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The possible influence of the components of the soil and the lithosphere on the development and growth of neoplasms

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Summary. The author reviews the background of the soil-cancer relationship. The study then goes into geocarcinogenic diseases in relation to soil composition, looking first at general factors: soil concentrations of selenium, caesium-rubidium-potassium, trace elements; natural radioactivity risks; cancer risks in connection with recycled waste water. In its final part, the study examines geocarcinogenic diseases linked with soil composition covering gastric cancer, cancer of the esophagus, urinary, breast, and bronchial cancer, pleural mesotheliomae and bone cancer.
Key words. Soil; cancer; water; geochemistry; pedology; selenium; geocarcinogenic diseases.

1. Background to the soil-cancer relationship

The first ideas relating soil and environment, on the one hand, and soil and cancer on the other stem from the not very scientific notion of 'cancer houses'.

In 1932, however, in a study covering 20 years in Lyons, Lumiere and Vigne found no differences with respect to deaths from all causes in so-called cancer houses. In a study carried out in Bristol between 1922 and 1927 and in Worcester between 1921 and 1930, the only scientific factor that emerged was that cancer-caused deaths tended to prevail in pairs, either people living in the same house or in adjacent houses (Stocks, 1935).

The first scientific hypothesis seems to be that of Haviland who together with Farr in 1868 published a geological map of England and Wales showing for the 625 registration districts colored areas denoting death rates of women by cancer between 1851 and 1860. This hypothesis, which was confirmed in later publications (1870/1888/1892), shows that the highest cancer rates occur mainly in zones with low-lying clay areas submerged by seasonal floods from bodies of water (The Fens, marshy plains in the east of England).

The lowest rates, on the other hand, were observed in

Table 1. Average death rate over 50 years of age according to soil type[90]

Soil groups	Number of municipalities	Average death rate over 50 years of age and percentage of 'plus' municipalities				
		1900–1910	1910–1920	1920–1930	1930–1940	1900–1940
Reclaimed peat	11	658 (82)	706 (82)	661 (55)	689 (82)	678
Peat	70	607 (63)	667 (60)	667 (53)	688 (57)	657
Sea-clay	275	595 (56)	654 (54)	667 (50)	693 (58)	652
Sandy	385	562 (48)	622 (49)	653 (50)	651 (55)	622
River clay	193	551 (43)	603 (40)	635 (46)	631 (41)	605
Loess and old soils	++	350	479	578	533	485

Table 2. Component elements of the lithosphere in %

Major elements as a % of the lithosphere	
Oxygen (O)	46.4
Silicon (Si)	27.8
Aluminium (Al)	8.0
Iron (Fe)	4.6
Calcium (Ca)	3.65
Sodium (Na)	2.4
Potassium (K)	2.5
Magnesium (Mg)	2.2
Trace elements	
Hydrogen (H)	1–0.1 %
Manganese (Mn)	
Phosphorus (P)	
Titanium (Ti)	0.45
	0.1–0.01 %
Carbon (C)	
Fluorine (F)	
Sulphur (S)	
Vanadium (V)	
Chromium (Cr)	0.02
Barium (Ba)	
Zirconium (Zr)	
Rubidium (Rb)	
Strontium (Sr)	
Chlorine (Cl)	
Other	< 0.01 %

limestone or chalk soils where the population is well above the water levels (southeast England).

A further study covering 1921–1930 shows zones of high and low cancer rates for women, though the data here differ a good deal from Haviland's (Stocks, 1939).

Different relationships between certain types of cancer and soil composition will be given later (Stocks, 1936/1937/1939; Legon, 1951).

And finally, in France in 1939, Delbet and Robinet in concluding their work on the causes of cancer in villages felt that there is a relationship between cancer frequency and the soil's relative magnesium deficiency.

It is, however, the statistical studies carried out in The Netherlands by S.W. Tromp and J.C. Diehl[90], on patients over the age of 50 between 1900 and 1940 in relation with soil conditions that set the definitive guidelines for this research (table 1).

The composition proposed by Goldschmidt in 1937 has been amended with only slight changes which are included[28] (table 2). The peaty and sea-clay soils show higher rates than the sandy river clay and loess soils. In the case of sandy soils, rates vary according to hygrometric level: dry (625), moist (650), wet (692). As far as the sources of water supply are concerned, rate variation is as follows: river water (606), heath water (594), dune water (585), well water (568). S.W. Tromp showed that water contained in river clays (low cancer rates) had higher levels of magnesium and manganese and less silicon than the peaty, sea-clay and sandy soils.

Between 1974 and 1978 the U.S. Subcommittee on the relationship between the geochemical environment and health and diseases confirmed a link between certain trace elements and cancer.

In 1975 I proposed that cancer epidemiology be called 'Geocancerology' which stresses the multiplicity of determinant factors which are relevant to the evaluation of cancer risks[59]. It is a question of 'the various relationships and intersections between geography in the broad sense, human ecology, environmental factors, the study of cancer, and all related sciences'.

In a report published by the UNESCO journal 'Impact', emphasis is placed on the importance of soils as determinant factors in human carcinogenesis[60a].

In 1982, at the Brussels International INEC Congress on Ecology, Geography, and Preventive Medicine, J.W. Dobrowolski submitted a comparative study on trace elements in the ground, drinking water, and diet in human and cattle leukemia[24]. J.W. Dobrowolski showed for leukemia outbreaks that there were clear magnesium, iron, cobalt and silicon deficiencies in the food chain together with excess lead, mercury, nickel as well as mycotoxins and nitrosamine precursors.

Finally, a communication from A.K. Brewer, R.L. Neulieb and M.K. Neulieb[9a] shows that four regions in different countries – the Navajo-Hopi Indian Reservation in the northeast Arizona semi-desert (USA), the Vilcabamba Valley in Ecuador, the Hunza Valley in northern Pakistan, a Caucasian mountainous plateau in the south of the USSR – have the following common characteristics: soil rich in caesium, rubidium, and potassium.

In the Arizona semi-desert high rubidium and potassium levels, the latter glucose-free, were found in the soil and water.

2. *Carcinogenic diseases in relation with soil composition*

Although it is a subtle one and difficult to highlight, this relationship definitely exists. This can be seen through general factors such as concentrations in the soil of certain mineral salts (selenium, potassium, rubidium, caesium) and of some trace elements as can be observed through radioactivity risks or risks due to the recycling of waste water.

2.1 *General factors*

2.1.1 Selenium concentrations in the soil. A selenium deficiency in humans may entail myopathy, cardio-myopathy, Keshan's disease and it may also enhance the development of cancer. Geographical factors have a primary role in selenium supply. In 1976 R.H. Shamberger showed that an inverse correlation exists between the selenium content level in animal fodder in different states of the US and average cancer-mortality rates (table 3). However, a significant drop in the cancer death rate appears with an increase in blood selenium. Schrauzer carried out a comparative study in 27 countries relating breast cancer to Se supply in the diet, showing an inverse

Table 3. Cancer mortality of white males aged between 55 and 64 and selenium levels of fodder in different states of the USA (R. H. Shamberger as quoted by H. Deelstra[2])

Number of states	Selenium level in ppm	Cancer caused deaths per 100,000 inhabitants, average and SD	Probability
6	0.26 + (very high)	392.0 ± 11.6	< 0.001
19	0.10–0.26 (high)	429.7 ± 12.8	< 0.001
11	0.06–0.09 (average)	450.0 ± 12.2	< 0.001
20		516.0 ± 10.7	...

correlation here too. There is a significant drop in breast cancer mortality with a corresponding increase in the blood Se level. In a study on trace elements, Schrauzer showed that Se has favorable effects on cancer of the colon, rectum, prostate, and breast (table 4). The mechanism referred to to demonstrate this preserving effect of Se against cancer may be linked to the discovery made by Rotruck et al. in 1972 of Se in glutathione-peroxidase. This enzyme has an anti-oxidant action on cell membrane, comparable to that of Vitamin E. Because of its strong anti-oxidant power, alpha-tocopherol inhibits the synthesis of lipid hydroperoxides and peroxides, whereas glutathione-peroxydase acts as a catalyst in their fragmentation, thus favoring the elimination of substances formed by cellular oxidative activity[20].

As far as supply is concerned, almost all of the Se absorbed comes from food, with air and water supplying only very little. Fish and shellfish, meat (offal in particular), and cereals contain higher levels of Se than vegetables. The latter, however, depend almost entirely on the chemical composition of the soil for their concentration (between 0.02 and 2.5 ppm in selenium bearing soil). The soil in Scandinavia, Scotland, England, Germany, Benelux, China, and New Zealand has low selenium levels. According to H. Deelstra[20], all these observations together lead to the hypothesis that Se could inhibit carcinogenicity with a daily intake of 300 µm being necessary and sufficient to reduce the cancer incidence.

2.1.2 Joint concentration of caesium, rubidium, and potassium in the soil. I have already referred to the communication of A. K. Brewer, R. L. Neulieb, and M. K. Neulieb[9a] which establishes that four regions have caesium, rubidium, and potassium rich soils in common. These soils would merely be pedological curiosities if it were not for the fact that the populations living there share a very low cancer rate. Rubidium concentrations in the soil vary between 1.5 and 1800 ppm with the mean level being 140 ppm. The caesium level is much lower, around 3 ppm. As to potassium, the average level is 1500 ppm. A. P. Vinogradov thus defined the K/Rb/Cs ratio for soil as 5000/50/1. Potassium, rubidium, and caesium are frequently associated in source rocks at the level of biotites, feldspars, triphylite, lipidolites, etc. A. K. Brewer et al. are of the opinion that the quasi zero rate in the four regions mentioned is a result of sufficient consumption of glucose-free Rb and K together with the consumption of substances favoring their transport.

Table 4. Direct and indirect correlations between cancer mortality (adjusted for age) and the consumption of certain trace elements in 28 countries. (M) males; (F) females. (Schrauzer as quoted by H. Deelstra[21])

Type of cancer	Correlation Direct p = 0.001	0.01	0.05	Inverse 0.05–0.01	0.001
Colon (M) (F)	Cd, Cr, Zn		Cu		Se
Rectum (M) (F)			Cr (F)		Se
Prostate (M)	Cd, Cr, Zn				Se
Breast (F)			Cu		Se
Ovary (F)				Mn, Se	
Leukemia (M) (F)	Cd, Zn	Cr, Cu		Se	
Lung (M)				As, Se	
Pancreas (M) (F)				(Mn), Se	
Skin (M) (F)	Cd, Cu, Zn			As, Se	
Bladder (F)				Se	
All (M) (F)			Cr	Se	Se

2.1.3 The presence of certain trace elements. The Schrauzer epidemiological study (1977) mentioned above in reference to Se, also looks at other trace elements with a view to considering a correlation between them and cancer mortality. It was thus discovered that for certain trace elements direct functions could be set whilst for others there was an inverse proportion (table 4).

2.1.4 Natural radioactivity risks. A remarkable study carried out by F. Steinhäusler et al.[84] shows that irradiation doses from natural radioactivity are by far higher than those from artificial sources. It is the inhalation of radioisotopes of radon and its derivatives which is the main component of the total dose from natural irradiation sources. This natural pollutant is present everywhere in varying doses. It was known as a cause of bronchial cancer among miners who were exposed to very high doses. Thanks to the work of F. Steinhäusler et al. we have found out that at least 15% of all bronchial cancer cases may be attributed to it (table 5).

2.1.5 Cancer risks linked to waste water recycling. In the United States since 1976, a number of authors such as T. Page et al.[58], J. Salg[76], M. Alavanja et al.[2], J. R. Wilkins et al.[94], R. J. Stuba[86] etc., have drawn attention to the possible relationships between the use of river water in food and a growth in cancer rates, gastrointestinal and urinary cancer in particular. A recent study carried out by S. A. A. Beresford[9] in the southeast of Great Britain shows a slight increase in stomach and urinary organ cancer in women in regions where at least a part of the drinking water comes from recycled waste water.

Table 5. Percentages for different parameters in bronchial cancer etiology as observed in Salzburg, Austria[84]

Parameters	% of bronchial cancer
Medical X-rays	1
Only through radon emanation inhalation	9
Professional exposure to airborne particles (including radon derivative inhalation)	10
Heavy smoking (including radon derivatives inhalation)	80
Total	100

Table 6. Comparative mortality figures for cancer of the stomach and breast in rural parts of England and Wales in 1921–1949, standardized for age and geological grouping[85]

County	Geology*	Stomach							Breast
			Comparative mortality figures**						C.M.F.
		Total	1921–39		1940–49		1921–49		1921–49
		deaths	M	F	M	F	M & F	Rank	F
Caernarvon	Old	1,227	204	242	212	265	227	1	93
Anglesey	Old	670	201	243	169	226	211	2	70
Merioneth	Old	443	169	240	175	181	193	3	93
Denbigh	Old	1,367	177	205	167	166	181	4	90
Cardigan	Old	682	148	179	154	168	162	5	106
Carmarthen	Old	1,217	150	161	141	175	155	6	86
Montgomery	Old	407	155	149	128	140	146	7	100
Isle of Ely	Rec	424	156	146	138	125	145	8	85
Flint	Co	751	140	152	131	139	141	9	109
Pembroke	Old	620	128	145	153	127	138	10	92
Durham	Co	3,050	125	146	130	148	134	11	91
Glamorgan	Co	1,706	125	141	127	149	133	12	84
Lincoln (Holland)	Rec	557	120	125	114	136	127	13	90
Cumberland	Old	1,232	129	127	130	126	126	14	94
Brecknock	Dev	385	110	115	112	130	117	15	76
Huntingdon	Lio	359	122	95	123	123	114	16	109
Westmorland	Old	359	114	137	62	116	110	17	100
Bedford	Lio	857	116	112	92	107	109	18	111
Rutland	Lio	160	105	97	125	115	108	19	100
Cornwall	Dev	1,712	108	106	106	107	107	20	91
Monmouth	Dev	421	105	99	107	113	105	21	92
Northumberland	CoTri	929	102	111	101	109	105	—	85
Yorks, W. Riding	CoLio	3,006	96	115	96	112	104	23	101
Peterborough	Rec	89	105	77	118	132	103	24	109
Cheshire	Tri	1,608	106	103	106	93	103	—	99
Shropshire	Old	1,184	98	102	103	102	101	26	90
Northampton	Lio	1,143	104	101	107	91	101	—	106
Derby	Carb	2,246	106	107	89	99	101	—	96
Radnor	Dev	140	114	86	96	94	100	29	71
Somerset	Tri	2,225	96	94	111	102	99	30	107
Lancashire	Carb	2,120	93	102	95	108	98	31	96
Oxford	Lio	925	105	100	93	74	96	32	100
Essex	Rec	2,250	95	85	101	101	94	33	105
Devon	DevCarb	2,199	95	91	94	97	94	—	100
Yorks, N. Riding	Lio	1,197	97	104	78	83	93	35	99
Norfolk	Chk	2,495	94	83	99	95	92	36	97
Buckingham	Chk	1,326	92	74	108	94	91	37	109
Gloucester	Lio	1,991	89	80	102	98	91	—	102
Stafford	Co	1,440	87	86	91	109	91	—	104
Wiltshire	Chk	1,373	98	81	98	88	91	—	97
Hereford	Dev	653	91	88	86	104	90	41	95
Dorset	Chk	923	95	88	99	73	90	—	96
Lincoln (Kesteven)	Lio	582	101	85	80	90	90	—	86
Warwick	Tri	1,182	86	86	95	93	88	44	106
Cambridge	Chk	686	87	93	88	82	88	—	108
Leicester	Lio	1,242	87	95	85	83	88	—	106
Yorks, E. Riding	Chk	782	82	94	82	91	87	47	97
Hertford	Chk	978	86	93	89	77	87	—	98
Berkshire	Chk	1,219	86	83	89	82	86	49	109
Lincoln (Lindsey)	Chk	1,114	84	85	83	90	85	50	97
Suffolk West	Chk	584	80	72	93	93	82	51	103
Nottingham	Tri	962	84	84	76	83	82	—	99
Southampton	Chk	1,763	82	77	93	72	81	53	101
Kent	Chk	2,393	80	77	85	80	80	54	104
Suffolk East	Chk	944	78	81	90	81	80	—	94
Sussex West	Chk	963	83	76	81	80	80	—	104
Worcester	Tri	811	73	78	85	82	78	57	110
Isle of Wight	Chk	190	80	81	72	72	78	—	117
Sussex East	Chk	1,166	90	69	76	69	76	59	111
Surrey	Chk	1,037	82	75	68	67	76	—	104

*Old = Cambrian, Ordovician, Silurian; Dev = Devonian, Old red sandstone; Car = Carboniferous limestone, Millstone grit; Co = Coal measures; Tri = Triassic and Permian; Lio = Lias and oolite; Chk = Chalk and greensand; Rec = Recent formations. **Standardized by applying to local population in 4 periods the national rural death rates at 16 sex-age groups.

2.2 Geocarcinogenic diseases linked to soil composition

2.2.1 Stomach cancer. The geographical link with stomach cancer is the oldest and most evident of all geographical links with different types of cancer. In the United Kingdom, an in-depth study carried out by Davies and Wynne Griffith (1954) sets a distinct relationship between soil with a high hygrometric level and gastric cancer. There is definitely a geographical aspect to gastric cancer; however, the determinant factors are not the soil's components (unusually high rates in Japan, Portugal, Iceland, Costa Rica, Chile; abnormally low rates in Egypt, Syria, and Thailand). To look at soil components: P. Stocks drew up a table for the United Kingdom giving comparative death rates from gastric and breast cancer between 1921 and 1949 according to soil geochemistry (table 6).

Some recent studies have contributed to the further understanding of determinant factors. Despite the fact that it essentially concerns a nutrition factor, the J.V. Joossens and J. Geboers[38] hypothesis in 1981 in Belgium on sodium chloride assumes that salt causes hypertonic properties of the gastric contents which in turn have a caustic effect of the stomach's mucosa which leads to atrophic gastritis. This favors the synthesis of endogenous nitrites thus favoring the formation of nitroso-derived carcinogens. In 1982, R. Armijo[3], in Chile, showed that gastric cancer can be significantly associated with farm activity. However, it seems that there is no statistically satisfactory relationship with nitrate intake in areas with high gastric cancer rates. This would imply the need to consider a cofactor such as Se deficiency as observed in high cancer rate vulcanic regions. In 1983 in Costa Rica, R. Sierra and R. Barrantes[81,82] show a statistically significant relationship between gastric cancer and the levels of potassium, zinc, and iron in the soil taking into account soil pH as well. Finally, A.V. Chalkin, A.P. Il'Ntskii, M.K. Il'Enkova, and N.L. Vlasenko[16] show that for Kalmyks, a Mongol people in the south of the USSR, there is an increase in gastric cancer frequency which goes hand in hand with non-acidity and high salinity of the soil and water. Quite curiously, table 4 doesn't say a thing about stomach cancer. However, the three cancerous digestive parts mentioned, colon, rectum, and pancreas, all three show a *selenium deficiency* which confirms R. Armijo's study[3] in Chile. Soil and water *alkaline pH levels* seem to be an unfavorable factor.

2.2.2 Cancer of the esophagus. An interesting study carried out by M.G. Kibblewhite, S.J. van Rensburg, M.C. Laker and E.F. Rose[39] in South Africa in 1984, shows a clear relationship between the structure of the geological sub-soil and the risk of cancer of the esophagus. Thus, low risk regions showed dolerite rich soils and high risk regions showed sedimentary rocks. The latter have lower levels of copper, cobalt, manganese, nickel, boron, zinc and molybdenum than the low risk regions.

2.2.3 Urinary cancer. Selenium deficiencies appear to be determinant factors in the development of prostate and bladder cancer (table 4). However, the main factor can be seen irrefutably in cancer of the urinary tract developed from *Endemic Balkan Nephropathy* (EBN) which was clearly shown by B. Marković[47]. It was demonstrated that the silicon level was 16 to 33 times higher in a renal parenchyma during EBN than in a normal kidney (I. Divev et al., 1975).

A link was set between this disease and the consumption of water temporarily polluted by silicon from silicate rich rock erosion in mountainous area. This type of pollution is at its highest in villages along waterways absorbing mountain stream water. Si is present in drinking water in part in the form of microparticles, and in part in an ionized form (B. Marković and S. Lebedev, 1965). In water responsible for EBN, there is 8 to 10 times more silicon than in normal water, 5.5 times more aluminium, 4.5 times more iron, 3.5 times more chromium, and 2.5 times more manganese.

According to King's theory, it is free silicic acid that is the true cellular poison; to a certain extent solubility and harmfulness go hand in hand. However, two problems remain pending: 1) there is no close link between the quantity of dissolved silicon and its sclerogenic power; 2) there is more of a link with crystalline silicon than with its solubility alone.

As to the toxicity of certain silicates, B. Marković et al. succeeded in experimentally producing a pathogenic effect with certain granites equivalent to that of quartz; whereas, King classifies granites among the least dangerous silicates. In any case, the most toxic ones are siliceous rocks which undergo metamorphic processes, such as quartz and mica-rich acid granites. Furthermore, we might add that today we know that very fine colloidal amorphous silica is capable of producing the same effects as quartz (Policard et al., 1960).

In EBN pathogeny, a decisive role may definitely be attributed to phagocytic silica charged macrophages. Cancer immunology studies carried out by B. Marković tend to show that polymerized silicic acid (SiO_2) could behave like an antigene, with the immunity process involving the release of muco-polysaccharides. EBN, furthermore, is not only a kidney disease, but rather a systemic one which can also attack bone marrow, the liver, spleen, stomach, and small intestine. However, we are most concerned with the kidney type since approximately 40% of EBN cases, it seems, give rise to cancer of the urinary epithelium. According to B. Marković's hypothesis, it is the polymerized silicic acid (SiO_2) which, during urinary discharge, is a source of persistent irritation for the urinary epithelium which thus becomes prone to carcinogenic action from various other factors. In order to remedy this dangerous situation, in some Yugoslav regions, water with a lower siliceous level has been supplied with results which could be encouraging.

2.2.4 Breast cancer. Once again we observe a selenium deficiency according to table 4; furthermore, a correlation may be set between blood selenium levels and breast cancer rates (table 7). According to H. Deelstra, all these observations together lead to the hypothesis whereby selenium could inhibit carcinogenesis with a daily intake of 300 μm which would appear to be necessary and sufficient to reduce the risk of cancer[20].

Table 7. Correlation between blood selenium levels and breast cancer rates (Schrauzer (1976) as quoted by H. Deelstra[21])

Regions	Blood Se levels (g/ml)	Breast cancer cases × 100,000
South America Asia	0.26–0.29	0.8–8.5
United States Western Europe Scandinavia	0.07–0.20	16.9–23.2

2.2.5 Bronchial cancer. As we recall, F. Steinhäusler et al.[84] showed a positive relationship between irradiation of natural origin and lung cancer with radioactive radon and its derivatives. This study covered some 10,000 individual measurements of natural irradiation in the urban area of Salzburg, Austria, where the environment is considered as not highly radioactive. The authors believe that at least 15% of bronchial cancer cases are due to radon and its derivatives.

2.2.6 Pleural mesotheliomae. In Turkey, in the province of Cappadocia, the villages of Karain and Tuzkoey and their immediate surroundings have recorded an abnormally high number of cases of pleural mesotheliomae. Geologically, the region is covered with vulcanic tuffs in which, according to K. R. Spurny[83], asbestos, glass, and zeolite fibers were detected. The inhalation of such a mixture could be a cause of the mesotheliomae. In fact, asbestos fibers, both chrysotile and amphibole, were detected in mesothelial tumors[6].

2.2.7 Bone cancer. A 1983 study carried out by L. N. Mkrtchian et al.[53] allowed to set out epidemiological ideas which apply to Armenia in the USSR. In that area a high number of cases of osteogenic sarcoma has been recorded and the authors have pointed out that these occur mainly in areas where the soil has low silicon, cobalt, and zinc levels with at the same time high boron levels, and both drinking and irrigation water showed a high calcium content.

3. Conclusions

Soil components definitely act as determinant factors leading to the appearance of certain types of cancer, at least seven. Not enough is as yet known about these relationships, and an in-depth study in this area will no doubt provide a significant channel for future research. This study merely aimed at setting the foundations for a science which should be considered as the basis of future discoveries.

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The influence of soil on infectious disease

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Key words. Infection; montmorillonite; soil minerals; soil natural products; soil aridity; soil pH; soil temperature; anthrax; coccidioidomycosis; histoplasmosis.

'... the regions in the Aveyron, where we find anthrax, have a calcareous clay soil, and the parts where anthrax is unknown have a schistose or granite soil.' (L. Pasteur[37])

As has been true for so many other aspects of microbiology, the early seminal observations on the roles of soil in infection were made a century ago by Pasteur. He demonstrated the capacity of earthworms to transport cylinders of earth from the depths to the surface. Thus, he proposed that the soil surface could become contaminated with pathogens from dead, decaying host tissues that had been deeply buried. Pasteur considered that one reason for the lack of anthrax in granitic soil might be the relative difficulty of earthworm survival in such terrain. We will suggest below an alternative theory for the uneven distribution of anthrax. Indeed, a considerable variety of mechanisms can be envisioned whereby soil could modulate the incidence and severity of specific infectious diseases. Possible mechanisms are listed in the table.

Suppression or strengthening of host defense by soil minerals

To test the likelihood of mechanism No. 1 in the table, 5 mg of sterilized soil was combined with 100 cells of *Staphylococcus aureus* in wound incisions in guinea pigs[41]. In the absence of soil, no infections ensued; with soil, infection developed in > 80% of the test animals.
Infection-potentiating factors were present in soils of either high or low organic content. In the latter, sand and silt were much less active than clay. Of the clay minerals, montmorillonite was more active than illite or kaolinite. Infection potentiation was correlated with cation exchange capacity. Thus, the authors proposed that organic components or montmorillonite, each strong in this attribute, can force detrimental amounts of cations into host defense fluids and tissues.
In a subsequent study with *S. aureus* and *Pseudomonas aeruginosa* in the same laboratory, 10 mg of sterilized montmorillonite particles, less than 2 μm in diameter, were reported to eliminate the anti-bacterial activity of 1 ml of serum as well as markedly impair the phagocytic and bactericidal ability of 25,000 leukocytes[21]. Unfortunately the investigators failed to determine which specific cation(s), if any, were being altered in availability by the clay mineral. Of the physiologically active metallic ions, only ferric iron consistently suppresses serum and leukocytic antimicrobial activities[68]; however, metallic ions, such as those of aluminium, that are considered physiologically inert have not been adequately studied. Future investigations might examine possible mobilization of aluminum from the clay silicates to suppress host defense, as well as possible ability of the silicates to increase the level of iron contamination in soil-infected wounds.
On the other hand, specific components of soils, if assimilated into the tissues via ingestion of plant or animal food or drinking water, could possibly strengthen host defenses against infection (item No. 2, table). The most obvious and well-studied example is that of the ability of soil mineral elements to improve resistance of tooth enamel to the acids formed by cells of *Streptococcus mutans*. In many reports on dental caries, prevalence is inversely correlated with fluoride ion levels in drinking water. However, when fluoride content of rock, soil, and water is low, effects of other minerals are sometimes noted. For example, caries prevalence of 1876 12–14-year-old lifelong residents of 19 communities with populations of 3000–15,000 in the eastern United States was examined[59]. The communities were situated on four different soil types and each used water containing < 15.7 μM F. Caries incidence was highest on the podzol soils of New England, lower on gray-brown and red-yellow podzols, and lowest on the subhumic gray soils of the South Atlantic states.
In New Zealand, the adjacent cities of Napier and Hastings have significantly different caries prevalence rates despite similar dietary habits, socioeconomic conditions, and fluoride content of drinking water. Vegetables grown in the Napier soil generally were found to be richer in molybdenum, aluminum, and titanium and poorer in copper, manganese, barium, and strontium, as compared with those grown in the Hastings soil[59]. The higher molybdenum content of the Napier vegetables was proposed as a factor in the lower prevalence of caries in the children of that city.
Other examples of the ability of soil minerals to strengthen host defense include enhancement of the microbicidal action of rodent and bovine neutrophiles by selenium[7] and of ovine and bovine macrophages by cop-