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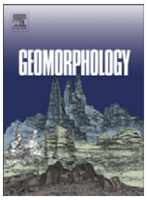

Elephants (and extinct relatives) as earth-movers and ecosystem engineers

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ABSTRACT

Modern African elephants affect habitats and ecosystems in significant ways. They push over trees to feed on upper branches and often peel large sections of bark to eat. These destructive habits sometimes transform woody vegetation into grasslands. Systems of elephant trails may be used and re-used for centuries, and create incised features that extend for many kilometers on migration routes. Elephants, digging in search of water or mineral sediments, may remove several cubic meters of sediments in each excavation. Wallowing elephants may remove up to a cubic meter of pond sediments each time they visit water sources. Accumulations of elephant dung on frequented land surfaces may be over 2 kg per square meter. Elephant trampling, digging, and dust-bathing may reverse stratigraphy at archeological localities. This paper summarizes these types of effects on biotic, geomorphic, and paleontological features in modern-day landscapes, and also describes several fossil sites that indicate extinct proboscideans had very similar effects, such as major sediment disturbances.

1. Introduction

Large and small animals disturb land surfaces with digging, burrowing, wallowing, trampling, and other behaviors whose effects may permanently influence landscape evolution (Butler, 1995). As expected, large mammals often have very large effects. This paper aims to describe and discuss the large and small effects of the largest terrestrial mammal, the African elephant. First I examine some of the ways in which free-roaming elephants shape and re-shape landscapes in contemporary African settings. A systematic quantification of the effects has not yet been reported, but general impacts of the actions are here summarized. I describe digging, trampling, rock polishing, and other effects such as habits of destructive feeding on vegetation. Next I describe fossil sites – some containing proboscidean bones – and attempt to explain how ancient sediments preserve traces of proboscidean behavior very much like the behavior of living elephants.

2. Animal landscape-sculptors and ecosystem-engineers

The ways in which terrestrial animals affect surface sediments are many and varied. Portions of the landscape may be re-shaped and effectively sculpted by animal behavior. Likewise, some animal behaviors may change vegetational communities by eliminating, damaging, or suppressing specific plant taxa.

Beavers (*Castor canadensis*) provide an example of both processes. They frequently stack and weave sections of tree branches and sticks and stabilize them with mud to build dams that create lakes and ponds, often diverting streamflow and altering habitats (see Naiman et al., 1988 and Butler, 1995: 148–183). An extreme example is in Wood Buffalo National Park, Canada, where beavers have built an 850-m-long dam in remote, flat wetlands within coniferous forest, a construction feat that probably stretched over many generations (http://www.pc.gc.ca/eng/pn-np/nt/woodbuffalo/ne.aspx; accessed 3 September 2010).

An example of smaller-scale animal landscape-sculpting is seen with modern wolves (*Canis lupus*), which dig out or enlarge natural rockshelters and earth hollows, especially in sand, to make dens for newborn pups (Mech, 1970: 118–123). Sometimes these sites are re-used but also are often abandoned, and other animals then sometimes adopt them for dens. Wolves are not the only diggers. Warthogs (*Phacocoerus aethiopicus*) in Africa modify existing ground openings such as erosion gullies or antbear burrows, or excavate when needed, creating shelter from predators at night or protection from heavy rain (Cumming, 1975). Fossorial rodents tunnel through sediments, some of which may contain archeological materials, either in open-air or cave/rockshelter settings, often destroying stratification or creating features such as stone lines that deceptively appear to be original strata (Bateman et al., 2003). Sometimes infilled remnants of animal burrows (called krotovinas) are preserved in ancient sediments (see, for example, Tappen et al., 2002).

Some animal effects on land surfaces are larger scale. Well-used animal migration routes following hilltops may become sunken trailways, such as the bison trails now adopted for highways and rail routes in the eastern United States. A still noticeable bison trail system is the Buffalo Trace in Indiana, also called the Vincennes Trace and Clarksville Trace, where US Route 150 follows it. Another long-

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distance bison trail has become the Natchez Trace Parkway from Mississippi to Tennessee. Similar animal-made routes are still being created and used today in southern Africa, where some game trails have been used by nomadic elephants for centuries (G. Haynes, 1991, 2001, 2005). Fig. 1 shows trails used by elephants (and other species) in Hwange National Park, Zimbabwe. These trails range from 30 to 50 cm wide and 5–15 cm in depth, depending on substrate and intensity of use. Elephant-use creates nearly flat-bottomed trails with fairly regular lateral margins, whereas hoofed animals may create trails with less even bottoms and margins. Parallel trails may be created and used in some places, especially when elephants move in greater numbers. The trails created and maintained by elephants are compacted and scuffed surficial sediments without covering vegetation, which has been worn off. Oftentimes fresh and trampled dung may form a carpeting on sections of the trails (as in Fig. 1 on the left), especially near water sources where elephant traffic is concentrated.

Laws et al. (1975) recognized that large African animals, such as elephants, interact with the environment in powerful ways. Currently researchers are carefully measuring how these interactions have “major organizing effects upon ecosystem processes as well as structure” (McNaughton et al., 1988: 799). Below I describe African elephant effects on land surfaces and ecosystems that I have observed or found in the literature.

2.1. Digging by elephants

Elephants are especially able to alter land surfaces on large and small scales. Elephants in Africa dig wells to reach subsurface water (Douglas-Hamilton and Douglas-Hamilton, 1975: 165; G. Haynes, 1988, 1991) and excavate into mineral deposits to ingest the sediments (Buss, 1990: 164–170) or to spread dust over their skins to protect against biting insects and harsh sunlight, leaving behind large holes and depressions in the ground (Fig. 2; also see figures in Buss, 1990:166).

Elephants visiting water holes in southern Africa may walk away from the pond bottoms with mud sticking to their legs and bodies, and also may ingest some mud, thus deepening and enlarging the water basins (Weir, 1969). Flint and Bond (1968) estimated that African elephants in Rhodesia (now Zimbabwe) removed 0.3 to 1.0 m^3 of mud every time they wallowed in mud. This process has been documented for other animals as well in other parts of the world (Butler, 1995). Elephants in Kenya have been recorded entering a cave system in Mt Elgon to scrape and feed on minerals from the cave walls in total darkness, thus reshaping the cave interior (Redmond, 1982). Buss (1990) found large elephant-excavated holes and pits in roadbanks and slopes within the Ngorongoro Crater. Analysis of the mineral samples suggested that the elephants were digging in the sediments specifically for manganese and cobalt, essential micronutrients, and regularly walked considerable distances to reach these sediments.

2.2. Elephants can smooth and polish rock surfaces

In the Sengwa Wildlife Research Institute, Zimbabwe, elephants polish rock faces when they press against stone surfaces to drink water from at least one spring issuing from the base of a bedrock ridge (Fig. 3). Elephants (and other animals) scratch themselves in African game reserves by rubbing their bodies against rocks and tree stumps (Fig. 4), wearing down the stone or wood surfaces and frequently producing glossy polish.

2.3. Elephants affect vegetational communities

Elephants also affect landscapes in other ways that do not directly involve sediments, such as stripping bark from live trees for

Fig. 1. Trails used frequently by elephants in Zimbabwe. On the left, a trail in loam showing compression up to 10 cm deep in the center; on the right, a shallower trail in loose Kalahari sand where the deepening results as much from pushing-up of sand to each side as from compression. Photographed in Hwange National Park; right photograph taken in late 1990s, left photograph taken 1983.

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Fig. 2. Elephant-dug pit in mineral sediments, Hwange National Park, Zimbabwe. Photographed in late 1990s.

nourishment, or pushing trees over to reach upper branches, often killing the trees. In Africa, elephants are sometimes considered problems because they cause the loss of plant species. Any other animals that may feed on those plants must either migrate or decrease in numbers as they lose forage sources. Elephants preferentially feed on certain plants in different seasons of the year, seeking moisture and nutrients from the tissues. In the dry season, grass – which is a favorite forage in the wet growing seasons – dries out and provides poor forage, so elephants must browse more often, seeking more woody vegetation, including leaves, twigs, and bark. Heavy feeding on woody plants may irreversibly damage whole stands of trees and bushes. According to Sikes (1971: 248), an adult male elephant in Africa may eat up to 150 kg of vegetable matter every day, but also damages even more than this daily while feeding ("it is a somewhat wasteful feeder") and moving through vegetation. Elephants are capable of opening up previously dense vegetation while feeding and trampling. Higher densities of elephants can completely remove large patches of woody vegetation, and open up ground for different sorts of vegetational communities, including patchy mosaics (Lindsay, 1990) or grasslands. According to Petrides and Swank (1964: 841; cited in Buss 1990:162), elephants may "maintain a relatively early successional stage of plant community development" by removing trees, often enabling other animal species to live in regions where they would not have been present otherwise. Once wooded habitats that have been cleared by elephants may experience an increase in animals that are mixed feeders and grazers. Such changes are major ecological impacts. Bell (1985) found that woodland dominated by the common genera *Acacia*, *Commiphora*, and *Adansonia* is particularly affected by the impacts of elephants, becoming more open and losing considerable numbers of trees because of elephant feeding. Such changes in biota also may affect geomorphological processes, such as fostering accelerated erosion or slowing the formation of soil horizons.

Fig. 3. Smoothed sandstone rock face where elephants (judging from the tracks in the streambed) and possibly other large mammals have pressed or rubbed against it while drinking from the spring. Photographed in Chirisa National Park, Zimbabwe, 1982.

Fig. 4. Smoothed and polished stump of *Combretum imberbe* (leadwood), rubbed by elephants in Hwange National Park, Zimbabwe. This is a very dense and strong hardwood, and this degree of polish indicates frequent heavy rubbing by elephants, suggesting what can also happen with rock surfaces. Photographed in the early 1990s.

2.4. Accumulations of elephant dung

Where elephants congregate, such as at preferred feeding patches or around water sources, dung may be so thick as to carpet the ground surface over large expanses (Fig. 5). An average size African elephant may pass up to 100 boluses of 1–2 kg each, generally in 20–30 defecations, every 24 h (Sikes, 1971: 107). Passage time of undigested food probably varies between about 20 to over 50 h, based on studies of a captive Asian elephant (Benedict, 1936).

Trampled dung concentrated in aggregation sites, such as margins of waterholes, would alter local sediment pH near surfaces and clearly add substantial amounts of organic matter to the mineral sediments. Measurements of the pH effects of different quantities and densities of elephant dung are not available, but overall the dung probably does not dramatically change landscape acidity or alkalinity except on very localized scales. The process of such heavy deposition of dung is usually seasonal. At the end of the season of deposition the organic matter may be overgrown with fresh vegetation and eventually incorporated into a litter zone until the next episode of dung deposition and trampling, expectably in a dry season when the ground cover is once again depleted and minimal. Elephants do not digest more than about half of what they eat. Because of the 1–2 day passage time in the gut the organic matter may be derived from forage ingested some distance away from the defecation sites; thus, undigested seeds or nuts may be distributed fairly widely and expand the range when they successfully germinate.

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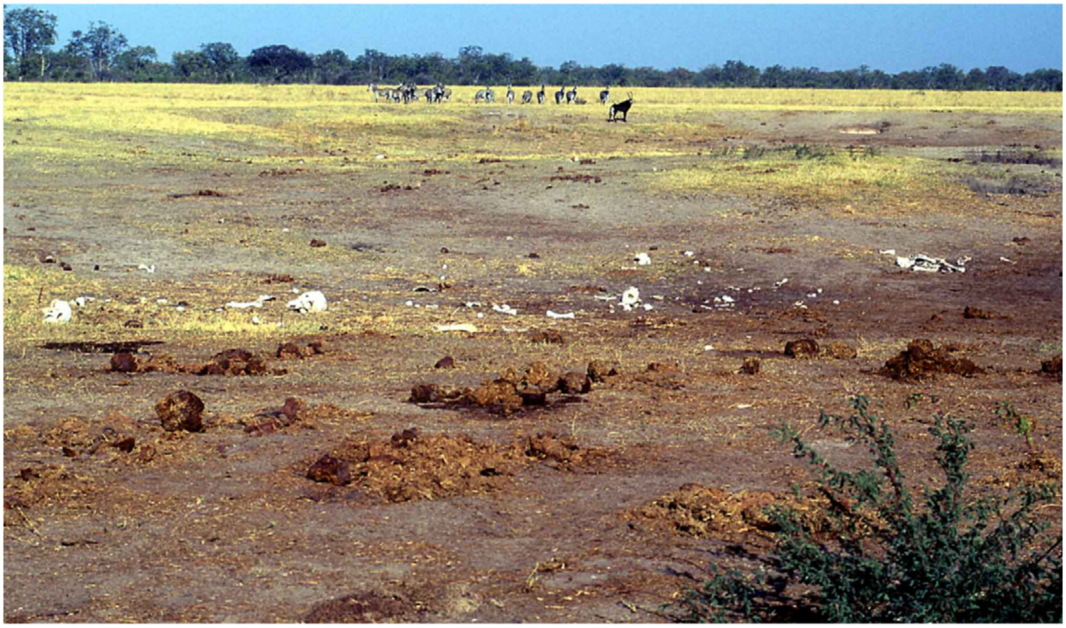

Fig. 5. Dung boluses, trampled dung, and elephant bones on a land surface at a water point, Hwange National Park, Zimbabwe. Photographed around 1983.

Some undigested materials in dung may be preserved in the sediments as future macrofossils or as objects that could be mistaken for human-made materials such as cordage manufactured from plant fibers (Fig. 6).

2.5. Elephants trample and disturb surface materials

A mature male African elephant may weigh over 5000 kg; a mature female may weigh 3000 kg (Sikes, 1971: Fig. 39, p. 179). The "foot-loading" of a walking modern elephant has been published (see Guthrie, 1990:263, referring to other sources) as 510–660 g/cm^2 — which is the force exerted per unit area of ground surface. This value is actually lower than the foot-loading of horse or bison, or even the much smaller saiga antelope, because the weight is spread over a much broader foot area than in the hoofed taxa. Table 1 shows foot-loading values for a variety of different northern taxa. So much force is exerted that each elephant footstep has the power to compact surficial sediments to a large degree. Studies of the effects of foot-loading from ungulate and human trampling are numerous in range management literature (for example, Ferrero, 1991; Mulholland and Fullen, 1991; Saravi et al., 2005), and show that large-mammal trampling reduces soil macropore space (impeding water infiltration and increasing surface runoff) and also lowers root biomass and whole plant biomass for many species, seriously decreasing the fertility index of land surfaces where trampling is intense. Some plant species may not survive elephant foot traffic; others may be depressed in growth and reproduction. Hence, vegetational communities may be greatly influenced, especially near water, along habitual trails, or in preferred feeding patches.

Surficial sediments and plants are not the only features that are impacted by elephant trampling. Elephant trampling also has a clear effect on future deposits of fossil bones. Surficial sediment grains may be abraded against bone surfaces when trodden under the great mass and large foot size of elephants, creating marks that may be mistaken for traces of butchering by hominins (Fig. 7). Bones may be marked by the abrasion, and they may be broken and scattered by kicking or dragging of elephant feet. These actions surely also affected animal bones in the distant past, subtracting some bone elements and modifying others within fossil assemblages.

Elephants often pick up objects to investigate before putting them down far out of the original place. Elephants are sometimes inclined to re-arrange the bones of dead elephants encountered at death sites (see Douglas-Hamilton and Douglas-Hamilton, 1975 for photographs of live elephants holding and moving bones). The weight of a trampling proboscidean can fracture animal bones, and on gravel surfaces the trampling can break stone pebbles and cobbles (Lopinot and Ray, 2007), creating false 'artifacts' such as flakes and flake-scarred 'cores' that have the characteristics of human-made materials.

Some elephant effects, such as digging, trampling, and dust-bathing, may accelerate erosion of the land-surface or disturb archeological deposits and invert depositional sequences, confusing

Fig. 6. Long woody plant fibers deposited in elephant dung, Hwange National Park, Zimbabwe. Photographed in mid-1980s.

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Table 1
A sample of foot-loading values by northern mammalian taxa, (from Guthrie 1990: 262–263, citing other sources).

Taxon	Foot-loading value (grams per cubic centimeter)
Bison bison bison	1000–1300
Equus caballus horse	625–830
Saiga tatarica saiga antelope	600–800
Loxodonta/Elephas elephant	510–660
Alces alces moose	420–560
Ovibos moschatus musk-ox	325–400
Rangifer tarandus caribou	80–140
Canis lupus wolf	89–114
Homo sapiens R. Dale Guthrie (barefoot)	200

future stratigraphic interpretations by mixing materials of very different ages.

Although many of the influences that elephants have on landscapes are localized and relatively small-scale, often they do have lasting effects on landform shapes and characteristics, recognizable thousands of years after creation. Table 2 summarizes some of the measurable or estimated effects that African elephants may have on modern landscapes.

3. Fossil evidence of proboscidean ecosystem engineering and earth-sculpting

3.1. Proboscidean effects on extinction

Owen-Smith (1987) proposed that landscape engineering by prehistoric proboscideans may have fostered the great Pleistocene diversity seen in non-analog animal communities of the time. Proboscideans were 'keystone' species that partly shaped ecosystems (a concept taken for granted by many paleoecologists, such as Robinson et al., 2003), mainly by influencing the survival or extent of some vegetational communities, as modern elephants are known to do. In the past, more sympatric taxa of proboscideans lived in the world, such as the two or three species of *Mammuthus*, one species of *Mammut*, and several other species of gomphotheres in the Americas. The cumulative effects of these large mammals kept many habitats in mosaic-state, with open glades and patches around wooded and grassy patches, and thus fostered faunal and floral diversity. Human foragers invaded the proboscidean ranges during the global dispersal of *Homo sapiens* after 100 ka, and they may have hunted mammoths and mastodons to extinction, setting off an ecological cascade of vegetational changes in North America that led to further extinctions of many other large herbivores.

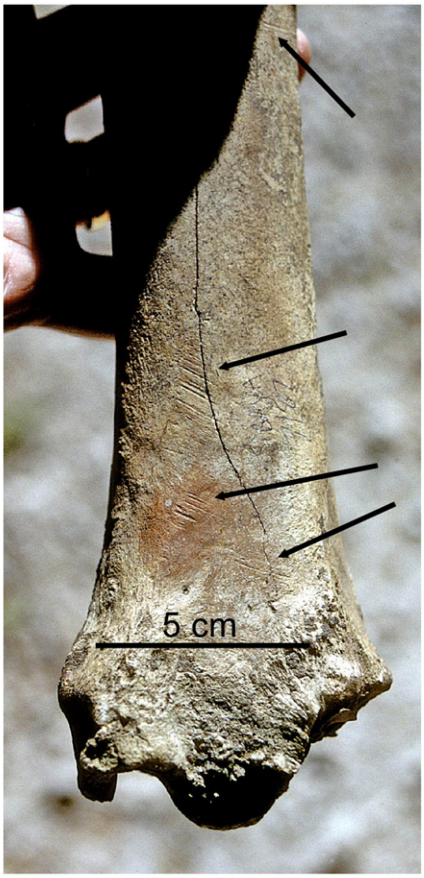

Fig. 7. Trample marks on a wildebeest (*Connochaetes taurinus*) tibia, made by elephants. Photographed in mid-1980s.

The debate continues over the ultimate cause(s) of the end-Pleistocene extinctions. Owen-Smith's hypothesis about mammoth/mastodon engineering of local environments is testable, if for example enough radiocarbon dates from the many taxa that died out actually do indicate that proboscideans died first. Abstracts and oral reports from one as yet inadequately published dating project (Graham et al., 1997, 2002; Graham, 1998), however, seem to indicate that proboscideans died out last, after all of the other well-dated extinct taxa had disappeared, in a two-step process which is the opposite of what Owen-Smith proposed.

3.2. Digging by mammoths

Blackwater Locality Number 1 in New Mexico – the original Clovis archeological site, after which Clovis stone spear points were named – contains spring conduits and wells attributed to human digging, including some of Holocene age (Green, 1962) and at least one that is late Pleistocene in age (C. V. Haynes et al., 1999). Well-digging by humans at the time of Clovis archeological culture is a significant event, since a Clovis-age drought (C.V. Haynes, 1991) has been postulated for much of North America just prior to the end of the Pleistocene, and may have figured in the process of megafaunal extinctions. The well at the site is a fairly narrow shaft or "circular pit" (C. V. Haynes et al., 1999:455) sunk through underlying sediments and infilled with sediments from above. It was discovered in 1964 and re-exposed in 1993. It is interpreted as an unsuccessful hole dug by Clovis people to reach ground water about 13,500 cal BP (C. V. Haynes et al., 1999). Fragments of mammoth and bison bones were found nearby in the archeological excavations. Bear, tapir, badger, and beaver were ruled out as excavators of the regular cylindrical pit, and no clear evidence clinches the case that humans dug the pit — such as the presence of artifacts or preserved shovel/scoop marks. It may be possible that a mammoth dug it using its trunk to grasp bundles of sediments and throw them aside, as happens in elephant country in Africa, for example. The 1.5 m depth is within the range seen in African elephant excavations for water in Zimbabwe (G. Haynes, 1991).

3.3. Mammoth tracks

Elephant-foot-size depressions (Fig. 8) on a buried occupation surface at the Murray Springs archeological site in Arizona, interpreted as mammoth tracks (C.V. Haynes, 1973; C.V. Haynes and Huckell, 2007), were created around 13,000 cal BP. The paleosurface is thought to be "a spring field where water oozed from…slopes" into a small stream (C.V. Haynes, 2007: 40). Mammoth bones were found below and atop the surface, some associated with stone artifacts. Besides making the tracks in saturated surficial sediments, mammoths had also scraped the ground in places within a dry or sluggish stream bed, possibly in search of water, as elephants do today in Africa

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Table 2
Measurements or rough estimates of elephants' potential geomorphic effects.

Action	Quantity or effect	Reference
Trampling (foot-loading) compression force	510–660 g per square centimeter	Guthrie (1990)
Trail creation/use	Depth of 'incision' = 5–15 cm or more, depending upon substrate; Width of trail = 30–50 cm, depending upon substrate (Note: trails may be created more by compression underfoot than by sediment removal/erosion)	G. Haynes, unpub. field notes
Sediment removed from water holes after wallowing, carried away on the body of each individual elephant	0.3–1.0	Flint and Bond (1968)
Dung deposited around water hole edges at drought refuges	Up to 2+ kg per square meter in dry season, depending upon intensity of use	G. Haynes, 1991, and unpub. field notes
Excavation of unconsolidated sediments (such as well-digging in sand) by an individual elephant in one session, using feet and trunk	1	G. Haynes, unpub. field notes
1-season removal of consolidated mineral sediment by multiple feeding elephants seeking micronutrients	1–3+ cubic meters, depending upon numbers and intensity of feeding	G. Haynes, unpub. field notes

(G. Haynes, 1991). The distinctive type of paleo-surface microrelief at the site provides a unique window into conditions of the past, implying drought that may have affected the entire region and beyond (C.V. Haynes, 1991).

Another fossil site with possible traces made by mammoth feet is Hot Springs, South Dakota. Nearly 60 mammoths and several individuals of other vertebrate and invertebrate taxa were trapped and died in a 20 m deep, steep, slick-sided karst sinkhole that had a warm spring at the bottom (Agenbroad, 1994; Thompson and Agenbroad, 2005) over the course of about 350–700 years, at 26,000 BP. The sinkhole filled with laminated layers of clay, silt, and sand around articulated and disarticulated (and unpermineralized) animal bones. In at least one locus, two sediment profiles contain disturbances of the horizontally bedded layers, interpreted as mammoth tracks (Fig. 9).

3.4. "Beast solonetz" sites

Some Siberian sites rich in mammoth bones appear to have been frequented by animals in search of mineral sediments. These sites also may contain abundant evidence of the human presence in the form of stone tools, used to kill or butcher mammoths at the localities. Derevianko et al. (2000:53) hypothesized that one such site, Shestakovo in western Siberia, was created between 25,600 to 18,040 BP by humans seeking mammoths that had been attracted to a "local geochemical landscape, i.e., the solonetz soil" which contains relatively high levels of potassium and magnesium. This sort of interpretation has acquired some traction in the literature. It is becoming better known that there are so-called 'beast solonetz' localities in eastern Europe and parts of northern Asia — mineral deposits visited by mammoths for generations, where deaths frequently occurred, and slumping of sediments (possibly caused by mammoth excavations) sometimes buried bones and preserved them for the long-term. Leshchinskiy (2001, 2006, 2009) proposed that Upper Paleolithic humans in northern Eurasia balanced the search for suitable toolstone against the search for large mammals. In his view, the largest archeological sites occur where sources of toolstone are located near mammoth migration routes in landscapes rich in calcium, magnesium, and sodium. Soffer (1993:40) also suggested that some central European (Moravian) mammoth-bone archeological sites, which are often huge and filled with thousands of bones, were located where they are because of the local mineral-rich sediments that attracted mammoths. Abraczinskas (1994) tested this possibility in North America with a spatial analysis of Michigan mastodont-bone sites and saline water sources, but the mastodon bone sites did not strongly correlate with the locations of the saline waters.

Fig. 8. An excavated paleosurface at the Murray Springs archeological site in Arizona, dated to about 13,000 cal BP (photograph provided by C. V. Haynes, Jr.). These are interpreted as mammoth footprints around the muddy edge of a pond. A skeleton of an adult female mammoth (*M. columbi*) is shown being excavated in the upper part of the photograph. Photographed in 1966.

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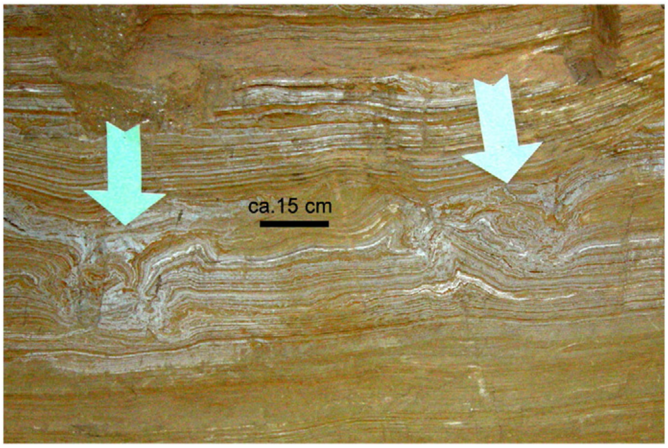

Fig. 9. Sediment disturbances thought to be created by mammoth feet at the Hot Springs Mammoth Site, South Dakota. Photographed in late 1990s.

3.5. Mammoth rub sites

Possible Pleistocene rub sites have been found in North America, such as at Sonoma Coast State Park in northern California (Parkman, 2002, 2009; Parkman et al., n.d.). These sites are specifically interpreted as places where now-extinct (Rancholabrean) large mammals scratched themselves against blueschist boulders and seastacks (Fig. 10), smoothing and polishing some parts of the rock surfaces (Fig. 11). The polished areas are often located much higher off the ground than can be reached by modern terrestrial mammals, such as cattle or horses. The smoothing affected high points on the rock surfaces rather than entire surfaces, indicating it was a mechanical process of contact abrasion rather than chemical process such as weathering or dissolution. The sites are possibly situated on a migration route that linked coastal prairies with the interior plains of California. Flaked stone artifacts have been found in excavations at the Sonoma Coast rub loci, but no direct dates are yet available on either the cultural materials or the rubbed rock surfaces. Humans quarrying toolstone from the sites may have removed much of the once polished outer surfaces of rock (Parkman, 2009). Parkman (2009) and Peterson (2003) name other possible rub sites in New Mexico, Nevada, Minnesota, and Wisconsin.

3.6. Mammoth bone accumulations as sediment traps

Loci where elephants died en masse or serially over time from noncultural causes are fairly uncommon, but enough have been recorded (for example, see G. Haynes, 1991) to lead me to think that noncultural sites containing multiple proboscidean skeletons were also expectably created in the ancient past. Multiple skeletons accumulate most often near water sources today in Africa, like the elephant die-off sites in Zimbabwe (G. Haynes, 1991), and waterside localities probably were also the settings for multiple mammoth/-mastodon deaths.

Conceivably, large numbers of proboscidean bones would act as sediment traps and divert streamflow and drainage, reshaping land surfaces and site topography. One possible example is the Colby Clovis site in Wyoming, dating to about 13,000 cal BP. More than 450 bones from seven *Mammuthus columbi* and a few other taxa were found along with flaked stone tools, including spear points probably used to kill and/or butcher the mammoths. Human stacking of carcass parts or skeletons along with some redeposition by water created two concentrated piles of bones and some scattering of others (Frison and Todd, 1986). Maps of bones (such as Fig. 2.8 in Frison and Todd, 1986, p. 44) and rose diagrams of the excavated bones (Frison and Todd, 1986: 53) suggest that water flowing in the steep sided and narrow paleo-stream dispersed some elements from the bone piles that people had made. Experiments done in a modern stream using recent elephant bones indicate that moving water disperses and also aggregates bones. Once bones are moved by water, according to Frison and Todd (1986:64), the "potential for subsequent movement is decreased." Bones may then become dams. When that happens, scouring and downcutting by water around the clusters or larger elements would cause bank slumping that might bury bones episodically (Frison and Todd, 1986: 80).

4. Conclusion

Proboscidean effects on ancient landscapes and archeological deposits perhaps are underestimated in some settings. A single trampling elephant can move large amounts of surficial materials just by the sweep of its feet. Elephant excavations for minerals or water directly shape parts of landscapes and also influence erosional effects. Elephant-abilities to sculpt land surfaces, alter vegetational communities, and produce mimics of artifacts make proboscideans an

Fig. 10. "Sea stacks" at the Mammoth Rub locus in Sonoma Coast State Park, California. Photographed in 2003.

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Fig. 11. Rock surface with a rubbed and polished patch in Sonoma Coast State Park, CA, possibly created by Pleistocene mammals. Photographed in 2003.

unusually important animal to consider in paleogeomorphological studies.

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