CHAPTER 17

GEOPHAGY AND THE INVOLUNTARY INGESTION OF SOIL

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CONTENTS

Geophagy or geophagia can be defined as the deliberate ingestion of soil. This is a practice that is common among members of the animal kingdom, including people. Any person who studies geophagy undertaken by humans will invariably confront a problem during their research. Few people will believe them. This is perhaps understandable for members of a developed urban society that is educated, has ready access to modern pharmaceuticals, and which has increasingly, in both a physical and mental sense, become more remote from soils. Yet many of these people will readily accept that wild animals deliberately eat soil. For example, television programs which feature wildlife may show animals consuming soil, with the presenter commonly stating that the soils are being eaten for their mineral nutrient content (although, as will be seen in the following sections, there are a variety of reasons why animals consume soil). But many people find it more difficult to accept that humans can deliberately eat soil. This ignorance of geophagy is not restricted to the layperson, because academic writers have used adjectives such as curious, odd, perverted, and strange when commenting on human geophagy. The use of such words demonstrates a misunderstanding of geophagy. The practice is common in certain human societies and can be readily found in many countries provided one has appropriate knowledge of the subject. An understanding of geophagy also allows an appreciation of the practice. There are perfectly sensible reasons as to why certain people deliberately eat soil, and the consumer can benefit from indulging in geophagy in a number of ways. It has been suggested that the practice should be considered within the normal range of human behavior (Vermeer, 1986), an enlightened viewpoint that I personally support. However, before the reader hurries away to indulge in geophagy, a word of warning is necessary. Aside from the benefits that eaten soils can impart to the consumer, very serious health problems may also result. These benefits and banes of soil consumption are considered in more detail later in Section

VI of this chapter, along with other aspects of geophagy undertaken by humans. This information follows a discussion about geophagy that is practiced by members of the animal kingdom other than humans. In addition to geophagy, many animals (including humans) also accidentally ingest soil. In order to appreciate geophagy in its proper context, this involuntary ingestion of soil is considered first (see also Chapter 14, this volume).

I. INVOLUNTARY SOIL INGESTION: DOMESTICATED ANIMALS

Grazing and browsing animals are especially prone to what is variously called accidental, involuntary, or incidental soil ingestion. Although both wild and domesticated animals can ingest soil involuntarily, the majority of research on this topic has concentrated on the latter largely because of the economic and health implications to humans. On farmland, pasture plants growing close to the surface are subject to soil contamination resulting from the effects of trampling by grazing animals, rain splash, or wind. Grazing animals will ingest soil that has adhered to vegetation because of these processes. Soil can also be licked from snouts and, on closely cropped pastures, can be ingested directly from the ground surface. The soil adhering to roots can be another source. For example, in a study undertaken on a semi-arid range located in Idaho in the United States, soil was ingested by cattle primarily with the roots of cheatgrass (*Bromus tectorum*) that were pulled up and consumed along with the aboveground plant parts (Mayland et al., 1975).

The amount of soil ingested can be quantified in a variety of ways (Healy, 1973). The ash content of feces from animals gives a measure of soil content, with a correction necessary for the ash contribution from undigested herbage. Treatment of ash with dilute acid gives an acid-insoluble residue (AIR) that allows a more accurate measure of soil content to be calculated. If the fecal output is known together with soil content of the feces, then the quantity of soil ingested can be determined. Alternatively, the titanium content of soil and feces can be used to estimate rates of soil ingestion (Miller et al., 1976). This method is based on the premise that titanium, which is abundant in soils (containing typically several thousand $\mathrm{mg\,kg^{-1}}$), is present only in small quantities (usually $<10\,\mathrm{mg\,kg^{-1}}$) in plants not contaminated with soil. Any titanium recorded in fecal samples can thus be assumed to originate from a soil source. With animals absorbing a negligible amount of ingested soil titanium, soil ingestion can be calculated using the equation:

$$\%\ \text{soil ingestion} = \frac{(1 - D_b)Ti_f \times 100}{Ti_s - D_b Ti_f} \qquad (1)$$

where D_b = digestibility of herbage, Ti_s = titanium in soil, and Ti_f = titanium in feces.

Research in New Zealand has indicated that sheep can ingest >75 kg of soil annually, and dairy cows can consume between 150 kg to 650 kg of soil per year (Healy, 1968). In New Zealand and elsewhere, seasonal variations of soil ingestion are marked, depending on soil type, weather, and management factors such as stocking rate and the use of supplementary feed. Within individual flocks and herds, significant differences in soil ingestion can be found between animals at any point in time, though there is some evidence to suggest that identical twins of cows have an inherited tendency to consume similar amounts of soil. In the UK, dairy cattle can ingest at certain times of the year >10% of their dry matter (DM) intake in the form of soil. For sheep, grazing typically closer to the ground, the figure may exceed 30% (Thornton, 1974). In countries such as New Zealand and the UK, the rates of soil ingestion are low during the summer months when there is an adequate supply of herbage. Soil ingestion is greater in the autumn, winter, and early spring months attributable to factors such as the low rates of herbage production.

There are a number of economic and health implications that are associated with the involuntary ingestion of soil. For example, animal production will be adversely affected if the consumption of soil reduces the digestible DM intake (Pownall et al., 1980). Also, as soil is highly abrasive to dentine, excessive tooth wear attributable to a high ingestion of soil can lead to culling at a comparatively early age because the animal can no longer graze efficiently (Healy & Ludwig, 1965). The abrasive effects on the alimentary tract could also prove irritating to animals; and may additionally increase their vulnerability to infections. The majority of research, however, has investigated the implications of ingested soils as a source of potentially beneficial mineral nutrients or of undesirable constituents such as pesticide residues, heavy metals, and radionuclides (Harrison et al., 1970; Beresford & Howard, 1991; Green et al., 1996; Lee et al., 1996; Abrahams & Steigmajer, 2003). As soil passes through the gastrointestinal tract of animals, en route it is exposed to digestive fluids that have the potential to extract soil elements thus contributing to the concentrations in these solutions. The release of elements such as cobalt, iodine, and selenium into the digestive fluids may be of benefit to the animal, because it is from the pool of elements in solution that essential mineral nutrients are absorbed into the bloodstreams of animals for distribution throughout their tissues. For example, in both New Zealand and Australia research has suggested that ingested soils can supplement iodine in potentially goitrous grazing sheep (Healy et al., 1972; Statham & Bray, 1975). Soils are a significant source of cobalt to grazing animals because they contain 100–1000 times more of this mineral nutrient than the pasture herbage they support. Cobalt is an essential constituent of vitamin B_{12}, the anti-pernicious anemia factor of liver that is produced by the synthesizing abilities of the symbiotic gastrointestinal bacteria of an animal. Research undertaken in the UK has shown that not only is cobalt extracted from soil in the rumen of sheep, but it is also synthesized into vitamin B_{12} as required by the animal (Brebner et al., 1987). Cobalt deficiency in sheep can thus be prevented by farmers dosing animals with soil (see also Chapter 20, this volume).

These examples demonstrate the importance of the direct soil–animal pathway of mineral nutrients that complements the soil-plant-animal route in agricultural systems. However, ingested soil can also be an important source of potentially harmful elements (PHEs) in geochemically anomalous areas such as mineralized and mined districts (Figure 1). This was found in a study undertaken in southwest England, a province that is extensively contaminated because of mineralization and a long history of mining and smelting. Here concentrations of soil arsenic are high, typically several hundred mg kg^{-1}, yet the aboveground pasture herbage when free of soil contains only about 1 mg kg^{-1} of this element (Abrahams & Thornton, 1994). Consequently, the soil–animal pathway is the dominant source of arsenic to grazing cattle in the province, with ingested soil contributing up to 97% of the total intake of this element (Table I). In contrast, the ingestion of soil is not

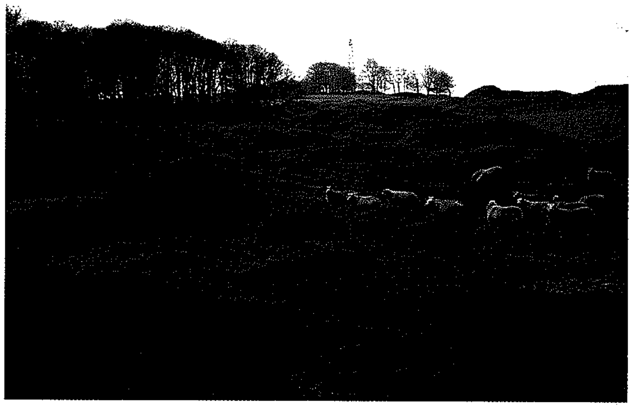

FIGURE 1 Sheep grazing mineralized ground disturbed by historical mining activity, Derbyshire, UK. At this locality the ingestion of soils containing high concentrations of fluorine and lead can contribute to health problems suffered by young livestock. (Photo: Peter W. Abrahams.)

TABLE I. Maximum and Minimum Soil and Washed Herbage Arsenic (As) and Copper (Cu) Concentrations, Rates of Soil Ingestion, and Calculated Intake by Cattle of the Two Elements

	Soil ingested (%)	*Soil concentration (mg kg^{-1})*		*Washed herbage concentration (mg kg^{-1} DM)*		*Daily intake as soil (mg day^{-1})*		*Daily intake as herbage (mg day^{-1})*		*Total daily intake (mg day^{-1})*		*% element ingested as soil*	
		As	*Cu*	*As*	*Cu*	*As*	*Cu*	*As*	*Cu*	*As*	*Cu*	*As*	*Cu*
April	1.5–17.9	19–320	12–319	0.06–1.1	10–23	9–189	6–154	0.8–15	108–294	10–196	250–396	80–97	3.7–59
June	0.2–3.9			0.03–0.8	8–15	2–47	2–62	0.4–10	104–210	2.5–57	113–236	41–93	2.1–34
August	1.4–4.7			0.10–1.0	9–15	8–101	6–79	1.1–13	123–194	10–113	113–273	79–96	3.2–36

Data are taken from a study undertaken in the soil-contaminated province of southwest England.

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so important in supplying copper to grazing cattle in southwest England. The mineralization and mining activity within this province has contaminated large areas of soil with this metal, but relative to arsenic, more copper is absorbed and transferred to the aboveground parts of the pasture herbage species. This reduces the importance of soil ingestion in supplying copper to the animals, although sites of particularly high rates of soil ingestion (e.g., 17.9%) and some contaminated locations can be areas where soil ingestion of this metal is significant (e.g., 59% of the total intake; Table I). To date, however, there is little information on the gut uptake of these elements and their transfer into animal products. In southwest England, much of the ingested arsenic is not available for uptake, and it is consequently found in animal feces. Still, some of the arsenic is known to be absorbed, and it has been reported that owners of arsenic-contaminated land in southwest England rent their fields to farmers wishing to present their livestock at agricultural shows. The resulting elevated intake and absorption of arsenic leads to a nice "bloom" on the coats of the animals and thus improving their appearance.

Ingested soils also have the potential to reduce the uptake of elements by animals. Adsorption on the organo-mineral cation exchange complex; sorption by hydrous oxides of aluminum, iron, and manganese; and the formation of stable complexes with soil organic matter are all mechanisms that can reduce the availability of elements to animals. In addition, antagonistic elements can be released from ingested soil. For example, the release of iron or molybdenum from soil in the stomach of sheep may interfere with copper metabolism, which leads to a disease known in the UK as swayback (Suttle et al., 1975, 1984). This disease affects the nervous system of newborn lambs. Its name is derived from the characteristic uncoordinated gait with the back legs swaying from side to side. In the UK this disease is more severe after mild winters, and forecasts as to the severity of the disease in lambs can be made on the basis of the number of days with snow cover. During mild, snow-free winters, soil ingestion rates are elevated and a high risk of swayback in spring is likely since intake of soil-contaminated herbage reduces the availability of copper to the ewe. Conversely, severe winters encourage supplementary feeding, limiting the intake of soil, and reducing the risk of swayback (although an additional factor here is that supplementary feeding of in-lamb ewes is likely to provide more copper than from pasture herbage alone) (see also Chapter 20, this volume).

II. GEOPHAGY IN THE ANIMAL KINGDOM

The deliberate ingestion of soil has been observed in both domesticated and wild animals, although research investigations have concentrated almost exclusively on the latter. Among terrestrial vertebrates, geophagy has been reported in many species of birds, reptiles, and mammals. Whereas humans may be geophagists and are a member of the latter class, this section of the chapter considers only other animal species. Table II illustrates that only carnivores have not been observed deliberately eating soil. The listing shown in this table, however, is certainly not complete with ongoing research adding knowledge to the number of species that indulge in geophagy. For example, avian geophagy was reported from the tropical island of New Guinea for the first time in 1999 when 11 bird species (all predominantly herbivores, and especially frugivores) were observed consuming soil (Diamond et al., 1999). It is also worth reporting that geophagy is not restricted to vertebrates; for example, isopods and butterflies are also known to deliberately consume soil.

Geophagy is a widespread practice that is reported from many parts of the globe. However, most observations on geophagical behavior come from North America and the savanna of Africa (Kreulen & Jager, 1984), perhaps reflecting a bias in the study of the ecosystems and animal species of these areas. Usually the soil intake is selective, with specific sites and sometimes even particular soil horizons being exploited (Figure 2). In the literature, these locations are variously referred to as mining sites, salt licks, natural salt licks, salines, mineral licks, natural mineral licks, or natural licks (Klaus & Schmid, 1998). The use of such terminology at times can be misleading, because the words "mineral" and "salt" suggest a chemical enrichment of soil, with animals indulging in geophagy to satisfy a mineral nutrient imbalance. This may be the case, but there are a variety of reasons as to why soils are deliberately consumed by animals, and not all are enriched in mineral nutrients. Consequently, the simple term "lick" is perhaps best, because its use does not imply a specific benefit that is gained from the soil.

The size of lick sites varies from small, unspectacular scrapes to large, treeless sites like those found within tropical rainforests. For example, in a study undertaken in Dzanga National Park (Central African Republic), the licks varied in size from 2000 m^2 to 55,000 m^2, with holes and caves excavated by the trunks, tusks, and front

TABLE II. Taxonomic Categories of Reptiles, Birds, and Mammals That Engage in Geophagy

Class	*Families*	*Representatives*
Reptilia	Iguanidae	Iguana
	Emydidae	Box turtle
	Testudinidae	Tortoise
Aves	Struthionidae	Ostrich
	Anatidae	Goose
	Aegypiidae	Palm-nut vulture
	Phasianidae	Pheasant
	Numididae	Guinea fowl
	Columbidae	Dove, pigeon
	Psittacidae	Parrot
	Musophagidae	Turaco
	Coliidae	Mousebird
	Sturnidae	Starling
	Ploceidae	Sparrow, weaver
	Fringillidae	Canary, bunting
Mammalia	Leporidae	Rabbit
	Sciuridae	Squirrel, woodchuck
	Erethizontidae	American porcupine
	Elephantidae	Elephant
	Equidae	Horse, ass, zebra
	Tapiridae	Tapir
	Rhinocerotidae	Black rhino
	Suidae	Bushpig, warthog, wild boar
	Tayassuidae	Peccary
	Camelidae	Camel
	Cervidae	Caribou, moose, mule deer, roe deer, sambar, white-tailed deer
	Giraffidae	Giraffe
	Bovidae	Antelope (e.g., duiker, gazelle), bighorn (e.g., Dall sheep), mountain goat, African buffalo, banteng, gaur, domestic ox, goat, sheep
	Indridae	Lemur
	Cercopithecidae	Baboon
	Colobidae	Colobus, langur
	Hylobatidae	Gibbon
	Pongidae	Chimpanzee, gorilla
	Hominidae	Man

After Kreulen & Jager, 1984.

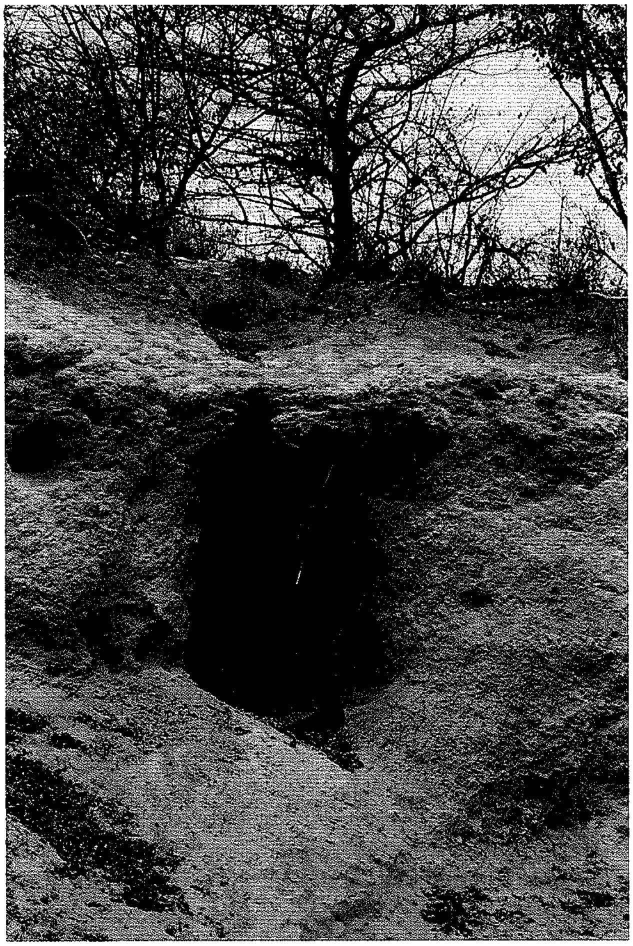

FIGURE 2 A soil lick located in the Mkomazi Game Reserve, Tanzania. The reserve ranger is standing in an excavation mined by animals, and other holes made by elephant tusks can be seen. This extremely alkaline, highly calcareous and saline-sodic soil, referred to as site 2 in Table III, may provide a range of benefits (e.g., sodium supplementation, an antacid function) to animals if consumed in appropriate amounts. (From Abrahams, 1999; Plenum Publishing Corporation.)

legs of the forest elephant, *Loxodonta africana cyclotis* (Klaus et al., 1998). There is considerable variability in the use of licks. Sites are not necessarily used by all species in an area, and while a particular species may utilize a lick at one location, the same species may ignore licks in other areas. Some observations on ungulates have recorded no differences in lick use among different sex and age groups, whereas other reports observe geophagy mainly or exclusively in pregnant or lactating females and/or juveniles. In the Yankari Game Reserve (Nigeria), all ages of warthog (*Phaco-*

choerus aethiopicus) exploit licks, in contrast to (mainly) adolescent hartebeest (*Alcelaphus buselaphus*; Henshaw & Ayeni, 1971). A seasonal use of licks is also evident (Kreulen & Jager, 1984). In both North America and Europe, a peak in lick use by ungulates is linked to forage changes during leaf flush in the spring. Similarly, in the arid areas of southern Africa, seasonality of lick use is associated with leaf flush at the beginning of the wet season. For the humid tropics, information on the seasonality of lick use is limited, although red leaf monkeys (*Presbytis rubicunda*) have been observed consuming mineral nutrient enriched soil from termite mounds in the rainforests of northern Borneo from April to August (Davies & Baillie, 1988). In contrast, the forest elephants in Dzanga National Park visit licks throughout the year though lick use decreases during the main fruiting season (Klaus et al., 1998).

The selective use of lick sites indicates that soils of these locations have certain qualities that animals find desirable. In northeastern Peru, mustached tamarins (*Saguinus mystax*) have been observed eating soil from a broken mound of leaf-cutting ants (Heymann & Hartmann, 1991). Geochemical analysis of the fine-textured soil revealed elevated concentrations of a number of elements (e.g., iron and potassium), which are attributable to the ants constructing the mound with deeper soil materials that are less leached than the surrounding surface soil. Red leaf monkeys in northern Borneo (see above) and chimpanzees (*Pan troglodytes schweinfurthii*) in Tanzania (Mahaney et al., 1996) are examples of other primates that have been reported to feed on soils (in both cases from termite mounds) that are similarly enriched in potentially beneficial mineral nutrients (such as calcium, magnesium, potassium, and phosphorus) and clay minerals. In the Kalahari sandveld of Botswana, geomorphological processes are important in the formation of licks, with fine-textured and nutrient-rich material accumulating in depressions (called pans) by sheet flow from adjacent areas following periods of heavy rainfall (Kreulen & Jager, 1984). The properties of lick soils can vary a great deal. For example, in the 1500 km^2 Mkomazi Game Reserve located in Tanzania, the three known lick soils show considerable chemical and mineralogical variability (Abrahams, 1999) (Table III). Despite such differences, some common properties of lick soils are

- A high content of clay-sized particles
- A high salinity
- Among saline (halomorphic) licks, sodium chloride and/or sodium sulfate may predominate in neutral or slightly acidic soils, whereas sodium carbonate and sodium bicarbonate are associated with alkaline lick sites
- High quantities of calcium and/or magnesium carbonate
- Licks may be chemically enriched (e.g., in nitrogen, sulfur, potassium, and phosphorus) because of fecal and urinary contamination; the excreta from diseased animals will heavily laden sites with pests, cysts, and nematodes

A common practice by research investigators is to compare the properties of lick samples with non-lick soils found in the same region. Differences, if any, between the two soil types can then lead to suggestions as to why animals are indulging in geophagy. Sodium often appears to be the major attracting substance of many licks (e.g., site 2, Table III), and it is known that herbivores can seek extra sources of this macronutrient because they have a sodium-specific perception and hunger mechanism that is activated, among other things, by depletion of this element (Denton, 1969). It is also appreciated that terrestrial plants may not accumulate sufficient sodium to satisfy the nutrient demands of an animal. There are a number of factors that can account for a seasonal demand of sodium that matches the periods of use of licks as noted above. For example, a temporary large increase in urinary and fecal output of sodium (attributable to a dietary change caused by the sudden transition from winter or dry season roughage to lush grass/browsing plants at the onset of spring or the wet season) will create a seasonal demand for this macronutrient that may be satisfied by the ingestion of appropriate soils (Kreulen & Jager, 1984).

Even though there is strong evidence that sodium-rich soils are a cause of geophagy, there are licks that are not enriched in this element (e.g., site 1, Table III) and clearly other benefits are sought by the geophagists. Licks may be exploited for mineral nutrients other than sodium, and calcium, iron, phosphorus, and sulfur have all been suggested as target elements. However, most licks contain relatively low concentrations of phosphorus, and wild animals indulge in osteophagy (the consumption of bone) as a source of this element, rather than geophagy. At high altitudes in the tropics, it has been suggested that ingested soils supplement African buffaloes (*Syncerus caffer caffer* (Sparrman)) and mountain gorillas (*Gorilla gorilla beringei*) with iron (Mahaney & Hancock, 1990; Mahaney et al., 1990). These animals may require relatively large amounts of this mineral nutrient for erythrocyte formation, in the same way that it is known that humans living at high altitudes need iron-rich food to increase erythrocytes in the blood.

TABLE III. Selected Geochemistry[a] and Mineralogy of Three Lick Soils From the Mkomazi Game Reserve, Tanzania

Geochemistry:

		Calcium		*Iron*	*Potassium*		*Magnesium*		*Sodium*		*Phosphorus*	
Site	pH	Total	Extr.	Total	Total	Extr.	Total	Extr.	Total	Extr.	Total	Extr.
1	4.3	280	230	42,000	2,000	225	940	88	120	9	1,250	8
2	11.0	91,000	360	8,400	160	7.5	8,000	13	12,600	11,875	<100	4
3	8.2	7,450	2,400	29,400	3,300	188	5,400	1,500	5,040	3,188	1,600	<8

Mineralogy:

Site	*Smectite*	*Illite*	*Kaolinite*	*Amphibole*	*Quartz*	*K Feldspar*	*Plagioclase*	*Calcite*	*Dolomite*	*Halite*	*Pyrite*	*Total*
1	0.0	0.0	41.0	0.0	52.6	2.4	1.8	0.0	0.0	0.0	2.2	100
2	11.6	0.0	7.3	0.0	17.8	5.7	26.3	26.1	3.8	1.4	0.0	100
3	2.3	8.8	12.0	8.7	32.2	10.0	16.9	0.0	1.5	3.7	3.9	100

[a] pH measured in 1:2.5 w/v water suspension. Total and extractable (Extr.) concentrations in mg kg^{-1}. The extractable concentrations are the water-soluble and exchangeable (i.e., adsorbed on soil particle surfaces) fraction of the element in the soil.

From Abrahams, 1999, Plenum Publishing Corporation.

The consumption of soil to obtain calcium has been substantiated for reptiles (e.g., the desert tortoise, *Gopherus agassizii*; Marlow & Tollestrup, 1982) and birds, though for the latter the most common explanation for geophagy is to provide grit. Because birds lack teeth, many ingest pebbles or coarse soil particles for the grinding of food in their gizzards (reptiles and ruminants are also known to ingest soil for the breakdown of food). But licks used by parrots in Peru (Figures 3 and 4) are fine-textured, which strongly suggests that these soils are not consumed to aid digestion (Gilardi et al., 1999). Instead the lick soils have a higher cation exchange capacity (CEC) than those from non-preferred sites, and bioassays have shown the ability of the soils to adsorb toxins (such as quinine) associated with the birds' plant diet. Geophagy by seed-eating birds has also been observed elsewhere, and it would appear that this soil consumption represents one weapon in the escalating "biological warfare" between plants and animals (Diamond, 1999). From a plant's evolutionary perspective, a seed needs to be enriched in nutrients both to support germination and subsequent growth, while nutrient-rich fruits attract animals like birds that disperse seeds following plucking and consumption. However, chemical toxins in seeds and fruit will be repulsive to animals thus inducing regurgitation or defecation of the former and deterring the harvest of the latter until the seed is viable. From an animal's evolutionary perspective, by overcoming the plant's toxin defenses a creature will obtain nutrients from seeds and fruit, and will outcompete other animals that find the diet repulsive and unpalatable. The ability of parrots (and other birds) to overcome plant toxins by indulging in geophagy would appear to suggest that they excel at the evolutionary "arms race" that exists between plants and animals. Many other animals may also benefit from geophagy and the ability of ingested soils to effectively detoxify plants. For example, this hypothesis has been proposed to explain the deliberate ingestion of soil undertaken by at least 14 species of non-human primates (Krishnamani & Mahaney, 2000), including apes (e.g., Sumatran orangutan, *Pongo pygmaeus abelii*), prosimians (mongoose lemur, *Eulemur mongoz*), New World monkeys (masked titi monkey, *Callicebus personatus melanochir*), and Old World monkeys (guereza monkey, *Colobus guereza*).

The research undertaken on the geophagous parrots of Peru has indicated that ingested soils may also serve a function other than the adsorption of toxins. Gastrointestinal cytoprotection results from the interaction of high surface area clays such as smectite and attapulgite with the gut lining (Gilardi et al., 1999). By

FIGURE 3 Red and Green Macaw eating a chunk of soil, Manu National Park, Peru (Frans Lanting/Minden/FLPA).

increasing mucus secretion and preventing mucolysis, clays in the gastrointestinal tract enhance the ability of the mucus barrier in protecting the gut lining from either chemical or biological insults, thereby alleviating the symptoms of diarrhea. The ingestion of soils containing clay minerals with a moderate to high surface area, together with the long time of passage of soil through the gastrointestinal tract, suggests the possibility of cytoprotection as an important function of geophagy undertaken by the Peruvian parrots.

Diarrhea (and other gastrointestinal upsets) can also be cured by geophagical practices because clay minerals are able to adsorb bacteria and their toxins. For example, chimpanzees in the Mahale Mountains National Park (Tanzania) have been observed consuming soil from termite mounds containing the clay minerals metahalloysite and smectite (Mahaney et al., 1996). This mineralogy makes the soil similar to the pharmaceutical Kaopectate that is used to treat minor gastric ailments in humans. The soils consumed by the chimpanzees could also function as antacids, with the commonly alkaline termite mound soils acting as a buffering agent to counteract the effects of acidic foods. Acidosis can also afflict wild ruminants such as the giraffe (*Giraffa camelopardalis*) and wild ungulates such as the mountain goat (*Oreamnos americanus*). The problem of acidosis associated with these animals arises due to the sudden dietary changes and the lush growth of vegetation that is coincident with the onset of spring or the early wet season (Kreulen, 1985). A sudden lack of fiber and the increase in readily fermentable carbohydrates (e.g., sugars) and soluble proteins lead to a drop in stomach pH that causes several ailments such as anorexia, diarrhea, and gastrointestinal irritation. As a source of calcium carbonate, potassium carbonate, sodium bicarbonate, sodium chloride, and montmorillonite clays, ingested soils can avert acidosis by preventing a decline in stomach pH and by improving digestion efficiency through altering the sites of digestion and absorption of carbohydrates and proteins.

FIGURE 4 Red and Green Macaw group feeding at a lick site, Manu National Park, Peru (Frans Lanting/Minden/FLPA).

Other motives that may lead to the deliberate ingestion of soil have been suggested (Kreulen, 1985; Klaus & Schmid, 1998; Krishnamani & Mahaney, 2000). These include:

- The use of soil as a famine food to ease the pangs of hunger during periods of starvation
- Microbial inoculation, where the ingestion of feces-contaminated soil facilitates the transfer of bacteria between animals, thus accelerating digestive adaptation within a population during periods of dietary change
- A behavioral tradition, where animals ingest soil because others are doing likewise

With licks providing a number of potential benefits to consumers, it is not surprising that geophagy has such a wide distribution in the animal kingdom. However, there are a number of costs that are also associated with geophagy, which include:

- The adverse physical effects of excessive tooth wear, erosion of the mucosal surfaces of the stomach and intestines, and obstruction of the digestive tract. Soils enriched in silica or sodium bicarbonate may be responsible for the development of kidney stones.
- The adsorption of nutrients by (for example) clay minerals may cause deficiency symptoms, while an excessive intake of an element can lead to mineral nutrient imbalances or problems of toxicity.
- Feces and urine accumulation at lick sites may cause problems of parasitism and disease. Soil fungi produce antibiotics that may have a bacteriostatic effect in the stomachs of animals such as ungulates.
- The attraction of animals to licks is associated with energetic costs and time lost for foraging. Lick sites may also be focal points of disease transmission and predation (including poaching).

Clearly, licks must provide benefits that enhance both animal performance and resource utilization, which compensate for the costs and risks associated with their use. "Aversion learning" may also lessen some of the adverse effects that are linked with geophagy (Kreulen, 1985). This practice is important not only to individual animals but, by influencing population densities and structures, it also has broader ecological consequences. Yet the extent of research dedicated to this practice is, to date, relatively limited. Consequently, much of what we know about geophagy practiced by wild animals is speculative, and many questions relating to (for example) how animals find appropriate soils for consumption, why they ingest them, the quantities that are consumed, and the implications of the soil ingestion still remain to be fully answered.

III. INVOLUNTARY SOIL INGESTION: HUMANS

All members of an exposed human population will ingest at least small quantities of soil. Foods, for example, may be contaminated with soil particles that are then inadvertently ingested. This contamination is especially likely in the tropics because of the tradition of drying foodstuffs like cassava and millet outdoors. Soil can also be ingested via inhalation. Particles entrained in the aboveground air can be inhaled, but while some will reach and be retained in the lungs, the bulk is trapped and ultimately taken over the epiglottis into the esophagus before passing through the gastrointestinal tract. Soil particles adhering to the skin of fingers can also be involuntarily ingested by so-called hand-to-mouth activity. Young children in particular can ingest significant amounts of soil through this behavior; their hands are typically contaminated with soil through normal play activities (Figure 5).

Most research undertaken on the involuntary ingestion of soil by humans has concentrated on young children. This group of the population can be expected to ingest the greatest quantities of soil involuntarily, and it will be the most vulnerable to any health effects. Research is difficult to undertake on such people, because observations that do not disturb children are difficult to conduct. Attempts have been made to estimate soil ingestion rates through recording the amount of soil on a child's hand and estimating the frequency of finger or thumb sucking (Ferguson & Marsh, 1993). However, ingestion cannot be estimated reliably without some knowledge of how much soil is removed during each mouthing action. This information has not been well recorded, and there is further inadequate

FIGURE 5 Hand-to-mouth activity displayed by a young child (Erika Stone; Photo Researchers, Inc.).

knowledge about the frequency of mouthing, and how much soil is retained on the hands following skin contact. Simple "soil-on-finger" estimates have therefore proved inadequate, and they have been superceded by more elaborate experiments using tracer elements. The ideal tracer element for estimates of soil ingestion by humans is one that is not present in food (or water or air or medications), is uniformly present in high concentrations in soil, and is poorly absorbed via the gastrointestinal tract (Binder et al., 1986). Another criterion for a gold standard tracer element is that the soil concentration should not vary significantly by particle size. No element exactly meets these ideal criteria with, for example, all tracer elements found to some extent in food. The mass-balance equation for a tracer element can be written:

$$I_a + I_{fo} + I_s + I_w = O_f + O_u \tag{2}$$

where the subscripts refer to intakes (*I*) of the element in air, food, soil, and water, respectively, and outputs (*O*) in feces and urine. Because some of these inputs and outputs are negligible for an ideal tracer element, Eq. 2 can be simplified to:

$$I_{fo} + I_s = O_f \tag{3}$$

that results in the soil ingestion estimate:

$$S_a = (O_f - I_{fo})/S_c \tag{4}$$

where S_a is the mass of soil ingested and S_c is the concentration of the tracer element in the soil (Stanek & Calabrese, 1991).

Table IV records data from three tracer studies estimating soil ingestion by children, and the varying values illustrate the difficulties in interpretation. For example, Study 1 made a number of assumptions including that the daily stool output averaged 15 g (dry weight) per child. A later adjusted recalculation using measured stool weights instead of the 15 g assumed in the original work gives lower estimates of soil ingestion. Table IV also illustrates the problem of poor intertracer consistency caused by errors in the mass-balance studies. For example, because titanium is widely used in inks, soil ingestion can be overestimated if a child eats printed paper or ingests ink residues sticking to the fingers. Such errors can be quantified, leading to adjustments in the soil ingestion estimates. This was done for the third study illustrated in Table IV. Using the original uncorrected data for six tracer elements, the mean soil ingestion estimates ranged from 21 to 459 mg day^{-1}. A marked improvement following adjustment led to a narrower range of 97–208 mg day^{-1}. Aluminum, silicon, and yttrium were considered to be the most reliable tracer elements in this particular study.

Despite efforts to improve the design of these soil ingestion studies, there still remains the problem of intertracer variability and the determination of which tracer element provides the best estimate of soil ingestion. There is a lack of information regarding the true variability of ingestion and the uncertainty of any average intake values. The limited number of investigations also provides little knowledge regarding factors such as the seasonal, regional, or ethnic variations in the rates of soil ingestion. Research undertaken in The Netherlands suggests that soil ingestion by children occurs mainly when the weather is dry and more time is spent outdoors (van Wijnen et al., 1990). The studies to date, however, do not address those children of tribal societies who live in a subsistence economy and who are

TABLE IV. Estimates of Soil Ingestion (mg day^{-1}) by Children

	Study 1		*Study 1 (adjusted)*		*Study 2*		*Study 3*		*Study 3 (adjusted)*
Tracer element	*Mean*	*Median*	*Mean*	*Median*	*Mean*	*Median*	*Mean*	*Median*	*Mean*
Aluminum	181	121	97	48	39	25	153	29	136
Silicon	184	136	85	60	82	59	154	40	133
Titanium	1834	618	1004	293	246	81	218	55	208
Vanadium							459	96	148
Yttrium							85	9	97
Zirconium							21	16	113

Note: Study 1: 59 children 1–3 years of age; Study 2: 101 children 2–7 years of age; Study 3: 64 children 1–4 years of age.
From Calabrese and Stanek, 1995.

most likely to inadvertently ingest the highest amounts of soil (Simon, 1998).

Young children with high hand-to-mouth activity will ingest more soil than older children, who in turn will involuntarily consume more soil than adults. Relative to studies investigating children, data quantifying the rates of soil ingestion by adults are more limited. The U. S. Environmental Protection Agency (EPA) concluded that adults could ingest 100 mg of soil day^{-1}, but this guidance figure would appear to be an overestimate. A pilot study undertaken on just six individuals, and using the tracers aluminum and yttrium, suggested a soil ingestion rate of approximately 50 mg day^{-1} (Calabrese et al., 1990). More recently a study on 10 adults used a tracer-based mass-balance study over 28 days of observation. The findings, representing the largest amount of data available on soil ingestion by adults, indicated an average estimate of 10 mg of soil day^{-1} (Stanek et al., 1997).

Regarding health, the implications of this involuntary soil ingestion to humans may prove to be beneficial. With foods in developing countries often contaminated with iron from soil residues on vegetables and cereals, it has been suggested that the contamination could be a good dietary source of this important mineral nutrient (Hallberg & Björn-Rasmussen, 1981). Considerably more work has emphasized the potentially deleterious effects of soil ingestion on health. In particular, ingested soils are likely to be a significant source of contaminants such as dioxins, and PHEs such as lead and the radionuclide isotopes, because there is only a limited uptake into the aerial parts of plants of these constituents from soils. In parts of Derbyshire (UK), soils are enriched in lead due to the weathering of mineral deposits and contamination associated with metalliferous mining. In a study undertaken in Derbyshire during the early 1970s, soil ingestion was found to be prevalent to an unexpected degree with 43% of children aged 2–3 years showing a pica for soil (Barltrop et al., 1974). An increased absorption of lead was found among children residing in villages near the extensive old mine workings, but the values found in blood and hair were still within the accepted normal range (Table V). A subsequent investigation in the same area showed that hand-wipe samples from children have relatively high lead concentrations, which suggested the importance of hand-to-mouth activity in transferring significant quantities of the metal to the child (Cotter-Howells & Thornton, 1991). The same investigation showed that many of the lead-rich soil grains were composed of pyromorphite, a stable soil–lead mineral that is only very slightly soluble and (presumably) has a low bioavailability to humans following ingestion.

TABLE V. Lead in Blood and Hair Samples Collected From Children Residing in High and Low Soil-Lead Areas of Derbyshire

	Geometric mean	
	Blood ($\mu g\ 100 ml^{-1}$)	*Hair ($mg kg^{-1}$)*
High soil-lead area:[a]		
No current pica (*n* = 27)	23.6	10.8
Present pica for soil (*n* = 16)	26.4	21.1
Low soil-lead area[b]		
No current pica (*n* = 17)	19.9	5.7
Present pica for soil (*n* = 16)	22.1	9.0

[a] Mean soil-lead concentration about 10,000 mg kg^{-1}.
[b] Mean soil-lead concentration about 500 mg kg^{-1}.
From Barltrop et al., 1974.

Lead poisoning is a very important issue in the United States with medical, learning, and social costs having broad and long-term implications. There has been a substantial decline in blood lead levels during the last decade, yet there are still 900,000 American children under 6 years old that have blood lead concentrations high enough to suggest impairment of intelligence, behavior, and development. Urban soils in large American cities form a reservoir of lead and other PHEs such as cadmium and zinc because of pollutants that include leaded gas and paint (Mielke et al., 1999). The ingestion of soil from gardens, school playgrounds, and other open spaces may therefore constitute a significant risk, especially because these urban soils will contain more soluble forms of lead (e.g., chloride and bromide) than the previously mentioned pyromorphite. Soil ingestion estimates are now routinely incorporated into all risk assessment procedures for contaminated sites in the United States (see also Chapters 8 and 23, this volume).

Other health issues may also be associated with involuntary soil ingestion. For example, doctors in the United States have recorded eosinophilia (a high count of a type of white blood cell that is usually found when a toxin or parasitic infection is present) in children admitted for treatment of lead poisoning following hand-to-mouth activity (Berger & Hornstein, 1980). The cause was attributable to infection with the larval form of the dog or cat parasite *Toxocara canis* or *T. cati*, respectively, which led to toxocariasis. Physicians managing children with lead intoxication following soil ingestion should therefore be aware of the possibility of concurrent parasitic infection. Toxoplasmosis is another disease associated with soil ingestion, attributable to the protozoan parasite *Toxoplasma gondii*, that sexually reproduces in cats who then release eggs in their feces to the soil. The ingestion of feces-contaminated soils by pigs, cattle, and sheep leads to their infection, and most people get toxoplasmosis from undercooked meat. However, the direct ingestion of soil by humans is a secondary source of infection. Medical opinion has insisted that *Toxoplasma* is nearly always harmless to people (Randerson, 2002), but recent research has suggested that by adversely affecting human behavior latent toxoplasmosis, the mildest form of *T. gondii* infection, might represent a serious and highly underestimated economic and public health problem (Flegr et al., 2002).

IV. HUMAN GEOPHAGY: HISTORICAL AND CONTEMPORARY PERSPECTIVES

The recognition that geophagy is widespread among non-human primates suggests that the deliberate ingestion of soil predates our evolution as a species. The oldest evidence of geophagy practiced by humans comes from the prehistoric site at Kalambo Falls on the border between Zambia and Tanzania (Root-Bernstein & Root-Bernstein, 2000). Here a calcium-rich white clay, believed to have been used for geophagical purposes, has been found alongside the bones of *Homo habilis* (the immediate predecessor of *Homo sapiens*). Migration transferred the practice from Africa to every other continent that has been permanently settled by humans, though there are some areas—Japan, Korea, much of Polynesia, Madagascar, and the south of South America—where geophagy is limited or unknown (Laufer, 1930). However, a lack of reporting on the practice is common, and because many geophagists are also reluctant to admit to soil consumption, undoubtedly the prevalence of geophagy is greater than suggested from literature sources.

Throughout history a large number of writers, including anthropologists, explorers, scientists and physicians have commented on geophagy. In the first century AD, both Dioscorides and Pliny mention a famous medicament known as *terra sigillata* (earth that has been stamped with a seal) otherwise known as Lemnian Earth (Thompson, 1913). This soil, derived from the Greek island of Lemnos, was mixed with the blood of a sacrificed goat, shaped into tablets somewhat larger than a thumbnail, stamped with an impression of a goat, and dried. Lemnian Earth was used for many maladies (but most notably for poisoning), and so great was the demand from the 13th to the 14th centuries, that almost every country in Europe strove to find within its boundaries a source of supply. Thus varieties of *terra sigillata* emanated from numerous localities including Bohemia, England, Italy, Malta, Portugal, Sicily, and the Mediterranean island of Samos. Some of these rival medicaments, notably *terra sigillata strigoniensis* or Strigian Earth derived from Silesia, acquired a considerable reputation. So valuable and respected were these that false Earths were also sold, leading Thevet to comment in 1554: "...... adulterate it considerably when they sell it to people who have no knowledge of it" (Thompson, 1913, p. 438). The fame of *terra sigillata* reached a peak at the end of the 16th century, and throughout the following 200 years the medicament was mentioned in most of the official medical books published in Europe. Its last appearance in any important pharmacopoeia was in 1848.

In the New World, geophagy was widespread previous to its discovery by Columbus. The oldest written history of Native Americans is provided by the explorer Alvar Nuñez Cabeza de Vaca who for 8 years (1528–1536) traveled through what is now known as the southeast United States (Loveland et al., 1989). Cabeza de Vaca writes of a tribe that was often exposed to starvation and they ate as much as they could, including soil. In another passage, the same explorer states that the fruit of the mesquite tree (*Prosopis juliflora*) was eaten with soil, making the food sweet and palatable. The Portuguese colonist and chronicler Gabriel Soares de Sousa provides the earliest (i.e., 1587) account of geophagy in South America. Commenting on the Tupinamba of Brazil, Soares describes how members of the tribe would commit suicide by eating soil "when they are seized by disgust or when they are grieved to such a degree that they are determined to die." The association of geophagy and suicide became a tragic part of American history. Slaves shipped across the Atlantic were responsible for the large-scale transfer of the practice from Africa. These slaves ingested soils perhaps to fill their stomachs as well as for medical (including nutritional) and cultural reasons (Hunter, 1973). Additionally large numbers indulged in excessive soil consumption not only to become ill and to avoid work, but also to commit suicide in the belief that their spirit would return to the African homeland (Haller, 1972). There are records of mass suicides caused by geophagy among plantation workers, and some estates were abandoned because of this practice (this problem was not confined to the Americas, since in 1687 approximately 50% of slaves in Jamaica died because of geophagy). Methods to deter the practice were harsh and included the use of facemasks, iron gags, chaining to plank floors, whipping, and confinement. The dismemberment of bodies of those who perished as a result of geophagy also proved effective, possibly because slaves believed that the spirit of a mutilated body could not return to the African homeland.

It was generally believed that African-Americans would cease the practice of geophagy following the termination of the slave trade and through the influence of Christianity. However, although the amelioration of life in the New World during the 19th century led to a decline of their medical problems that were associated with geophagy, the practice persisted for reasons other than as a means of committing suicide. For three-quarters of a century following the Civil War, geophagy in the United States was mentioned for the most part only incidentally in a few articles on the poor Whites of the American South as one of their numerous eccentricities. An anonymous writer in 1897 commented on the "clay-eaters" of Winston County, Alabama, who consumed a "dirty white" or "pale yellow" colored soil found along the banks of a small mountain stream (Anonymous, 1897). The quantity eaten at any time varied from a pea-sized lump consumed by a child or beginner, to a piece the size of a man's fist for those who had eaten it for many years. Although the life expectancy of the clay-eaters was apparently not affected, they developed anemic, pale complexions. Several years later, Dr. Charles Wardell Stiles demonstrated that the anemia was attributable to hookworm disease that also caused the geophagy (ingested soils are reported to alleviate the gastric pain associated with hookworm disease).

A pioneering study reporting geophagy among African-Americans in 1941 proved to be the beginning of a number of important investigations on the subject (e.g., Dickins & Ford, 1942). Geophagy was found to be extensive among black children, (especially pregnant) women of the American South, and the U. S. postal system used to deliver soil to friends and relatives who had migrated to the North. By the early 1970s, the practice could still readily be found, and was recorded as a structured custom embedded in a well-defined system of beliefs and rituals. Within a decade it was reported that the forces of urbanization and modernization had caused a decline of geophagy among the African-Americans (additionally the same report noted the increasing consumption of baking soda and laundry starch substitutes used instead of soil; Frate, 1984). Nevertheless the practice of geophagy can still be found relatively easily. A medical report in the early 1990s indicated that the prevalence of pica (of which geophagy was a predominant form) had stabilized among pregnant women, affecting about one-fifth of high-risk patients (defined as rural blacks, with a positive family history of pica; Horner et al., 1991).

Relative to the number of studies undertaken on African-Americans, investigations on North American Indians are very limited. Nevertheless, geophagy was described in the early 1980s as widespread among certain desert-dwelling Indian tribes of the American southwest (Fisher et al., 1981). Here the consumption of soil fluorine has been reported to lead to skeletal fluorosis. The problem was exacerbated because people of such tribes have a high prevalence of renal impairment that results in a decreased excretion of fluoride.

Elsewhere in the world, geophagy can be commonly found in particular areas and among certain societies. For example, the practice remains widespread throughout Africa (Abrahams & Parsons, 1996), and some recent research undertaken in Kenya indicates the contemporary prevalence of geophagy. In a cross-sectional study of 285 school children aged 5–18 years, 73% were reported to consume soil (Geissler et al., 1997). The prevalence decreased with age for both sexes up to the age of 15, then remained stable for girls between 15 and 18 years but continued to decrease for boys in that age range. The median amount consumed daily was 28 g, but it varied between individuals from 8 to 108 g. A cross-sectional survey of 275 pregnant women undertaken in the same country revealed that 56% consumed soil regularly (Geissler et al., 1998). The median estimated daily intake was 41.5 g (range 2.5–219.0 g). Namibia is an example of an African country where the practice had not been reported until recently. Then, in 1997, a study undertaken on 171 pregnant women in eastern Caprivi found that some 44% admitted to eating earth and utilized soil taken primarily from termite mounds (Thomson, 1997). This investigation suggests that a lack of reporting on the practice may be contributing to a significant underestimation of geophagy. This is likely not only in Africa but also elsewhere such as the Middle East and Southeast Asia where few contemporary reports on the practice have been published. Hawass et al. (1987) recorded the first cases of geophagy undertaken by adults in Saudi Arabia, while the widespread and reasonably frequent occurrence of geophagy in Indonesia, where the practice has been ongoing for generations, has recently been reported by Mahaney et al. (2000).

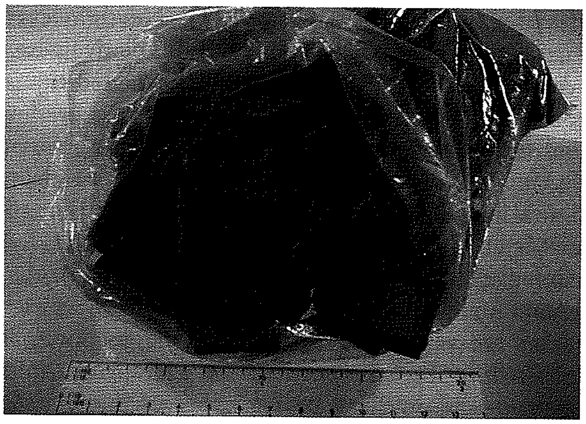

FIGURE 6 A 1-kg bag of sikor purchased from a shop in Birmingham, UK. Local pregnant Bengali women mainly consume the tablets that may be a significant source of iron. (Photo: Peter W. Abrahams.)

Although geophagy can be found relatively easily in many developing countries and among the more tribally oriented people (e.g., the Aborigines of Australia; Abrahams & Parsons, 1996), in many of the developed nations the forces of modernization and urbanization could be expected to lead to only infrequent reported cases. In the UK, pica undertaken by humans in the 1920s was described as very uncommon and confined almost entirely to the "abnormal cravings" of pregnant women and the "dirt-eating propensities" of children (Foster, 1927, p. 72). In the early 1970s, a study of 100 pregnant women revealed cravings for normal food and drink substances, but pica was not recorded (Dickens & Trethowan, 1971). Nevertheless, geophagy can be easily found in the UK by those with a desire to investigate the practice. Soil, variously known as sikor, mithi, patri, khuri, kattha, poorcha, or slatti, is traditionally taken by Asian ethnic groups as a remedy for indigestion and as a tonic during pregnancy (Figure 6). The soil is imported from the Bengal region of south Asia, and is sold by weight in shops throughout the country (e.g., Birmingham, Bristol, London, and Swansea). Geophagy appears to be so well established as a custom of Bengali society, that immigration into the UK has resulted in the cultural transfer of the practice. The likelihood is that immigration into other developed nations has also transferred the practice in recent years or decades.

It is clear that geophagy is not limited to any particular age group, race, sex, geographic area, or time period. Nevertheless, the practice is especially associated with certain regions and people (e.g., contemporary developing nations, people of low socioeconomic status, children, pregnant women). Typically only specific soils are consumed, and are selected for desired qualities of (for example) color, odor, flavor, texture, and plasticity. Often the material is a ferruginous clay, but other soils are certainly sought. In Africa, sand may be exploited both within the Sahara Desert of Mauritania and Ghana's Volta River delta (Vermeer, 1987). However, alluvial clay-enriched soil, from depths of 30–90 cm, are a common source of geophagical material. Scrapings from mudwalls of structures can also provide soil for occasional needs. In West Africa shales are mined and processed for geophagical use (Vermeer & Ferrell, 1985), and a field study in eastern Sierra Leone indicated that 50% of pregnant women regularly consume clay found in the interior of termite mounds (Hunter, 1984). In the same country another (less commonly used) geophagical source of clays are the nests of the mud-daubing wasp (genus *Synagris*).

Following collection, some rudimentary preparation of the soil may then occur. For example, tablets of sikor are made by compressing the soil prior to baking. The latter operation has the desired effect of destroying the eggs of potential intestinal parasites and produces the distinct smell of smoke to which the Bengali women are attracted. In eastern Guatemala, holy clay tablets known as pan del Señor (bread of the Lord) or *tierra santa* (sacred Earth) are produced following excavation (Hunter et al., 1989). Lumps of clay are pounded into small pieces before being crushed and passed through a 1-mm sieve. Water is added to produce a smooth dough-like material, and ceramic or wooden molds are then firmly pressed into the clay to produce tablets with a holy image. The tablets are sliced and trimmed with a carving knife and sun-dried for 24–48 hours before redistribution to retailers throughout Guatemala and the neighboring countries of Belize, Honduras, and El Salvador (Figure 7).

The qualitative and quantitative estimates of soil ingestion attributable to geophagy indicate the large quantities that can be consumed. For example, 3–4 tablets of sikor (about 64 g) may be ingested daily by pregnant Bengali women. The average daily consumption of soil by pregnant women in Africa has been reported as 30–50 g (Vermeer, 1987). Sometimes geomania is encountered, whereby people develop a craving and uncontrollable urge for eating soil (Halsted, 1968). This is evident from the quotations given to the interviewers of black women of the American South during the middle decades of the 20th century: "I feel awful, just about crazy when I can't get clay"; "I craves

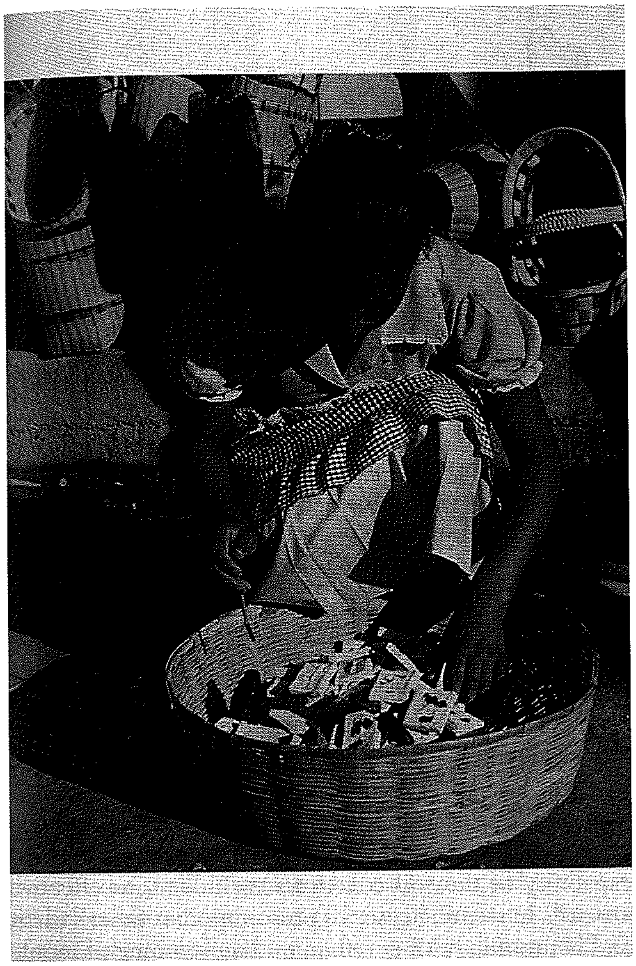

FIGURE 7 A vendor selling tablets of *tierra santa* in Central America. The soil is used as a pharmaceutical, and with its religious associations it provides psychological comfort. Here, the woman is daubing candy makers' red dye onto the tablets to simulate the blood of Jesus. (Photo: John M. Hunter.)

it"; "I crave something sour like the taste of clay" (Edwards et al., 1959, p. 811; Ferguson & Keaton, 1950, p. 463). The cravings may be difficult to control. Avicenna, the Arabian philosopher and physician who lived about 1000 years ago, talks of the necessity of the whip in controlling boys from geophagy, while restraints or prison was used for older people. He also records how "incorrigible ones are abandoned to the grave," demonstrating the hazards of persistent and excessive soil consumption. Avicenna was the first to mention the benefit of iron preparations in treating geophagy, and the association between iron and the ingestion of soil is still of considerable debate today as will be discussed further in the next section.

V. THE CAUSES OF HUMAN GEOPHAGY

It may be thought that the causes of soil consumption can be easily established by interviewing geophagists. However, many people who undertake the practice are reluctant to admit to soil eating. Perhaps they have a sense of shame or guilt, and fear that the interviewers may view the trait negatively. In some societies, as commonly found in Africa, the practice is more overt and open discussion is possible (Vermeer, 1987), but even in such situations many geophagists are at a loss to explain their desire for soil. One evident feature is that they generally like the practice, since many speak positively about the qualities (e.g., taste, feel, or odor) of the soil that is consumed. Despite the difficulties of obtaining information from geophagists, the practice is known to have multiple causes including those listed below.

Soil as a food and food detoxifier—The use of soil as a food supplement during periods of famine has been frequently recorded, as the ingested soil gives a sensation of fullness to the stomach. For example, Alexander von Humboldt on his travels in South America at the beginning of the 19th century recorded the eating of clay by the Ottomac tribe in the Orinoco Valley (Ross, 1895). Local supplies of fish and turtles were curtailed during the time of annual flooding, and Humboldt records how 12.5- to 15-cm diameter balls of mainly alluvial material were prepared and eaten by the Ottomacs in "prodigious quantities." Such consumption of soil is not restricted to distant times. In China, a country where traditional knowledge of famine foods has been transmitted between generations, soils have been utilized during famine as recently as about 40 years ago (Aufreiter et al., 1997), while in 2002 food shortages were reported to be causing geophagy in Malawi.

Closely associated to the practice of geophagy undertaken during periods of famine is the use of soils by humans in plant detoxification. Many plants containing toxins are consumed during periods of food shortage, but the mixing of soil with such plants adsorbs the potentially harmful chemicals and renders the food palatable. In this way the most important African famine food, the wild yam *Dioscorea dumentorum* Pax., is detoxified through the use of clay. Elsewhere, Native American populations have been reported to mix soil with acrid acorns, tubers, and berries as a corrective of taste. Indeed, the Aymara and Quechua people of the Andes Mountains of Bolivia and Peru still continue to eat wild potatoes by dipping them in a thick slurry of clay that effectively adsorbs potentially toxic glycoalkaloids (Johns, 1986). The importance of these "potato clays" can be judged from the suggestion that because all wild potatoes are poisonous to humans, the domestication of the modern potato (the world's premier vegetatively propagated cultigen) may have required geophagy at first.

Perhaps as an extension of its use during times of famine, soil can also be consumed as a regular food item. A study of African-American women in the late 1950s reported that many ate soil as part of the menu, and the meal seemed incomplete without it (Edwards et al., 1959). In Turkey, clay has been reported as used for snacks in place of candy or chewing gum. The literature also reports the use of soil as a sort of relish, condiment, or delicacy.

Psychiatric and psychological causes of geophagy—Pica is common in institutionalized mentally retarded people, and soil is one of the nonfood items commonly sought. It may be considered that the mentally retarded cannot discriminate between food and nonfood items, but a study in the United States showed that individuals are often aggressive in seeking the nonfood item of their choice, and they are quite deliberate about what they ingest (Danford et al., 1982).

Other research undertaken in the United States has demonstrated that pica in early childhood is related to elevated, extreme, and diagnosable problems of bulimia nervosa in adolescents. This suggests that pica may be a symptom of a more general tendency to indiscriminant or uncontrolled eating behaviors.

A psychological cause for geophagy is also evident. For example, pregnant African-Americans have commented on feelings of anxiety and agitation that are overcome by experiencing a sense of satisfaction following the consumption of soil. Similarly, the holy clay tablets that are consumed in Central America (Figure 7) provide psychological comfort by helping to allay anxieties associated with ill health or pregnancy (Hunter et al., 1989).

The consumption of soil as a pharmaceutical—Soil may be the world's oldest medicine recorded as a pharmaceutical throughout history. The pre-modern Chinese extensively utilized soil in medicines with, for example, the pharmacologist Li Shi-Chen in 1590 listing 61 uses for soil materials in treating a variety of conditions (Root-Bernstein & Root-Bernstein, 2000). Such multiple applications of soil in treating ailments is still evident (e.g., Figure 8), although their effectiveness as a medicine for treating so many maladies must be questioned. The varieties of *terra sigillata* utilized throughout Europe for some 2000 years are recorded as used for a number of ailments including plague, the bites and stings of venomous animals, malignant ulcers, nose bleeds, gout, dysentery, and poisoning (Thompson, 1913). Certainly, *terra sigillata* would have proved effective in treating the latter due to the ion exchange capability of the soil constituents. Indeed, so effective are soils in treating cases of poisoning that fuller's earth and bentonite, both enriched in the clay mineral montmorillonite, are used in contemporary developed nations as an antidote for poisons such as the herbicides paraquat and diquat.

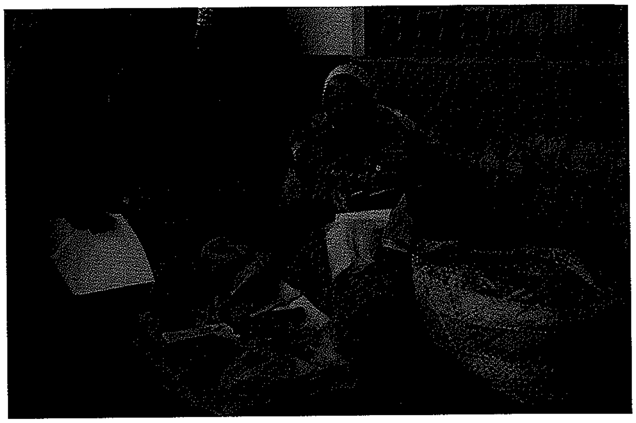

FIGURE 8 A vendor selling traditional soil/herbal remedies (the cylindrical-shaped objects) in the central market of Kampala, Uganda. The distinctive medicines, typically broken up and mixed with water before drinking, are used for treating a large variety of ailments such as asthma, nausea and vomiting, syphilis, poisoning, and anemia. (Photo: Peter W. Abrahams.)

Contemporary modern societies also utilize kaolin and smectite clays for treating gastrointestinal disorders. It should be of no surprise, therefore, that the literature describing human geophagy mentions the effectiveness of ingested soils in treating gastrodynia (stomachache), dyspepsia (acid indigestion), nausea, and diarrhea. For example, the chief geophagical clay entering the well-developed West African market system comes from the village of Uzalla, Nigeria (Vermeer & Ferrell, 1985). The clay, called *eko* by the villagers who prepare the material, is obtained from the working of Paleocene shales, and it is used as a traditional medicine including its use for, among other treatments, stomach and dysenteric ailments. Some 400–500 tonnes of *eko* is reportedly produced each year and widely redistributed to markets greater than 1600 km from the source. Mineralogical analysis of *eko* indicates a kaolinitic composition similar to the clay in the modern pharmaceutical Kaopectate.

A cultural explanation for geophagy—For some people there are symbolic links between themselves, fertility, blood, ancestors, and graves that are strengthened through the ingestion of soil. For example, among the Luo people of western Kenya, soil is eaten openly by women of reproductive age (Geissler, 2000). There is a particular preference for soils from termite mounds that have a symbolic significance because of their red color (i.e., the color of blood), intense taste, fertility, the use of their material for building dwellings, and their location that may be coincident with sites of burials or former habitation. Luo children learn earth-eating by observation and imitation within the family, but girls and boys have different views on the practice. Boys have to stop indulging in geophagy in order to "become men."

The consumption of soil for physiological reasons—It is commonly assumed that humans ingest soils to satisfy a nutritional deficiency. Such a physiological explanation for geophagy is an attractive hypothesis, and certainly soils have the potential to supply mineral nutrients to the geophagist. Hydrochloric acid is secreted in the stomach and is a major component of gastric juice that is consequently strongly acidic (pH is dependent upon physiological parameters, varying from 1 to 2 when fasting to 2 to 5 when fed; Oomen et al., 2002). But the pancreatic secretion of bicarbonate ions that neutralizes acid from the stomach modifies conditions in the small intestine where a higher pH (i.e., less acidic) environment exists (the small intestine consists of three sections: duodenum, pH 4–5.5; jejunum, 5.5–7; and ileum, 7–7.5). The human digestive system can thus be considered to be a two-part, acid-alkaline extraction system that operates on any soil constituent passing through the gastrointestinal tract. For example, ingested clays encountering the acidity of the stomach will release elements by cation exchange reactions, while iron oxide and other minerals can be expected to be partially solubilized. Mineral nutrients released in the stomach may then be adsorbed by soil constituents as they enter the small intestine, because the adsorption of nutrients tends to increase with pH. Soil extractants such as 0.1 M hydrochloric acid can be used in simple laboratory experiments to simulate human digestion and its effects on the availability of mineral nutrients to the geophagists. Table VI provides a summary of such experimentation that has been undertaken on samples collected within Africa. This table illustrates the varying ability of the different soils in supplying mineral nutrients to the geophagist following their consumption.

As previously explained there is strong evidence that sodium-rich (saline) soils are a cause of soil ingestion by members of the animal kingdom. But salt has never been shown to be a stimulus in primate geophagy, and most soils utilized by humans are reported to be essentially salt free. This means that its craving is an improbable cause of the practice. Indeed geophagists can deliberately add salt to the soil that they then consume: a practice that is, for example, commonly undertaken by pregnant women in Nigeria. Calcium and iron are the two mineral nutrients that are frequently implicated in the physiological explanation for geophagy. Daily calcium needs increase for pregnant women from 800–1200 mg day^{-1}, primarily to provide the nutrient for fetal skeletal growth and development. In Africa, research has demonstrated that geophagy is especially common among women belonging to non-dairying tribes that have consequently a depleted intake of calcium (Wiley & Katz, 1998). The ingestion of calcium-rich soil therefore provides a plausible explanation for geophagy as was made, for example, in a study reported in 1966 on the non-milk-drinking Tiv tribe of Nigeria (see Table VI). However, such explanations remain speculative because there are no detailed, consistent, and well-controlled data to support any observation that human geophagy represents a craving generated by a nutritional deficiency (Feldman, 1986; Reid, 1992). Nevertheless, some soils do have the potential to supply various mineral nutrients to the geophagist in significant quantities, even if the soils are not consumed to satisfy a physiological requirement. Table VI shows the varying quantities of iron that can be extracted from geophagical soils following laboratory experimentation. Some soils appear to be poor providers of iron, but others are capable of contributing toward a significant proportion of the Reference Nutrient Intake (RNI) for this element. For example, research undertaken on Kenyan girls and boys in 1998 (see Table VI) indicated that on average ingested soils were providing 32 and 42%, respectively, of the RNI for iron. However, such findings have been criticized recently, because the laboratory extractions ignore the effect of changes in the Eh/pH regime and kinetics during passage of soil through the gastrointestinal tract. Consequently, new experimental methods for the estimation of the bioaccessible fraction of elements (defined as the fraction of a substance that is soluble in the gastrointestinal environment and is available for absorption) are being developed. One such method, the physiologically based extraction system (PBET), is an *in vitro* procedure that incorporates gastrointestinal tract parameters representative of a human (such as stomach and small intestine pH and chemistry, soil-to-solution ratio, stomach mixing, and stomach emptying rates). Recent experimental work simulating this extraction

TABLE VI. Extractable Concentrations (mg kg^{-1}) of Selected Macro- and Micronutrients Determined From Geophagical Materials Collected Within Africa

Date of study and origin of sample	*Calcium*	*Copper*	*Iron*	*Potassium*	*Magnesium*	*Manganese*	*Sodium*	*Zinc*
1966, Nigeria[a]	3910	—	—	53	2005	—	44	—
1971, Ghana	120	—	—	165	31	—	—	—
1973, Ghana[b]	1133	10	95	130	331	<1	—	15
1984, Nigeria[c]	265	0.6	134	41	179	29	—	30
1991, Cameroon	77	—	9	45	—	—	—	—
Gabon	68	—	4	87	—	—	—	—
Kenya 1	791	2	7	432	135	63	—	3
Kenya 2	220	1	12	793	112	349	—	5
Nigeria	19	2	10	102	9	nd	—	3
Togo	120	—	5	177	—	—	—	—
Zambia[d]	142	11	74	93	60	19	—	2
Zaire	16	—	497	84	—	—	—	—
1997, Uganda[e]	1341	2.1	528	763	458	59	186	6.7
1997, Uganda	1800	—	326	460	1180	50	143	4
Zaire	440	—	380	1730	4100	12	3140	2
1998, Kenya[f]	—	—	169	—	—	—	—	2.7
1998, Kenya[g]	—	—	103	—	—	—	—	1.7

[a] Mean of two samples collected from soil pits that are utilized by the Tiv tribe.
[b] Median concentrations determined from 12 samples.
[c] *Eko* clay.
[d] Sample from the Kalambo Falls archaeological site.
[e] Median concentrations determined from 12 samples used as traditional medicines.
[f] Mean concentrations determined from 48 samples of soil that are typically consumed by boys and girls.
[g] Mean concentrations determined from 27 samples of soil that are typically consumed by pregnant women.
nd = not detected.
Adapted from Abrahams & Parsons, 1996.

system has confirmed the bioaccessibility of iron from Ugandan soils including those from termite mounds. This indicates that their consumption will satisfy a major proportion of the geophagist's RNI for this nutrient (Smith et al., 2000). However, bioaccessibility estimates vary according to the type of *in vitro* procedure employed, and more research is required to establish which method most accurately reflects the human *in vivo* situation (Oomen et al., 2002).

VI. HUMAN GEOPHAGY: BENEFITS AND BANES

The preceding section reveals how ingested soils, as a medicament, food detoxifier, psychological comforter, and a supplier of mineral nutrients, can have a positive role in human society. Although people may seek a particular outcome by indulging in geophagy, at times the ingestion of soil can confer multiple benefits to the consumer. For example, there is a long association of the practice with pregnancy, and it has been suggested that during the first trimester ingested soils will adsorb dietary toxins that are potentially teratogenic to the embryo, while simultaneously quelling the common symptoms of pregnancy sickness. In the second trimester, when pregnancy sickness usually ends, soils may serve as a source of mineral nutrients, and calcium supplementation may aid in the formation of the fetal skeleton, and reduce the risk of pregnancy-induced hypertension (Wiley & Katz, 1998). Despite such benefits, problems may arise if inappropriate quantities or types of soil are ingested. Paradoxically, even though soils can be a source of mineral nutrients to the geophagist, the cation exchange and adsorption properties of soil constituents have been reported to result in deficiency symptoms of certain elements. In Turkey, iron-deficiency anemia has been linked to the consumption of clays (mainly sepiolite and montmorillonite) of high CEC (Minnich et al., 1968). Clinical trials confirmed the effectiveness of the clays in adsorbing iron, and the conclusion of the study indicated the prominent role of geophagy in contributing to the problem, although other nutritional and parasitic factors were also probably involved in the anemia.

The adsorption of potassium by soil constituents can induce hypokalemia in an individual that is reflected by abnormally low concentrations of this element in the blood. Literature from the mid-1800s indicates that the condition was, along with iron-deficiency anemia, common among black slaves. The concurrent iron and potassium deficiency was associated with a disease known as cachexia Africana, the symptoms of which could be relieved through the use of iron- and potassium-containing tonics (Cragin, 1836). Today, hypokalemia attributable to geophagy is only occasionally reported. For example, an isolated case was recorded in the late 1980s of an African-American woman who had a 25-year history of geophagy. An increase in her soil consumption produced a condition similar to that associated with cachexia Africana. However, symptoms abated following potassium replacement and cessation of soil consumption (Severance et al., 1988).

The association between geophagy and zinc deficiency has been noted in a number of countries. In Turkey, soil consumption can be commonly found among village women and children, and the practice is linked to a combined deficiency of iron and zinc, and the latter causes symptoms of growth retardation and delayed puberty (Çavdar et al., 1980). Physical growth and improved sexual maturation were observed in patients following zinc supplementation. There may be a number of causes of the pathogenesis of the zinc deficiency in these patients. The high cereal diet of the Turkish villagers provides little zinc because the phytate-rich food depresses the bioavailability of the metal (the phytate in cereals binds zinc to produce a highly insoluble complex that prevents its absorption). Thus in people who already have a low intake of zinc, geophagy can be considered as an accelerating factor leading to a deficiency of this metal, and ingested soil adsorbs significant quantities of zinc through cation exchange reactions. Additional factors may also be important; for example, of 300 Aboriginal people examined in a study located in the northwest of Australia, half of the individuals had low plasma zinc concentrations (hypozincemia). Geophagy and the high cereal diet of the Aborigines causes a decreased absorption of zinc, and an excessive loss of the metal from these individuals also occurs attributable to intestinal parasites and excessive perspiration. All the requirements are therefore present in the north of Australia for zinc deficiency to be widespread among Aboriginal people (Cheek et al., 1981).

Potentially life-threatening hyperkalemia, an abnormally high potassium concentration in the blood, has been associated with geophagy (Gelfand et al., 1975). This condition is attributable to the absorption of potassium released from ingested soils that are enriched in this element. However, hyperkalemia and its links with geophagy have only been occasionally reported, but the widespread contamination of soils with lead provides another example of toxicity that can be associated with the ingestion of soil, deliberate or otherwise. With lead being especially harmful to the developing brains and nervous systems of young people, there must be a concern if children are consuming soils enriched in this metal, especially with recent research suggesting that there may be no safe level of lead for children (Canfield et al., 2003). Furthermore, lead toxicity will not be restricted to children. As an example, Wedeen et al. (1978) reported on a 46-year-old American black woman who was found to have lead poisoning. The consumption of garden soil with a lead content of $700\,\mathrm{mg\,kg^{-1}}$ resulted in damage to the patient's red blood cells, brain, and kidneys. Yet studies investigating the lead intoxication of geophagists remain limited, and bearing in mind that potentially deleterious quantities of this metal may be bioavailable even from soils that contain normal amounts of lead, further investigations are urgently required.

The biotic component of soils can pose hazards to geophagists because the eggs or larvae of parasitic worms (geohelminths) can be consumed, although infection is likely to be significantly reduced if subsoil or baked soil is utilized. Ascariasis and trichiuriasis are caused by the ingestion of *Ascaris lumbricoides* and *Trichuris trichiura* eggs, respectively, while toxocariasis occurs through infection with the larvae of *Toxocara canis* or *T. cati*. Hookworm infection can occur via the oral ingestion of *Ancylostoma duodenale* and *A. ceylanicum* (though skin contact with soil is the main cause of infection). It has been suggested that chronic liver disorders and cirrhotic changes may be associated with ingested soil bacteria and fungi.

Excessive tooth wear is another consequence of human geophagy, though the problem has been seldom reported in the literature (Abbey & Lombard, 1973). Rather, more attention has focused on the internal accumulation of soil that can lead to constipation, the reduction of the power of absorption of food materials by the body, severe abdominal pain, and obstruction and perforation of the colon. In pregnant women, this can lead to dysfunctional labor and maternal death (Key et al., 1982). Deleterious outcomes in fetuses and infants of mothers who practice geophagy are also likely, although the lack of research means that the quality of any evidence is poor. Clearly, the strong association of geophagy with pregnancy warrants further investigations on this important topic.

FIGURE 9 Dietary soil supplements for sale. Behind the humor of the cartoon is the serious message that contemporary urban societies may be at risk for ill health because they are not ingesting soil that can afford them appropriate protection. (From Kate Charlesworth.)

VII. CONCLUSIONS

This chapter considers both the involuntary and deliberate ingestion of soil by humans and other members of the animal kingdom. To many people, the word soil is commonly understood to be the material directly underfoot, as with organic-enriched topsoil. Although this material may be ingested involuntarily by humans and grazing animals, it is often strenuously avoided by geophagists. For example, human geophagists in Africa commonly exploit material from excavations that extend into clay-enriched subsoils or even further to underlying soft shales *in situ*. This mining zone is free of most organic matter and parasitic infestation. In such cases, clay eating may be a more accurate term for the geophagical practice, rather than soil consumption. With the close association between geophagy and pregnancy, sometimes the expression pregnancy clay may be appropriate (Hunter, 1993).

To date soil ingestion, whether involuntary or deliberate, has received relatively sporadic attention in the medical, sociologic, veterinary, or soil science literature. Yet such ingestion is demonstrably widespread and has important consequences for members of the animal kingdom. For example, it has been controversially suggested that modern urban human societies may experience health problems since their contact with (and ingestion of) soil is diminishing (Hamilton, 1998). Consequent decreasing human exposure to soil mycobacteria may contribute to the increasing prevalence of allergic and autoimmune diseases (e.g., asthma, diabetes, rheumatoid arthritis) that have been observed in affluent societies over the past 20 years (Figure 9). Similarly, a recent decline of intestinal worm infection (e.g., *Ascaris lumbricoides*) in people of developed societies may be the cause of the increasingly common inflammatory bowel diseases that are now being recorded.

Relative to involuntary ingestion, geophagy is associated with a more substantial intake of soil. The functionality of non-human geophagy is not argued, whereas human geophagy has been typically viewed as a low-status, deviant, or highly suspect behavior, which is limited to marginal or deprived societies. A more enlightened appraisal is to realize that humans have frequently turned to geophagy as a useful way of overcoming problems that they experience. So important was the practice that it became embedded in the culture and customs of societies, which were perpetuated by learning rather than instinct. Although advances in education and medicine have caused a significant decline in the practice, geophagists still continue their indulgence in spite of the ill effects that can occur (perhaps some people may not connect any health problems with geophagy, or their beliefs are strong enough to overcome the fear of any ill effects).

There is evidence to suggest that geophagy is now attaining renewed and serious interest within the academic fraternity. Hopefully this will lead to future multidisciplinary research that will investigate the issues that have been hinted at in this chapter. For example, the role of ingested soil in either supplying mineral nutrients such as iron, or PHEs such as lead or radionuclides to humans needs to be quantified by undertaking properly controlled *in vitro* and/or *in vivo* studies. Such research will create a better understanding of the implications of soil ingestion that would benefit epidemiological and risk assessment studies. This should be considered as urgent bearing in mind the widespread nature of soil ingestion and human nutritional imbalances.

SEE ALSO THE FOLLOWING CHAPTERS

Chapter 5 (Uptake of Elements from a Biological Point of View) · Chapter 8 (Biological Responses of Elements) · Chapter 14 (Bioavailability of Elements in Soil) · Chapter 20 (Animals and Medical Geology) · Chapter 23 (Environmental Pathology)

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