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The association of endemic elephantiasis of the lower legs in East Africa with soil derived from volcanic rocks

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Summary

Endemic elephantiasis of the lower legs in Ethiopia, which reaches a maximum of 86·7 per 1,000 adults in affected areas, is related to the distribution of red clay soil derived from volcanic rocks, particularly basalt. Prevalence falls rapidly on leaving these areas.

This observation has been tested in regions of non-filarial elephantiasis reported in Kenya and north-western Tanzania and further investigated in volcanic areas of Rwanda where the disease had not previously been reported. The same relationship is found to occur in these areas. The limitation to the lower legs of the barefooted section of the farming community suggests that the aetiological factor or factors enter by the feet.

The occurrence at high altitude (over 1,200 metres) is noted and the predominance of basalt or basalt-like lava in each case is considered significant. The altitude governs rainfall and temperature and thus governs the type of soil produced.

The soil produced from these rocks is rich in colloidal iron oxide, alumina and silica, to which a number of metallic ions are adsorbed. This soil is a reddish-brown clay which, when wet, is strongly adherent to the skin. The derived ions are known to be toxic to human tissue and absorption through intact human skin has been shown to occur experimentally. It is suggested that absorption of these irritants through the bare feet is responsible for the irreversible damage to the lymphatic channels.

The present studies support the hypothesis that "high-altitude" elephantiasis of the lower legs in East Africa is a geochemical disease.

Introduction

The existence of an endemic but non-filarial elephantiasis of the legs in East Africa has been recognized since the papers of LOWENTHAL in Uganda (1934), of MACFIE in Ethiopia (1936), of CLARK in Kenya (1948) and of JORDAN in Tanzania (1956).

The disease was limited to defined areas, and no cause was found. The problem has been restudied in recent years by COHEN (1960), who concluded that a congenitally hypoplastic lymphatic system might be incriminated but OOMEN (1969) demonstrated that the disease was widespread in Ethiopia, involving the Semitic Amhara people as well as Cushite Galla and resident Moslems of Arabic origin, an observation which suggested a local aetiological agent rather than a congenital hypoplasia.

The possibility of a crypto-filarial aetiology was investigated by workers of the U.S. Naval Medical Research Unit (NAMRU III) at Addis Ababa during 1972–74 in extensive field surveys, using fluorescent antibody and blood filtration techniques. "The results of these surveys effectively lay to rest the long-held suspicion of a filarial aetiology for the elephantiasis seen in the Ethiopian Highlands." (NAMRU Report 1973.)

The failure to implicate onchocerciasis was reported by TEN EYCK (1974) and by OOMEN (1969).

More recently, PRICE (1974a) noticed an association of the disease with areas of "tropical red soil" in Ethiopia, and described the rapid fall in prevalence on leaving the red soil area. This association has now been investigated in other East African countries and the findings are reported here.

First, the Ethiopian experience is summarized. The hypothesis of an aetiological relationship between soil and elephantiasis is then tested in two other East African areas where non-filarial elephantiasis prevalence has previously been observed. Finally, surveys in areas with volcanic geology in Rwanda, where elephantiasis has not previously been reported, are described.

Distribution of elephantiasis in Ethiopia

The origin of 800 patients who attended an elephantiasis clinic in Addis Ababa was noted, and located on a wall-size map of the country. Attempts were then made to correlate this with data on climate, altitude, vegetation, population, genetics and geology. These correlations suggest a possible association with the geology of the affected areas, in particular with the basalt rocks which largely underlie them.

The areas of prevalence were visited and it was noted that the disease was limited to the barefooted section of the community. Surveys by market counts indicated that the disease was more closely related to the extent of the "tropical red soil" developed from the basalt, rather than to the basalt itself. In some areas the soil cover extended beyond the limit of bed rock and the disease pattern followed this extension.

An accurate soil map of the country was not available but extensive geological surveys had been made and reported by MOHR (1962), who prepared a small-scale map (1963) on a scale of 1:2,000,000. This was used as an indication of the parent material of the soil and the locations of the villages with elephantiasis patients were plotted on this geological map. The small-scale reproduction in Fig. 1 shows a sample of these.

The distribution of the disease suggests an association with soil derived from basalt rocks. The basalt area of the country covers more than 200,000 km²; the fertility of the soil attracts an agricultural population of 20·5 million people. Extensive studies reported elsewhere

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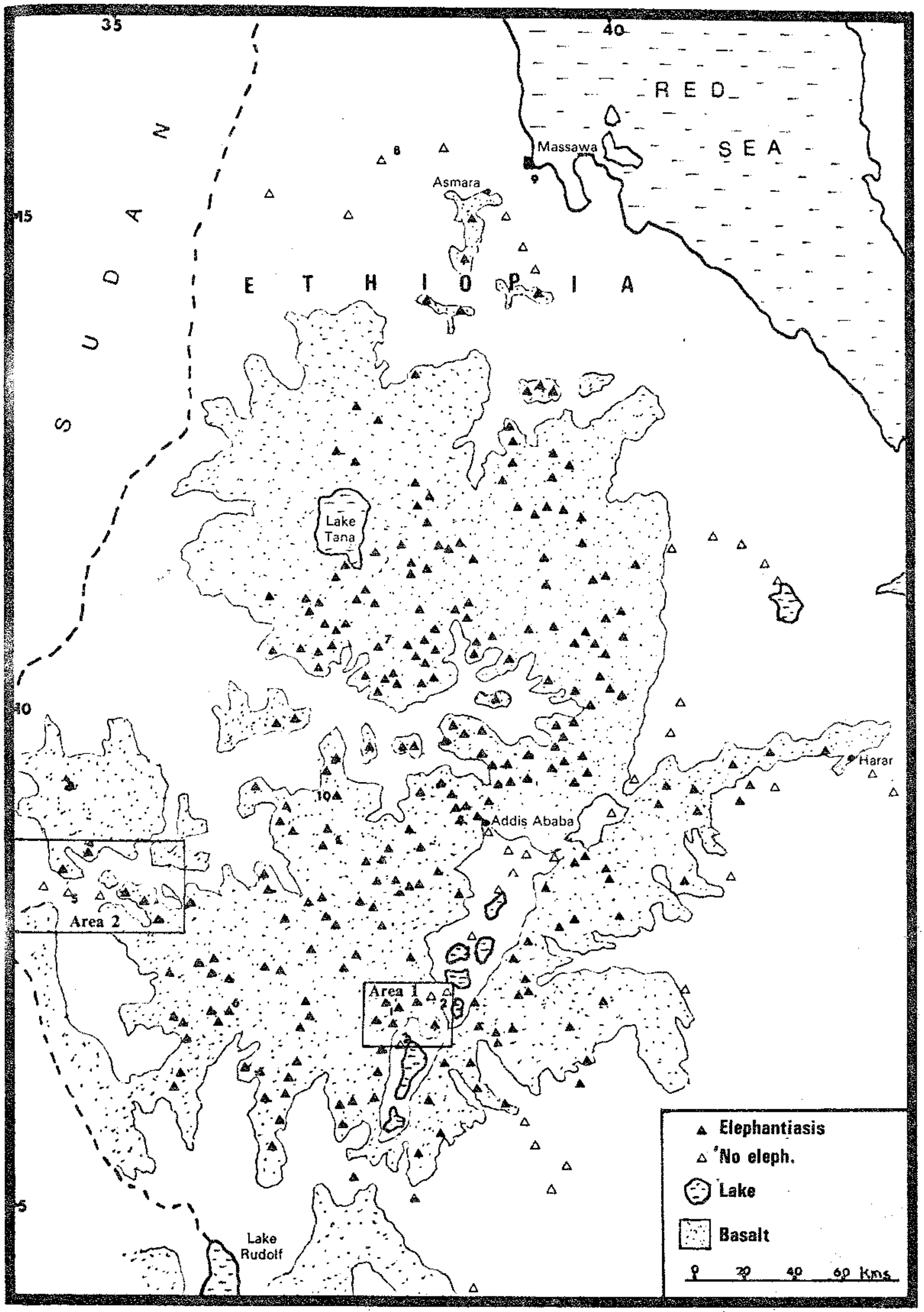
Figure 1


35
40
RED SEA
Massawa
Asmara
SUDAN
ETHIOPIA
Lake Tana
Addis Ababa
Harar
Area 1
Area 2
Lake Rudolf
15
10
5
Elephantiasis
No eleph.
Lake
Basalt
0 20 40 60 Kms

(PRICE, 1974b) indicate that among the 49·8% who are adults — 10·2 million — there are between 200,000 and 350,000 cases, a prevalence of 10 to 17 per 1,000 total population.

In an earlier count of 247,908 adults in 56 markets, OOMEN found a prevalence of 27 per 1,000 adults or 13·5 per 1,000 population.

In order to test a possible relationship to basalt rock or derived soil, attention was paid to the border areas, two of which are indicated in Fig. 1. The results of these surveys are presented here.

The Soddu-Wollamu area of Ethiopia (Area 1 on Fig. 1)

This area was chosen because of the knowledge of local soils that was available. Studies had been undertaken by soil scientists for the Wollamu Agricultural Development Unit and I am indebted principally to Mr. C. J. Birchall for the soil and geological data in the present study.

A detailed report of this survey has been published (PRICE, 1974a) and the results are summarized in Table I. It will be seen that elephantiasis prevalence is on average 53·8 per 1,000 market adults on the "red soil" area, falling rapidly to 10 per 1,000 within 25 km of the edge of this area.

The exact limits of the geological formations underlying these areas are not known, but the parent material of the elephantiasic areas is deeply weathered basalt and ignimbrite; the non-elephantiasic area is volcanic ash and riverine and lacustrine alluvium.

The survey also suggested a relation between the degree of prevalence and the proportion of barefootedness in the population.

The Dembidollo-Gambela area of Ethiopia (Area 2 on Fig. 1)

This area was chosen because it contained the only *Wuchereria bancrofti* area in Ethiopia and because the geological distinctions were clearly defined. The survey was made with a geologist, Mr. Aberra Mogussie, of the Department of Geology of the National University, Addis Ababa. The highlands, at an altitude of 1,600 m (5,200ft), have a thick volcanic basalt cover and are abruptly interrupted on each side of the Gambela valley by a precipitous escarpment which rapidly descends to 540 m (1,760ft) at Gambela. In the valley the soil is alluvium lying on granitic or gneissic "basement" rocks.

The highland population are Cushite Gallas who cultivate the fertile "red soil" which develops from the basalt cover. The lowland Nilotic people live on the relatively poor, sandy, alluvial soil along the Baro river and survive mainly by fishing and hunting.

Wuchereria bancrofti and *Onchocerca volvulus* are common in the lowland area; *O. volvulus* also occurs on the highlands.

The estimate of prevalence of elephantiasis in the highland areas was made on counts of adults attending the weekly markets. In the lowland area, markets were not a feature of the social scene and information was obtained from a number of sources in that area. Among these, Dr. Reynolds (medical officer during 13 years at Pokwa, the only hospital of the area) stated that he had seen only five cases of elephantiasis of the legs in that period; the local Greek trader, who has lived and travelled constantly in the area during the past 21 years, stated that he had never seen a case, and the Gambela Health Centre reported that the only cases who attended had come from the Dembidollo highlands. No cases were seen personally during the visit.

Details of the findings are summarized in Table
It will be noted that the prevalence of elephantiasis fe
from 60 per 1,000 adults on the volcanic highlands t
0·1 on the sandy lowlands, a direct distance of abou
30 km. High prevalence areas were on upland savannah
and non-elephantiasis areas were in forest lowland. I
terms of geology, high prevalence areas were on basal
and non-prevalence areas were on basement rock, viz
granite and gneiss.

The geology of elephantiasis areas in Kenya and north-wes Tanzania

The Mount Kenya area of endemic elephantiasi
described by CLARK has been revisited to confirm th
continued presence of elephantiasis. The north-wester
area of Tanzania could not be reached for securit
reasons but the contiguous area of Burundi has bee
visited. The results of these visits follow. The purpos
was to compare the clinical features of the disease wit
those seen in Ethiopia, and to note the relationship t
volcanic rocks and soil.

The Mount Kenya area

CLARK (1948) described the disease which he calle
lymphostatic verrucosis as occurring "around the foo
of Mount Kenya and the Aberdare mountain range"
where it was "very common". He reported 200 case
seen during three years and remarked on the limitatio
to the lower legs below the knee. There are no specie
of human filaria in the area.

According to present enquiries, the disease is sti
present in these areas except on the west. During a sho
visit, 25 cases of elephantiasis were seen in five days, a
of the lower legs below the knees. Half of these wer
below the age of 30, the youngest being aged 12 years.

The report of the geologist, W. A. Fairburn, in th
official geological survey of the Ministry of Natura
Resources, Nairobi, states that the dominant rocks of th
affected areas are olivine-basalt and older volcanics. Th
disease does not, however, occur on the drier wester
slopes where rainfall is below 1,000 mm annually. Th
difference can be related to the poor soil developme
which occurs when rainfall is restricted. The populatio
on this side is also limited.

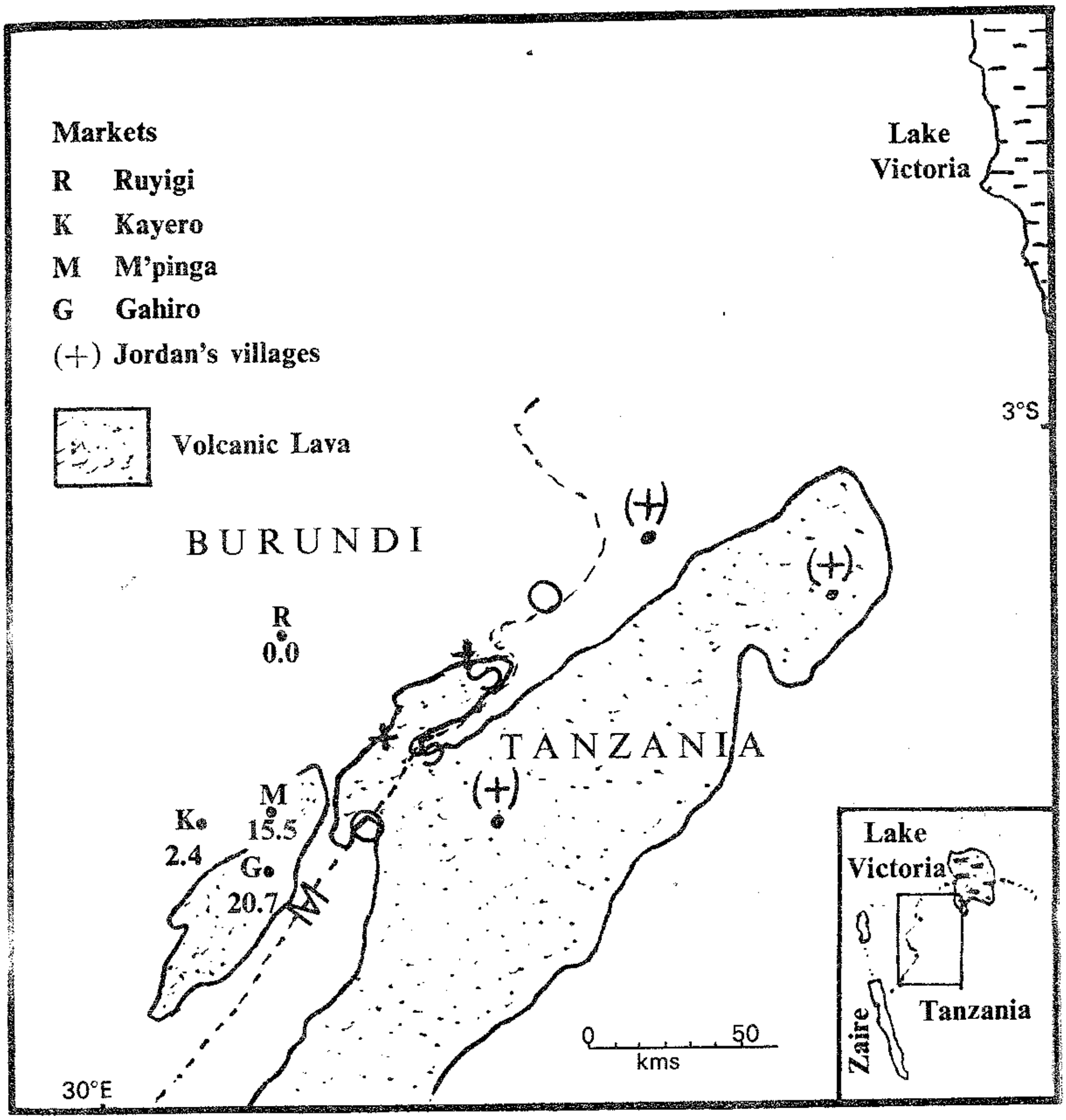
The altitude of the affected areas is 1,220-2,300
(4,000-7,000ft).

The Mosso area of north-west Tanzania and south-we Burundi

In 1956, JORDAN and his co-workers reported an ar
of non-filarial elephantiasis in Tanganyika, south-we
of Lake Victoria, at an altitude of 1,220-1,830
(4,000-6,000ft) above sea-level. The disease was di
covered during a national filariasis survey when nig
bloods of 475 persons in this area, of whom 12 ha
elephantiasis, were all negative for *W. bancrofti*. Th
compared with a prevalence of only eight cases in 6,8
night blood specimens in other villages in Tanzan
which were free of *W. bancrofti*. One of the worke
TRANT, revisited the area and found 62 further case
Onchocerciasis did not occur in the area. A possibili
of *Dipetalonema perstans* aetiology was suggested. T
location of the named affected villages is indicated
the map of Fig. 2.

The projected visit was frustrated at the last mome
by a security ban, but a visit was allowed to the co
tiguous areas of Burundi. Elephantiasis was found to
widespread there but the extent of the survey was limit

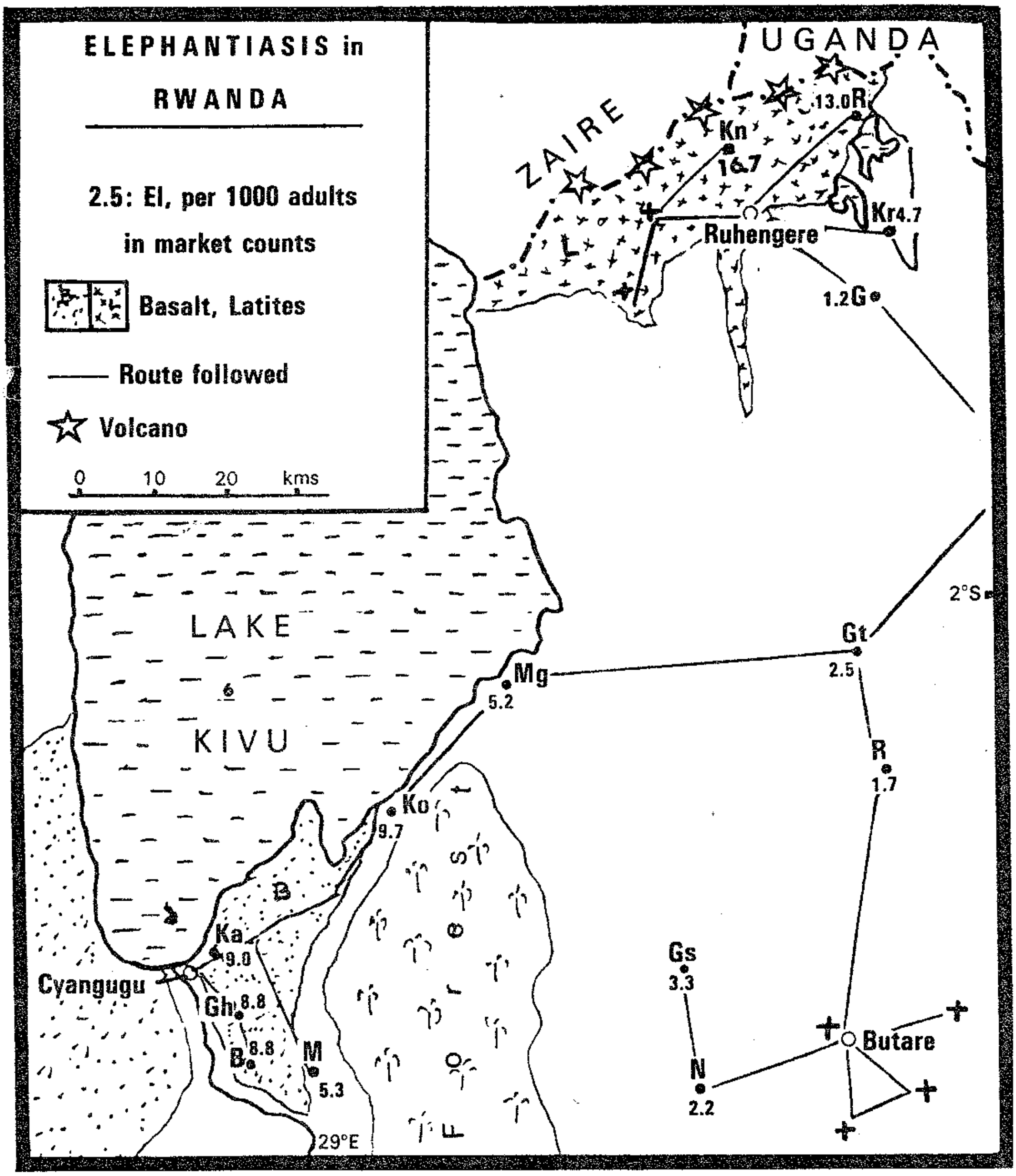
Figure 2
PREVALENCE in the MOSSO REGION



by lack of roads. However, attention was concentrated on an area around Mpinga where the red soil of the Mosso valley gave way to the sandy soil of the quartzite mountain crest. The occurrence of three markets in this area facilitated the work. The Mpinga market was located at the stream which divided the "red clay" from the sandy soil. The population was much greater on the more fertile "red clay" side, and it seemed likely that the site of the market was chosen because the sandy soil would not be muddy, sticky and slippery after rain as is the red clay. Gahiro market was entirely within the red soil and Kayero entirely within the sandy brown soil area. In each case, the market is the only one in the district.

The count of the Mpinga market was separated according to whether the people were coming from the red-clay side or the sandy brown soil side. The results of the counts are given in Table I. Locations are indicated on Fig. 2.

Figure 3



The rapidity with which the prevalence diminishes at the edge of a "red soil" area is shown by the differential count at the market at Mpinga which straddled the border between the two types of soil. On the red-clay side 25 cases were observed in 1,208 adults (20·7 per 1,000) against two cases in 822 adults (2·4 per 1,000) on the sandy side. This sudden diminution in prevalence corresponds with that observed in the border area of Ethiopia.

The results suggest an association between the red-clay and the prevalence of elephantiasis, the rate of which is similar to that obtained on the Tanzanian side of the border studied by JORDAN in 1956, 12 cases among 475 adults (25·2 per 1,000).

Table I – Market counts at limit of red-soil areas

Location of market	No. of markets	Adults counted	No. of elephs.	Eleph./1,000 (range)
On red clay				
Ethiopia: Soddu-Wollamu	5	28,247	1,521	53·8 (42·9–69·2)
Dembidolo-Gambela	6	10,772	655	60·8 (47·8–86·7)
Burundi: Mosso area* Gahiro-Mpinga	2	1,208	25	20·7 bis
Off red clay				
Ethiopia: Soddu-Wollamu	3	9,488	95	10·0 (7·9–10·2)
Dembidolo-Gambela†	–	41,000 (census)	5	0·1
Burundi: Mosso area* Kayero-Mpinga	2	822	2	2·4 (0·0–3·7)
Ruyigi	1	489	0	0·0

*Mpinga market is astride the red-clay limit. Counts on the clay side are here separated from those on the sandy side (see text). The combined count was 15·5 per 1,000 adults.
†Markets are not a feature of Gambela area; see text.

Table II – Relationship of elephantiasis to geology

Prevalence area	Eleph. per 1,000 adults	Altitude m (ft)	Dominant geology	Ref.
Ethiopia: Soddu-Wollamu	40·9	2,000 (6,500)	basalt	Mohr (1971)
Dembidolo	60·9	1,600 (5,200)	basalt	Mohr (1971)
Kenya: Mount Kenya area	+	1,540 (5,000)	basalt kenytes*	Fairburn (1966)
Tanzania-Burundi: Mosso region	20·7	1,500 (4,950)	basalt	Gérards (1975)
Rwanda: South Kivu	8·4	1,500 (4,950)	basalt	Cahen (1954)
Volcano area	13·5	2,000 (6,500)	latites† banakites‡	Cahen (1954)

*Kenytes are "lava flows of olivine-bearing phonolites".
†Latites are "rocks with basaltic features, especially by containing olivine".
‡Banakites are "a variety of olivine-bearing trachybasalts" (Penguin dictionary of Geology).

Information on the geology of the area has been provided by Monsieur Gérard of the Musée Royale at Tervuren in Belgium. The parent material of the red clay soil in the Mosso is "extruded basaltic lavas and dolomitic rocks"; the sandy-brown soil on the upper slopes is derived from quartzites. This information, with that from a geological map in the Geological Survey of the Ministry of Mines, Tanganyika (1960) Memoir No. 1, is presented in Fig. 2. The locations from which information has been obtained, including that of JORDAN, are shown on this map.

The present observations confirm that the non-filarial elephantiasis of Kenya, north-western Tanzania and adjacent areas of Burundi occurs on soil from volcanic rocks which include basalt.

Elephantiasis survey in Rwanda

To test the geochemical hypothesis further, a survey of elephantiasis in neighbouring Rwanda was undertaken during a period of one month, and covering 1,500 km in rural areas.

Rwanda is a highland plateau with average altitude of 1,700 m (5,600ft), bordering the west branch of the African Rift system. Average temperature is 20°C; average annual rainfall is 1,200 mm, being highest on the slopes of the volcanoes in the north which reach over 4,200 m (14,000ft) high. The fertile soil of this area attracts a population of about 250 per km², among the highest in rural Africa. The total adult population is about two million.

Thirteen markets were counted to include places where elephantiasis was stated by the Health Services to be present, and also some outside these areas. A total of 18,661 adults were counted among whom were 112 cases of elephantiasis of the lower legs; a further 133 cases were observed in clinics in areas other than markets. Prevalence in the markets varied from 1·2 to 16·7 per 1,000 adults. The areas of high prevalence are indicated on Fig. 3 and include the foothills of the volcanoes in northern Rwanda, and the southern shores of lake Kivu. An additional area in the south is contiguous with northern Burundi, where a previous survey indicated a prevalence of 11·0 per 1,000. Further details of the surveys in both countries are reported elsewhere. (PRICE, 1976.)

Fig. 3 also indicates the areas of volcanic lava and it will be observed that these are also the areas of high prevalence of elephantiasis. The rate is lower in the south of Lake Kivu, but the population has been displaced on several occasions in recent years by political disturbances, and the present prevalence may not be fully representative.

The parent rocks of the soil in southern Kivu are basaltic lava which was extruded through cracks in the surface rocks. The lavas from the five volcanoes in the north vary in type but are mainly latites which are described geologically as "basalt-like rocks" differing mainly in the type of feldspar present.

Discussion

These studies indicate a relationship between elephantiasis of the lower legs and soil derived from floods of lava, notably basalt. Basalt is a dark, heavy rock, fine-grained or glassy, and rich in calcium, iron, aluminium and combined silica. It contains a variety of metals that contribute to the fertility of the soil. The reddish-brown rusty colour of the soil is an expression of the high iron content. The floods of lava may emanate from vents, as in the prehistoric volcanoes of Mount Kenya and Rwanda, or through fissures in the earth's crust, as in Ethiopia, the Mosso area of Tanzania-Burundi and south of Lake Kivu. These relationships are summarized in Table II.

The observation that the disease is limited to the barefooted section of the agricultural population in areas of high prevalence suggests that the aetiological factors may be absorbed through the feet.

It is noted that the areas of high prevalence of elephantiasis are, in general, highland areas around 1,500 m (5,000ft). These areas are close to the points of emanation of the lavas, and the altitude ensures enough rainfall, at suitable temperature, to produce a fertile soil and support a large population which reaches the highest density of rural populations in Africa.

Lava is unstable material at surface temperatures and pressure. The minerals disintegrate steadily under the influence of warm rain, over periods of thousands of years, into their components which are predominantly those of iron oxide, alumina and silica. These are reconstituted into the more stable silicate clay minerals (notably kaolinite) and the hydroxides of iron and aluminium. Clays are composed of small crystals of these minerals in colloid size, with maximum length of 2 microns to which a variety of metallic ions are adsorbed. The resulting red-brown, slippery and sticky clay is familiar to all who visit the areas and adheres strongly when wet to the feet and lower legs of the agricultural worker.

The possibility that colloid particles of this clay enter through the skin of the feet of these workers gains support from the metal analysis of femoral nodes (HEATHER and PRICE, 1972, PRICE and PITWELL, 1973).

In the first study, using transmission and scanning analytical electron microscopy and other techniques, accumulations of inorganic materials, particularly silicon and aluminium, were located in macrophages of lymph nodes of Ethiopian subjects, with and without elephantiasis, and it was suggested that these played a part in the onset of the disease.

In the second study, femoral nodes from 18 with elephantiasis and 11 without were examined for metal content by spectrographic analysis after incineration and digestion with hydrogen peroxide. Residues in both groups contained aluminium and silicon, and a variety of other metals.

In a more recent (unpublished) study, using a similar technique on femoral nodes of five elephantiasis patients from Ethiopia, Dr. Michael Thampson of the Imperial College of Science and Technology, identified the presence of significant amounts of Si, Ca, Mg, Al, Fe, Ti, Mn, Cu, Pb, Ni, Ca, Sr and traces of other metals in each node. These metals are those which are either the major constituents of igneous rocks or are trace elements associated with them (MITCHELL, 1964), and so occur in the soils derived from these rocks. It is presumed that the similar elements found in the nodes originate in these soils.

The derived ions of iron, aluminium and silicon and some heavy metals are irritant to human tissue and a possible source of damage to the endothelium of the lymphatic vessels which convey them away from points of absorption through the skin. The mechanism of absorption of ions through the human skin, in particular those of iron, is described by EDELBERG (1971). He refers to experiments of SUCHI with $FeSO_4$, showing that the sweat duct lining of the corium is ion-permeable if an electrical potential difference exists between solution and cell-surfaces. The skin-surfaces, when wet with sweat, are electro-negative, and the colloids of iron and aluminium hydroxides are electro-positive, and the firm adherence of clay to the skin is a common observation. The observed concentration of small round cells around sweat ducts where they penetrate the epidermis may then represent a reaction to entry of these ions.

These findings, together with the field observations of the distribution of the disease, strengthen the case for considering highland-elephantiasis of the lower legs to be a geochemical disease resulting from damage to the local lymphatics by substances absorbed from the soil through the bare feet of an agricultural community.

Acknowledgements

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References

Clark, M. (1948). Lymphostatic verrucosis in the Fort Hall district of Kenya. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **42,** 287–290.

Cahen, L. (1954). *Géologie du Congo Belge.* Liege: Vaillant.

Cohen, L. B. (1960). Idiopathic lymphoedema of Ethiopia and Kenya. *East African Medical Journal*, **37,** 54–74.

Edelberg, R. (1971). Electrical properties of skin. In: *Biophysical Properties of the Skin*, ed. H. R. Elden, Vol. I, p. 519. New York: Wiley Interscience.

Heather, C. J. & Price, E. W. (1972). Non-filarial elephantiasis in Ethiopia: analytical study of inorganic material in lymph nodes. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **66,** 450–458.

Jordan, P., Trant, M. H. & Laurie, W. (1956). Non-bancroftian elephantiasis in Tanganyika. *British Medical Journal*, **1,** 209–210.

King, B. C. (1970). Vulcanicity and rift tectonics in East Africa. In: *African Magmatism and Tectonics*, ed. Gifford & Gass. Edinburgh: Oliver & Boyd.

Lowenthal, L. J. A. (1934). On the probable inclusion of several diseases in the title "Mossy Foot". *Annals of Tropical Medicine and Parasitology*, **28,** 47–62.

Macfie, J. W. S. (1936). Mossy Foot in Northern Ethiopia. *Annals of Tropical Medicine and Parasitology*, **30,** 299–303.

Mitchell, R. L. (1964). In: *Chemistry of the Soils*, ed. F. E. Bear, 2nd edition, p. 327. London: Chapman & Hall.

Mohr, P. A. (1963). *Geological Map of Horn of Africa.* Fulham, London: Philip & Tracey Ltd.

Mohr, P. A. (1971). *Geology of Ethiopia.* Addis Ababa: University College Press.

NAMRU-3 (United States Naval Medical Research Unit) (1973). *Resumé of Research Activities*, p. 18. Addis Ababa.

Oomen, A. P. (1969). Studies on elephantiasis of the legs in Ethiopia. *Tropical and Geographical Medicine*, **21,** 236–253.

Price, E. W. (1974a). Relationship between endemic elephantiasis of the lower legs and the local soils and climate. *Tropical and Geographical Medicine*, **26,** 225–230.

Price, E. W. (1974b). Endemic elephantiasis of the lower legs in Ethiopia: an epidemiological survey. *Ethiopian Medical Journal*, **12,** 77–90.

Price E. W. 1976. Endemic elephantiasis of the lower legs in Rwanda and Burundi. *Tropical and Geographical Medicine*, **28** ~~(in press)~~. 283

Price, E. W. & Pitwell, L. R. (1973). The mineral content of inguinal nodes in barefooted people. *Journal of Tropical Medicine and Hygiene*, **76,** 236–238.

Ten Eyck, D. R. (1974). Elephantiasis of the lower extremities in Ethiopia: failure to implicate onchocerciasis as an etiological agent by skin-snip and fluorescent antibody staining techniques. *American Journal of Tropical Medicine and Hygiene*, **23,** 35–40.