

Fate and Transport of Microbes in Water, Soils and Sediments

Microbial Survival in the Environment – Pathogens

Pathogen survival:

- Differs widely among microbes:
 - Bacteria: spores survive better than vegetative cells
 - Also differs between Gram-positive and Gram-negative bacteria
 - Some Gram-positives, e.g., enterococci, survive better than Gram-negatives, e.g., *E. coli*
 - But, Gram-negative bacilli are more resistant than Gram-negative or Gram-positive cocci to antimicrobial chemicals
 - Fungi: spores survive better than other forms
 - Viruses: non-enveloped viruses survive better than enveloped viruses under most environmental conditions
 - Envelopes are relatively fragile compared to outer capsids (protein coats)
 - Parasites: protozoan (oo)cysts and spores and helminth ova survive better than active life stages of these parasites or than those with no resting or special environmental forms

Survival of Selected Pathogens

- *E.coli* 0157:H7
 - Better survival at lower temperatures
 - Can enter VBNC state
 - In Water: >91 days at 8°C; 49-84 days at 25°C
 - In Soil: Up to 8 wks at 25°C; >99days under fluctuating temperature (-6 to 20°C)
 - In Manure: >1 year under fluctuating environmental conditions (non-aerated); 47-120 days (aerated)
- *Yersinia enterocolitica*
 - In Water: 64 weeks at 4°C
 - In Soil: 7-10 days at 30°C

Survival of Selected Pathogens

- *Cryptosporidium parvum*
 - In Water: >12 weeks at 4°C; 10 weeks at 25°C
 - In Soil: 8 weeks at 4°C; 4 weeks at 25°C
 - In Manure: 8 weeks at 4°C; 4 weeks at 25°C
- *Giardia lamblia*
 - Less stable under all conditions

Survival of Selected Pathogens

- Poliovirus
 - In Water: >70 weeks in groundwater at 8-10°C
 - In Soil: > 50 weeks at 8-10°C
 - In Sewage: 45 minutes in Raw Sewage at room temperature; 28 days in Septic Tank Effluent
- Norwalk Virus (by RT-PCR)
 - In Water: >70 weeks
 - In Soil: >70 weeks

Survival

Pathogen		Survival time in fresh water and sewage at 20-30°C
Viruses	Enteroviruses	<120 days, but usually <50
Bacteria	Fecal Coliforms	<60 days, but usually <30
	Salmonella	<60 days, but usually <30
	Shigella	<30 days, but usually <10
	Vibrio cholerae	<30 days, but usually <5
Protozoa	Entamoeba Histolytica	<30 days, but usually <15
	Cryptosporidium parvum	>12 months
Helminths	Ascaris lumbricoides	Many months

Pathogen		Survival time in soil at 20-30°C
Viruses	Enteroviruses	<100 days, but usually <20
Bacteria	Fecal Coliforms	<70 days, but usually <20
	Salmonella	<70 days, but usually <20
	Vibrio cholerae	<20 days, but usually <10
Protozoa	Entamoeba Histolytica	<20 days, but usually <10
	Cryptosporidium parvum	>12 months
Helminths	Ascaris lumbricoides	Many months

TEMPERATURE

- Greater Inactivation/death rates at higher temperatures
- Lower survival rates at higher temperatures
 - But, some microbes will grow or grow better at higher temperatures
- Many microbes survive better at lower temperature
 - Some bacteria experience “cold injury” or “cold shock” and cold inactivation; VBNC
- Thermal inactivation differs between dry heat and moist heat
 - Dry heat is much less efficient than moist heat in inactivating microbes
- Some microbes survive very long times when frozen
 - Other microbes are destroyed by freezing
 - Ice crystals impale them
- Increased environmental temperatures can promote pathogen spread by insect vectors (mosquitoes, flies, etc.)

pH

- Relative acidity or alkalinity
- A measure of hydrogen ion (H^+) concentration
- Scale:
 - 1 (most acidic) to 14 (most alkaline or basic)
 - pH 7 is neutral
 - Moving toward pH 1 the substance is more acidic
 - Moving toward pH 14, the substance is more alkaline.
- Extreme pH inactivates microbes
 - Chemically alters macromolecules
 - Disrupts enzyme and transport functions
 - Some enteric pathogens survive pH 3.0 (tolerate stomach acidity)
 - Some pathogens survive pH 11 and fewer survive pH 12

Microbe or Group	pH Growth Range
Molds	0.2 - 11
Yeasts	1.5 - 8.5
Salmonella	3.6 - 9.5
<i>Listeria monocytogenes</i>	4.2 - 9.6
<i>Yersinia enterocolitica</i>	4.2 - 9.0
<i>Escherichia coli</i>	4.3 - 9.0
<i>Bacillus cereus</i>	5.0 - 9.5
<i>Campylobacter</i>	5.0 - 9.0
<i>Shigella</i>	5.0 - 9.2
<i>Vibrio parahaemolyticus</i>	5.0 - 11
<i>Vibrio cholerae</i>	5.0 - 9.5
<i>Clostridium perfringens</i>	5.0 - 8.5
<i>Clostridium botulinum</i>	4.3 - 8.5

Microbes are most stable in the environment and will grow in media (e.g., foods) in the mid pH range

Moisture Content or Water Activity

- Drying or low moisture inactivates/kills some microbes
 - Removing water content of some foods can preserve them
- Moisture content of foods is measured as water activity, A_w .
- A_w : ratio of the water vapor pressure of the substrate to the pressure of pure water at the same temperature.
- Vapor pressures is hard to calculate, so an alternative method is used to measure A_w in food science:
- $A_w = \text{moles of water} \div (\text{moles of water} + \text{moles of solute})$
- Pure water has a water activity of 1.00.
- If 1 mole of a solute is added, then the solution has an A_w of 0.98.
- A_w is measured on a scale of 0.00 to 1.00.
- Most fresh foods have a water activity of 0.99.
- Most spoilage microbes do not survive if an A_w below 0.91.
 - some yeasts and molds that can survive at water activity of 0.61.

Physical Factors Influencing Survival, Continued

- Ultraviolet radiation: about 330 to 200 nm
 - Primary effects on nucleic acids; absorbs the UV energy and is damaged
- Sunlight:
 - Ultraviolet radiation in sunlight inactivates microbes
 - Visible light is antimicrobial to some microbes
 - Promotes growth of photosynthetic microbes
- Ionizing radiation
 - X-rays, gamma rays, beta-rays, alpha rays
 - Generally antimicrobial; bacterial spores relatively resistant
 - Main target of activity is nucleic acid
 - Effect is proportional to the size of the “target”
 - Bigger targets easier to inactivate; a generalization; exceptions
 - Environmental activity of ionizing radiation in the biosphere is not highly antimicrobial
 - Anthropogenic ionizing radiation used in food preservation and sterilization

Atmospheric and Hydrostatic Pressure

- Most microbes survive typical atmospheric pressure
- Some pathogens in the deep ocean are adapted to high pressure levels (hydrostatic pressures): barophiles
 - Survive less well at low atmospheric pressures
 - Spores and (oo)cysts survive pressure extremes
- High hydrostatic pressure is being developed as a process to inactivate microbes in certain foods, such as shellfish
 - Several 100s of MPa of pressure for several minutes inactivates viruses and bacteria in a time- and pressure-dependent manner

Chemicals and Nutrients Influence Microbial Survival

- Antimicrobial chemicals
 - Strong oxidants and acids
 - Strong bases
 - Ammonia: antimicrobial at higher pH (>8.0)
 - Sulfur dioxide and sulfites: used as food preservatives
 - Nitrates and nitrites: used as food preservatives
 - Enzymes:
 - Proteases
 - Nucleases
 - Amylases (degrade carbohydrates)
 - Ionic strength/dissolved solids/salts
 - High (or low) ionic strength can be anti-microbial
 - Many microbes survive less well in seawater than in freshwater
 - High salt (NaCl) and sugars are used to preserve foods
 - » Has a drying effect; cells shrink and die
 - Heavy metals:
 - Mercury, lead, silver, cadmium, etc. are antimicrobial
- Nutrients
 - for growth and proliferation
 - Carbon, nitrogen, sulfur and other essential nutrients

Biological Factors Influence Microbial Survival

- Chemical antagonistic activity by other microorganisms:
 - Proteolytic enzymes/proteases
 - Nucleases
 - Amylases
 - Antibiotics/antimicrobials: many produced naturally by microbes
 - Oxidants/oxides
 - Fatty acids and esters; organic acids (acetic, lactic, etc.)
- Predation
- Vectors
- Reservoir animals

Climate and Weather

- Weather changes can cause microbe levels to increase or decrease
- Often based on the ability of the microbe to proliferate or persist
 - Microbes may “bloom” or increase in warm weather
 - Ex.: *Vibrio* bacteria increase in NC coastal water and shellfish in warmer months
- Wet weather mobilizes microbes from land sources and in bottom sediments and delivers or resuspends them into water resources
- Cold weather can cause microbes to persist (survive longer) in environmental media; greater inactivation at higher temperatures
- Seasonal events associated with the birth of animals harboring and excreting pathogens
 - Ex.: Calving season causes increased infection and excretion of *Giardia lamblia* cysts and other enteric parasites by calves

Potential Mechanisms of Climate Change Impact on Infectious Disease

- More rapid development/growth of pathogen
- More rapid vector development
- Reduced over-winter mortality
- Increased pathogen transmission
- Increased host susceptibility
- Unclear temperature effect
- Expanded ecology
- Precipitation effects/Drought

Climate Sensitive Diseases

- **Vectorborne Diseases:**
 - Malaria (Mosquito)
 - Dengue Fever (Mosquito)
 - Lyme Disease (Tick)
 - Rocky Mountain Spotted Fever (Tick)
 - Erlichiosis (Tick)
 - Other vectorborne viruses

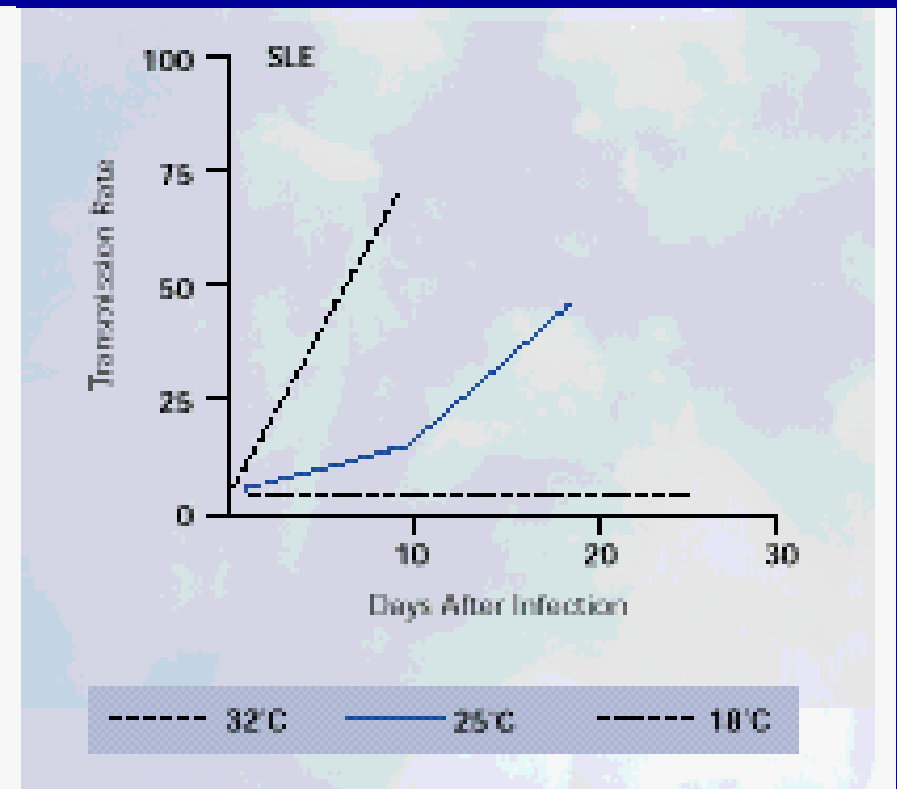
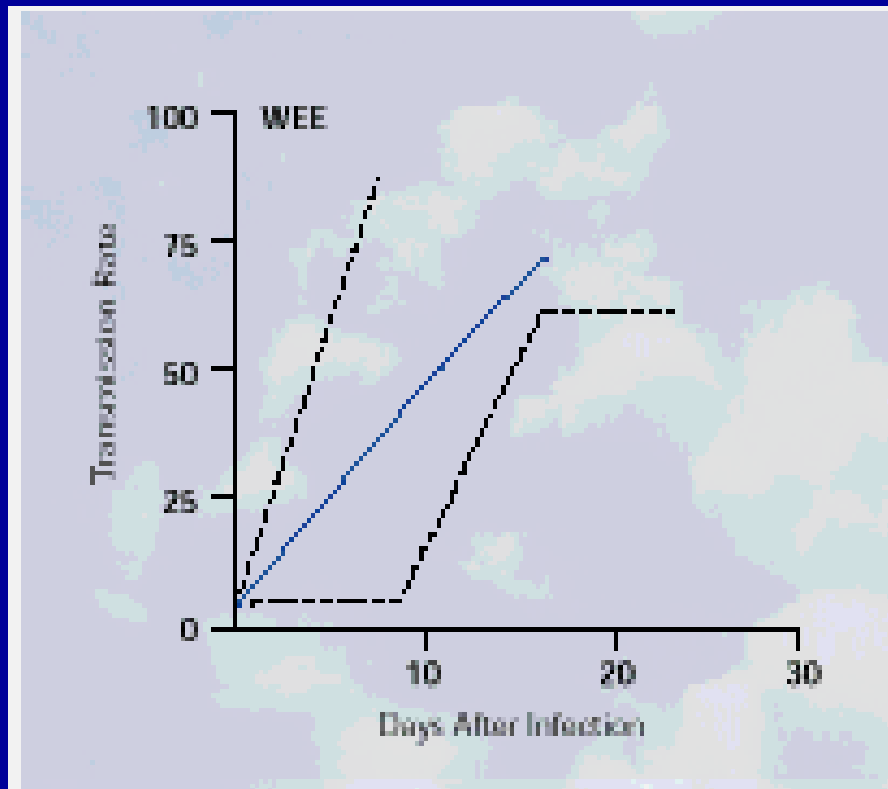
Climate Sensitive Diseases

- **Waterborne Diseases**
 - **Cholera**
 - **Leptospirosis**
 - **Schistomiasis**
 - **Other enteric diseases associated with fecal wastes**
 - **Cryptosporidiosis, Giardiasis, etc.**

Temperature and Relative Humidity

- **Vector-borne Infectious Diseases**
 - Mosquitoes, ticks, other blood-sucking arthropods
 - Influences on vector survival and distribution
 - Influences on multiplication of the microbe
 - examples: St. Louis and Western Equine Encephalitis Viruses

Effect of Temperature on Equine Encephalitis Growth in Mosquito Hosts



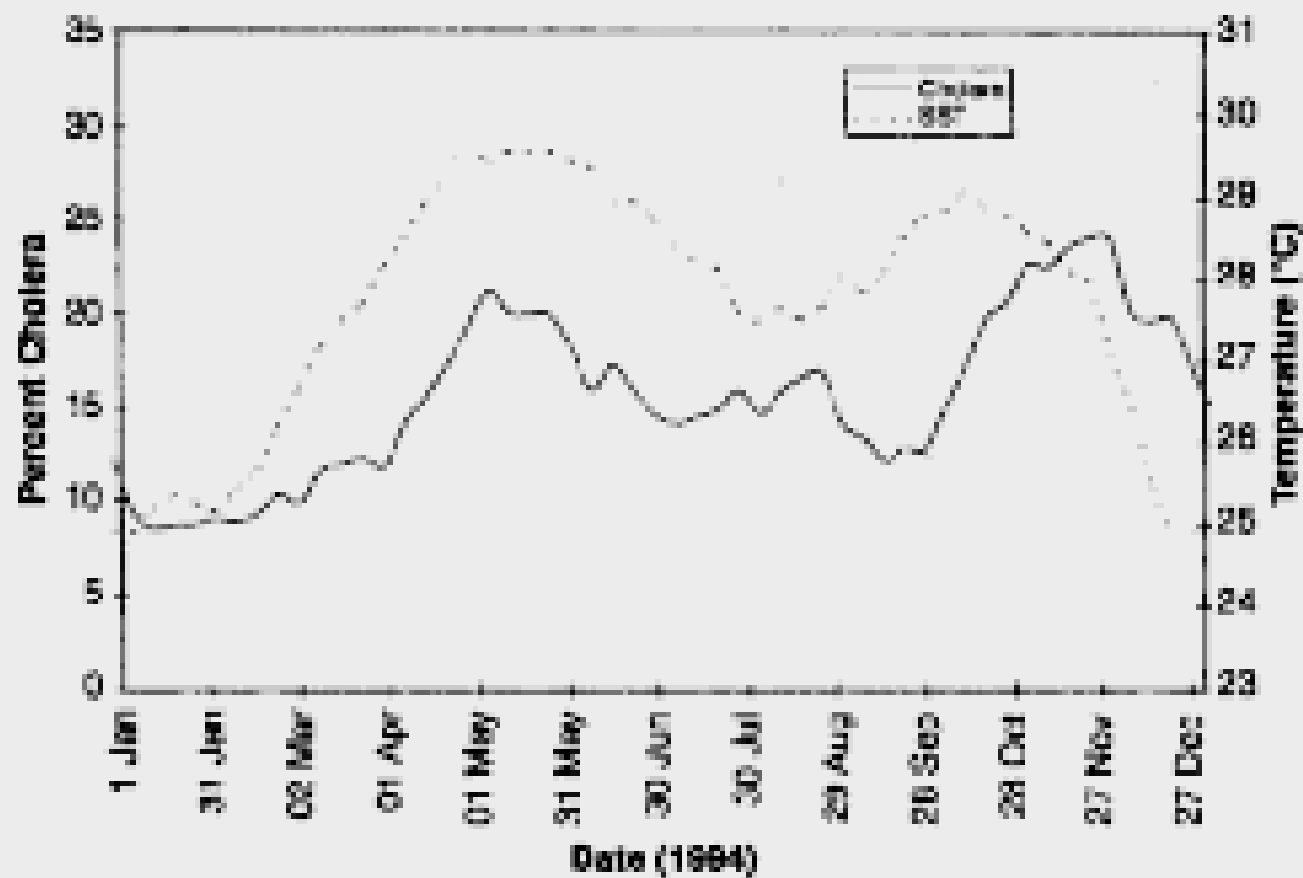


Figure 3. Relationship between sea-surface temperature and cholera case data in Bangladesh from January to December 1994.

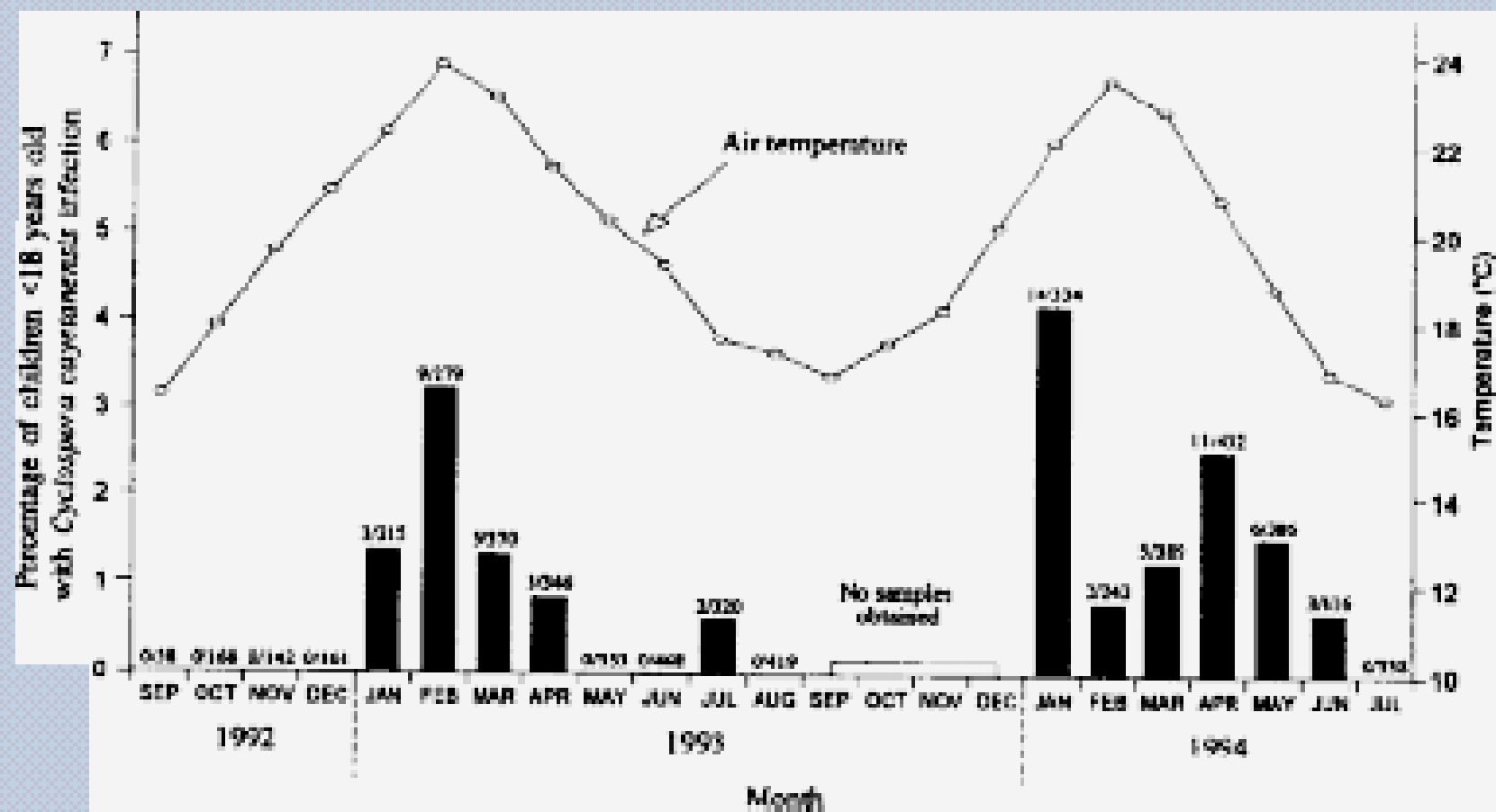


Figure 4. The prevalence of *Cyclospora cayentensis* infection in children younger than 18 years of age and the air temperature in Lima, Peru (September 1992–July 1994). Lima is in a desert region where the rainfall is <2 cm/year.

Precipitation

- **Effects from normal rainfall and severe events**
- **Low rainfall and low RH impede breeding and survival of mosquitoes carrying pathogens**
- **Flooding increases waste runoff, drowned animals, and increased human contact with contaminated water (drinking, ambient, fishing, etc.)**

El Nino-Southern Oscillation

- A recurrent climatic variation involving warming of surface water in the equatorial Pacific, decreased barometric pressure in the Eastern Pacific and weakening westerly surface winds
- Alterations of rainfall distribution in the tropics and changes in global weather patterns.
- Increased rainfall associated with outbreaks of leptospirosis, Rift Valley Fever, hantavirus pulmonary syndrome, malaria, Ross Valley Fever, and others
 - Possible link between 1991-95 El Nino, with inv=creased temperature and increased Cholera in the Bay of Bengal and in Latin American Pacific waters

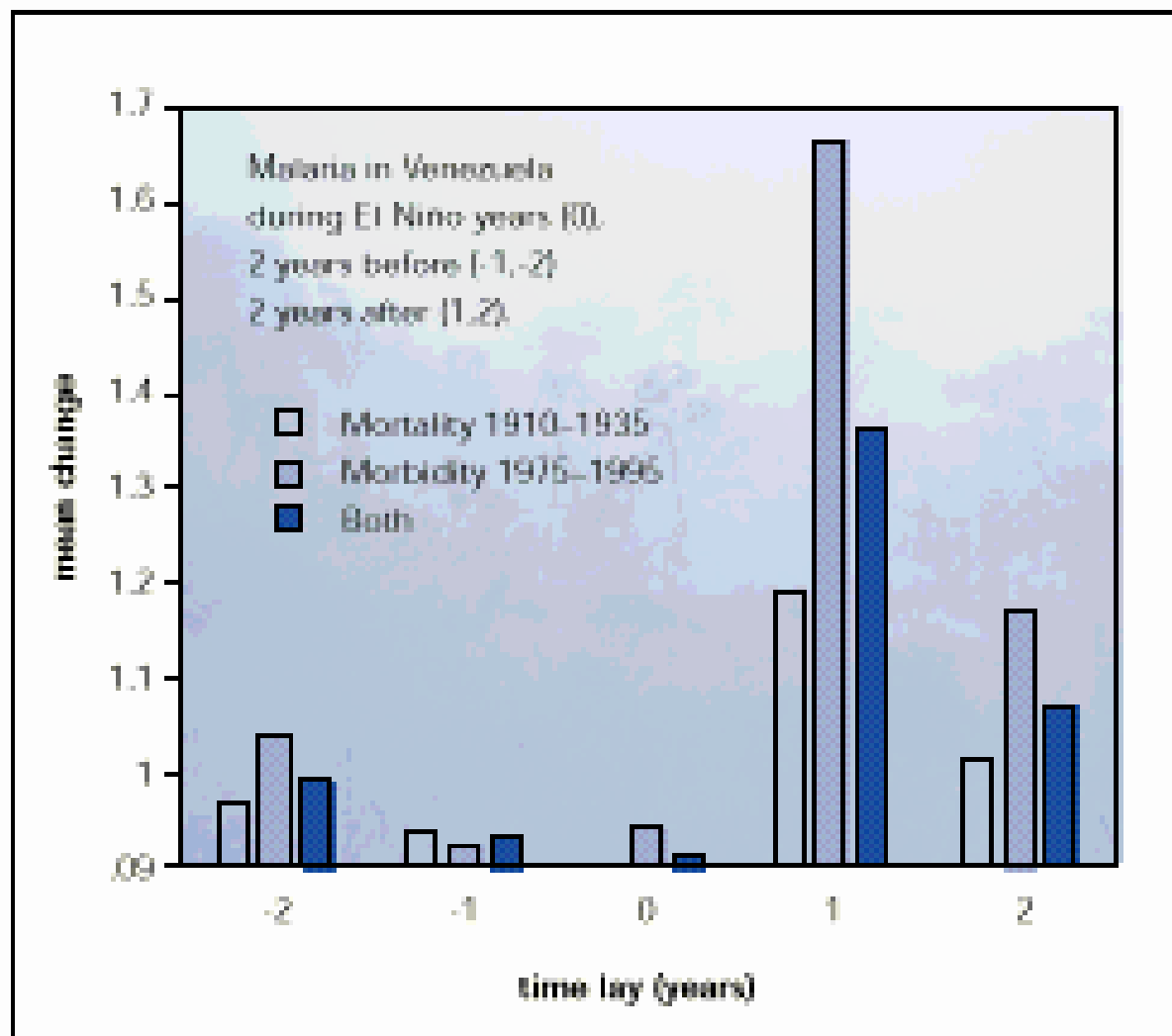
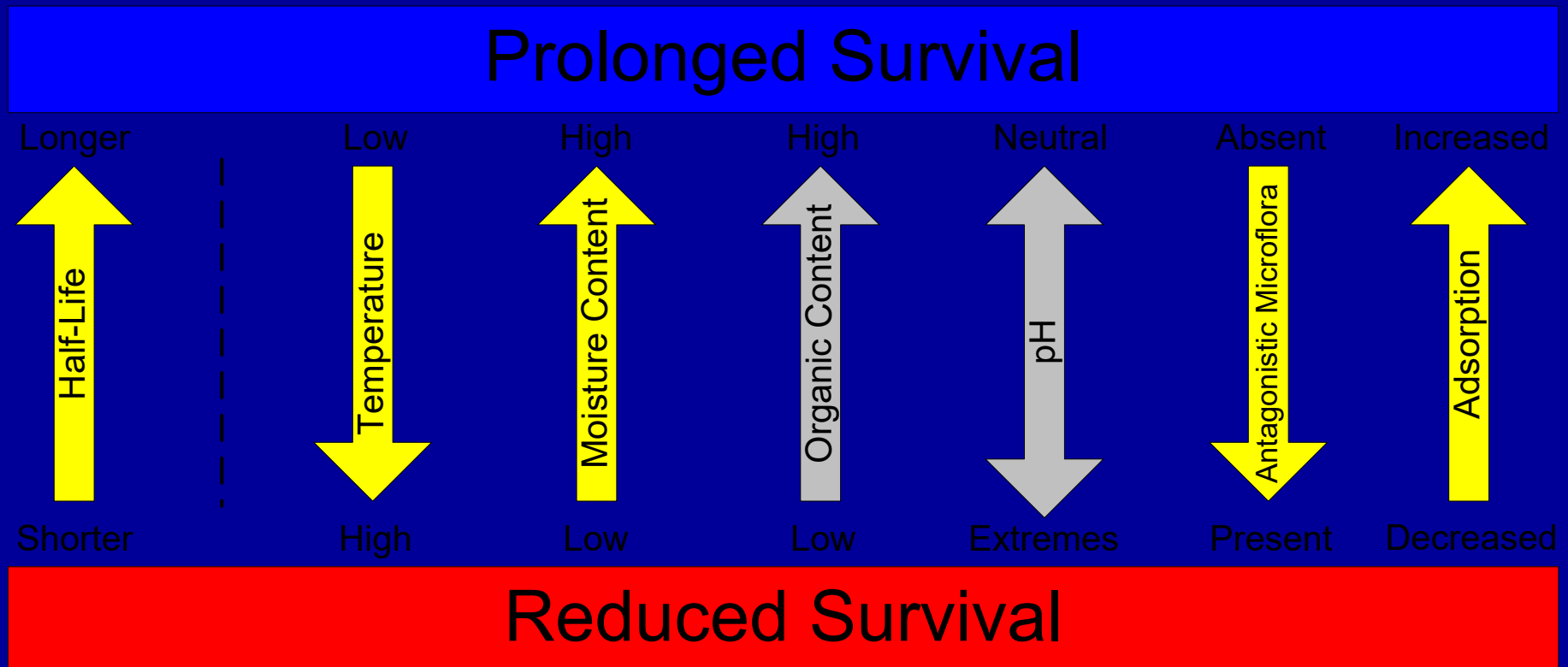


Figure 2. Malaria in Venezuela During El Niño

Beema, M.J. & Dye C., 1997. "Cycles of Malaria Associated with El Niño in Venezuela." *Journal of the American Medical Association*. 278; 1772-74.
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Factors Influencing Microbe Survival and Movement in Soils

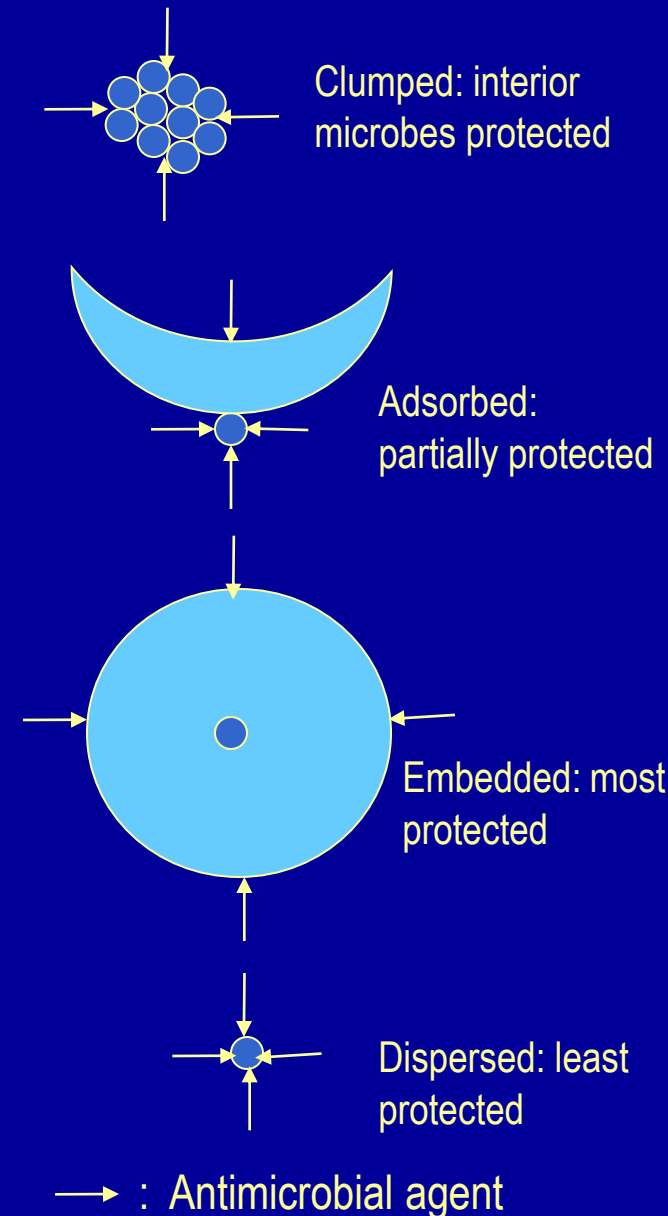


Soil Factors Influencing Microbe Survival

- Soil texture: the size of the soil particles
- Soil mineralogy and chemistry: the chemical composition and structure of the soil influences microbial survival
- Soil microbial activity is active against pathogens
 - Aerobic microbial activity, especially, is active against pathogens
- Soil pore saturation
 - Saturation mobilizes microbes
 - Increases movement and possibly survival
- Pathogen association with soil particles can protect them from inactivation
 - Adsorption of microbes to particles is usually protective

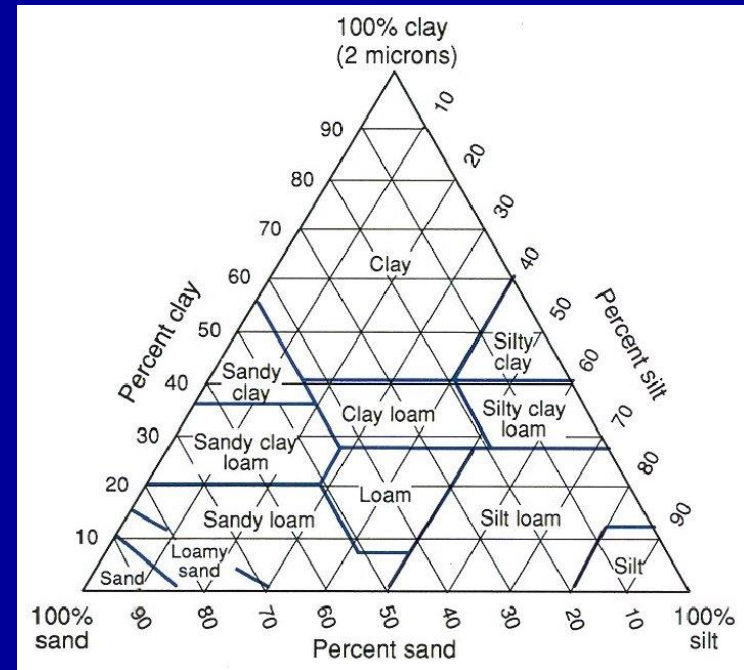
Role of Solids-Association in Microbial Survival

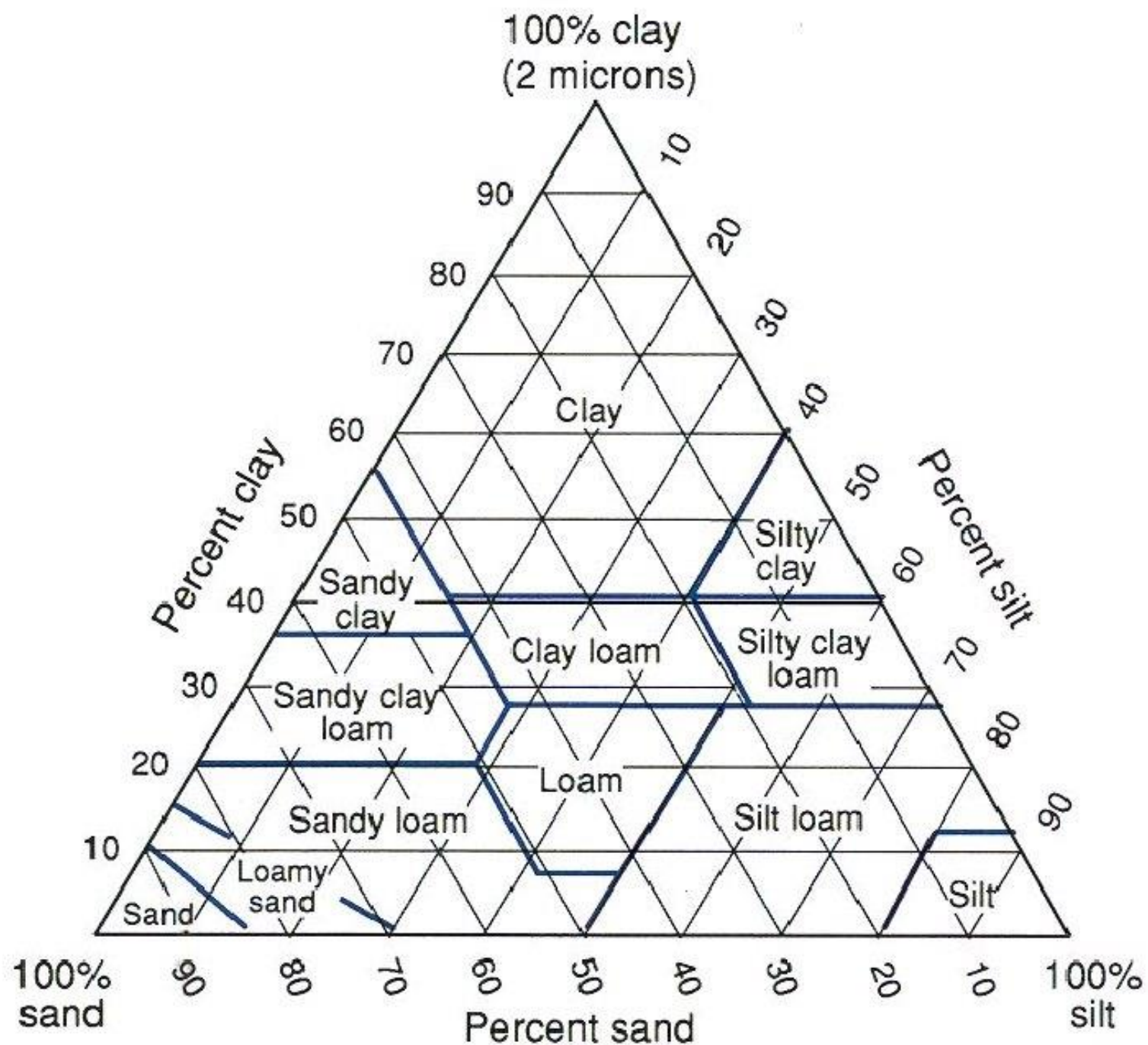
- Microbes can be on or in other, usually larger particles or they can be aggregated (clumped together)
- Association of microbes with solids or particles and microbial aggregation is generally protective
- Microbes are shielded from environmental agents by association with solids
 - Extent of protection depends on nature of solids-association
 - See diagrams, right
- Extent of protection depends on composition of particle
 - Organic particles often are highly protective of microbes
 - Biofilms protect microbes in them
 - React with and consume antimicrobial chemicals
 - Inorganic particles vary in protection
 - Opaque particles protect against UV and visible light
 - Inorganic particles do not always protect well against chemical agents
 - Some inorganic particles are antimicrobial
 - Silver, copper and other heavy metals



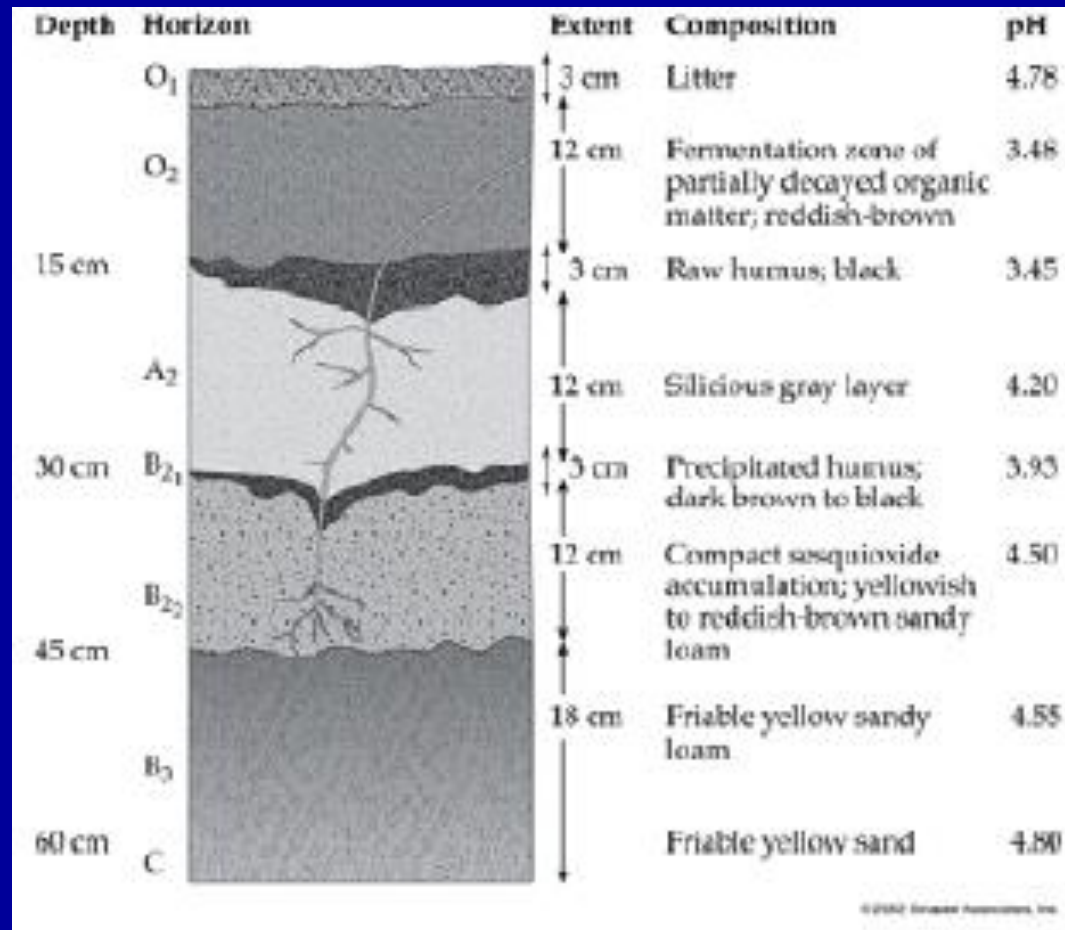
Soil Texture: A Classification System

- Classification of soils based on relative proportions of clay, silt and sand
- Important descriptor of microbial habitat
 - indicates spatial interactions
- Different size soil particles adsorb water and charged ions differently, depending on surface area exposed
- Microbes and soil particles can interact to form soil aggregates
 - These hold soils together and reduce surface soil losses to wind and water erosion
- Influences pathogen survival
 - Pathogens can adsorb to soil particles and be protected
 - Pathogens in unsaturated (vadose), aerobic zone inactivated more rapidly than in saturated zone
 - Pathogens in saturated zone move rapidly with the water in the soil pore spaces





Soil Profiles – Typical Layers



Soil Horizons: Soil Properties According to Depth

- Distinct soil horizons or layers; form from weathering processes
- Layers have distinct chemical compositions; determines:
 - amounts and state of organic matter
 - amounts of nutrient elements
- Each layer supports varying amounts and types of microbial communities
 - Surface layers of soils (O layers) are organic
 - Dominated by organic matter (e.g. leaves, twigs, etc.) (= O1 layer)
 - Dominated by unrecognizable organic matter in next lower layer
 - some decomposition has occurred (O2 layer)
 - Sub-surface soil layers (A layers): various combinations of organic and mineral materials which experience increasing amounts of leaching (= eluvial layers)
 - Lower layers (B layers): experience leaching and horizontal movement of materials (= illuvial layers)
 - Lowest soil layers (C layer) experience least weathering; in contact with bedrock

Microbial Survival in Soils

- Increased survival with increased clay content; adsorption
- Decreased survival with decreased moisture content and desiccation
 - % moisture below 1-10% is microbiocidal
- Decreased survival at increasing temperature

Types of Mobility in Porous Media

- Active Transport
 - Some bugs are motile
- Advective transport
- Diffusive/Dispersive Transport
 - Brownian Motion
 - Mechanical Dispersion

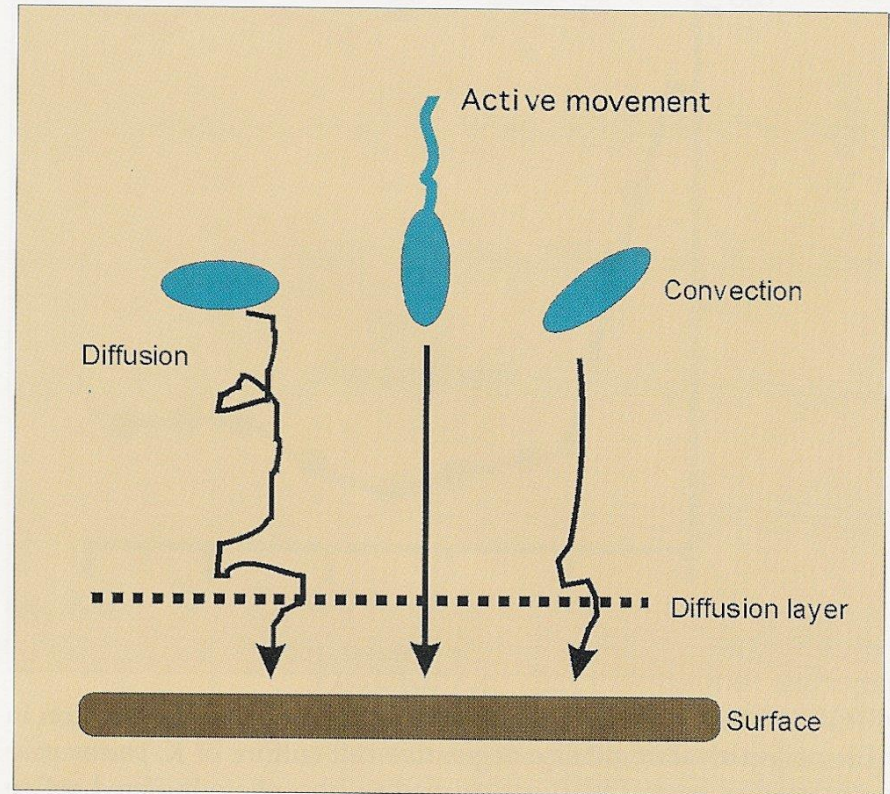
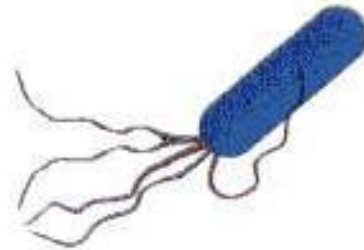


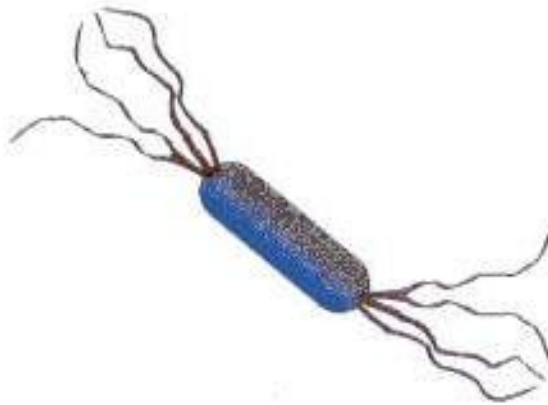
FIGURE 7.5 Different ways in which a cell can approach a solid surface. (Modified with permission from van Loosdrecht *et al.*, 1990.)



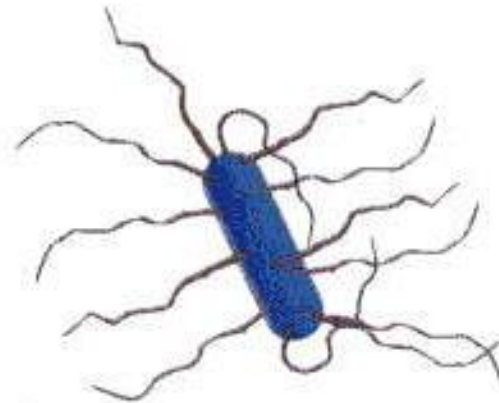
Monotrichous



Lophotrichous



Amphitrichous

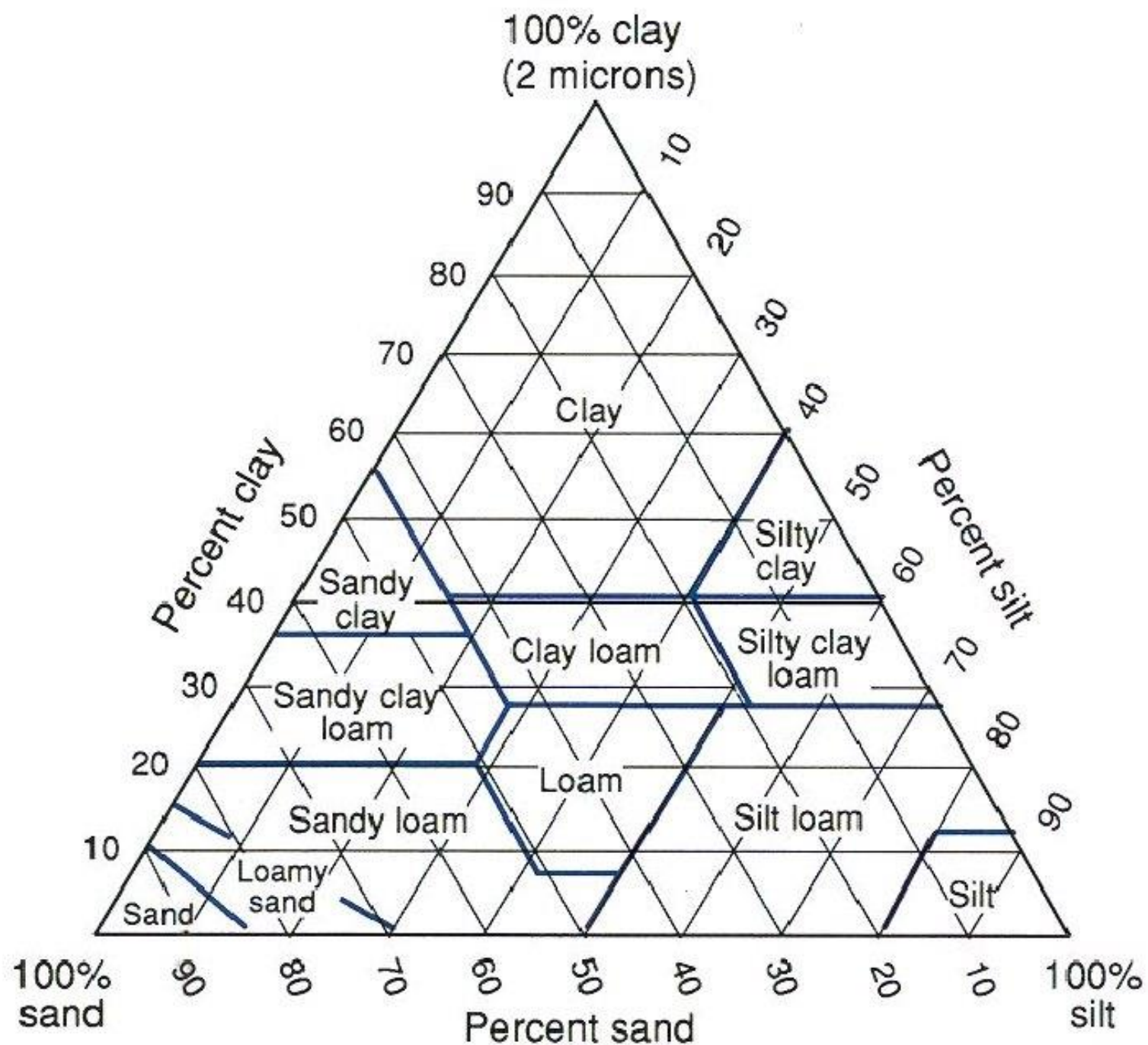


Peritrichous

FIGURE 2.10 Arrangement of flagella extending from the cell envelope.

Extrinsic Factors Influencing Microbial Transport Through Soil

- **Soil texture:** Transport through sand > silt > clay
- **Size of microbe:** smaller microbes penetrate soils better
 - Transport of virus > bacteria > protozoa
- **Soil moisture:**
 - transport for saturated soil > unsaturated soils
- **Surface charge on microbes: generally negative**
 - less sorption to negatively charged colloids
 - More sorption to positively charged colloids
- **pH:** in relation to microbe isoelectric point and charge
- **Hydrophobicity:** influences sorption and transport
- **Organic matter:**
 - often decreases adsorption
 - competitive binding to adsorption sites on soils
 - Microbial activity and biofilms
- **Hydrogeological Factors:**



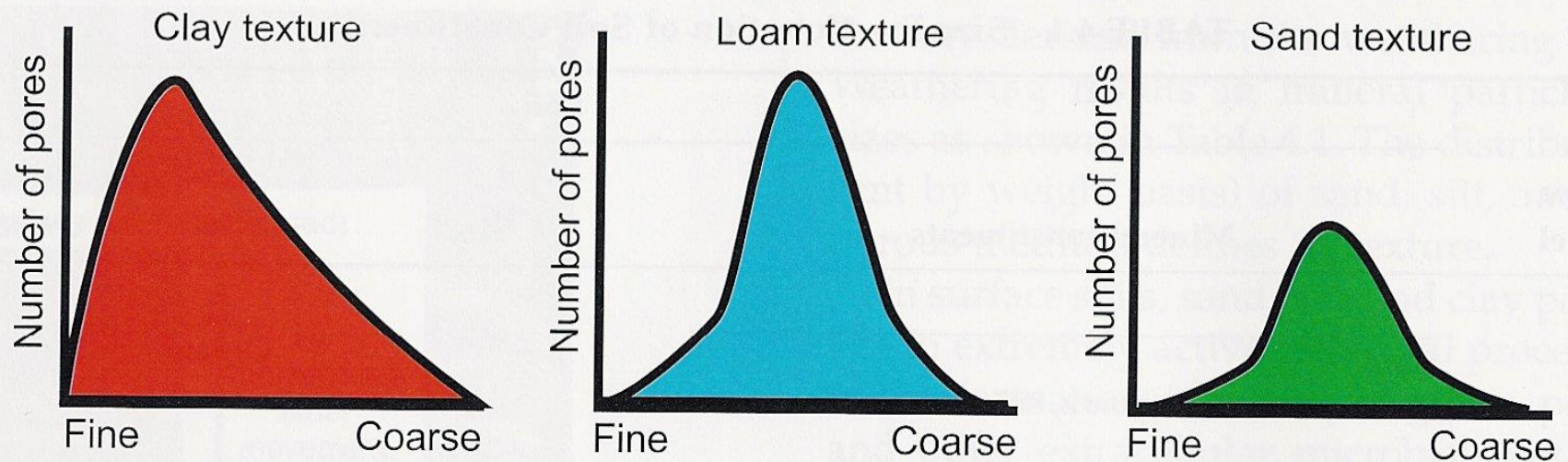


FIGURE 4.4 Typical pore size distributions for clay-, loam-, and sand-textured horizons. Note that the clay-textured material has the smallest average pore size, but the greatest total volume of pore space.

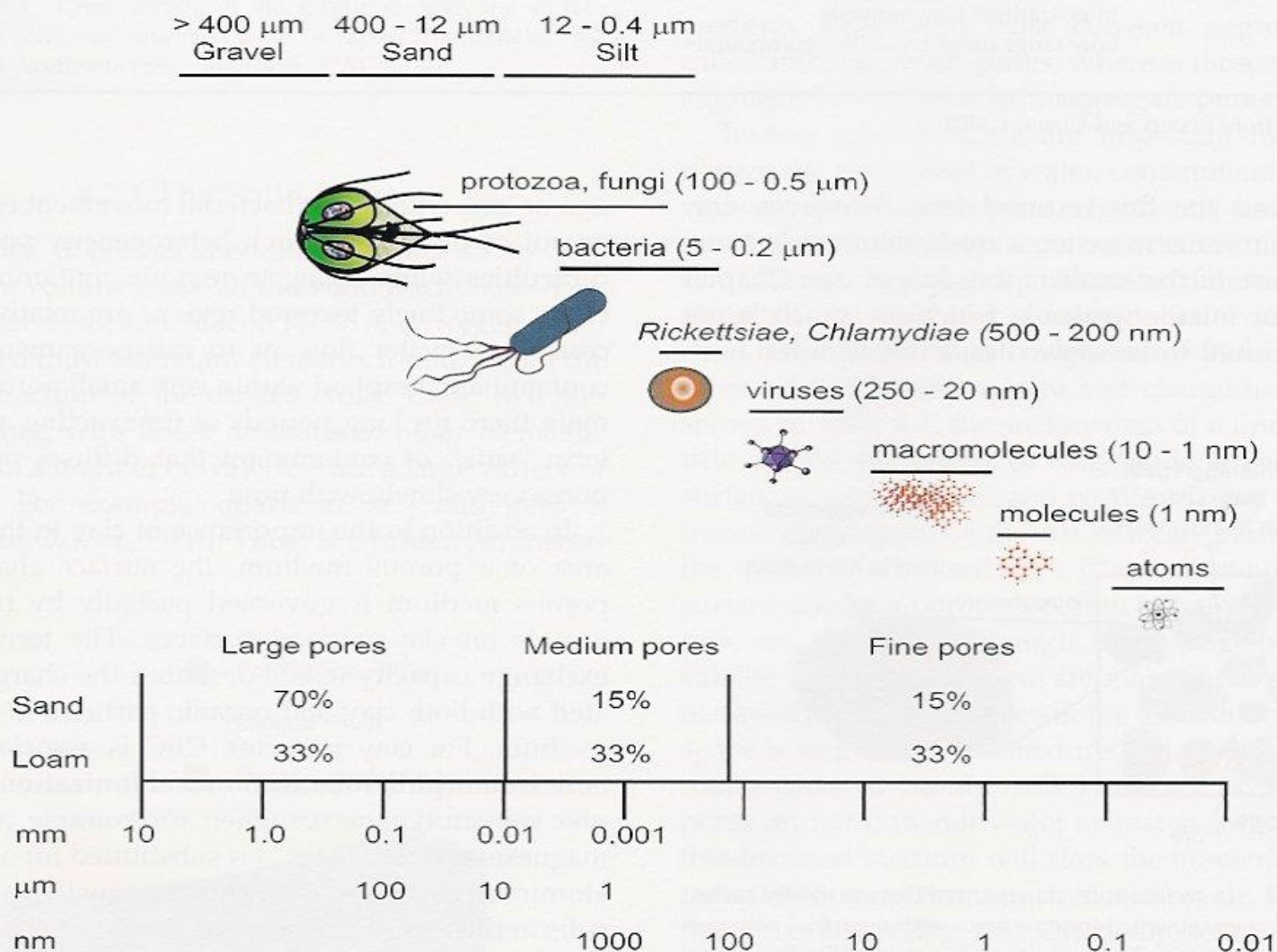


FIGURE 4.5 Comparison of sizes of bacteria, viruses, and molecules with hydraulic equivalent diameters of pore canals. (Adapted from *J. Contam. Hydrol.*, 2, G. Matthess, A. Pekdeger, and J. Schroeder, Persistence and transport of bacteria and viruses in groundwater—a conceptual evaluation, 171–188, © 1988, with permission from Elsevier Science.)

Adsorption/Adhesion

- May be reversible or non-reversible
- 3 main forces
 - Electrostatic
 - Hydrophobic
 - Van der Waals forces

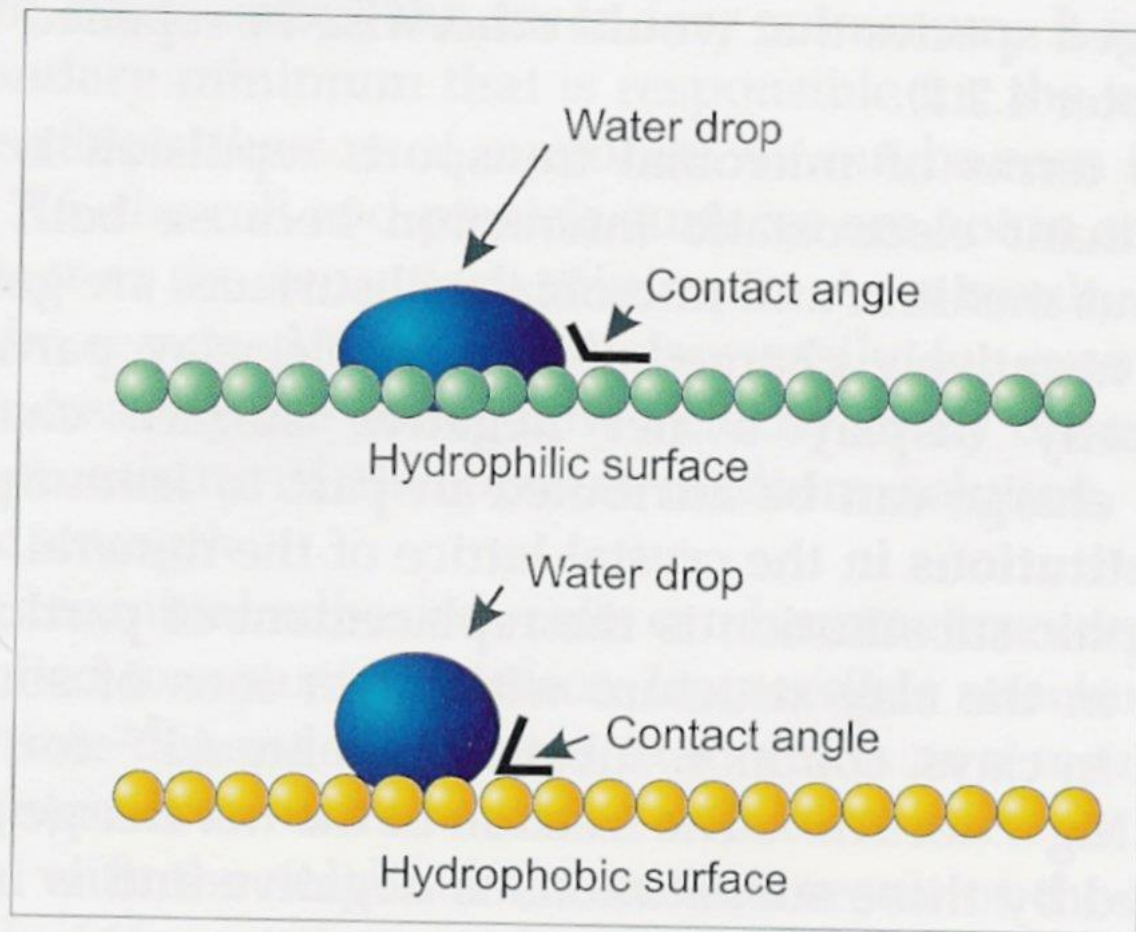
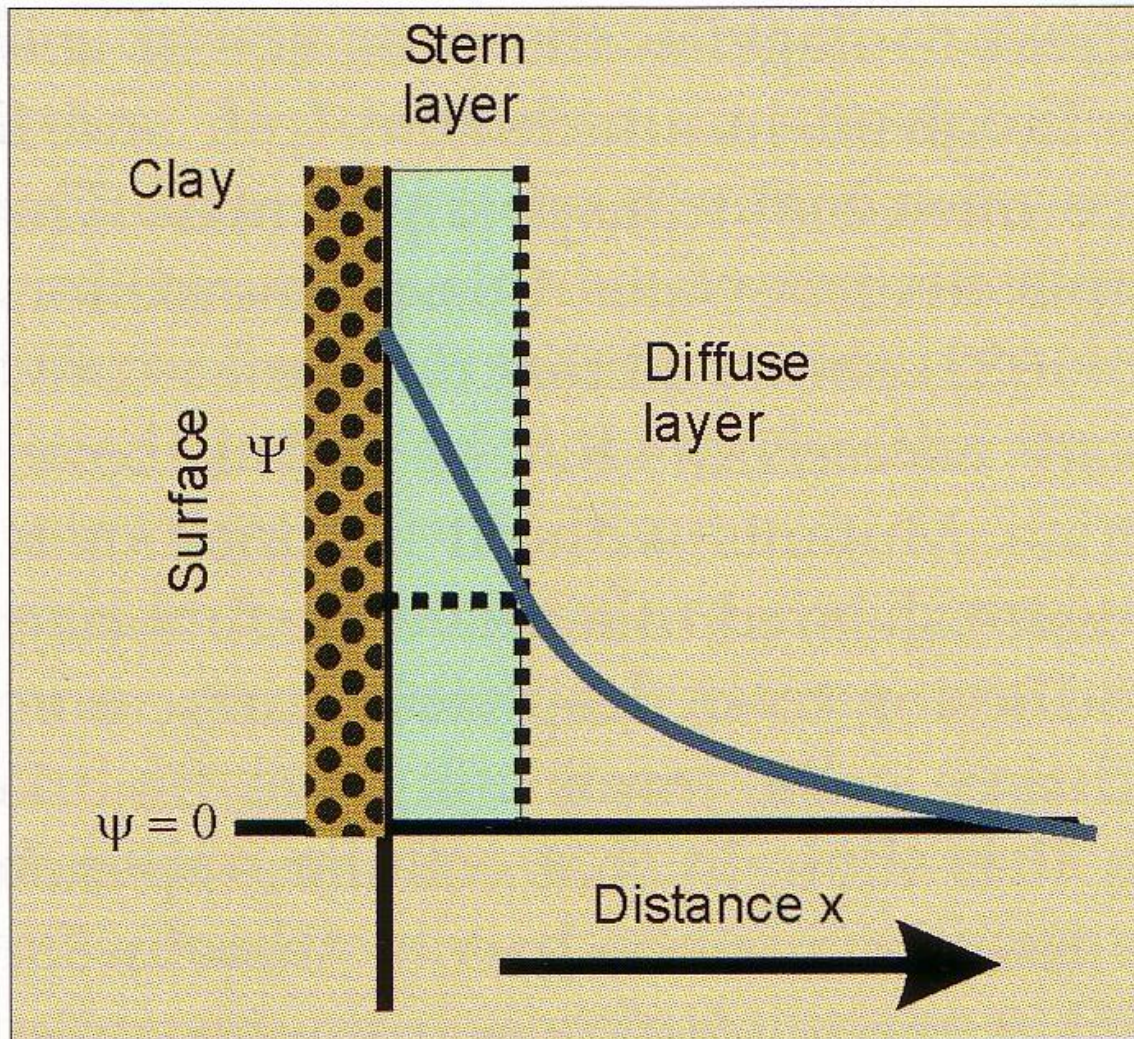


FIGURE 7.9 Water, which is a polar material, spreads out on a hydrophilic or polar surface but forms a round bead on a hydrophobic or nonpolar surface. The angle that describes the interaction of a water droplet with a surface is called the contact angle.

DDL Theory of Colloidal Attachment



IEP (pI)

Electrophoretic
Mobility

Stern Layer

Gouy Layer

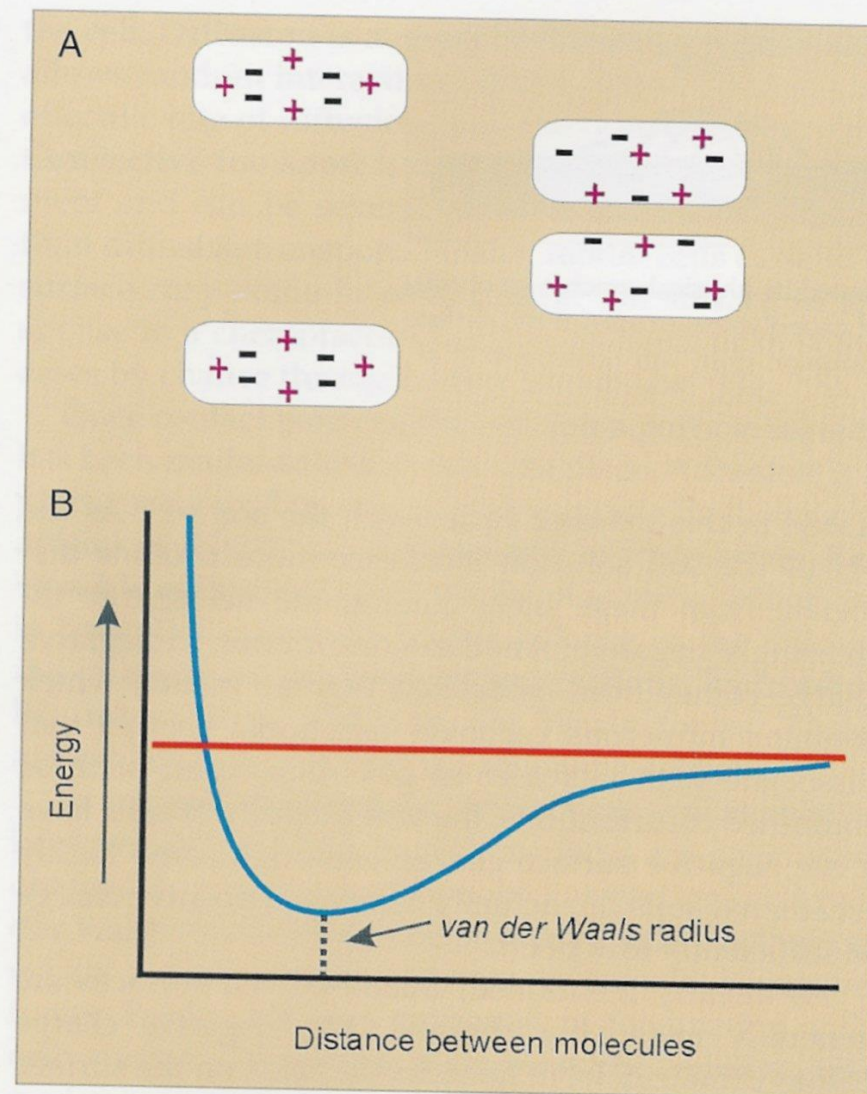


FIGURE 7.8 (A) For a neutral molecule the charge distribution in a molecule can vary to produce a net electrostatic attraction, allowing the molecules to approach very closely. This is a very weak attraction called the van der Waals force. Van der Waals forces can become strong if they are numerous enough. (B) As two molecules approach each other, the van der Waals attractive force increases to a maximum, then decreases and becomes repulsive.

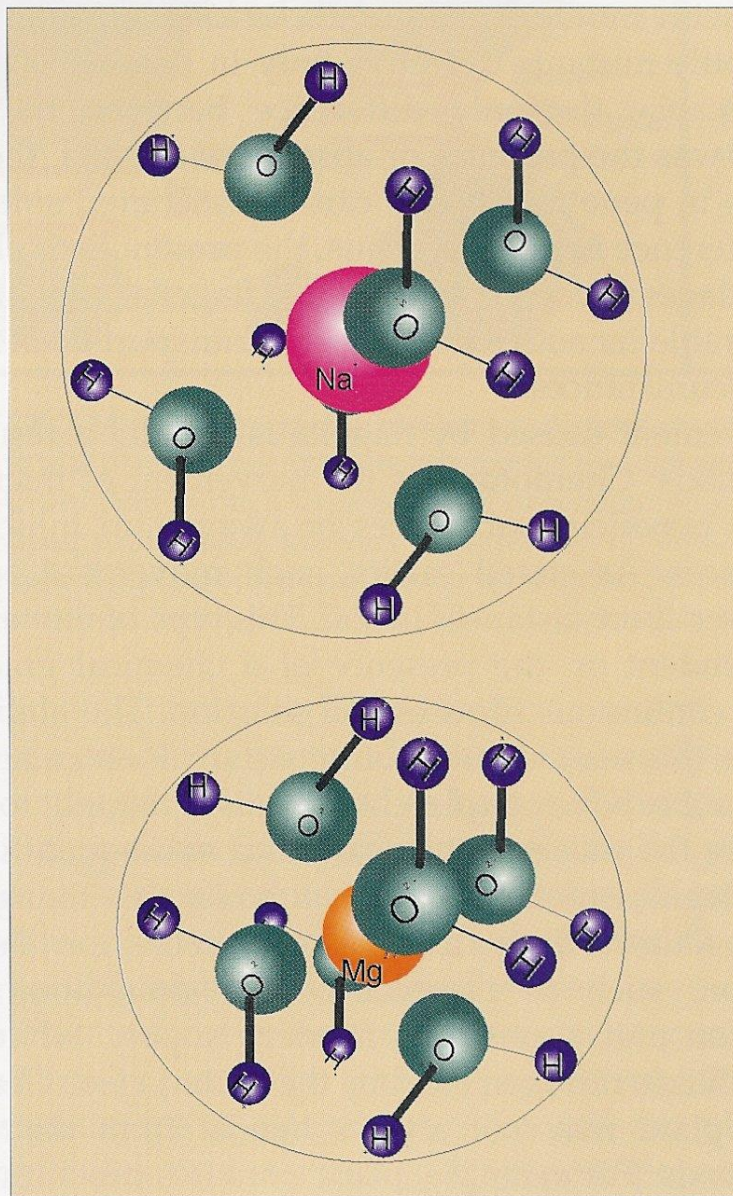


FIGURE 7.12 The radius of hydration of a cation in soil depends on the charge density of the atom. In the example shown, magnesium has a higher charge density than sodium and thus attracts water molecules more strongly resulting in a larger radius of hydration.

Advective transport

- Transport by the flow of groundwater
- Governed hydraulic head
- Generally considered to be laminar

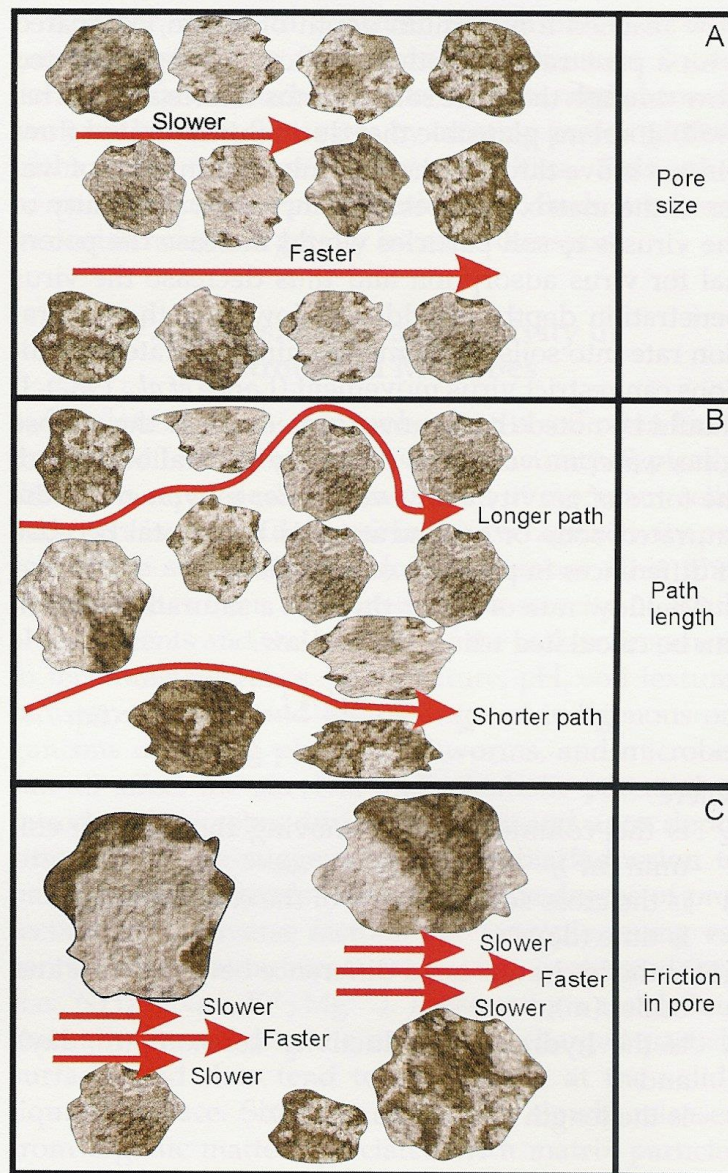


FIGURE 7.14 Factors causing mechanical dispersion at the scale of individual pores. A) microbes are transported through small pores more slowly than through large pores; B) depending on pore sizes and shapes, path lengths can vary considerably; C) flow rates are slower near the edges of the pore than in the middle. (Modified with permission from Fetter, 1993, © MacMillan Magazines Limited.)

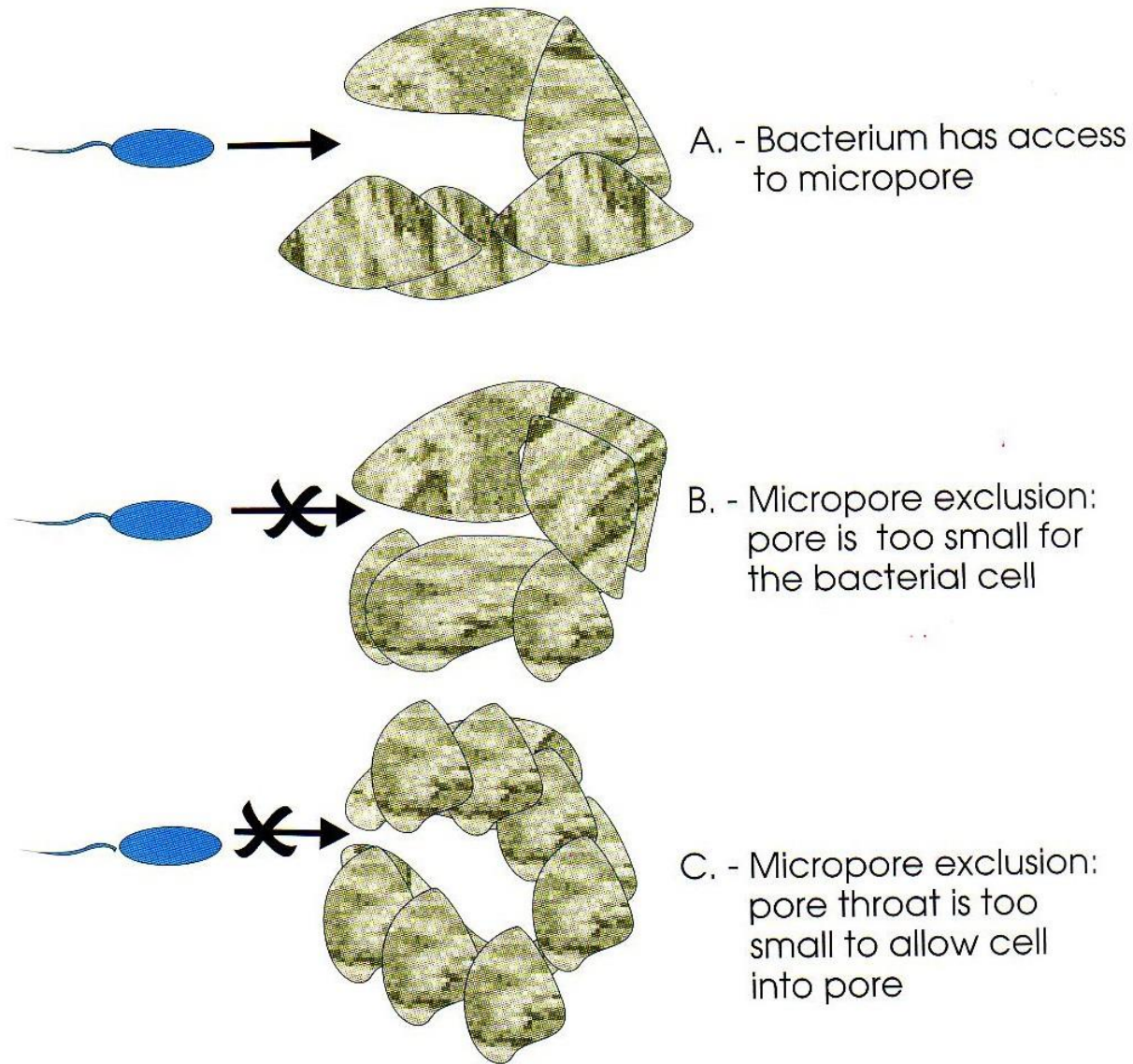


FIGURE 7.1 Exclusion of a bacterial cell from microporous domains in structured porous media.

