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ANALYSIS OF PARASITES IN EARLY 19th CENTURY PRIVY SAMPLES

BLOCK 1191

WILMINGTON, NEW CASTLE COUNTY, DELAWARE

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Historical Perspective

The Delaware Bay and River provided a hospitable environment for the early settlers of the mid-Atlantic region. The Swedes were the first to settle Fort Christiana (now Wilmington) in 1638 and they were soon followed by the Dutch, English, Welsh, Scotch, Irish and Germans. Only one black man was known to reside in early Fort Christiana but, by 1776, approximately one-fifth of the population was of African descent[1-4].

Farming (wheat, corn and fruit) was the primary livelihood in early Delaware. A shipbuilding industry using abundant forest products was soon established. By 1803, a bolting cloth factory, a distillery and thirteen mills existed along the Christiana River. The chemical industry was established in 1830 and the population of Wilmington grew with the arrival of other industries. By 1840 the population was 8,367, in 1880 42,478, and by 1920 it was 110,168[1-4].

Most of what we know about the health of residents of Wilmington is based on the writings of Dr. John Vaughn, a Wilmington physician[5]. The attitude of many physicians at that time, including Dr. Vaughn, was that fevers were caused by excitability of the nervous system and the irregular action of blood vessels. Diseases were, at times, attributed to contagion produced by a diseased body, air from the lungs or even body odors. In addition to contagion, several other causes were given: gaseous wastes of the marshes, putrification of slime on the waterfront and decaying vegetable matter in the city gutters. Vaughn reported the existence of mosquitoes along the waterfront, but never correlated their presence with any disease. In fact, he wrote that the yellow fever epidemic (a viral disease we now know to be transmitted by mosquitoes) was caused by the miasmatic fog from the marsh.

Vaughn reported that although the summer of 1802 brought an epidemic of yellow fever, the winter months were essentially free of disease. March entries into his diary recorded influenza outbreaks. Intestinal disorders, due to consumption of "imperfect" (frost damaged) fruit, occurred in July. Epidemic typhus which began in August ended with the fall frosts. The following winter again was essentially disease free. In early spring (1803) influenza and scarletina were the predominant diseases. A number of intestinal disorders (noted as diarrhea, cholera and dysentery) were reported in June, July, and August. Typhus occurred again in September.

Vaughn noted that frosts and winter ended the epidemics of yellow fever and typhus. It was his intent to correlate changes in weather with the occurrence of disease. He thought he might predict recurrent forms of disease and be able to deal with them before they reached epidemic status. Again, he clearly had no understanding that mosquitoes served as vectors of infectious agents.

Although his observations were notable, his treatments were, by today's standards, primitive. He bled his patients to depress the circulatory system and blistered them to stimulate blood flow. He induced sweating, purging and vomiting. Calomels and mercury were used as purgatives while alkalies (table salt, mustard, garlic and ammonia) and quinine were used to relieve fever. He did not believe in tonics, particularly those containing alcohol, to prevent disease, but rather advised the use of warm clothing and coffee before morning exercise.

Vaughn, although clearly stating that yellow fever was caused by the miasmatic fog, had some awareness that the typhus epidemic in August (1803) was related to contact between the sick and healthy. The existence of the typhus bacterium, *Rickettsia prowazekii*, and its transmission by the body

louse, Pediculus humanus, were unknown. On clinical grounds alone he recognized diarrhea, cholera and dysentery as separate diseases. He stated that dysentery was not a contagious disease, yet spoke of several members of the same family being ill.

The Host-Parasite Relationships

Parasitism can be defined as an intimate living relationship between organisms of two different species in which the parasite is the organism dependent on its host, usually for some essential nutrient, and the host is the organism that provides for that parasite[6-7]. Diseases frequently result from parasitic infection. This infection is both abnormal and pathologic, yet the parasitic infection becomes chronic and does not usually kill its host.

Humans may be the hosts for parasites. They may be the only host, the accidental host, or may be only one of several hosts for that parasite. The definitive host is the host in which the parasite reaches sexual maturity. The intermediate host, usually an invertebrate, is one in which the parasite undergoes early development. Helminths (worms) are frequently parasites of man. Their success is in part due to their eggs which resist environmental destruction. Man usually becomes infected by inhaling eggs or by ingesting eggs with either fecally contaminated water or food.

The common helminths infecting man in North America are cestodes, nematodes and trematodes. The cestodes (or tapeworms) are long, flat, ribbon-like worms. They have a scolex (or head) with suckers or hooks with which they attach to the host's intestine. There may be as many as 2000 proglottids (or segments) behind the scolex in the adult worm. The proglottid is active in reproduction; each contains both male and female organs and may produce up to 100,000 eggs. The more mature proglottids are at the posterior

of the worm where they break off and are released with their host's feces. These worms have no brain, no sense organs and no digestive system of their own; they must absorb their nutrients directly from their host.

Nematodes (roundworms) are frequently free-living inhabitants of the soil, but many species are parasitic in plants and animals. They are slender, pointed worms and are covered by a protective cuticle. The sexes are separate and fertilization is internal. The females may produce up to several million eggs in their lifetime.

The trematodes are often much smaller than either cestodes or nematodes. The adult digenetic trematode usually possesses two prominent suckers. The anterior sucker is the oral sucker surrounding the mouth and the ventral sucker (or acetabulum) is a holdfast. The life cycle of a trematode is often quite complex; a number of hosts may be involved. The larval forms in the intermediate host develop asexually. Sexual reproduction occurs only in the adult worm. Both male and female organs are present in a single worm and either self-fertlization or cross-fertilization between two individuals occurs. Eggs are released by the female and hatch when they reach water. A ciliated form called a miracidium hatches and swims until it encounters and penetrates a snail that can serve as an intermediate host. Within the snail the parasite multiplies and matures to produce a tailed form called the cercaria. This form emerges from the snail, swims until it encounters a second intermediate host (e.g., crab, fish or plant) on which it encysts. This encysted form (the metacercaria) is later ingested by the vertebrate host (i.e., human), the metacercaria is released and matured to the adult form and the cycle is complete. Many of the stages of the life cycle are represented by unique morphological forms.

The eggs produced by any of these three types of worms may be released unfertilized, fertilized or embryonated (fertilized and with some degree of larval development). The egg shell is several layers thick: a complex matrix of protein mucopolysaccharide, lipid and chitin. Those molecules give the resistance needed against degradation by external environmental factors. The number of eggs released by an adult worm varies with the species, but it may be as high as 100,000 - 200,000 eggs per day. The larvae which hatches may be a miniature adult or may be a special form adapted for penetrating the next host.

Paleoparasitology as a Science

Reviews of medical history indicate that little is known about the medical and nutritional status of past populations[7,8]. Reports tend to concentrate on the unusual rather than the common diseases and document the diseases of the upper class, who could afford medical care, rather than the common people.

In ancient times little was known about parasites except that they existed[9]. Although there was a general conception that many diseases were due to both real parasites and imaginary parasites, it was generally thought that parasites arose spontaneously from decaying matter and might even metamorphose into higher animals. Redi disproved the idea of spontaneous generation in the 17th century but it was not until the 18th and 19th century that parasitology began to develop as a science.

Under usual circumstances human bodies decay rapidly following death. Few diseases (i.e., syphilis, tuberculosis) have left evidence on skeletal bones. Evidence of parasitic infection has been documented in preserved mummies and bog bodies[8,10]. More evidence has been found in coprolites (preserved fecal deposits) and cess material. Adult worms have rarely been found, but parasite ova are often present.

The excavation of the privies in Wilmington was to preserve historical artifacts and to provide information about the residents using the privies. Dr. Vaughn's diary provides us with descriptions of the major diseases affecting some of the Wilmington residents; parasite ova analysis provides us with insight into some of the chronic enteric infections.

Materials and Methods

All four privies were located at Front and King Streets in Wilmington, Delaware. Privy 37 was known to be in use from 1790 to 1820. Privy 14 was used from 1790 to 1830. Both privies 5 and 6 were used from 1880 to 1920. Privies 37 and 14 were barrel privies set in a pit. The soil outside the barrel was clay, compact and sticky. The samples from the privies were dry. Privies 5 and 6 were brick-lined privies; the samples were wet and odoriferous. Each privy had been used by at least one family. There is evidence that some of the barrels had been cleaned. As the families left their homes the privies were abandoned. Garbage was often piled on top, soil was added and a clay cap formed. One of the privies had been limed.

All samples were identified as to feature (privy) and level, each level representing a 6 inch depth. One gram aliquots were obtained by randomly removing portions of the sample. The aliquots were suspended in 90 ml distilled water (100 ml total volume). The samples were then centrifuged at 6000 RPM for 10 minutes. The sediment was treated with 10% formalin for 1 hour and centrifuged again[11]. The sediment was resuspended in an equal volume of Lugol's iodine solution and immediately spread onto glass microscope slides. The dried smears were covered with glass coverslips and observed at 100X magnification with a Bausch and Lomb microscope. The entire 1 gram sample was analyzed; the data are expressed as to both types and numbers of parasites in that sample.

Results

No protozoan cysts were observed in any of the samples. Helminth ova were observed in 14 of the 23 levels examined. The data are shown in Table 1 segregated by privy (feature) and level. The life cycle of each parasite found is presented in Appendix A; photomicrographs with figure legends are presented in Appendix B. Privy (feature) 37 contained both the common roundworm, *Ascaris lumbricoides* (Figure 1 & 2) and the whipworm, *Trichuris trichura* (Figure 3). Except for level 5, the numbers of *A. lumbricoides* were approximately 4 times greater than *T. trichura*. In privy 14, in the four levels which contained parasites, *T. trichura* was always present. *Ascaris lumbricoides* was found in levels 8 and 10, the lancet fluke *Dicrocoelium dendriticum* (Figure 4) was found in both levels 8 and 9, and the pinworm, *Enterobius vermicularis* (Figure 5) was found in level 11.

Feature 6, levels 12 and 13 contained both *A. lumbricoides* and *T. trichura* ova. Levels 14, 17, 18 and 19 contained no parasites. Level 15 contained *Strongyloides stercoralis* larvae (Figure 6). This was a free-living population since it contained male worms. Feature 5 contained *A. lumbricoides* and *T. trichura* ova as well as trematode, *Fasciola hepatica* (Figure 7) and *D. dendriticum*, ova. No parasites were found in levels 12 and 13.

Table 1. PARASITES FOUND IN FOUR 19th CENTURY PRIVIES IN WILMINGTON, DELAWARE

Level	Feature 37 (1790-1820)	Feature 14 (1790-1830)	Feature 6 (1880-1920)	Feature 5 (1880-1920)
1				
2				
3				
4	*A. lumbricoides* 8 *T. trichura* 190			
5	*A. lumbricoides* 1307 *T. trichura* 351			
6	*A. lumbricoides* 672 *T. trichura* 165			
7		*A. lumbricoides* 9 *T. trichura* 24		
8		*D. dendriticum* 2		
9		*D. dendriticum* 2 *T. trichura* 20		
10		*A. lumbricoides* 51 *T. trichura* 84		
11		*A. lumbricoides* 87 *T. trichura* 91 *E. vermicularis* 25	*A. lumbricoides* 2	
12		*T. trichura* 37	*T. trichura* 1	no parasites found
13		no parasites found	*A. lumbricoides* 107 *T. trichura* 21	no parasites found
14		no parasites found	no parasites found	*F. hepatica* 1 *D. dendriticum* 2
15			*S. stercoralis* larvae 16	*F. hepatica* 1
16			no parasites found	*A. lumbricoides* 28 *T. trichura* 6
17			no parasites found	
18			no parasites found	
19			no parasites found	
20				

Parasites per gram sample
See Appendix A for life cycles of these parasites.

Conclusion

There are a number of conclusions that can be drawn from the data obtained on the samples taken from the four privies.

1. Regardless of time, the predominant parasites were the common roundworm, *Ascaris lumbricoides*, and the whipworm, *Trichuris trichura*.
2. All *Ascaris lumbricoides*, *Trichuris trichura* and *Enterobius vermicularis* were of human origin.
3. The two trematodes, *Fasciola hepatica* and *Dicrocoelium dendriticum* were probably from accidental human infections or were contaminants from sheep.
4. *Strongyloides stercoralis* was probably originally of human origin but the larvae are now in a free-living state in the privy samples.
5. Earlier privies (existing prior to the installation of the city sewer in 1890) had greater numbers of parasites and more different kinds of parasites.
6. Helminth ova are a reliable indicator of fecal material while examining samples obtained from privies.
7. Archeological information concerning human helminth parasites obtained from privies is reliable since helminth ova are relatively stable and the privy provides good protection from external contamination and environmental degradation.

It would be interesting to speculate that perhaps intestinal parasites were the cause of the "noncontagious dysentery" reported by Dr. Vaughn in the summer of 1803.

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APPENDIX A:

Life Cycles of Helminths Found in the Privy Samples

The parasites found in the privy samples are presented to show the complexity of their life cycles and their relationship to humans.

ASCARIS LUMBRICOIDES (nematodes)

Ascaris lumbricoides is the common roundworm of humans found in the upper part of the small intestine[6,7,12]. The female is 20 - 35 cm X 3 - 6 mm with a straight tail; the male is smaller (15 - 31 cm X 2 - 4 mm) and has a curved tail. The female lays as many as 200,000 eggs per day. The eggs are fertilized but not developed (unembryonated) when passed in the host's feces. The life span of these worms is approximately 1 year.

Once the eggs are passed, embryonation takes place in the soil. If the embryonated eggs are swallowed by a human they hatch in the presence of bile. The second-stage larvae penetrate the wall of the intestine, enter small blood vessels and are carried to the liver. They migrate to the heart through the inferior vena cava and finally reach the lungs through the pulmonary circulation. The worms actively migrate up the bronchi into the trachea, move across the epiglottis and are swallowed. The worms move through the stomach and finally reach the intestine. Here they molt twice, mature into adults and mate. When only female worms are the cause of the infection viable but unfertilized eggs are layed. These eggs are characterized by the absence of a cortical layer, a thinner shell and loosely organized yolk.

Pathologies associated with ascarid infections are inflammation, obstruction of the intestine, blockage of bile duct, perforation of the intestine and aberrant migration (i.e., to the brain) of the worm. In light

infections these worms may go unnoticed; however, passage of an adult worm in the stool or by regurgitation during vomiting may be hard to ignore. The eggs are extremely resistant to freezing, chemical disinfectants and sewage treatment and infections are easily acquired following ingestion of raw vegetables where "night soil" has been used as fertilizer and where drinking water has been polluted. Humans are the only host for Ascaris lumbricoides.

TRICHURIS TRICHURA (nematode)

Trichuris trichura, the whipworm, is cosmopolitan[6,7,13]. Even though there are several trichurids, host specificity is the rule: T. trichura is found only in humans, T. vulpis in the dog, and T. suis in the pig. These worm eggs are morphologically identical except for size: T. trichura (50 - 54 μm X 22 - 24 μm), T. vulpis (70 - 89 μm X 32 - 43 μm), and T. suis (60 - 68 μm X 28 - 31 μm).

The female worm is 35 to 50 mm in length and the male is 30 to 45 mm. The adult worms live in the transverse and descending colon where the front (thread-like) end of the worm is embedded in the epithelium of the intestine. The worms mate and the female produces approximately 3000 - 5000 eggs per day. They are barrel-shaped, bile-stained (brown) and have bipolar projections which look like plugs. The fertilized eggs are deposited in the soil in feces and must undergo development before they become infective. The infective eggs are swallowed by the human and hatch in the small intestine. The larvae penetrate the intestinal epithelium and molt four times; finally they are released and are carried passively to the large intestine.

The symptoms associated with mild trichurid infections are limited to nervousness, headache and insomnia, but may include vomiting and abdominal distension in heavier infections. Severe infections may result in rectal

prolapse. Proper disposal of sewage is the only way of preventing infections. Where untreated human feces are used to fertilize crops infections usually are present.

ENTEROBIUS VERMICULARIS (nematode)

Enterobius vermicularis, the pinworm or threadworm, is a common parasitic nematode usually affecting children less than 12 years of age[6,7,14]. Humans are the only known natural host for *E. vermicularis*. The adults live in the lumen of the transverse colon and rectum. The female measures 6 - 12 mm X 0.3 - 0.5 mm; the smaller male measures 2 - 5 mm X 0.1 - 0.2 mm.

The adult worms copulate in the intestinal lumen; each female produces approximately 10,000 fertilized but unembryonated eggs (50 - 60 μm X 20 - 30 μm). During the night, the female migrates through the anus onto the perianal skin where she expels her eggs and dies. The eggs embryonate and are infective within 6 hours.

Scratching contaminates fingers during restless sleep and oral infection occurs. The eggs hatch into second-stage larvae once they reach the small intestine. Development proceeds from second to fourth stage larvae. Emerging adults are usually found in the large intestine. Eggs have also been known to hatch at the original site of deposition with the second stage larvae crawling back through the anus into the rectum and finally into the colon. Occasionally larvae may accidentally enter the vagina or urinary bladder causing aberrant infections. Pathological lesions are limited usually to the gastrointestinal tract, anal and perianal regions. Frequently secondary bacterial infections occur. Occasionally intestinal obstruction occurs when large numbers of adult worms block the intestinal lumen.

Transmission of the pinworm is usually by the oral/fecal route. It is passed directly by hand-to-mouth transfer or indirectly through water and food. It is associated with people living under crowded conditions. Infrequent bathing, common use of contaminated underclothing and bedding, and contaminated dust contribute to its spread.

STRONGYLOIDES STERCORALIS (nematode)

Strongyloides stercoralis occurs not only in humans, but also nonhuman primates and dogs. It can also exist as a nonparasitic, free-living form in the soil[6,7,15].

Free-living phase. Second stage rhabditiform larvae are deposited in the soil in feces. Following two molts, the worms become free-living adults of both sexes. After mating the female produces embryonated eggs. This cycle can continue in the soil or a third stage larvae can develop which has the ability to penetrate the skin of its host and begin a parasitic infection.

Parasitic Phase. Penetration of the skin occurs through a hair follicle or skin abrasion. Larvae penetrate a blood vessel and are carried in the blood to the alveolar spaces of the lungs. They actively crawl up the bronchi, pass through the trachea, into the pharynx, go over the epiglottis and get swallowed. The larvae undergo a final molt in the small intestine and become parasitic females.

Female (2 - 3 mm X 0.1 mm) worms live within the columnar epithelium of the small intestine. Eggs are laid and hatch in the epithelium. The larvae migrate into the intestinal lumen and leave in the feces. Occasionally the worms undergo another molt. The latter route is responsible for autoinfections which are often quite severe because of contaminating enteric microorganisms.

DICROCOELIUM DENDRITICUM (trematode)

Dicrocoelium dendriticum causes lancet-fluke disease[6,7,16]. It is primarily a parasite of sheep and cattle although a number of other species have been reported to be infected.

The adult fluke is small, transparent and elongate measuring 5 to 15 mm by 1.5 to 2.5 mm. It has both oral and ventral suckers. The digestive system consists of a pharynx, directly behind the oral sucker, and a digestive tract which branches to form paired cecae. The fluke has both testes (male) and ovaries (female). Both organs terminate in the genital atrium; self-fertilization ensures large numbers of eggs.

The fluke eggs are operculate (having a lid-like cap), slightly asymmetrical and dark brown. They measure 36 to 48 μm by 20 to 30 μm and are embryonated when passed.

The eggs are passed in the feces of the definitive host (usually cattle or sheep). Although they are embryonated they do not continue to develop until ingested by a terrestrial snail. The miracidium emerges from the egg in the digestive tract of the snail. It enters the digestive gland (liver-like organ) where it becomes a primary sporocyst. This sporocyst then divides asexually giving a second generation of sporocysts which, in turn, develop into tailed cercariae. These cercariae emerge from the daughter sporocysts and migrate to the respiratory tissues of the snail. There they mass together in the slime produced by the snail and are shed as the snail creeps over vegetation.

The terrestrial snail was the first intermediate host. The small field ant (Formica fusca) becomes the second intermediate host as it ingests the snail slime contanining the cercarial flukes. The cercariae penetrate the gut wall of the ant and encyst in the abdomen. These cysts finally develop into

infective metacercariae. Infection occurs when ants containing metacercariae are ingested by grazing cattle and sheep. Humans also becomes infected when accidentally ingesting infected ants.

The fluke usually is found in the gallbladder and bile ducts of the definitive host. Symptoms in humans are usually mild and are limited to fullness of the abdomen and flatulence.

FASCIOLA HEPATICA (trematode)

Fasciola hepatica is much larger than *Dicrocoelium dendriticum*[6,7,17]. The adult worm measures 30 mm by 15 mm. *F. hepatica* eggs are also operculate and unembryonated when passed in the feces but are ellipsoid and much larger (130 - 150 μm X 53 - 90 μm) than the eggs of *D. dendriticum*.

The sheep is the usual definite host; however, cattle and rabbits may act as reservoirs. Eggs passed in the feces embryonate as soon as they are in water. They hatch in approximately 15 days; the operculum of the egg opens and the miracidium is released into the water. It swims until it finds a snail (usually *Lymnea truncatala*). It penetrates, migrates and finally encysts in the snail's digestive gland. Developmental stages within the snail include sporocysts, rediae and cercariae. The cercariae leave the snail in slime, encyst and develop as a metacercariae on vegetation. The infectious metacercariae are ingested by herbivorous animals as they graze. The trematodes excyst in the small intestine, penetrate the wall of the intestine, migrate through the peritoneal cavity and enter the liver. The adult worms burrow through the liver leaving excrement and fertilized eggs behind as they feed on liver cells and blood. Aberrant infections can also occur--worms can migrate to the lungs or brain or can attach to the pharynx.

Humans usually become infected by either eating infected raw sheep liver or contaminated aquatic plants (i.e., watercress) in salads. Obstruction of the liver can occur but more frequently symptoms (anorexia, pain, vomiting) vary with the number of worms and degree of tunneling in the liver or bile ducts. Attachment to the pharynx leads to edema (swelling) and intense throat pain.

APPENDIX B:

Photomicrographs of Helminth Ova and Larvae Found in the Privy Samples

Figure 1. *Ascaris lumbricoides*. Fertilized, unembryonated ascarid ovum. The outermost mammillated cortical layer is characteristic. (X500)

Figure 2. *Ascaris lumbricoides*. An unfertilized ascarid ovum characterized by a thin inner layer. Unfertilized eggs are present in feces in infections in which only female worms are present. (X500)

Figure 3. *Trichuris trichura*. A barrel-shaped egg with characteristic prominences at each end. (X500)

Figure 4. *Dicrocoelium dendriticum*. An ovoid, thick-shelled, dark colored egg. (X500)

Figure 5. *Enterobius vermicularis*. An embryonated pinworm egg containing an infective larvae. (X500)

Figure 6. *Strongyloides stercoralis*. Free-living male larvae. (X50)

Figure 7. *Fasciola hepatica*. A sheep liver fluke egg which has lost its operculum (cap). (X500)

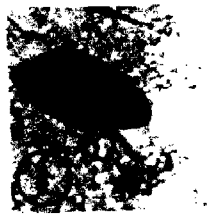
Figure 8-10. *Ascaris lumbricoides*. Ascarid eggs showing increasing sediment accumulation. (X500)

Figure 11. *Trichuris trichura*. Trichurid egg which has filled with sediment. (X500)

Figure 12. *Trichuris trichura*. Cracking of a trichurid egg by a salt crystal. (X500)

2

3



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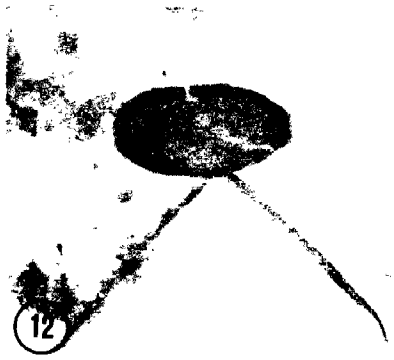

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APPENDIX C:

Research Related Problems

Artifacts. A number of contaminating biological materials are also present in privy samples. Great care is needed to eliminate these materials from the analysis:

- plant material - fibers, roots, root hairs, pollen grains
- human cells - intestinal ephithelial cells, blood cells
- food residue
- mite eggs
- plant nematode larvae
- diatoms and yeast

Biomedical Problems. Analysis of privy samples to date indicates a potential risk of infection particularly to personnel working with sample material. Aerosols created during the sorting process (with screen and hose) are potentially infectious following inhalation. Wounds on hands and other parts of the body during accidents may also provide entry into the body. Most pathogenic bacteria such as those causing tuberculosis, typhoid, typhus, cholera, whooping cough and syphilis (the major bacterial diseases of the 19th century) are usually quite fastidious and probably would not still be viable. The spore-forming pathogens causing lockjaw and anthrax are more likely to survive. No information exists as to the viability of smallpox virus or enteric viruses such as poliovirus or hepatitis A. Preliminary information obtained during this work indicates that helminth ova may hatch.

Much of the disease potential can be decreased by personnel wearing disposable surgical masks and gloves, by normal hygienic washing (particularly the hands), and changing of clothing (which should be washed in detergent and chlorine bleach).

The Effect of Time on Helminth Ova. Helminths are particulary tenacious because of the chemical composition and stability of their egg shell. It was evident from the samples during this study that environmental conditions may affect parasite ova as much as time. *Ascaris lumbricoides* (Feature 6: 1880-1920) appears to crack and eventually fill with sediment (Figures 8-10). *Trichuris trichura* (Feature 14: 1790-1830) apparently loses the mucoid plugs and fills with sediment (Figure 11). Fragility of the egg can be seen in Figure 12 as a salt crystal causes it to crack.