Form with Mound Condition

Condition	Conical	Pyramidal	Total	Unknown
Good-Excellent	13 (81%)	3 (19%)	16	1
Fair	7 (54%)	6 (44%)	13	0
Poor	8 (61%)	5 (39%)	13	1

Relationship of Construction Material to Mound Condition

Mound condition appears to be preserved by the presence of gravel or rock in the structure, regardless of what other material is present (Table 3). This is one of the most distinct relationships we found, with 47% of the mounds in good-to-excellent condition containing rock somewhere in their construction. The fact that rock is used in sheathing and revetment may account for this relationship.

The Relationship of Layering in Construction to Mound Condition

Layering correlates in a minor way with condition (Table 4). A larger proportion of the mounds with layered interiors survived in good-excellent or fair condition, but there is no difference between fair and good-to-excellent condition for this characteristic. Layering may increase the stability of a mound, making the mound less likely to undergo mass wasting or subsidence. Different-textured layers may affect the water content of the mound, channeling water away from the mound interior rather than allowing saturation and subsequent slumping to take place.

The Relationship of Surface Preparation to Mound Condition

As with layering, the pre-construction preparation of the ground surface corresponds somewhat with mound durability. Prepared surfaces occurred twice as often in mounds in excellent to fair condition than in mounds in poor condition (Table 5). Leveling and organic layer removal during surface preparation probably reduces subsidence, which would provide irregular surfaces into which erosion could begin to make in-roads.

The Relationship of Revetments to Mound Condition

Revetments were uncommon, occurring in only seven of the mounds analyzed (Table 6). Their distribution by condition, however, shows that there is a strong correspondence between the occurrence of a revetment and a mound's resistance to

TABLE 3. A Comparison of Mound Condition with Materials Used in Construction

Condition	Clay[a]	Silt or Loam	Sand	Gravel or Rock	Total
Good-Excellent	9 (53%)	6 (36%)	4 (24%)	8 (47%)	17
Fair	7 (62%)	6 (46%)	4 (38%)	0	13
Poor	8 (57%)	4 (28%)	3 (21%)	1 (7%)	14

(a) Percent refers to the percent of mounds in each condition group with this material as a major constituent.

TABLE 4. Occurrence of Layering in Mound Construction, by Mound Condition

Condition	Layering Present	Layering Absent	Total	Unknown
Good-Excellent	9 (40%)	8 (60%)	17	0
Fair	8 (42%)	4 (44%)	12	1
Poor	6 (20%)	7 (39%)	13	1

TABLE 5. Preparation of the Pre-Construction Surface by Leveling, Humus Removal, or Laying of a Clay, Sand, or Stone Foundation Layer Compared with Mound Condition

Condition	Preparation Present	Preparation Absent	Total	Unknown
Good-Excellent	6 (40%)	9 (60%)	15	2
Fair	5 (42%)	7 (58%)	12	1
Poor	2 (20%)	8 (80%)	10	4

TABLE 6. The Occurrence of a Revetment Around the Mound Perimeter, by Mound Condition

Condition	Revetment Present	Revetment Absent	Total	Unknown
Good-Excellent	5 (31%)	11 (60%)	16	1
Fair	1 (8%)	11 (92%)	12	1
Poor	1 (8%)	11 (92%)	12	2

degradation. Although only 8% of mounds in the fair and poor categories had revetments, this design feature was present in nearly one-third of the better preserved mounds. The revetment apparently reduces lateral displacement of mound material, and prevents small erosion networks from forming near the mound base and migrating upward, creating gullies. As discussed further under degradation processes, it is also possible that a revetment discourages agricultural activity, which is a significant threat to mound longevity.

The Relationship of Sheathing to Mound Condition

The strongest relationship we obtained between any design feature and mound condition was the occurrence of sheathing (Table 7). Thin layers

TABLE 7. The Occurrence of Sheathing on Mounds, by Mound Condition

Condition	Sheathing Present	Sheathing Absent	Total	Unknown
Good-Excellent	7 (44%)[a]	9 (66%)	16	1
Fair	0 (0%)	11 (100%)	11	2
Poor	2 (14%)[b]	12 (86%)	14	0

(a) Six are rock or gravel-surfaced, one clay-surfaced.

(b) One rock-surfaced, one clay-surfaced.

or admixes of gravel, angular stone, or clay occurred in nearly half of the best preserved mounds, whereas sheathing was absent among mounds in fair condition and occurred only 14% of the time in the poorly preserved mounds. A sheathing of stones impedes the movement of air and water over the mound surface, reducing erosion. It also discourages plowing, which was found to be a major cause for mound degradation.

The Influence of Construction Sequence on Mound Condition

Intuitively, one would expect that mounds that had been built in stages, with decades to a century or more elapsed between construction episodes, would tend to be more stable and durable on the long-term than mounds built as a single or staged event. The contrary appears to be true, or at least we can say that single-event or phased construction is not a detriment to mound longevity. As Table 8 shows, single-event and short-term phased mounds account for 56% of the good-to-excellent category and successively less as mound condition declines. We cannot explain this, though it may be related to the fact that in staged mounds successive stages tend to be eccentric from the earlier stages, which may result in irregular loading and uneven subsidence. Phased and single-event mounds, on the other hand, tend to be concentrically constructed, which results in even load distribution between fill of upper and lower layers.

The Effect of Subsurface Tombs on Mound Condition

Subsurface tombs, which are underground vaults that closely resemble waste cribs or vaults, are common beneath burial mounds in the study sample. Constituting a void space, typically beneath the mound apex, such vaults should have caused mound subsidence once the burial vault collapsed, thus contributing to decline of the structure. However, there is a positive relationship between the presence of subsurface tombs and mound condition (Table 9). In fact, in only one case was subsidence detected in the profiles of the mound sample (Case #55, Mound C from Helena Crossing). This mound had been repaired aboriginally with additional fill, and was in good condition at the time of excavation (Ford et al., 1940). This finding provides encouragement that the presence of waste cribs or vaults is not likely to have a significant effect on the long-term durability of waste covers. Subsidence, if it occurs, is likely to come within the estimated 100-year period of institutional controls, and can be repaired to minimize its impact on structure longevity.

TABLE 8. A Comparison of Mound Construction Sequence with Mound Condition

Condition	Single Event	Short-Term Phased	Long-Term Staged	Total	Unknown
Good-Excellent	5 (31%)	4 (25%)	7 (44%)	16	1
Fair	3 (30%)	1 (10%)	6 (60%)	10	3
Poor	1 (11%)	2 (22%)	6 (67%)	9	5

TABLE 9. The Occurrence of Subsurface Tombs Beneath Mounds, by Mound Condition

Condition	Tomb Present	Tomb Absent	Total	Unknown
Good-Excellent	7 (41%)	10 (59%)	17	0
Fair	3 (27%)	8 (73%)	11	2
Poor	3 (23%)	10 (77%)	13	1

Potential Intervening Variables: Age and Environment

Although there are strong associations between certain design characteristics and mound longevity, it is possible that the sample is biased in at least one of two ways. The better preserved mounds, with their apparent design advantages, may simply be younger than more degraded structures, which lack more "advanced" characteristics. It is also possible that design is regionally variable and that climatic disparities between regions have been the sole cause of differences in mound condition. To explore these possibilities we compared mound condition to age and environment, as defined previously.

Age was clearly not a factor (Table 10). In fact, the better preserved mounds, such as the Seip group (Shetrone and Greenman 1931) and the Pazyryk Mounds of Siberia (Artamonov 1965; Rudenko 1970), included all the oldest mounds and relatively few more recent structures. It is worth noting that younger mounds were commonly built in pyramidal form, whereas the oldest mounds were all conical, pisiform, or some variant on that shape. Age, rather than being a contributing factor, is merely correlated with a design feature that itself contributes to structure integrity.

Dividing the 44 cases in our database into regional groups reduced the sample size to meaningless levels in some of the design categories. We therefore combined fair and poor condition into one group. The design characteristics used in this portion of the analysis are those that showed the strongest association with mound condition: revetments, sheathing, and a subcategory of material, the occurrence of rock in construction. In all cases, characteristics associated with better condition in one region exhibit the same association in the other region (Table 11). However, the use of rock, the material from which revetments and sheathing are most often made, and therefore the occurrence of sheathing and revetment, is more common in the northern region than in the southern. This is probably due to the greater availability of stones in the glaciated regions of the northern Midwest.

On the basis of this analysis, we conclude that the optimum mound design among those analyzed is a conical mound built on a prepared surface in one construction episode or in closely spaced construction phases. The optimal mound is composed of layers with different textures covered by a sheathing of gravel or stones and supported by a revetment of clay, shell, or stones. Conversely, rectilinear sides, unprepared surfaces,

TABLE 10. A Comparison of Mound Age and Condition

Condition	1000 B.C. to 300 B.C.	300 B.C. to 700 A.D.	700 A.D. to 1700 A.D.	Total	Unknown
Good-Excellent	5 (29%)	6 (35%)	6 (35%)	17	0
Fair		6 (50%)	6 (50%)	12	1
Poor		6 (46%)	7 (54%)	13	1

TABLE 11. Good-to-Excellent and Fair-to-Poor Mound Groups from Northern and Southern Geographic Areas Compared by Three Design Characteristics Positively Associated with Mound Condition

A. Northern Region

	Revetment		Sheathing		Use of Rock	
Condition	Present	Absent	Present	Absent	Present	Absent
Good-to-Excellent	3 (33%)	6 (66%)	5 (56%)	4 (44%)	7 (70%)	3 (30%)
Fair-to-Poor	2 (28%)	5 (72%)	1 (12%)	7 (88%)	1 (14%)	6 (86%)

B. Southern Region

	Revetment		Sheathing		Use of Rock	
Condition	Present	Absent	Present	Absent	Present	Absent
Good-to-Excellent	2 (33%)	4 (66%)	2 (28%)	5 (72%)	3 (43%)	4 (57%)
Fair-to-Poor	0	17 (100%)	1 (6%)	16 (94%)	0	14 (100%)

fine-textured matrix in a single layer without sheathing or revetment, and construction on an unprepared surface contribute to mound instability.

The optimum characteristics are embodied in the Seip Mounds, a pair of 1700 to 2300-year-old Hopewellian mounds located in Ohio (Shetrone and Greenman 1931) (see Appendix B). Figure 9 shows examples of these mounds. Mound 1 built in two phases, was constructed on a surface that was first stripped of humus and covered with a clay floor. A tomb was excavated into this floor and the whole area covered by a primary mound of clay and loam. This mound was covered with a layer of gravel that was thicker at the toe of the mound and thinned toward the tip, forming both a sheathing and revetment. A secondary mound was then built concentrically atop the first, with a sand floor overlying exposed subsoil under the portion of this mound that extended beyond the toe of the primary mound (see Figure 1). The secondary mound was made up of two layers of clay overlain by layers of soil from a nearby habitation site. There is evidence for a small amount of slope wash erosion following emplacement of the final soil layer, after which the builders laid a foundation of large stones around the mound perimeter and then covered this and the rest of the mound with gravel. Again, the gravel layer was thick at the base, forming a revetment, then thinned toward the apex. On the top of the mound, the gravel formed no more than an admixture with the loam of the underlying layer. This mound showed no evidence of any kind of post-construction damage. Mound 2 was built in the same way, but consisted of only a single construction phase.

The findings of this analysis contradict one of the observations made by Walters (1987; Lindsay et al. 1982), who noted that rock riprap may not be needed where vegetation is dense, but should be used in areas with sparse cover. Our quantitative analysis shows that even in the densely vegetated areas of the American Midwest and Southeast, rock coverings, even if they are only an admixture with finer soil, retard mound degradation. Revetments, whether of rock or some other resistant material, have the same effect.

MOUND DEGRADATION

A second application of archaeological mound analogs is to provide an understanding of the contributions of various erosive agents to mound degradation. Three natural erosion processes and

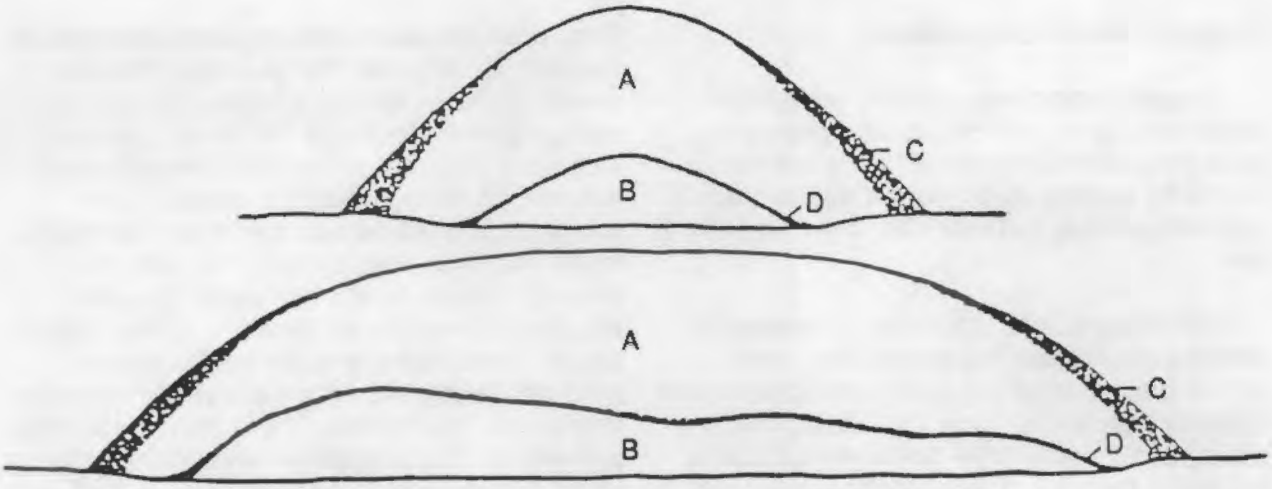

FIGURE 9. Cross-Section of Seip Mound No. 1, Showing How the Gravel Revetment-Cum-Sheathing Was Placed [(Upper, transverse. Lower, longitudinal). A, upper sterile portion. B, primary mound. C, outer retaining wall of gravel. D, inner retaining wall over primary mound]. Detail of the mound's edge is presented in Figure 1B. From Shetrone and Greenman (1931).

three types of anthropogenic damage were identified. Sheet erosion, mass wasting, and river erosion are the natural processes; agriculture, vandalism, and borrowing/military activity are the anthropogenic ones. An additional cause of damage, which is not included in the analysis because it affects all mounds, is archaeological excavation. Many mounds were completely destroyed in the process of investigation.

Definition and Identification of Degradation Processes

Sheet erosion, the washing of sediment more or less uniformly from a surface, is evident from finely stratified deposits of sediment around the toe of a mound. Such erosion was distinguished from agriculturally generated damage in two ways. If there is evidence of plowing in the surface of, but not beneath finely stratified sediment, then the plowing post-dates the erosion. Likewise, if finely stratified deposits are reported at the toe of a mound, but the excavator reports that the site has not been plowed, the damage is identified as sheet erosion. Gullying—a more extreme form of erosion—in the absence of evidence for agriculture is included in the sheet erosion category.

Mass wasting is the simultaneous failure and collapse of entire blocks of matrix, and can be distinguished either in mound profiles or as slumped areas on the mound surface. Walters (1987) identified mass wasting as a major type of degradation in mounds of the American Midwest, attributing it to a combination of steep slopes and heavy precipitation.

River erosion is largely self explanatory. Some mounds located on floodplains were damaged when the river changed course, as evidenced by cut banks formed in the mound matrix.

Agriculture as used here includes both plowing and the grazing of cattle. Its occurrence was determined either from excavator's descriptions, photographs of the mound sites, or evidence of a plow zone in stratigraphic profiles.

Vandalism, or, more aptly, looting, is the intentional excavation of pits into a mound in search of valuables and other artifacts. It is distinguishable from mass wasting by stratigraphic evidence and/or the position of the resultant depression and spoil pile on the mound surface.

Borrowing and military activity consist of movement or removal of large amounts of mound matrix either to facilitate gun emplacements or for use as fill elsewhere. Leveling of a mound for construction of other structures in its place or on its reduced surface is included in this damage category.

Causes of Mound Degradation

The most commonly occurring degradation processes are, in order of decreasing frequency, agricultural activity, vandalism, and sheet erosion. Borrowing and military activity are less common, and mass wasting and river erosion are relatively rare.

When degradation processes are compared with mound condition, it is evident that some erosive processes have a greater impact on mound longevity than others (Table 12). Sheet erosion and agricultural activity are both common among mounds in the fair and poor condition categories, but almost nonexistent in the best preserved mounds. Vandalism and borrowing/military activity occur in similar frequencies in all condition categories, an observation with serious implications for waste management.

Regardless of how well a mound, or, in the future, a waste cover withstands erosion and agricultural activities, it may still have its utility as a moisture barrier compromised by human activity. First, because mounds/waste covers stand out as discrete piles of soil on the landscape, they are accessible as sources of fill material and provide vantage points attractive to the military. Second, as long as waste covers, like the analogous burial mounds, are distinguishable as human-made structures, they will be easy for future generations to find and mine. Waste forms in the low-level category include not only grouted or otherwise stabilized waste from processing of nuclear materials, but also contaminated equipment, reactor parts, and large pieces of metal and other materials from processing facilities. These materials may be attractive to our descendants, who may seek them either as curiosities or as raw material for their own technologies. The Adena and Hopewell mounds of the United States, the Iron Age mounds of the Pazyryk Valley in Siberia (Rudenko 1970), the long barrows of the British Isles and Northern Europe, and grave mounds in the Middle East (e.g., Glob and Bibby 1960) have been systematically plundered of their valuable contents (Figure 10). All are obviously unnatural and are easy prey for individuals capable of finding them on the landscape.

TABLE 12. Causes of Damage to Mounds in Each Condition Group

Condition	Sheet Erosion	Mass Wasting	River Erosion	Agriculture	Vandalism	Borrow, Military	Total Cases
Good-Exc.	1 (7%)	0	0	0	5 (33%)	3 (20%)	15
Fair	6 (60%)	0	2 (20%)	6 (60%)	5 (50%)	3 (30%)	10
Poor	5 (36%)	2 (14%)	2 (14%)	11 (78%)	5 (36%)	3 (21%)	14
Total	12 (31%)	2 (5%)	4 (10%)	17 (44%)	15 (38%)	9 (23%)	39

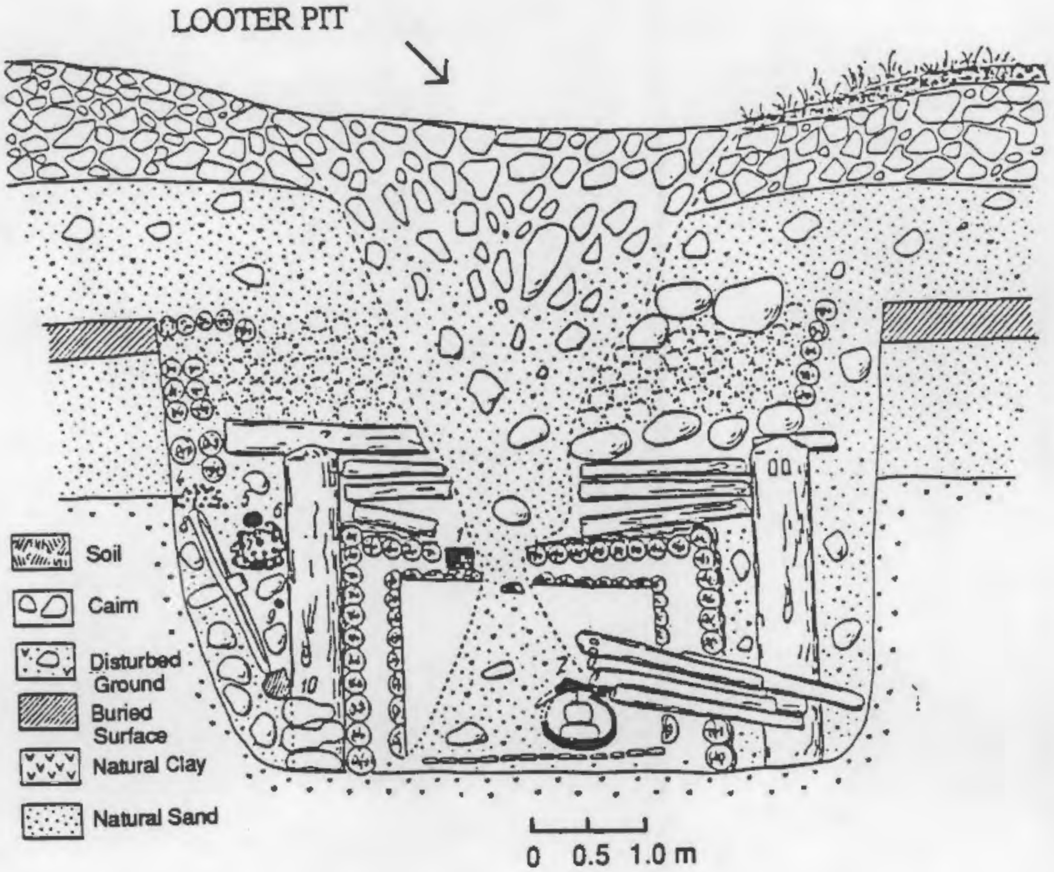

FIGURE 10. The Barrow 5 at the Pazyryk Site, Siberia, Showing the Detail of its Below-Grade Tomb. Note how easily a looter was able to locate and penetrate the tomb, despite the fact that it had not collapsed. Penetration of waste covers in this way would virtually eliminate the cap's ability to prevent water infiltration.

CONCLUSIONS AND RECOMMENDATIONS

Ancient mounds are a promising source of information about the long-term performance of waste-site closure caps, with which they are closely analogous. The literature on archaeological mounds is extensive, and contains a wide range of potential data on engineering design characteristics and processes of degradation. Analysis of a sample of this information base enabled us to identify the following as important components of a durable mound: surface preparation, layering, single event construction, revetment, sheathing and the use of rock in construction. We recommend analysis of a larger sample of this literature, including foreign-language texts and reports on sites in wider ranges of environmental settings. Such an analysis would allow us to better understand the influence of environment on the performance of various designs, to add detail, and to determine the statistical robustness of the conclusions drawn here.

What is lacking from the literature base is information on the physical and hydraulic properties of construction materials and on the hydraulic properties of the mounds as whole systems. This kind of information will have to be obtained through field research on a small sample of mound sites. Based on our findings, we recommend the investigation of mounds from two well-preserved groups in the Eastern United States and from one or more groups in the Gila and Salt river basins of Arizona. Groups in the eastern United States are Seip in Ohio (Shetrone and Greenman 1931) and Pinson in Tennessee (Mainfort 1985), descriptions of the designs of which are already available. Seip mounds were built in what proved to be the optimum design for durability; the Pinson Mounds are protected in a state park and have been the subject of minimally destructive archaeological studies. Researchers currently conducting archaeological projects should be approached to collaborate with the DOE on collection of data from mounds in their study areas. Research should include obtaining solid cores for measurement of soil physical and hydraulic properties and collecting data on water distribution in the mound by destructive analysis of soil samples. Use of neutron probes for measuring soil water might be possible, but constraints on the transportation and use of equipment with radiation sources may make this impractical.

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APPENDIX A

A BIBLIOGRAPHY OF LITERATURE ON ARCHAEOLOGICAL MOUNDS THAT IS APPLICABLE TO RESEARCH ON WASTE COVER ANALOGS

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APPENDIX B

EXAMPLE OF THE FORM USED TO COLLECT DATA ON ARCHAEOLOGICAL MOUNDS FOR THE LOW-LEVEL WASTE NATURAL ANALOGS PROJECT

Mounds Analog: Form #20

Mound Name or Number: Mound #2 or the Seip Mound of the Seip Mound Group.

Location: Paxton Township, Ross County, Ohio.

Environmental Setting: Within the Paint Creek Valley. The site is situated on the third terrace above the creek. The valley is bordered by low hills, 500 ft. elevation, which are part of the Appalachian foothills.

Current Size: The mound was last measured in 1909. Composed of three lobes, the largest is toward the west end, and measured 120ft. in diameter and 20ft. high. The central lobe was 70ft. in diameter and 12ft. high, and the southern and smallest lobe measured 40ft, in diameter and was 6ft. high.

Original Size: The mound appears very close to its original size and configuration.

Current Shape: Three conjoined conical mounds.

Original shape: Same as above.

Age: Hopewell.

Manner of Determination: Relative dates based upon artifact typology. The mound was investigated prior to the advent of radiocarbon dating.

Estimated Extent of Erosion: Erosion appears to have been minimal, which seems to be attributable to a gravel edge and covering which served to buttress the mound slopes and redirect water off the mound.

Erosion Type: Not applicable, see above.

Construction History: This mound was built in a single construction event, i.e. a single mound of fill covering an activity surface. The soil used for the mound was locally derived loam and humus. This was capped by an outer covering of large limestone gravels and clay. The gravel and clay covering apparently became cemented over time making its removal quite difficult. This covering was supported by a rough dry masonry foundation which completely encircled the the mound and consisted of 6 to 100 pound limestone and sandstone blocks. This foundation ranged from 2 to 2.5ft. deep and varied in width from 5 to 7ft.

The mound site was prepared by removing the humus and surface soil in the vicinity of the construction site down to gravel. The surface was then leveled using gravel, clay, logs, and brush as fill material. This surface was subsequently covered with a layer of fine sand between .5 and 2in. thick. Charnel structures were then erected on this surface evidenced by post hole outlines. The charnel house was burned prior the the construction of the primary mound. Puddled clay was employed in the construction of raised funerary platforms which were covered by the charnel structures. These platforms (24 in number) averaged 6 x 8ft and 8in. high. Used as crematory surfaces the puddled clay became baked and extremely hard, discoloring the earth for several inches in depth. These surfaces were eventually covered by fill and capped by the gravel layer.

MORPHOLOGY/PHYSICAL PROPERTIES

Stratification: Detail not provided.

Texture: N/A

Bulk Density: N/A

% Compaction: N/A

Water Conductivity: N/A

Substrate Characteristics: Unknown

Plan and Profile Drawings: See attached

Notes/comments: Shetrone and Greenman (1931), based upon their excavations of adjacent mound #1, believe this mound may actually be a unfinished core or primary mound which never received its its outer soil and gravel covering.

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APPENDIX C

DATA ON THE CONDITION AND DESIGN AND SOIL PHYSICAL CHARACTERISTICS OF A SAMPLE OF ARCHAEOLOGICAL MOUNDS

Table C1. Data on Condition, Design Features, and Environment Obtained from a Sample of Archaeological Mounds.

Case #	Shape	Condition	Damage *(1)	Const. Seq.	Materials	Age	layered?	Foundation * (2)	Revetment	Surfacing	Basal Tomb	Setting
#1	Platform, Ter, Pyd	Good	SW/G	Staged, (6)	Clays & Sandy silts	A 900 to 1150	Y	UNK	UNK	N	N	Floodplain
#2	Platform, Rec.	Fair /Poor	G/V	Staged, (4)	Clay & Silty loam	B 50 to A 200	Y	CF	N	N	UNK	Upland
#3	Platform, Pyd	Fair	Unkwn	Staged	Sandy Loam, Sand, & Clay	A 30 to 90	Y	SF	N	N	N	Upland
#4	Conical, rnd	Fair	PLW	Staged, (5)	Clay & Loam	A 380	N	SS	N	N	Y	Upland
#5	Conical, Conj.	Good	V	Phased	Sand, Clay, Sandstone	A 80 to 100	Y	SS, CF, RB	N	Y, RK	Y	Upland
#6	Platform, Ter, Pyd	Good>Poor	MIL,FILL	Phased, (3)	Clay, Cane, & Sand	A 900 to 1300	Y	N	N	N	N	Floodplain
#7	Conical, Trun.	Fair /Poor	SW,PLW,V	Staged (2)	Clay & Sandy Clay	B 300 to A 700	N	N	N	N	N	Floodplain
#8	Conical, Trun.	Ukwn	Unkwn	Unknown	Clay	B 100	N	UNK	N	N	Y	Terrace
#9	Platform, Rec.	Good	None	Staged,(4)	Gravelly Clay	A 950 TO 1250	Y	N	N	Y, CP	N	Upland
#10	Conical, Rnd	Good	Unkwn	Phased	Gravel & Clay	A 950 TO 1250	Y	N	N	N	N	Upland
#11	Calm, Rock	Fair	V	Single event	Rock Calm & Earth	B 1000	N	N	N	Y, RK	Y	Upland
#12	Conical. Rnd	Fair	SW/E/V/PLW	Single event	Sand & Shell	B 300 TO A 700	Y	N	N	N	N	Floodplain
#13	Conical. Rnd	Fair	Unkwn	Unknown	Unknown	A 1100	UNK	N	N	UNK	UNK	Upland
#14	Conical, Trun.	Fair-Poor	PLW/RIV	Staged	Sandy Loam, Sandy Clay	A 1450 TO 1650	Y	N	N	N	Y	Floodplain
#15	Conical. Rnd	unk	FILL	Staged (2),	Sand, Alluvial Silt & Clay	B 1000 TO B 300	N	N	N	N	Y	Floodplain
#16	Conical, Trun., Elip.	Good	V	Unknown	Logs & Brush Incorporated	B 1000 TO B 300	N	UNK	N	N	Y	Floodplain
#17	Conical, Trun., Elip.	Fair/Poor	SW/SL/V/FILL	Staged (3)	Loamy Clay	B 1000 TO B 300	Y	SS, CF	N	N	N	Terrace
#18	Platform, Pyd, Rec.	Fair/Poor	Unkwn	Variable	Variable	Unknown	Y	UNK	UNK	UNK	N	unk
#19	Platform, Pentagonal	Good	FILL	Phased (8),	Shell, Sand, & Clay	A 1200 TO 1700	Y	SH	Y, SH	N	N	Floodplain
#20	Conical, conj	Excellent	None	Single event	Loam, Gravels, & Clay	B 300 TO A 700	Y	SS, SF	Y, RK	Y, GVL, CY	Y	Terrace
#21	Platform	Excellent	None	Staged (2)	Loam, Gravels, & Clay	B 300 TO A 700	Y	SS, CF	Y, RK	Y, GVL	Y	Terrace
#22	Platform	Good	None	Staged (2)	Loess	B 50	N	N	N	N	N	Floodplain
#23	Conical and platform	Poor	PLW/FILL/G	Variable	Silt Loams & Massive Clays	A 500 TO 900	Y	VAR	UNK	N	UNK	Floodplain
#24	Platform, Trun	Poor	PLW,V,IRV/SW	Unknown	Sandy Loam & Heavy Clay	A 700 TO 1200	N	UNK	N	N	N	Floodplain
#25	Platform, Trun	Fair/Poor	RIV/PLW	Loaded	Sandy Loam & Heavy Clay	A 1200 TO 1700	Y	N	N	N	N	unk
#26	Conical, Elip.	Poor	PLW	Unknown	Sandy Silt	Unknown	N	UNK	N	N	N	Terrace
#27	Conical	Poor	FILL/PLW	Staged	Clay, Talus	B 300 TO A 700	Y	SS	Y, CY	Y, FC	Y	Upland
#28	Conical	Poor	PLW/V	Unknown	Unknown	A 700 TO 1200?	N	N	N	N	N	Floodplain
#29	Conical	Unkwn	Unkwn	Staged (2)	Sand & Shell	A 1000 TO 1300	Y	SF	N	N	Y	Floodplain
#30	Conical, trun	Poor	PLW	Phased (4)	Unknown	A 1100 TO 1400	N	N	N	N	N	UNK
#31	Conical	Unkwn	FILL/E/PLW/V	Unknown	Loam, Clay, Loess	A 1400 TO 1600	N	N	UNK	N	N	Terrace
#32	Conical	Unkwn	FILL	Staged (2)	Clay	B 830 TO B 250	N	N	N	N	Y	UNK
#33	Unkwn	Good	None	Staged (2)	Sand & Shell	A 800 TO 1200	N	N	Y? SH	N	Y	Floodplain
#34	Conical	Good	None	Single event	Humus & Sand	A 900 TO 1200	N	N	N	N	-Y	Floodplain
#35	Conical	Good	None	Staged (2)	Silt	B 500	N	SS	N	N	N	Terrace
#36	Ukmwn	Poor	PLW/V/FILL	Variable	Unknown	B 300 TO A 400	UNK	UNK	UNK	N	N	Floodplain
#37	Conical, Ellp	Unkwn	Unkwn	Staged (2)	Unknown	A 100 TO 200	UNK	N	N	N	Y	Terrace
#38	Circular Rise	Good	Unkwn	Single event	Rock	B 1000 TO B 300	N	N	N	Y, RK	N	Upland
#39	Circular Rise	Unkwn	Unkwn	Single event	Soil & Rock	B 1000 TO B 300	Y	N	N	Y, RK	N	Upland
#40	Long Barrows	Variable	VAR	Variable	Variable	B 4000 TO B 2000	UNK	VAR.	Y, RK	UNK	VAR.	VAR
#41	Conical, Ellp	Good	None	Acetionary	Shell	B 5000 TO B 2000	N/A	N	N	N	N	Floodplain
#42	Platform, pyd, sq.	Fair/Poor	PLW/SW/V	Unknown	Sand	A 1200 TO 1700	N	SF	N	N	N	UNK
#43	Circular Rise	Unkwn	Unkwn	Unknown	Clay	B 1000 TO A 700	N	UNK	UNK	N	UNK	Terrace

Table C.1. (continued)

Case #	Shape	Condition	Damage *(1)	Const. Seq.	Materials	Age	layered?	Foundation * (2)	Revetment	Surfacing	Basal Tomb	Setting
#44	Platform,ovale,or rec	Poor	SL	Staged (3)	Clay & Silt	B 3000 TO A 200	Y	N	N	N	N	UNK
#45	Platform, pyd, sq.	Poor	PLW/FILL	Staged (2)	Unknown	A 1600 TO 1700	N	N	N	N	N	Floodplain
#46	Conical	Good	FILL	Staged	Clay, Rock, Gravel	B 300 TO A 300	N	SS, RB	Y, RKN	UNK	N	Upland
#47	Stone & Earth Carin	Good	None/V	Single event	Earth & Rock	B 1000 TO B 300	N	N	N	Y, RK	N	Upland
#48	Conical, Conj	Fair	SW	Unknown	Loess	A 1400 TO 1600	N	N	Y, RK	N	Y	Upland
#49	Conical	Good	V/FILL	Phased (3)	Clay & Rock	B 1000 TO A 700	Y	N	N	N	N	Upland
#50	Conical, elip	Poor	PLW/G	Single event	Sandy Clay	B 1000 TO A 300	N	N	N	N	Y	Terrace
#51	Conical	Gone	SW/G/V	Staged (3)	Clay &Sand	B 300 TO A 700	Y	N	N	N	Y	Terrace
#52	Platform, pyd, rec.	Poor	SW/SL/V	Phased (4)	Clay & Sand	A 1600 TO 1700	Y	EL	N	N	N	Terrace
#53	Conical, trun	Poor	PLW/RIV	Staged (2)	Sand	B 1000 TO B 300	N	N	N	N	N	Floodplain
#54	Conical	Variable	PLW/V	Staged (2)	Clay & Loam	A 0 TO 200	Y	SS, CF	N	N	N	Terrace
#55	Platform, pyd, sq.	Poor	PLW	Staged (3)	Clay	A 1400 TO 1600	Y	N	N	Y, GVL	N	Upland

Footnote

1. SW= Sheet Wash, G= Gullying, V= Vandalism, PLW= Cultivation/Grazing, Mil= Military, Fill=Use as borrow material, Riv= River erosion, and SL= Slump

2. CF= Clay Floor, SF= Sand Floor, SS= Humus Cleared, SH= Shell, RB= Rock Base, EL= Earth Lodge, CP= Clay Plaster, FC= Fired Clay, GVL= Gravel, RK= Rock, CY= Clay, N= None

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