Cryptosporidium parvum transport through variably charged soils

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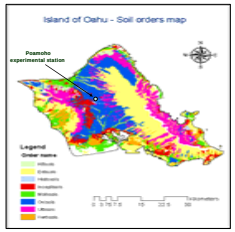
Abstract

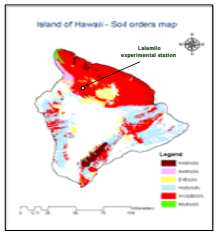
Cryptosporidium parvum, an enteric pathogen, causes cryptosporidiosis in humans and cattle. Oocysts are the encysted, environmental form of this obligate pathogen and are primarily spread through the feces of the infected host. Young calves are particularly susceptible to infection and oocysts from livestock operations can be transported from agricultural watersheds to both surface waters and shallow ground water. Oocysts cannot be easily killed by chlorination; so sand or sand/anthracite filtration often serves as the primary mechanism for removal during water treatment. Most studies assessing the transport behavior of oocysts in soils have employed "permanently charged soils" (PCS) that are typically found in temperate regions throughout the globe. However "variably charged soils" (VCS) predominate in many tropical regions (e.g., Hawaii, Brazil, Puerto Rico) and in the southeastern United States. Unlike PCS, the charge on VCS is highly pH-dependent, because these soils generally have an abundance of highly reactive metal hydroxide surface functional groups. Although the iron and aluminum oxides in VCS promote sorption of negatively charged oocysts, aquifers in regions characterized by VCS may still be vulnerable to *C. parvum* contamination because of warmer temperatures and higher dissolved organic matter (DOM) content. DOM has been shown to reduce removal efficiency in PCS. Few studies have addressed transport of oocysts in VCS soils.

In our study, transport and attachment experiments involving two compositionally different soils from Hawaii were conducted using oocysts-sized microspheres and formalin- inactivated oocysts. "Poamoho" soil, from the island of Oahu is of volcanic origin that has undergone intense weathering. Consequently, it has a very high iron oxide and clay content. The much younger Lalamilo soil, derived from volcanic ashes of the island of Hawaii, is comparatively fine-grained with a high organic content. Transport of microspheres and oocysts within preferential flow paths was observed for the Poamoho soil, suggesting that oocysts contamination of ground water cannot be ruled out. Although a high-degree of attachment also occurred in the Lalamilo soil, attachment was much more reversible, suggesting that, once contaminated, this soil could serve as a potential reservoir for oocysts that could subsequently result in the contamination of surface and ground water during storm events.

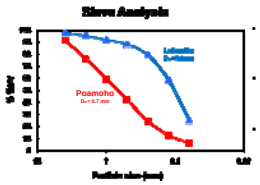
Objective

To compare the fate and transport of oocysts and other colloids through low organic/high metal oxide Oahu soil (e.g., Poamoho Oxisol) and high organic volcanic ash Hawaii soil (e.g., Lalamilo Inceptisol)

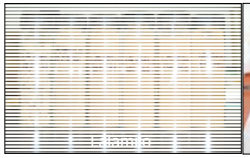




Mineralogy and particle size distributions of Hawaiian soils



- Mineralogy for each HI soil type were assessed by XRD analyses with post-processing by RockJock software
- The amorphous nature of these soils makes them difficult to identify and characterize
- Bulk density and porosity were determined by weight differential for dry packed and water-saturated columns



The primary composition of the Lalamilo soils is soil organic matter (~40%) and iron in the form of maghemite (15%), a mineral formed by the oxidation of magnetite

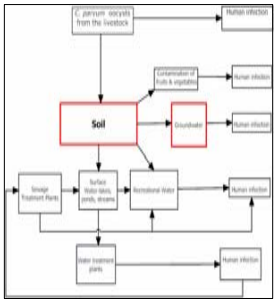
The Poamoho soils have high clay content (~70%) and iron oxide as maghemite (17%) and hematite (5%)

Name	Lalamilo (Island of Hawaii)	Poamoho (Island of Oahu)
Order	Inceptisol	Oxisol
Particle Density (g/cm³)	2.37	2.66
Bulk Density (g/cm³)	0.6	1.1
Porosity	0.70	0.68
pH(1:1, KCl)	5.8	5.3
D_{50}(top soil) (mm)	0.10-0.21	0.50-0.70
Non-clay materials (wt %)		
Quartz	0.9%	0%
Labradorite Feldspar	12-16%	0%
Magnetite	2-3%	0%
Hematite	0%	5-8%
Maghemite	15%	17-19%
Organic matter	36-43%	0%
Total non-clay	82-84%	24-32%
Clay Materials		
Ferruginous Smectite	7-13%	0-5%
Amorphous Kaolinite	0-0.3%	29-44%
Illite	7-9%	7-17%
Halloysite	0%	14-24%
Total clay	16-18%	68-76%

Why work with *Cryptosporidium*?

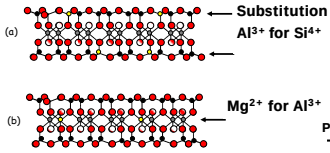
Location	Year	Country	Infected	Source	Probable Causes
Carrollton, Georgia	1987	US	13,000	River	Treatment plant (TP)*
Milwaukee, Wisconsin	1993	US	419,000	Lake	TP
Saitama	1996	Japan	8,700	River	TP
Clitheroe, Lancashire County	2000	UK	2,000	River	Livestock
Lusaka, Zambia	2000	Africa	26% of sample population	Fecal samples	Drinking water/animals / poor sanitation
Finger Lakes, NY	2005	US	3,800	Recreational Water	TP
Goncalves Dias, Brazil	2006	South America	37% of sample population	Fecal samples	Drinking water/animals /Poor sanitation
Davis County, Utah	2007	US	2,000	Recreational Water	TP

* Failure of treatment plant



Permanently charged soils (PCS)

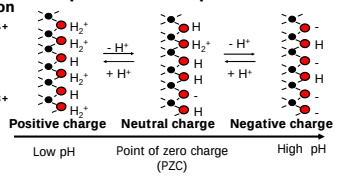
Charge due to substitution



- **Permanently charged soils usually have a 2:1 clay mineralogy. This consists of two silicon tetrahedron between the Al octahedron structure. The yellow colored atoms represent the source of deficient charge within PCS (a)**
- **Charge is not a function of solution chemistry**

Variably charged soils (VCS)

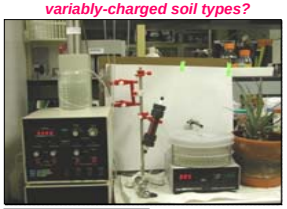
Charge due to protonation/deprotonation

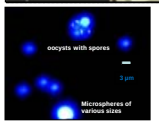


The surface of variably charged soils (VCS) may be charged. Depending on pH, solution chemistry will alter the charge on the soil surface

Flow through column study

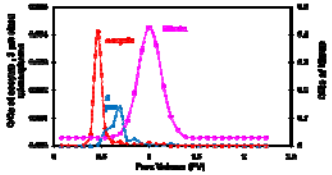
Are there differences between oocyst and oocyst surrogate transport through variably-charged soil types?





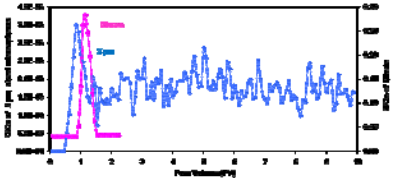
Background solution : NaCl (~2 mM)
Flowrate : 1.6m/d
pH : 7.2 (Poamoho), 8.5 (Lalamilo)
Temperature : 20°C
Microspheres (2 µm) added: 10^8/mL
Microspheres (3 & 5 µm) added: 10^7/mL
***C. parvum* oocysts added: 10^6/mL**

Breakthrough curve of oocysts and microspheres in Poamoho soil



- "Velocity enhancement" of oocysts & microspheres
- Cumulative recovery of oocysts & microspheres was 0.37% and 0.57%

Breakthrough curve of 2 µm sized microspheres in Lalamilo soil

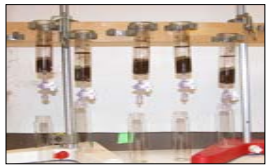


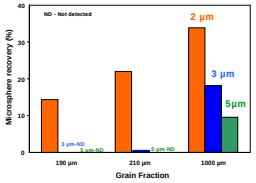
- Reversible attachment of the microspheres. Only the 2 µm sized microspheres were transported, the 3 µm and 5 µm sized microspheres were strained out. The cumulative recovery of the 2 µm sized microspheres was only ~0.26%
- The transient nature of the breakthrough could be due to high organic content in the soil

Static column study

Does grain size affect oocyst-sized microsphere transport through variably-charged soils?

Microspheres recovery from columns filled with different grain fractions of Lalamilo soil





Background solution : NaCl (~2 mM)
pH : 8.5
Temperature : 20°C
Influent concentration (Co) microspheres : 2 µm - 10^8/mL, 3 µm, 5 µm - 10^7/mL

Plot of microsphere recovery plotted as a function of grain size within column. The grain fraction numbers described above were obtained from the grain size analyses

- Recovery of microspheres is a function of grain size
- The larger (3 µm & 5 µm) microspheres were not recovered from columns containing soils with the smallest average grain diameter. Thus,3 µm and 5 µm sized microspheres may have been strained by the fine grained soil

Conclusions

- **It appears that the transport of oocysts will occur even in high iron, high-clay tropical soils via preferential flow paths**
- **The volcanic ash soils might serve as a reservoir of oocysts**
- **These pathogens may be mobilized during storm events and enter surface or groundwater**

Future studies

- **To test our hypothesis, we will assess the role of macropores by using sonication to destroy preferential flow structure (Poamoho soil)**
- **In the case of the Lalamilo soil, the effect of soil organic matter will be assessed by purging the POC via combustion or extraction**
- **Other studies include effect of organic carbon (anionic surfactants and cow manure) on the transport of oocysts in both the soils**

References & Acknowledgements

- Abudalo, R. A., et al. (2005), Effect of Ferric Oxyhydroxide Grain Coatings on the Transport of Bacteriophage PRD 1 and *Cryptosporidium parvum* Oocysts in Saturated Porous Media, *Environ. Sci. & Technol, 39,* 6412-6419
- Miller, G., et al. (2004), Transport of *Cryptosporidium* Oocysts in Porous Media: Role of Straining and Physicochemical Filtration, *Environ. Sci. Technol, 38,* 5932-5938

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