Buried Artifacts in Stable Upland Sites and the Role of Bioturbation: A Review

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Burial of artifacts in Holocene soils developed in pre-Holocene sediments on stable uplands is commonly interpreted as resulting from post-depositional accretion of sediment. However, soils are by nature dynamic and burial or displacement of artifacts can and does occur due to "normal" syndepositional and post-depositional biomechanical pedogenic processes. This paper presents a review of the role of bioturbation in artifact burial. © 2002 John Wiley & Sons, Inc.

INTRODUCTION

Burial of artifacts in Holocene soils that are developed in pre-Holocene deposits on relatively stable uplands is commonly interpreted as resulting from post-depositional accretion of eolian,[1] colluvial, or alluvial material, and less commonly from vertical movement of the artifacts themselves. The purpose of this paper is to emphasize the dynamic nature of the soil medium and to provide a brief review of bioturbation as an artifact burial mechanism and site formation process.

All soils are by nature dynamic (Johnson and Watson-Stegner, 1990; Johnson, this issue), even where developed on relatively stable geomorphic surfaces such as nearly level uplands, because they form through the vertical and lateral translocation of particles by less than obvious biomechanical processes. Where not environmentally restricted, biologic processes dominate in every soil exposed at the surface. Soil biota such as earthworms, ants, fossorial vertebrates, among others, continuously mix and displace particles, including artifacts, through burrowing and mounding, which tend to displace larger objects downward (Wood and Johnson, 1978) and smaller objects upward (Robertson and Johnson, 2001). Additional displacement occurs through tree-uprooting, which tends to translocate objects up-

[1] While it is recognized that atmospheric dust-fall is an ongoing global phenomenon, this paper is directed toward those areas where eolian influx during the Holocene has been "negligible" (i.e., where pedogenic processes have completely assimilated any influx of eolian material into the evolving soil without producing a cumulic profile).

ward (Wood and Johnson, 1978).[2] As a result of bioturbation, any artifact dropped onto the surface of a soil is subjected to translocation processes soon after it hits the surface. Bioturbation is not just a post-depositional process that may locally impact an already buried site, but rather it is one of the mechanisms by which artifacts become buried on nonaccreting upland surfaces. In fact, burial of artifacts on stable uplands is a predictable and natural consequence of biologic processes.

BIOTURBATION AND ARTIFACT MOVEMENT

Many studies now link the movement of artifacts and other objects within soils to biota. In one experiment conducted by Armour-Chelu and Andrews (1994), a single large, deep-burrowing earthworm (*Lumbricus terrestris*) was placed in one of two cylindrical glass jars measuring 30 cm in diameter and 60 cm in height. Both jars contained soil and small mammal carcasses placed on the soil surface. At the end of 2 years, the mammal bones in the jar containing the single deep-burrowing earthworm had been displaced vertically at least 24 cm and laterally 15 cm. In contrast, the mammal bones in the jar without an earthworm showed no lateral or vertical displacement.

Bocek (1986, 1992) conducted an experiment to ascertain the impact of rodent activity, mainly the pocket gopher *Thomomys bottae*, on archaeological materials at the Jasper Ridge Site in Stanford University's Biological Reserve, San Mateo County, California. The site is an unplowed, grass-covered tract that contains an Early Late Horizon component dating to A.D. 900. A 1-by-2 meter test unit that had been excavated in 1981 and subsequently backfilled with screened dirt that contained no materials larger than 0.6 cm in diameter was re-excavated in 1988. The re-excavated fill contained 8% of the total cultural and rock material between 0.6 cm and 1.8 cm in diameter and 15% of material between 1.8 cm and 3.5 cm in diameter, all recovered by screening. The introduction of this new material into the test unit was interpreted by Bocek as due to lateral transport by rodents from the surrounding unexcavated portions of the site. It was estimated that at this rate it would take only 88 years for the entire test unit to be refilled with cultural material. Bocek concluded that rodent activity increases site depth through burial of objects, that it increases site area, and that it decreases the average densities of those artifact sizes that are small enough to be transported within the rodent burrows (because the test unit was enriched in those fractions at the expense of the surrounding site area).

Working in abandoned agricultural fields in South Carolina, Michie (1990) found

[2] It is recognized that other, nonbiologic processes (e.g., freeze–thaw, shrink–well, etc.) can displace objects in soils (Van Vliet-Lanoe, 1985) in a manner comparable to that caused by biologic agents. For example, Darwin (1896) recorded during one wet–dry cycle 5.24 mm cumulative movement of a stone due to shrink–swell activity. While it is not my intent to disregard other, equally plausible processes of stone or artifact movement, the focus of this paper is on bioturbation processes. For a comprehensive discussion of other processes that can displace artifacts, the reader is referred to Wood and Johnson (1978), Johnson et al. (1987), and Schiffer (1987).

that over an approximately 100-year period, 35% of all shell fragments used to fertilize the field before abandonment in the 1870s, now occurred between the 15-cm-thick plowzone and 60 cm depth. Michie attributed this downward movement of shells into subplowzone horizons to bioturbation and gravity (for further studies on bioturbation and displacement of materials, see Cahen and Moeyersons, 1977; Moeyersons, 1978, 1989; Villa, 1982; Stein, 1983; Carter, 1990; Johnson, 1990; McBrearty, 1990; Mace et al., 1997; Van Nest, 1997; Leigh, 1998; Blackham, 2000; Van Nest, this issue).

Biogenic Burial Processes

Biogenic burial of artifacts occurs as a result of both within-soil borrowing of soil fauna, and the translocation of small particles (less than the diameter of their burrows and biochannels) from depth to the surface, in the form of mounds. This results in gradual burial and downward gravitational displacement of larger surface objects or artifacts. This simple and often subtle process of stone or artifact burial through ejection of fine soil particles onto the surface is captured in Figure 1, where surficial gravels in a parking lot are being buried beneath finer-grained material associated with an ant mound. Darwin (1896) observed that larger artifacts, such as the Stonehenge monolith depicted in Figure 2, become buried because of surface casting outside the circumference of the stone which raises the level of the ground surface around the stone. He noted that earthworm burrows beneath the stone collapse over time, causing the overlying stone to settle and sink. Bocek (1986) invoked a similar mechanism by rodents in which their habitual tunneling under larger artifacts, as opposed to over or alongside them, caused them to sink into underlying open cavities. Eventually, these processes lead to complete burial of the artifact often without changing the elevation of the ground surface (Lyford, 1963).

Depth of artifact burial ultimately corresponds to the base of major biologic activity (Johnson and Watson-Stegner, 1990), demonstrated by a noticeable decrease in fecal pellet and biovoid (burrow) abundance (Balek, 1995). In Mollisols and Alfisols of the Midwestern United States, and in other soils outside the United States (e.g., Australian “duplex” soils of Bishop et al. [1980]), this depth commonly approximates the uppermost part of the B horizon. Evidence of much deeper burrowing and downward translocation of objects has been recorded from African sites (Brink, 1985). Termites in the Kalahari sands of Rhodesia burrow down 1.8–2.4 m and bring precious metals up into their mounds (West, 1970).

Soil-Turnover and Artifact Burial Rates

Biogenically-induced soil turnover rates leading to artifact burial vary widely depending on the suite and makeup of the soil fauna. Humphreys and Mitchell (1988) compiled a list of average mounding rates for different soil fauna from North America, Africa, Australia, and Eurasia. They found that the average estimated amount of material brought to the surface from lower horizons within a 1000-year

Figure 1. Photograph showing process of artifact burial through soil fauna mounding activity. The process depicted consists of fine-textured materials being brought to the surface, from depth, in the form of burrow mounds (which in this example is an ant mound). The ejected fines bury the gravel (artifacts) exposed at the surface.

period can vary from as little as 30 mm for woodlice, snails, cicadas, and beetles; 40–1000 mm for ants; 50–150 mm for termites; 80–1600 mm for small mammals; 500 mm for crayfish; to as much as 7000 mm for earthworms. In some humid regions, such rates have led to overturning of the upper 30–50 cm of soil in less than 1000 years.

Gophers in California are estimated to overturn 3-15 m^3/ha/yr of soil based on

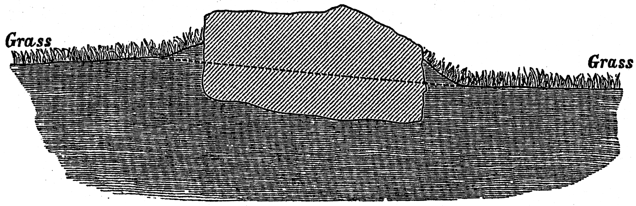

Figure 2. Cross-section documenting subsidence of a Stonehenge monolith due to earthworm burrowing and surface casting of ejected soil material along the stone perimeter (from Darwin, 1896).

an average mounding rate of 2–3 mounds/day/gopher, with each gopher ejecting 2.3 kg/day of soil (Bocek, 1986). At this rate, Bocek calculates that the surface soil can be completely reworked in 5–7 years by within-soil gopher burrowing and back-dirt mounding activities alone.

Crayfish activity in southern Indiana can add 800 g/m^2/yr of soil from depth to the surface in the form of chimneys (Thorp, 1949). The number of chimneys per acre can vary from an observed 625 in Indiana to an estimated 20,000 to 50,000 in east Texas.

In an area of Mollisols in southwestern Indiana, Baxter and Hole (1967) observed 1531 ant mounds within a one hectare area. The ant mounds covered 1.7% of the ground surface and volumetrically contained an average of 34 m^3 of soil per hectare. Baxter and Hole calculated that the whole area would be covered with mounds in about 700 years. Lyford (1963) estimated that ants in New England forests can generate a surface cover 25–45 cm thick in 3000–4000 years based on an average density of 1.2 mounds/m^2, or 62,500 mounds/ha. According to Thorp (1949), individual anthills in Colorado can reach diameters up to 6 m and can be seen on aerial photographs. Thorp (1949) estimated that individual ant mounds in Utah may contain 136 kg of soil, while those in the Great Plains are conservatively estimated to contain 77 kg of soil. For 20 ant mounds per acre, as much as 1.5 metric tons of earth may be piled at the surface throughout the Great Plains region in the form of ant mounds (Thorp, 1949). In southern Wisconsin forests, ant mounds can reach heights of one meter with basal diameters up to 3.25 m (Salem and Hole, 1968). Calculations from New South Wales indicate that 841 g/m^2/yr of soil is brought to the surface in the form of ant mounds, and 133 g/m^2/yr of soil is cast onto the surface by earthworms, yielding a combined soil turn-over time of the upper 30 cm every 430 years (Humphreys, 1981). I observed in the Chicago, Illinois region ant mounds with basal diameters of 87.5 cm and heights of 35 cm.

Based on observations of recent mine spoil in western Illinois, Caspall (1975) estimated that the upper 15 cm of soil is displaced at least every 50–100 years through earthworm and ant mound formation. Shaler (1891) found that earthworms, on average, added 0.25 cm a year of fine material to the surface while Darwin (1896) estimated 0.5 cm. Langmaid (1964) observed rapid, earthworm-induced changes in virgin New Brunswick forest soils where within 4 years after earthworms invaded the soil, there was complete mixing of pre-existent A and E horizons into a thick A horizon.

Given the above estimated and observed soil mounding and turnover rates, relatively rapid burial of artifacts is possible, especially if several different fauna occur at any one site. Termite activity in South Africa caused up to 6 mm of subsidence of concrete-block benchmarks in a 2-month period (16 mm in 2 years), and 12 mm of lateral displacement within 5 years (Watt and Brink, 1985). Burrowing and mounding associated with termites, ants, and earthworms in sands at the Kalina archaeological site in Gombe, Kinshasa buried artifacts as deeply as 2.7 m in 5000 years (Moeyersons, 1989). Darwin (1896) recorded earthworm-induced burial rates of artifacts ranging from 1.9 cm in 2.5 years to 37.5 cm in 32.5 years, and Atkinson

(1957) reported rates of 6.3–30 cm in 30 years. In California, Bocek (1986) calculated an artifact burial rate of up to 60 cm in 1000 years from rodent activity, and Erlandson (1984) noted that historic shells dated between A.D. 1500 and 1550 occurred 20–30 cm below the surface, yielding an artifact burial rate by gophers of 5.5 cm every 100 years. At sites on the South Carolina coastal plain, artifact burial rate was calculated at 5.5 cm in 1000 years (Michie, 1990).

Bioturbation and Artifact Disposition

Soil fauna burrowing and mounding activity and tree-uprooting can affect artifact disposition in several ways. Through burrowing and mounding, artifacts can become displaced and sorted vertically by size thereby destroying stratigraphic integrity. Generally, artifacts (stones) whose diameters are less than the diameter of the burrows of soil fauna may be translocated upward and deposited in mounds. For example, studies indicate that crayfish (Robertson and Johnson, 2001), pocket gophers (Johnson, 1989), and mole-rats (Mbenza et al., 1989) will shift rock fractions smaller than the diameter of the burrows to the surface. I have observed concentrations of fist-sized cobbles in back-dirt piles formed outside the mouths of burrows of unidentified large mammals. These cobble-rich piles stood in marked contrast to the surrounding undisturbed soil with no cobbles at the surface.

In the Tularosa Valley of New Mexico, Johnson (1997:181, 187) examined the stones brought up by badgers at 100 of their burrows in an 83 by 159 m tract (13,197 m^2); the largest stone measured 29.2 cm in diameter and weighed 5.5 kg (12.1 lbs), and the average diameter of the 100 largest stones was 9.3 cm.

Artifacts whose diameters are larger than the diameter of the burrows gradually become buried or gravitationally displaced downward to the lower depth of major biologic activity where they may become concentrated to form pseudo-artifact horizons. To this point, Bocek (1986, 1992), Erlandson (1984), and Johnson (1989) warn that observable cultural stratigraphy may actually represent faunal-related horizons and not separate cultural components because the distribution of artifacts may be completely unrelated to prehistoric human behavior. Erlandson found a bimodal vertical distribution of artifacts associated with a small, single component campsite in southern California that he related to gopher activity. The artifact zones corresponded to gopher burrow zones concentrated at 15–20 cm depth and 50–55 cm depth. Bocek (1986) observed a similar phenomenon associated with rodent burrowing elsewhere in California in which single component artifacts were vertically separated into biogenically-produced cultural horizons of smaller artifacts near the surface and larger ones near 40 cm depth.

The ability of soil fauna to sort particles by size can also occur at very small scales, as shown in Figure 3, which is a photograph of a soil thin section taken from the bioturbated Ab horizon of the last interglacial Sangamon Soil in western Illinois (Balek, 1995). Here, particles have been biogenically sorted in such a manner that sand-sized minerals are preferentially clustered along the biochannel wall. A fining in grain size occurs with increasing distance from the channel wall. Ar-

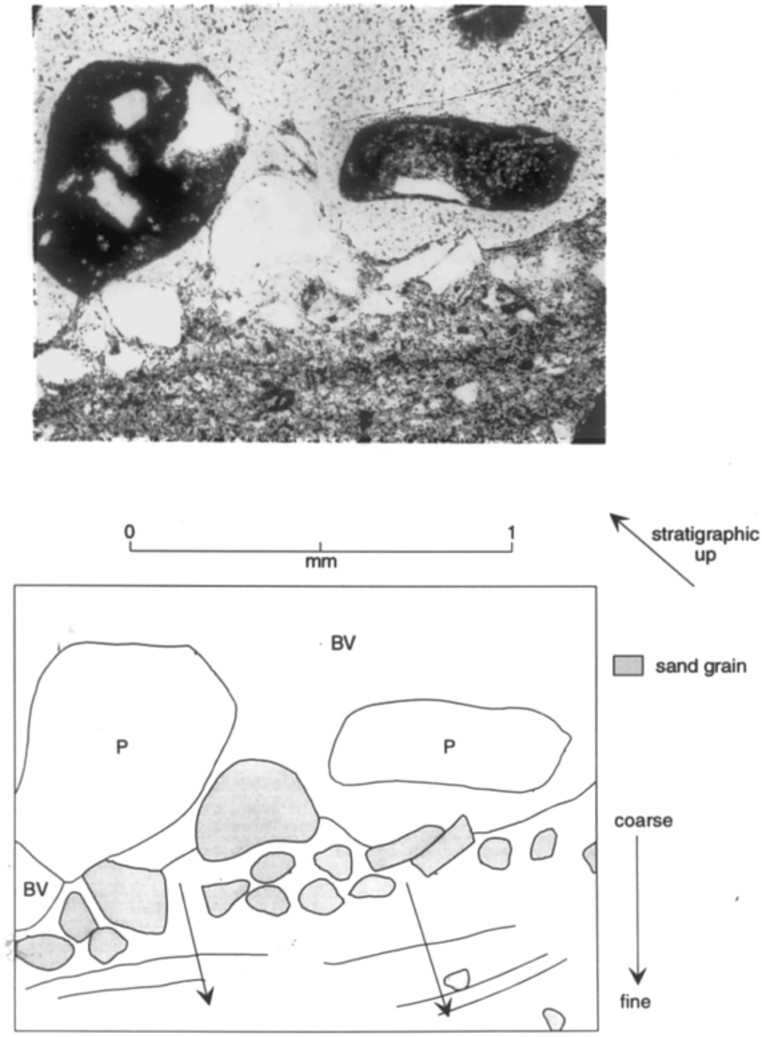

Figure 3. Photograph (top) and tracing (bottom) of a soil thin-section taken from the bioturbated Ab horizon of the Sangamon Soil in western Illinois. Photograph shows fecal pellets (P) in a paleochannel (or biovoid, BV). Biogenic sorting of mineral grains by size is seen in the preferential clustering of sand-sized minerals along the paleochannel wall and a fining in grain size with increasing distance from the wall (from Balek, 1995).

mour-Chelu and Andrews (1994) noted in their experiment that earthworms vertically displaced smaller bone elements more than larger ones, with the smaller ones becoming concentrated at depth.

While some studies suggest that certain styles of bioturbation may destroy the stratigraphic integrity of archaeological materials (e.g., badgers, armadillos), others, as indicated by Darwin's (1896) worm observations, document the preservation of original horizontal and vertical relationships of cultural material. In this case, Darwin spread a layer of lime over an abandoned pasture. Six years later, he spread a layer of coal cinders over the same field. Ten years after the start of the experiment, Darwin dug a trench and found a layer of cinders 2.5 cm below the surface and a layer of lime 7.5 cm below the surface. He concluded that the objects began as a layer on the surface and were buried and moved downward as a layer. Upland sites in Illinois (Van Nest, 1997), Missouri (Kreisa, 1995), and California (Johnson, 1989) are known to retain vertical stratigraphic relationships in which buried artifacts of older cultures underlie buried artifacts of younger cultures. Michie (1990) found that while temporally-distinct cultural horizons in upland sites on the coastal plain of South Carolina generally retained their vertical stratigraphic relationships, there was some mixing of artifacts from different periods. He found sherds of the same vessel scattered through a 45-cm-thick vertical sequence, part of which contained older Archaic artifacts. Despite such mixing, Michie noted that depth of burial per cultural horizon was consistent from site to site and concluded that the long-term effect of bioturbation was to generally preserve the cultural stratigraphy. Such may not always be the case, though, for Carter's (1990) study of age-stratified land snails in Britain indicated that stratification was completely destroyed by earthworms within 450 years.

Mixing of temporally distinct cultural materials can be expected to occur in woodlands and forested areas (Schaetzl et al., 1989, 1990), where tree-uprooting can displace entire soil profiles to at least one meter depth (Lutz and Griswold, 1939) and displace any rocks or artifacts that may be within the dislodged soil material. On at least one occasion, while participating in a Phase I archaeological survey in the forested areas of Fort Leonard Wood in south-central Missouri, I observed prehistoric artifacts exposed in the soil of an uprooted tree. Similarly, in the Cambria pines near Heart's Castle on the California coast, prehistoric lithic artifacts were observed mixed throughout the soil near an uprooted tree (observed by M. A. Gasson and D. L. Johnson, personal communication; D.L. Johnson, 2000). Soil sloughing from the root plate into the underlying cavity can mix artifacts from different periods.

DISCUSSION

The crux of this paper is to impress upon those who participate in archaeological, geomorphological, and pedological work that biomechanical processes impact "stable" upland, nonaccreting archeological sites disrupting the original archaeological patterns (Schiffer, 1987). Artifacts can be sorted by size, become temporally mixed, and can be displaced laterally and vertically. Site formation process studies should focus equally on both the internal dynamic biomechanical attributes of soil genesis and the external processes, such as erosion, deposition, and eolian infall that affect artifacts, the soil surface, and the soil horizons. The external processes are succinctly summarized by Michie (1990:43):

> Whenever artifacts are buried, we have been trained to think in contemporary geologic thought and consider the processes responsible for burial. More often than not, we look for evidence of fluvial deposition, aeolian sands, colluvium, or any combination of these processes. Furthermore, we've been trained to believe the age of the artifacts within the deposit is a reflection of depositional antiquity. For example, if we find Late Archaic cultural material within a deposit, we naturally assume that the associated soils were deposited sometime during or after the occupation. We are encouraged to think this way because many sites have been buried by a series of dynamic processes. We have only to look at deep site profiles along major streams and see the layers of silts, clays, sands, and other sediments to be convinced that rivers breach their banks and deposit sediments along levees. When sand is being blown across dunes we realize the dynamics of wind, and when hills erode we see the accumulation of colluvium. Such examples are all around us, and consequently we learn to recognize the very processes that have shaped our world. It all seems to be related to erosion and deposition.

However, this emphasis on geologic processes in artifact burial leads to the misconception that soils developed on stable surfaces are static entities (Atkinson, 1957). We implicitly, and sometimes explicitly, reason that if erosion or deposition is negligible, then the surface is stable, and so is the soil. And, if the soil is stable, then any artifact dropped onto the surface will remain at the surface so long as deposition of new sediment does not bury it (e.g., Waters, 1992; Waters and Kuehn, 1996). However, a stable geomorphic surface does not mean that the soil is stable or static (Atkinson, 1957). Internal biomechanical processes continually create a dynamic medium through which artifacts discarded onto the surface are readily displaced vertically and laterally. As early as 1957, Atkinson warned archaeologists that earthworm activity could alter the stratigraphic relationships of artifacts and that their ability to displace artifacts downward could not be ignored. Earthworms, however, are only one among many motile faunal lifeforms that cause bioturbation.

CONCLUSION

Burial of most, if not all, artifacts in stable upland soils developed in pre-Holocene sediments in nonfeature contexts, is due to vertical movement of the artifact in response to normal biologic activity, namely, burrowing and mounding by earthworms, ants, and other fauna, and by tree-uprooting. As long as soil biota continue to exist and create voids through which artifacts can fall, and as long as lifeforms continue to mix the soil matrix through preferential ejection of materials from depth onto the surface in the form of burrow mounds, or through tree uprooting, artifacts will be displaced.

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REFERENCES

Armour-Chelu, M., & Andrews, P. (1994). Some effects of bioturbation by earthworms (Oligochaeta) on archaeological sites. Journal of Archaeological Science, 21, 433–443.

Atkinson, R.J.C. (1957). Worms and weathering. Antiquity, 31, 219–233.
Balek, C.L. (1995). A reassessment of the genesis of the Sangamon stone line and texture contrast profile in McDonough County, western Illinois. Unpublished doctoral dissertation, University of Illinois, Urbana.
Baxter, F.P., & Hole, F.D. (1967). Ant (Formica cinerea) pedoturbation in a prairie soil. Soil Science Society of America Proceedings, 31, 425–428.
Bishop, P.M., Mitchell, P.B., & Paton, T.R. (1980). The formation of duplex soils on hillslopes in the Sydney Basin, Australia. Geoderma, 23, 175–189.
Blackham, M. (2000). Distinguishing bioturbation and trampling using pottery sherd measures, Tell Fendi, Jordan. Geoarchaeology, 15, 469–497.
Bocek, B. (1986). Rodent ecology and burrowing behavior: Predicted effects on archaeological site formation. American Antiquity, 51, 589–603.
Bocek, B. (1992). The Jasper Ridge reexcavation experiment: Rates of artifact mixing by rodents. American Antiquity, 57, 261–269.
Brink, A.B.A. (1985). Engineering geology of southern Africa, Volume 4. Pretoria: Building Publications.
Cahen, D., & Moeyersons, J. (1977). Subsurface movements of stone artefacts and their implications for the prehistory of Central Africa. Nature, 266, 813–815.
Carter, S.P. (1990). The stratification and taphonomy of shells in calcareous soils: Implications for land snail analysis in archaeology. Journal of Archaeological Science, 17, 495–507.
Caspall, F.C. (1975). The movement of stones in surface mine spoils. Proceedings of the Association of American Geographers, 7, 49–55.
Darwin, C. (1896). The formation of vegetable mould through the action of worms. New York: D. Appleton.
Erlandson, J.M. (1984). A case study in faunalturbation: Delineating the effects of the burrowing pocket gopher on the distribution of archaeological materials. American Antiquity, 49, 785–790.
Humphreys, G.S. (1981). The rate of ant mounding and earthworm casting near Sydney, New South Wales. Search, 12, 129–131.
Humphreys, G.S., & Mitchell, P.B. (1988). Bioturbation: An important pedological and geomorphological process. Abstracts (Volume 1). 26th Congress of the International Geographical Union, Sydney, Australia.
Johnson, D.L. (1989). Subsurface stone lines, stone zones, artifact-manuport layers, and biomantles produced by bioturbation via pocket gophers (Thomomys bottae). American Antiquity, 54, 370–389.
Johnson, D.L. (1990). Biomantle evolution and the redistribution of earth materials and artifacts. Soil Science, 149, 84–102.
Johnson, D.L. (1997). Geomorphological, geoecological, geoarcheological and surficial mapping study of McGregor Guided Missile Range, Fort Bliss, New Mexico, Miscellaneous Report of Investigation No. 157. Plano, TX: Geo-Marine, Inc.
Johnson, D.L., & Watson-Stegner, D. (1990). The soil-evolution model as a framework for evaluating pedoturbation in archaeological site formation. In N.P. Lasca & J. Donahue (Eds.), Archaeological geology of North America (pp. 541–560), Centennial Special Volume 4. Boulder, CO: Geological Society of America.
Johnson, D.L., Watson-Stegner, D., Johnson, D.N., & Schaetzl, R.J. (1987). Proisotropic and proanisotropic processes of pedoturbation. Soil Science, 143, 278–292.
Kreisa, P.P. (1995). Phase II excavation and evaluation of seven sites at Fort Leonard Wood, Pulaski County, Missouri, Research Report No. 21. Urbana, IL: University of Illinois, Public Service Archaeology Program.
Langmaid, K.K. (1964). Some effects of earthworm invasion in virgin podzols. Canadian Journal of Soil Science, 44, 34–37.
Leigh, D.S. (1998). Evaluating artifact burial by eolian versus bioturbation processes, South Carolina sandhills, USA. Geoarchaeology, 13, 309–330.
Lutz, H.J., & Griswold, F.S. (1939). The influence of tree roots on soil morphology. American Journal of Science, 237, 389–400.

Lyford, W.H. (1963). Importance of ants to brown podzolic soil genesis in New England, Paper Number 7. Petersham, MA: Harvard Forest.
Mace, J.E., Graham, R.C., & Amrhein, C. (1997). Anthropogenic lead distribution in rodent-affected and undisturbed soils in southern California. Soil Science, 162, 46–49.
Mbenza, M., Aloni, K., & Lubuimi, M.L. (1989). Le rôle des rats-taupes dans la mise en place actuelle de certains pavages résiduels des sols des régions tropicales humides à saisons contrastées. Geo-Eco-Trop, 11, 127–137.
McBrearty, S. (1990). Consider the humble termite: Termites as agents of post-depositional disturbance at African archaeological sites. Journal of Archaeological Science, 17, 111–143.
Michie, J.L. (1990). Bioturbation and gravity as a potential site formation process: The Open Air Site, 38GE261, Georgetown County, South Carolina. South Carolina Antiquities, 22, 27–46.
Moeyersons, J. (1978). The behavior of stones and stone implements buried in consolidating and creeping Kalahari sands. Earth Science Processes, 3, 115–128.
Moeyersons, J. (1989). The concentration of stones into a stone-line, as a result from subsurface movements in fine and loose soils in the tropics. Geo-Eco-Trop, 11, 11–22.
Robertson, K., & Johnson, D.L. (2001). Crayfish origin and distribution of rock fragments in an Illinois catena, Manuscript on file. Urbana: University of Illinois.
Salem, M.Z., & Hole, F.D. (1968). Ant (Formica exsectoides) pedoturbation in a forest soil. Soil Science Society of America Proceedings, 32, 563–567.
Schaetzl, R.J., Johnson, D.L., Burns, S.F., & Small, T.W. (1989). Tree uprooting: Review of terminology, process, and environmental implications. Canadian Journal of Forest Research, 19, 1–10.
Schaetzl, R.J., Burns, S.F., Small, T.W., & Johnson, D.L. (1990). Tree uprooting: Review of types and patterns of soil disturbance. Physical Geography, 11, 277–291.
Schiffer, M.B. (1987). Formation processes of the archaeological record. Albuquerque: University of New Mexico Press.
Shaler, N.S. (1891). The origin and nature of soils, Twelfth Annual Report. Washington, DC: U.S. Geological Survey.
Stein, J.K. (1983). Earthworm activity: A source of potential disturbance of archaeological sediments. American Antiquity, 48, 277–289.
Thorp, J. (1949). Effects of certain animals that live in soils. Scientific Monthly, 68, 180–191.
Van Nest, J. (1997). Late quaternary geology, archaeology and vegetation in west-central Illinois: A study in geoarcheology. Unpublished doctoral dissertation, University of Iowa, Iowa City.
Van Vliet-Lanoe, B. (1985). Frost effects in soils. In J. Boardman (Ed.), Soils and Quaternary landscape evolution (pp. 117–158). New York: Wiley.
Villa, P. (1982). Conjoinable pieces and site formation processes. American Antiquity, 47, 276–290.
Waters, M.R. (1992). Principles of geoarchaeology: A North American perspective. Tucson: University of Arizona Press.
Waters, M.R., & Kuehn, D.D. (1996). The geoarchaeology of place: The effect of geological processes on the preservation and interpretation of the archaeological record. American Antiquity, 61, 483–497.
Watt, I.B., & Brink, A.B.A. (1985). Movement of benchmarks at the Pienaarsrivier survey base, Engineering geology of southern Africa, Volume 4. Pretoria: Building Publications.
West, W.F. (1970). The Bulawayo symposium papers: No. 2 "termite prospecting." Chamber of Mines Journal, 12, 32–35.
Wood, W.R., & Johnson, D.L. (1978). A survey of disturbance processes in archaeological site formation. Advances in Archaeological Method and Theory, 1, 315–381.

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