CHAPTER 10

GEOLOGICAL BASIS OF PODOCONIOSIS, GEOPHAGY AND OTHER DISEASES

The direct entry of soil into the human body, its effects, both biochemical and physiological, is an interesting field of study within medical geology. These processes enable geochemists and human and animal physiologists to study the direct link between soil chemistry, soil mineralogy and health. This chapter deals with two processes-geophagia and podoconiosis that clearly establish such a link. While the health effects of trace elements that enter the human body via food and water have been studied for many decades, the effect of inorganic minerals such as those found in rocks and minerals, on human and animal health is less known and has now aroused considerable scientific interest.

GEOPHAGY

Geophagy is defined as deliberate and regular consumption of earthy materials such as soils, clays and related mineral substances by humans and animals (Abrahams and Parson, 1996). Even though it is a practice that is found in all continents, it is most commonly seen in the tropics, notably in tropical Africa. This habit of soil-eating is particularly common among pregnant women and is listed as the ‘craving’ for extra-ordinary food or non-food substances (Geissler et al., 1999). Alexander von Humboldt, who explored South America observed the practice of geophagy during his expeditions in Orinoco in Venezuela during the period 1799-1804 (Keay, 1993). The Ottomac people who practiced this soil-eating habit in Venezuela apparently did not eat every type of clay but chose only the clays which contained the ‘most unctuous earth and smoothest to touch’. Further, it had not caused any problems of health to these people, whereas other tribes who ate different soils became sick. This early observation by Alexander von Humboldt caused much interest in medical science much later and the debate whether there are district benefits in soil-eating, such as trace element inputs, and whether these geological materials bestow other physiological and biochemical benefits still goes on.

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Wilson (2003) notes that many hypotheses have been advanced to explain geophagic behaviour, notably, detoxification of noxious or unpalatable compounds present in the diet, alleviation of gastrointestinal upsets such as diarrhoea, supplementation of mineral nutrients, and as a means of dealing with excess acidity in the digestive tract. Soil-eating is not only practiced by humans but animals such as monkeys, chimpanzees, gorillas, birds, reptiles and horses. Why do humans and animals consume soil? This intriguing question will probably be answered by a number of investigations currently being carried out to resolve conflicting views and to make an objective judgment regarding clinical, medicinal and nutritional implications of the practice (Reilly and Henry, 2000).

In the search for the geochemical characteristics that may confer medical benefits, clays figure most prominently in all the geophagic materials. Clay mineralogy is therefore considered to be an important component in the assessment of the different hypotheses.

One of the scientific approaches to test the possible beneficial effects of geophagic materials on human health is to first study their detailed chemistry and mineralogy and then to consider the biological effects of the elements and minerals thus isolated. Mahaney et al. (2000) studied the mineral and chemical analyses of soils eaten by humans in Indonesia. Five Javanese soil samples, including three earths eaten by humans as a therapeutic medicine, were analyzed along with the suitable control samples-those that were not eaten. The soils that were eaten had a high content of hydrated halloysite and kaolinite. The expandable clay mineral smectite was also present along with hydrated halloysite in a ratio of nearly 1.1. Mahaney et al. (2000) considered only Na, Mn, K, and S as the possible candidates that stimulate geophagy. What is worthy of note however, is that in all cases the eaten soils had predominantly higher levels of 1.1 clay minerals than the 2.1 minerals which predominated in control soils. These authors were of the view that soils can adsorb dietary toxins, normally present in the plant diet or those produced by microorganisms. The toxic alkaloids such as quinine, atropine and lupamine were thought to be adsorbed by these soils from Java and hence the soil-eating habit by some Javanese people.

According to a study by Johns (1986), some Indian tribes from Bolivia Peru and Arizona consumed four different geophagic clays of which the most widely used, was the interstratified illite-smectite together with smaller amounts of other clay minerals such as kaolin and chlorite. The explanation given was that geophagy functions as a detoxification method to enable the consumption of species of wild potatoes. Consuming clay with potatoes was considered to be effective in eliminating the bitterness of food and in preventing stomach pains and nausea. Further, all clays were effective in the adsorption of the glycoalkaloid tomatine over a range of simulated physiological conditions. Tomatine adsorption capacities of the clays were usually intermediate between those of pure smectite and kaolinite, but for one clay it was significantly higher than smectite (Wilson, 2003).

In many countries in Africa, kaolinite was the dominant geophagic clay which was even available in local markets (Johns and Duquette, 1991). Here the explanation for the geophagy was that it alleviates diarrhoea and sickness during pregnancy (Figure 10.1). Interestingly, this could be compared to the kaolinite-based western medicines taken for alleviating gastro-intestinal malfunctions.

Fig. 10.1. "Clay Sweets" for pregnant women in Bangladesh (photo Dr. Rohana Chandrajith)

Mineral nutrient supplementation is one of the main explanations for the prevalence of geophagy among people living in tropical countries. This hypothesis was tested by Abrahams and Parsons (1997) who analyzed the chemical composition of geophagical soils from Thailand, Uganda and Zaire. It was reported that they all had low organic matter (0.2-1.5%) and clay contents (15-28%). Wilson (2003) however suggested that some soils had high cation exchange capacities (CECs) and the dominance of the non-clay fraction of the soils were indicative of inadequate dispersion, a common problem in highly weathered tropical soils. The sand and silt fractions also were considered to contain clay minerals in an aggregated form. The conclusion from the study of Abrahams and Parsons (1977) was that these soils could supply a significant proportion of the recommended intake (UK Dept. of Health) for some minerals nutrients, up to 17% in the case of Fe.

A further study by Abrahams (1997) on 13 geophagic soils from Uganda, many of which were sold in local market as medicines showed that they had a high (>50%) clay mineral content dominated by kaolin minerals (85%).

Geissler et al. (1999) who studied geophagy among pregnant Ugandan women reported that most women (73%) were eating soil at a median intake of 41.5 g (range 2.5-290 g) per day and that most women (84%) ate soil at least once a day. When asked why they eat soil, 26 women (68%) answered that they “like it” or that it is tasty and that eating it “felt nice” in the mouth and satisfied them.

Geissler et al. (1997) in a previous study on geophagy among school children in western Kenya Nyanza province reported that over 70% of a sample of school children consumed soil at an average rate of ~30 g daily. The sources of the geophagy materials were from termite mounds, edges of paths and gullies, weathered stones and walls of huts.

The chemistry and mineralogy of geophagic soils from Zimbabwe, North Carolina- USA, and Hunan Province- China, were studied by Aufreiter et al. (1997). The soils from Zimbabwe which came from termite mounds contained kaolinite as the main clay mineral. American samples were dominated by halloysite while the Chinese samples had an abundance of smectite. These workers concluded that the results were consistent with the effects desired by the consumers of the soils, namely alleviation of diarrhoea (Zimbabwe), unspecified health benefits (North Carolina) and as famine food (China).

Geophagy among Animals

Geophagy is quite common among animals. The exact reasons why animals consume soil are not clear even though many hypothesis pertaining to the beneficial aspects of soil ingestion have been advanced. Wilson (2003) has summarized some of the more recent work carried out on geophagy in the animal kingdom.

As in the case of human geophagy, clay mineralogy is the more dominant factor in animal geophagy as well. Two studies on geophagy in birds (Diamond et al., 1999; Gilardi et al., 1999) concluded that from among the clay minerals consumed, smectite was dominant. The geophagic materials were assumed to reduce the bioavailability of poisonous or bitter-tasting compounds such as alkaloids and tannic acids in fruits and seeds.

Cattle and elephants (Figure 10.2) are among the large mammals studied for their geophagic habits (Klaus et al., 1998; Abrahams, 1999; Mahaney et al., 1996). In these cases, there was no definite conclusion as to the geophagy, but prevention of gastrointestinal upsets, alleviation of sodium deficiency and acidosis were speculated.

Fig. 10.2. Elephants feeding at a soil lick site in the Udawalawe National Park, Sri Lanka (photo courtesy of Enoka Kudavidanage)

Geophagy in horses has also been regarded as a sign of nutritional deficiency (Ralston, 1986). McGreevy et al. (2001) carried out a geochemical analysis of 13 equine geophagic sites from different parts of Australia. They observed higher concentrations of iron and copper in the soils eaten as compared to the control sites and suggested that these elements provide the stimulus for geophagia. What was interesting also, was how the geophagic horses may have sensed the increased concentrations of these elements in soils.

Gorillas, monkeys and chimpanzees have been the subject of several investigations for their geophagic habits. Subsamples of termite mound soil used by chimpanzees for geophagy and top soil (never ingested by them) from the forest floor in the Mahale Mountains, National Park, Tanzania were analyzed (Mahaney et al., 1999) to determine the possible stimulus or stimuli for geophagy. Here too, the ingested samples had a dominant clay texture, equivalent to a clay stone. Interestingly the clay mineral metahalloysite found in these clays eaten by the chimpanzees, is also an ingredient in the pharmaceutical Kaopectate TM, used to treat minor gastric ailments in humans. The fact that these soils had a high pH range of 7.2 to 8.6 also indicates a possible antacid property of the eaten soils.

Ketch et al. (2001) argue that these chimpanzees selectively consume certain plant species for their medicinal value, and that they could also perhaps engage in geophagy for similar reasons.

Several case studies of geophagy among several species of monkeys and gorillas (Mahaney et al., 1993; Mahaney et al., 1995; Bolton et al., 1998; Heymann and Hartmann, 1991; Setz et al., 1999; Mahaney, 1993) indicate a clay mineral dominance and a possible ability to absorb toxins and function as a mineral supplement.

Wilson (2003) critically reviewed the studies mentioned above. He was of the view that there is no single explanation for the geophagic behaviour in animals, including man. What was lacking in these studies was the insufficient characterization of the mineralogy and chemistry of the geophagic materials. He suggested that the following information is required for such geochemical characterization:

(a) The nature of the constituent kaolin minerals and their abilities to coagulate, aggregate and/or dispense under acid conditions.

(b) The occurrence of interstratified kaolinite-smectite and whether this mineral could account for the anomalously high cation exchange capacities (CEC) of geophagic soils/clays.

(c) The nature of the smectite minerals, particularly the occurrence and extent of interstratification with other layer silicates or interlayering with non-exchangeable Al-hydroxides, since this relates to the ability of the clay to adsorb potential toxins.

(d) Characterization of the iron oxide minerals and determination of the ratio of reactive to non-reactive species in relation to supplementation of Fe in the diet.

(e) Occurrence and nature of aluminous minerals and whether they function effectively as natural antacids.

It appears likely that the pleasant touch of the ingested clay is the initial stimulus for geophagy in animals and that it subsequently becomes a learned behaviour. It could also well be that clays have many useful medicinal properties which the animals use for a more general and all round well being rather than for a specific ailment.

INGESTION OF GEOMATERIALS FOR HUMAN HEALTH-THE MEDICAL CONCERNS

In spite of the seemingly beneficial aspects of geophagy as discussed above, there is undoubtedly much apprehension and debate about the benefits and the toxicity of ingestion of geomaterials. Tateo et al. (2001) attempted to study the laboratory simulation of the digestive process using 14 different herbalists' clays for internal use as found in the Italian market. The digestion experiment consisted of two stages (i) involving acidic solutions (matching the stomach environment) (ii) reproducing bile-pancreas juices. These authors observed that one effect of clay digestion is the dissolution of carbonates, transferring Ca and Mg from the solid to the digestive solutions along with an increase of pH.

As shown in Figure 10.3 there is a bimodal distribution of pH, from 1 to 3 and from 5 to 6. Some elements such as Al, P, Be, Sc, V, Fe, Cu, Zn, Ga, Ba, La, Nb, and REE were associated with a lower pH and others such as Ca, Sr, Mg with higher pH. The element concentrations in the final solution were then compared with the maximum daily dose as given by drinking water regulations. Among the elements not hosted into the carbonates, Al showed high concentrations. Tateo et al. (2001), on account of the hazardous chemical elements that were detected, warned of the risk involved in using geomaterials for health and suggested that further multidisciplinary research be conducted with clay mineralogists, toxicologists and physiologists.

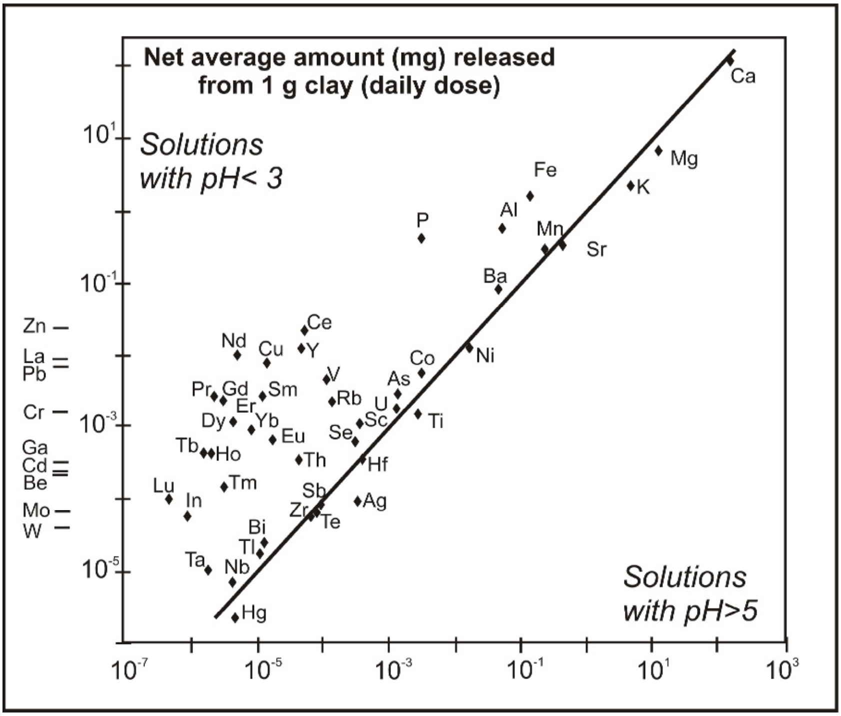

Fig. 10.3. Average concentration of analysed elements released into solution from 1 g of clay at different pH with clay/water at 1:10 (Tateo et al., 2001)

PICA (Persistent Ingestion of Non-Nutritive Substances) of clay or geophagy is known to bind potassium in the intestine leading to severe hypokalemic myopathy (Ukaonu et al., 2003). It may also cause a number of serious conditions such as heavy metal poisoning, hyperkalemia, iron and zinc deficiency, vitamin deficiency, intestinal obstruction or perforation, dental injuries and parasitic infestations (Rose et al., 2000; Federman et al., 1997). Pregnant women who eat 1 lb of clay per week have been known (Simulian et al., 1995). Woywodt and Kiss (1999) reported a case of an adult, non-pregnant African woman with perforation of the Sigmoid colon due to geophagia. Since geophagic patients do not normally wish to divulge this clay-eating habit, plain X-ray films are the diagnostic procedure for soil detection in the human body (Fig 10.4).

Fig. 10.4. Plain abdominal X-ray film of the patient on admission to the hospital. Free intra-abdominal air is present and the entire colon appears to be densely impacted with radio opaque material that proved to be dry soil (Woywodt and Kiss, 1999; copyright ©1999, American Medical Association. All Rights Reserved)

PODOCONOSIS-A GEOCHEMICAL DISEASE

Podoconiosis is a disease characterized by swelling and deformity of the legs associated with enlargement of the draining lymph nodes (Figure 10.5). It is also termed non-filarial elephantitis (Price, 1988, 1990). This disease is predominantly found in regions of tropical Africa where fine reddish brown soils are prevalent and in areas of high altitude (>1250 m), modest average temperature (20°C) and high hot season rainfall (>1000 mm annually) (Price and Bailey, 1984). This epidemiological relationship is seen in the Wollamu district of Ethiopia, Nyamkere range of Kenya, Tanzania, Rwanda, Burundi, Cape Verde Islands and Cameroon Highlands (Harvey et al., 1996). The special geochemical features as seen in these tropical regions clearly imply a geographical specificity to Podoconiosis.

The superimposition of the prevalence data for the disease showed a correlation where the areas coincide with a distribution of alkali basalt rocks. The extremely fine particles (<5 μm) seen at these sites are formed by the intense rock weathering so typically seen in the tropical lands.

Fig. 10.5. A young Ethiopian with bilateral idiopathic elephantiasis and marked lymphostatic verrucosis on both feet and a view of the foot of an African from Zimbabwe. There is thick diffuse hyperkeratotic swelling, again confined to the lowest part of the leg (photo by Dr. E.W. Price, Copyright Springer, Germany).

Interestingly, the analyses of particles from a digest or a diseased femoral lymph node (Price and Plant, 1990) showed an identical size range (i.e. 0.3-6 μm) which suggested that either the toxic particles are within this size range or that a smaller size facilitated the uptake into the tissues. The analysis of these microparticles showed that they consisted mainly of Si and Al, with lesser amounts of Ti and Fe suggesting the possible presence of the aluminum silicate kaolinite, silica in the amorphous state with some quartz and iron-oxide. The natives of these areas which have very fine soil mineral particles walk barefooted and it has been suggested that the abrasions in the feet caused thereby serve as entry points for the tiny particles, which finally enter the lymph nodes (Price and Henderson, 1978; Blundell, et al., 1989).

As discussed in the review of the geochemical factors linked to podoconiosis by Harvey et al. (1996), Hochella (1993) noted that the toxicity of a mineral is related to:

(a) Mechanical or dimensional properties, namely the size of particles in diseased tissues. Smaller particles are rapidly absorbed through the abrasions of feet and transported in lymphatics. In the case of other particles, a specific fibrous shape is the most important toxicological determinant (Stanton et al., 1981). No preponderance of fibrous minerals was observed in the case of podoconiosis.

(b) With decreasing size, the surface area to volume ratio of particles increases and different chemical properties gain importance. Among these factors which determine the ability of particles to interact in biological systems are (i) surface and near surface composition, (ii) surface atomic structure, (iii) surface microtopography, (iv) surface charge, (v) pH, (vi) dependence on surrounding solubility, (vii) durability (dissolution rate) and (viii) associated minor and trace elements.

The nature of the interaction of these mineral phases with the effector cells of the immune system, notably the macrophage, finally determines the ability of the mineral to produce the diseases. This is termed the pathogenicity of the mineral. The cell takes up the mineral particles which then are activated to produce many chemical species which in turn damage the biomolecules. Finally, inflammation and fibrosis result. If the cells die as a result of the activation mentioned earlier, the mineral particles are then available for re-uptake and the process continues (Driscoll and Maurer, 1991; Gabor et al., 1975; Kennedy et al., 1989).

A disease, termed Kaposi's Sarcoma (KS) is very similar to podoconiosis and is also found mostly in Africa. Ziegler (1993) noted that the prevalence of both podoconiosis and KS in highland areas of Africa, close to volcanoes is suggestive of a shared pathogenetic relationship due to exposure to volcanic soils. KS is believed to arise in the lymphatic endothelium and is associated with chronic lymphoedema. Figure 10.6 illustrates the geographic distribution of Kaposi's Sarcoma in Africa and relation of ultra basic basalt provinces and prevalence of podoconiosis.

Podoconiosis and KS are excellent examples of diseases which clearly illustrate the interrelationship between Geology and Health in tropical areas where the pathways of chemical elements and minerals from the immediate environment to the body is direct. The term "geochemical diseases" is attributable to such cases where the aetiology of a certain disease is almost directly and clearly related to a characteristic elemental composition of the immediate geological environment.

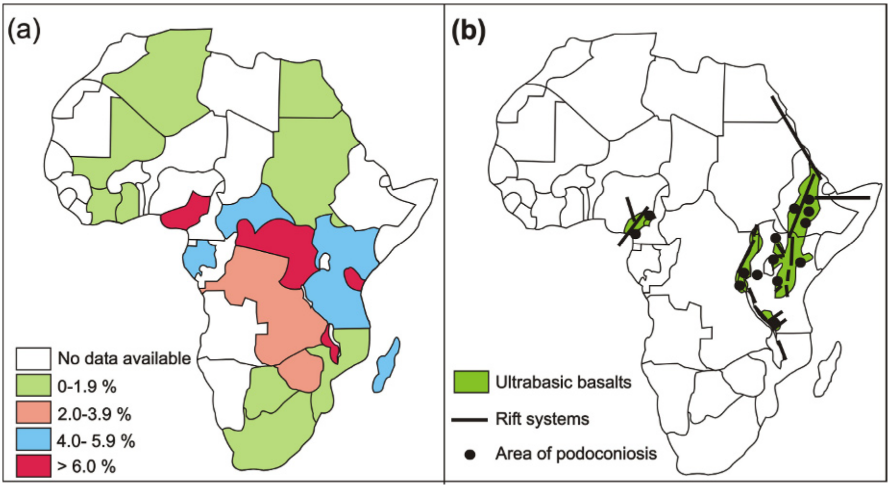

Fig. 10.6. (a) The geographic distribution of Kaposi's Sarcoma in Africa. Proportional rates (percent KS divided by total cancer over the reporting period) in African males prior to 1981; (b) Relationship of ultra basic basalt provinces and prevalence of podoconiosis in the East African Rift System (Ziegler, 1993)

NATURAL DUST AND PNEUMOCONIOSIS

Direct inhalation of very fine soil particles (2 to 63 μm) is another route by which minerals may get into the human body. Derbyshire (2003) reported a case study in High Asia (Himalayas-Karakoram and Tian Shan-Pamir areas) where whole communities of people were exposed to the adverse effects of natural (aerosolic dust). The exposure levels had reached those normally found in areas of high-risk industries.

The reasons for this area being the world's most efficient producer of silty debris were:

- (a) high known uplift rates (up to 12 mm/yr)
- (b) unstable slopes
- (c) glaciations and widespread rock break up during freezing
- (d) soil weathering due to hydration.

Further, the characteristic properties of these loess included high porosity and collapsibility on wetting. Mineralogically, they consisted of angular, blade-shaped quartz grains (~60-65%) with minor feldspars, micas and carbonates. Clay minerals were in the range of 12-15%.

The prevalence of silicosis, as studied by the use of chest X-rays, showed 1.03-10% cases in the Gansu Province, China. In some parts of India, too, inhalation of natural dust has resulted in a high prevalence of silicosis. Norboo et al. (1991) and Saiyed et al. (1991) reported cases of progressive massive fibrosis. In the Ladakh region in India, where these studies were done, wind-blown loessic dust, including aggregates of the finest fractions was a clear health hazard. Adults in the age range 50-62, had up to 45% silicosis problems. Bulk chemical analysis of lung tissues had showed that over 54% of the inorganic dust was silica.

The case studies described in this chapter illustrate the fact that human beings and animals are only a part of the large scale geochemical cycles of elements. The geochemical pathways of the physical environmental link up with the biochemical and physiological pathways in the human body. Medical geology is concerned with total geochemical cycling and further information is now emerging on the roles played by minerals within the human body.