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Geological factors in the emergence of infectious diseases
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ABSTRACT: GEOLOGICAL FACTORS IN THE EMERGENCE OF INFECTIOUS DISEASE

Many of the determinants of human morbidity from emerging infectious diseases can be construed—either directly or indirectly—as relating to environmental change. Little attention has been paid to the infections associated with geological processes, arguably because ‘medical geology’ has only recently become an established and legitimate field of study. This paper focuses specifically on infections, and their associated pathologies, directly or indirectly influenced by geological conditions. Specific diseases occur in relation to the nature of their ‘geogenic driver’ at three major levels of environmental change: that is, local, regional and global. The paper reviews the pathological mechanisms of pulmonary tuberculosis secondary to silicates, and geological factors impacting on the transmission of coccidioidomycosis and Lyme disease. Further examples discussed include the close relationship between water-borne infections and geological processes and formations, and the disease potential from long-range dispersal of pathogens (such as in dust storms). We contend that the geosphere is an under-recognized factor affecting the emergence and pathological profiles of infectious diseases.

INTRODUCTION

The emergence and re-emergence of infectious diseases over the last couple of decades pose a significant public health problem and have triggered widespread concern among health professionals and communities. Globally, we confront a formidable range of actual and potential pathogenic threats, including mosquito-borne diseases, such as dengue and malaria, and ever-growing numbers of zoonotic organisms, such as those originating in primates (eg HIV; montagnac, birds (eg West Nile virus; avian influenza) and rodents (eg hantaviruses and arenaviruses) (eg Subler 2002; Mouchet, 1997).

Many of the determinants of human morbidity from these emerging diseases can be construed—either directly or indirectly—as relating to environmental change. Factors leading to emergence have been well described, and include ecosystem injury from urbanization, deforestation, climate change, and changing patterns of travel and trade (Aron, 2001). A specific example is large-scale dam construction, which has been linked to numerous adverse effects, including epidemics of malaria, schistosomiasis, and other parasitic infections, such as onchocerciasis and typhoid fever (Patterson, 1997).

Although pathogen emergence has been linked to numerous ‘drivers’ (ie any factors that change an aspect of an ecosystem), less attention has been paid to the infections associated with geogenic processes, arguably because ‘medical geology’ has only recently become an established and legitimate field of study (Mukkot, 2002; Skinner, 2003; Selinus et al. in press). Since the formation of the Earth 4.5 billion years ago, geological environments have been changing constantly under the influence of natural physical processes such as volcanism, erosion, and geothermal or seismic events. Life, including microorganisms, evolved to adapt to such changing environments, and so far there is no sign of new infectious pathogens responding to natural or anthropogenic disturbances in novel and unexpected ways.

This paper focuses specifically on infections directly or indirectly influenced by geological conditions. We contend that the geosphere is an under-recognized factor affecting the relationship between changing environments and the emergence and re-emergence of infectious diseases. Using the comprehensive framework provided by the Millennium Ecosystem Assessment (2005), specific diseases are discussed in relation to the nature of their geogenic ‘driver’ at three major levels of environmental change: that is, local, regional and global.

1. LOCAL GEOLOGICAL FACTORS

Localized natural processes may facilitate geogenic infections, such as through geological processes. The use of travel for bathing, particularly where immersion of the body occurs, is a well-established risk factor for certain endemic forms of primary amoebic meningitis (usually caused by Naegleria fowleri; Vesnaver, 1990). More commonly, however, disease transmission occurs with anthropogenic interventions. With the advent of agriculture millennia ago, and later mining, the first non-natural changes to geological environments took place. These anthropogenic disturbances were first highly localized because of limited human technology, but have nevertheless been significant enough in some cases to lead to changes in infectious disease patterns. Eizer (2008) has summarized the numerous health problems of gold miners who worked underground in many countries: Australia, North America, South America, and Africa. infections formed a large component of the burden of disease, including increased frequency of pulmonary tuberculous; increased frequency of insect-borne diseases, such as malaria and dengue fever; and increased prevalence of certain bacterial and viral diseases. In a number of situations, the infection is not specifically related to geogenic exposure; for example, HIV rates are elevated in miners but secondary
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...to particular lifestyle factors. Epidemics often relate to the arrival of large numbers of non-urban humans, such as occurred with skin diseases such as yaws in Africa (Hackett, 1984) and with malaria and Ross River virus outbreaks during gas field development in Papua New Guinea (Hil, 1987).

However, mining activity can act to increase disease transmission. A recent study in the Burdwan district, West Bengal, examined the relative densities of a disease vector, Culex quinquefasciatus, infection rates, microfilariae-density and microfilaraemic persons in the village versus non-village areas (Adhikari, 1995). All these indicators were significantly higher in village areas, in turn accounting for an elevated prevalence of filariasis. Fungal infections such as sporotrichosis—a skin and lymphatic infection—which affected 3,000 miners in the Transevai in the 1990s, has been traced to sources such as mine timbers, which served as a reservoir of the fungus (Quinlan, 2000). However, other analyses indicate that mine soils may carry and transit a range of fungi, including sporotrichosis and others such as paracoccidiomycosis, histoplasmosis and nocardiasis (a cause of onchomycosis and superficial skin infections) (Rochdyus, 1996; Gugnani, 1989).

Pulmonary tuberculosis (TB) is one of the major diseases that have been linked to local anthropogenic geologic change. Some occupational groups, and arguably communities generally, are at increased risk of TB because of their exposure to silica (quartz) dusts. Silicotics have significantly increased standardized mortality rates from tuberculosis (TB) and occupational tuberculosis (Bodach, 1995).

The possible mechanisms by which silicotics predispose to immunologic impairment and tuberculosis are described in Ding (2002). Silica has been shown to increase the risk of TB in a range of contexts, with risk estimates ranging from a doubling of risk of TB in South African Gold miners (Kleinman, 1997) to a nine-fold risk among silicotics patients in Hong Kong (Chang, 2001). A recent paper reviewing the health of Indian miners also reported that pulmonary tuberculosis was an important complication, seen in up to 50% of patients of silicotics in some populations (Jindal, 2001). Patients with silicotics tuberculosis or other forms of infection are often have significant expectoration, hemoptysis, fever, and rapid progression to respiratory failure. The infection risk may also be elevated in the absence of concurrent pulmonary pathology (bid.). The risk remained elevated even after the exposure to silica dust has ceased, a finding that supports a call for longer-term health surveillance of local populations exposed to short-term geologic hazards such as volcanic eruptions (Weinstein, 2002).

In some situations, water-borne infections have a close relationship to geologic processes and formations. Unique conditions—such as subsurface geological formations—may therefore create unexpected risks in terms of pathogen transmission. Recent work has focused on relationships between microbial survival and hydrogeologic parameters, including the fate and transport of microbes in groundwater/aquifer media. Microbial movement and viability is affected by flow velocity, source types, geologic porosity, salinity, particle size, specific surface area, temperature, pH, and other chemical characteristics of water and mineral composition of the aquifers. A 1998 outbreak in Texas attributed to Cryptosporidium was associated with chlorinated wells located in limestone (Banrook, 2000). Because Cryptosporidium is resistant to many water disinfecting agents, the parasite must be physically removed by filtration. However, in the Texas outbreak, limestone and fractured bedrock failed to provide adequate natural filtration (Roberson, 1997).

In another localized outbreak, Norwalk virus gastroenteritis affected 900 people in an Arizona resort. The infection was traced back to a contaminated well, which remained contaminated even after prolonged pumping. It was eventually determined that effluent from the resort’s sewage treatment facility was seeping through fractures in the subsurface rock—with minimal filtration—into the deep well used for water supplies (Lewson, 1991). The geological implications of such findings in securing effective sanitation and safe water supplies will clearly grow in importance with the advancing rate of human implantation on geologic systems.

Geological compounds and infectious agents may even act as co-carcinogens. A possible interaction between asbestos and the SV (simian virus)-40 virus in the development of mesothelioma has been suggested in recent studies. Shewan (2000) argues that SV-40, which is probably transmitted by the inadvertent administration of contaminated poliovaccines to millions of people in Europe and the United States between 1955 and 1963, appears to be the best candidate as a co-carcinogen with asbestos in the development of human mesothelioma.

2. REGIONAL GEOLOGICAL FACTORS

Many geological structures and processes may be considered at a regional scale, including pedogenesis, soil types, processes or deforestation of trace elements, and the predominance of a particular geologic formation. As human populations have expanded and technology improved, anthropogenic changes to the geologic environment have also expanded, many operating at a regional scale. All these factors, both natural and/or artificial, may in turn impact upon infectious disease patterns and susceptibilities in human populations.

Analysis of bacteria and fungi in sand- and dust-storms have identified a wide range of airborne pathogens, including Aspergillus, Actinomyces, Pseudomonas, and Staphylococcus species, suggesting that sandstorm dust is a prolific source of organisms linked to human illness (Kwaasti, 1998).
Among the best characterized of dust-associated infections result from the spores of the dimorphic fungus Cryptococoides
jinnsite, which grows in topsoil. In the past few decades, the
incidence of coccidiodomycosis has shown a marked
increase in semiarid regions of the Western Hemisphere,
particularly California (Centers for Disease Control, 1994).
Approximately 60% of infected patients are asymptomatic;
the remainder can develop a spectrum of manifestations that
range from mild to moderate influenza-like illness to pneumo-
nia to disseminated disease, including meningitis.

Soil conditions are a major determinant of the distribution
and abundance of this environmental hazard: soil nature,
temperature and moisture content combine to permit an
accumulation in the soil of viable spores. Where such condi-
tions are prevalent, the disease is endemic (and ecologic).
And outbreaks among non-immune, non-resident people
entering such an area are common. It is also well-established
that cases are common after dust storms (Pappagianis,
1978; Flynn, 1970; Williams 1979). More recently, an associ-
ation with earthquakes has been identified, in which massive
of spore-laden dust become airborne with seismic shock
waves. Schneider (1997) reported a 1994 outbreak of 203
coccidioidomycosis cases (including 3 fatalities), peaking 2
weeks after an earthquake in California. The majority of
cases (95%) and the highest attack rates (114 per 100 000
population) occurred in the town of Bakersfield. Environ-
mental data indicated that large dust clouds, generated by land-
slides following the earthquake and strong aftershocks in the
Santa Susana Mountains north of Bakersfield, were dis-
persed into nearby valleys by northeast winds. A case-control
study in the community indicated that physically being in a
dust cloud (odds ratio, 3.0; 95% CI, 1.6-6.4; p<0.001) and
time spent in a dust cloud (P<0.001) significantly increased
the risk for being diagnosed with acute coccidioidomycosis.

Geological attributes may also act hydrolytically on infectious
disease transmission, such as through the effect of soil types
and mineral constituents on distributions of disease vectors
and reservoirs. An example is the association between soils
and the distribution of the coccidoides troca, troxidus spo-
fate, the vector of Lyme disease, human granulocytic ehr-
lichiosis, babesiosis, and other pathogens (Bunnell, 2003).
Environmental data and geographic information system
(GIS) modeling in Wisconsin and Illinois indicated that soil
type and land cover are very important determinants of
dispersal of ticks in the environment, even when the host
population is adequate (Gubala, 2002). With regard to soil
cover, tick presence was positively associated with affected
soil types of sandy or loam-sand textures covering sedimen-
tary rock, while absence was associated with acidic soils of
low fertility and a clay soil texture, and Precambrian bedrock.

Similar relationships between soil qualities and the disease
vector trocaz richus were found in Scandinavia (Jensen,
2000).

In some circumstances, levels of heavy metals, and the

toxic reactions they produce in the human body, may
increase likelihood of pathogen transmission. For example,
there is some evidence of an interaction between

arsenic and hepatitis E infection. In Taiwanese villages
in which chronic arsenicosis is hyperendemic, hepatitis E surface
antigen chronic carrier status with liver dysfunction appears
to have significant role in the development of arsenic-induced
liver cancer (Hsu, 1996). Despite its use as an antimicro-
bial in the era before antibiotics, arsenic may also have the
capacity to raise the risk of infection given its association
with the development of diabetes mellitus, extensive skin changes
(e.g. keratoses) and peripheral vascular disease (Tseung-
G, 1988). However, these pathways remain relatively specula-
tive and have yet to be confirmed in large scale studies.

3. GLOBAL GEOLOGICAL FACTORS

In the last few decades, there has been a growing awareness
that some environmental changes occur on a scale that
affects global ecology: atmospheric, hydrogeological, and
food production systems worldwide have been transformed
in ways that sometimes leads to the emergence of human
infectious diseases.

By the processes of deforestation and water abstraction for
irrigation, areas with moist rich soils can be changed into dry,
dusty plains subject to severe wind erosion. In its extreme
form, this process is referred to as desertification, and can
result in vast areas (eg much of northern Africa and China)
that act as sources for globally dispersed dusts. Anthropo-
genic influences (such as from farming and irrigation) have
contributed to dust formation by enhancing the process of
deresertification, with losses of over 10 million hectares (~29
million acres) of farmland per year (Griffin, 2001). Estimates
suggest that annual volumes of over 1 billion tons are trans-
ported from the main African deserts alone (Moulin, 2001).

The respiratory impact of North African dust on Caribbean
and South-American ecosystems is well established, as is the
mobility associated with atmospheric dispersed dust in
High Asia (Deryshka 2003). Surprisingly, the microbiology
and infectious disease risk associated with massive atmos-
pheric soil and dust transportation has not been studied in any
detail. This paucity of research is surprising given the potential
risks of long-range microbial dispersal. As Griffin (2001) notes,
if storm-blown African loessics can survive transoceanic trans-
port and arrive in the Caribbean, 'then so can the much more
verisstae, tolerant and adaptive microbe'.

This warning is substantiated both by laboratory findings
(ie indicate a tenfold increase in normal microbial fall-out
during dust events) and by violent outbreaks of foot and
mouth disease in storms that can be spread internationally
by airborne viruses; Donaldson, 2002). Although no out-
breaks of human disease have yet been attributed to the
intercontinental airborne transportation of pathogens, this is perhaps only a matter of time: globally, desertification contin-
ues to alter the geological environments that will make such infectious disease outbreaks a realistic possibility.

5. CONCLUSION

In this paper we have highlighted how changes to the geosphere can impact on human disease burdens, looking specifically at infectious diseases. These processes may occur in conjunction with infection-promoting disruptions in the biosphere (cf. the emergence of watertable crypto-
sporidiosis), the atmosphere (cf. climate change and the re-emergence of vectorborne disease), and biophase (cf commerce and travel-related dispersal of pests and pathogen(W) (Suthers, 2004).

This pattern of emerging infectious diseases associated with ecosystem disruptions is referred to as the "third ep-
idiological transition." The first epidemiological transition occurred with the advent of agriculture and cities, and its accompanying change in disease burden from famine to con-
tagious (crowd) disease; the second with the industrialisation and the advent of the cardiovascular diseases and cancers of affluence; and the third, underway at present, is the disrupt-
ion of global ecosystems (McMichael, 1993). As Alouhet (1997) notes, the need for and almost aggressive utilisation of new areas and resources may have serious epidemiologi-
ical consequences.

The geologic processes described above clearly form a major component in understanding this third disease transition. As Sutteiser (2004) notes, to understand the dynamics of Infectious disease we must account for factors impacting on ecosystems, including geological processes, ranging from local disturbances—such as mining—to changes playing out on a global scale. The natural time-scale of geographic events may also be disrupted by humans: unlike more gradual geological processes, anthropogenic interventions often cause dramatic changes in much shorter time frames, often within the period of a single human generation.

In summary, the process of adapting to and remodelling the health effects from ecosystem disruption requires an intim-
ate understanding of the relationship between human health and ecological health. Geological environments are integral to most of Earth’s ecosystems, and should be consid-
ered explicitly in our understanding and evaluations of how environmental processes impact on health. In this review, we hope that we have reinforced the need for research in medical geology in order, ultimately, to decrease global disease burdens.

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ABSTRACT

Human beings can be exposed to arsenic from a variety of environmental and occupational sources. Arsenic is a toxicogen and has been suggested to be the most possible cause of an endemic pericardial atrial fibrosis disease known as 'blackfoot disease' (BFD) along the southwestern coast of Taiwan. According to an early epidemiological study, patients with BFD suffered from a high mortality rate (4.94 per 100 patients) and the causes of death were mostly attributed to cardiovascular diseases (44%). Later epidemiological studies carried out in the BFD villages demonstrated that the excess mortality of cardiovascular diseases was associated with the arsenic content in the well water. The relative risk mortality from ischamic heart disease (IRD) were 1.0, 2.5, 4.0 and 6.5, respectively, for those with cumulative arsenic exposure (CAE) of 0, 0.14-4.9, 10.0-19.9 and >20.0 mg/l respectively. These recent studies analyzing the association between arsenic exposure and IRD in the residents of the BFD villages clearly showed that IRD was associated with CAE in a dose-response pattern. For those with CAE of 0, 0.1-4.9 and >20.0 mg/l, the prevalence rates of IRD were 5.2%, 10.9% and 24.1%, respectively (p < 0.001); and the adjusted odds ratios (95% confidence intervals) were 1.00, 1.60 (0.48-6.34), and 3.90 (1.11-12.85), respectively. In conclusions, long-term arsenic exposure as demonstrated from epidemiologic studies in Taiwan is associated with increased risk of IRD and cardiovascular mortality. The mechanism of arsenic-induced atherosclerosis requires further investigation.

INTRODUCTION

An extensive pathologic study done in early 1960s demonstrated that 30% of the BFD patients had histologic lesions compatible with thromboangiitis obliterans and 70% showed changes of arteriosclerosis obliterans (Yeh and Hsu, 1963). Since arteriosclerosis is a systemic disease, which might not only involve the lower extremities, it is rationale to look into the problem of IRD, which represents atherosclerotic involvement of the coronary arteries. In this paper, the author briefly reviewed the association between arsenic exposure and IRD from epidemiologic studies carried out in Taiwan.

ARSENIC EXPOSURE AND CARDIOVASCULAR MORTALITY

The annual death rate of BFD patients was relatively high and has been estimated to be 4.84 per 100 patient-years after