2008

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Reinhard, Karl, "Pathoecology of Two Ancestral Pueblo Villages" (2008). *Karl Reinhard Papers/Publications*. 62.
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Pathoecology of Two Ancestral Pueblo Villages

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Pathoecology is the study of the biotic, abiotic, and cultural environments of disease (Martinson et al. 2003). A parasitic infection is the result of the pathoecological interaction of host behavior, parasite life cycle, the environment in which both life forms live, the nutritional status of the host, and host physiological responses to all of these factors. Parasites contribute to anemia in many ways. Some, such as hookworm, actually consume blood and cause iron loss through their activities. For other parasites, symptoms such as profuse diarrhea reduce intestinal absorption of nutrients. Others, such as certain fish tapeworms, actually compete for absorption of nutrients necessary for blood cell production. Often these causes of anemia are interdependent. Human behavior is one of the keys to understanding pathoecology (Martinson et al. 2003; Reinhard 1988, 1992a; Reinhard and Buikstra 2003; Reinhard et al. 2003). Thus, for the pathoecologist studying human health, one goal is to identify the human behaviors related to environmental conditions that promote or reduce disease. Relevant aspects of behavior include population density, seasonal movement, excreta disposal patterns, diet, and personal hygiene (Reinhard 1992b). To examine the complexity of pathoecology among the Ancestral Pueblo culture of the Colorado Plateau, I compared two Ancestral Pueblo villages: Salmon Pueblo, New Mexico, (formerly known as Salmon Ruin) and Antelope House, Arizona (Figure 1). Parasitism and nutritional deficiency are both causes of anemia. Previous work (Reinhard 1992b) showed that these sites represented the extremes in anemia. Through this comparison, one begins to understand the pathoecology of ancient anemia.

Figure 1. Location of Antelope House in Canyon de Chelly, Arizona, and Salmon Pueblo on the San Juan River, New Mexico. Salmon Pueblo is also known as Salmon Ruin.

The two sites have Pueblo III period occupations in very different locations (Figure 1). Antelope House is located in a large rock shelter in a canyon bottom in Canyon de Chelly National Monument. Excavation was done by Morris (1986) of the National Park Service between 1970 and 1974. The cave was inhabited by Ancestral Pueblo people between A.D. 500 and 1250. Salmon Pueblo is on the San Juan River. Excavation of Salmon Pueblo was initiated in 1970 by Irwin-Williams (Bohrer and Adams 1977). These excavations ended in 1978. Tree ring evidence indicates that construction of Salmon Pueblo village began in A.D. 1088. It was occupied until it was destroyed in a catastrophic fire between A.D. 1280 and 1290 (Reed 2006:296). At the peak occupation of Salmon Pueblo, it had in excess of 300 inhabitants.

Salmon Pueblo was built on an alluvial fan overlooking the floodplain of the San Juan River. Meander scars show that the river was once close to or in contact

with the alluvial fan where the Pueblo was built (Nials and Reed 2006). The location of the Salmon Pueblo village along the river provided ready access to arable land. The flood plain itself was arable and there are two near-by drainages that could have been farmed. Today, the floodplain itself is very moist, with dense vegetation cover. The trash deposits near Salmon Pueblo were washed away at some time in the past.

Likewise, the moist environment of the canyon bottom near Antelope House made it an ideal place for farming. Most trash deposits and an unknown number of rooms were lost to flooding at Antelope House.

Materials and Methods

Analysis of the contents of 292 coprolites (paleofeces or dried feces) formed the basis of this study of the pathoecologies at the two sites. Sampling strategies during excavation of these sites optimized diversification. In selecting coprolites, it is ideal to diversify the sample so that defecations by as many different individuals as possible are obtained. Obviously, sites with several latrines and occupied for longer periods of time offer better conditions for diversifying coprolite samples than do single latrine sites from short occupations. Antelope House reflects the former situation and contained several hundred separate latrine deposits. The Antelope House analysis included 180 coprolites selected from 34 separate latrine areas. Differences in texture, coloration, and size were considered to avoid sampling the same defecation twice. Salmon Pueblo reflects the latter situation, with only one large latrine suitable for study. Other large latrines excavated at Salmon Pueblo were burned and the carbonized coprolites in them were not suitable for study. In order to increase heterogeneity, Salmon Pueblo coprolites were recovered from alternate levels in alternate grid squares. Of an estimated 4,000 coprolites collected, 112 were analyzed.

The macrofossil analysis of the coprolites used procedures outlined by Fry (1977). The specimens were cleaned, photographed, sketched, measured, weighed in grams, and described in terms of surface morphology and visible inclusions. Subsamples were removed from each coprolite: 1 g samples from Antelope House and 1.0–2.5 g samples from Salmon Pueblo. These were rehydrated, disaggregated, screened, concentrated by centrifugation, and, in the case of macroscopic components, dried. As a general procedure, the entire coarse fraction was separated into individual components, which were weighed separately. The fine fraction was subsampled by weight, and approximately one third of the fraction was fully separated into the various components. The remainder of the fine fraction was scanned for unique items, such as seeds and ectoparasites, but was not otherwise sorted. The microscopic fraction was examined for parasite remains after Reinhard (1985a) and Reinhard et al. (1988). Parasite identifications are based on morphological similarities to modern comparative materials. Microscopic remains were sedimented by gravity in acetic formalin alcohol. A sample of the uppermost sediments was pipetted onto a glass microscope slide with a drop of glycerol,

covered with a cover slip, and sealed. After parasitological analysis, microscopic sediments were processed for pollen (Bryant 1974; Clary 1984; Martin and Sharrock 1964). A minimum of 200 pollen grains was counted for each specimen (Barkley 1934). Dietary interpretations of the pollen data are based on percentage expressions of these counts. Recently, a second analysis of coprolites from Salmon Pueblo was conducted (Reinhard et al. 2006b). This analysis relied on analysis of very small residues less than 0.5 millimeters in size.

Most North Americans are unfamiliar with parasites even though they are important to human health on a global scale. Although less sensational than emergent viral disease such as Ebola and West Nile, parasites nonetheless take a tremendous, chronic toll on humans all over the world. The phylum Platyhelminthes, or flatworms, contains two parasitic classes. One class is the Cestoda which includes the tapeworms. The second parasitic class is the Trematoda which includes the flukes. Of the tapeworms, eggs of the families Hymenolepididae and Taeniidae have been found in Southwest U.S. coprolites. In shape, tapeworms resemble bands of tape or ribbons. The hymenolepidids that parasitized ancient southwesterners were quite small. The dwarf tapeworm, *Hymenolepis nana*, is the smallest tapeworm that infects humans. In contrast, some taeniid species are at least 50 cm long. Flukes are similar to the free-living flatworms (*Planaria* spp.) that are commonly used as experimental animals in biology courses. The exact fluke species that is represented by eggs in prehispanic coprolites is unknown. Roundworms are more common parasites of prehispanic southwesterners. Roundworms are in the phylum Nematoda and are unsegmented worms. The pinworms (*Enterobius vermicularis*), hookworms (family Strongyloidea), and threadworms (*Strongyloides* sp.) are roundworms. Most, if not all, basic biology laboratories use the giant intestinal roundworm of pigs, *Ascaris suum*, as a dissection animal. Students are therefore usually very familiar with the form of roundworm parasites. More recently, coprolites from each site were tested for the flagellated protozoan parasite *Giardia lamblia* (Gonçalves et al. 2002; Wilson et al. 2006). Coprolites from Antelope House have been tested for the amoebid that causes amoebic dysentery, *Entamoeba histolytica* (Gonçalves et al. 2004). Both of these protozoa are common causes of diarrhea, especially in babies and children. High worm infections are accompanied by high protozoal infections in the modern world, and it is almost a certainty that protozoal parasites (*Entamoeba* and *Giardia* species) were more common at Antelope House as well. Therefore, protozoa-caused diarrhea and anemia were probably greater problems for Antelope House inhabitants than for those at Salmon Pueblo.

Results

The two sites had very different levels and types of parasitism. Only 9 (8%) of the Salmon Pueblo coprolites contained eggs of parasitic worms and only one species is represented, the pinworm (*Enterobius vermicularis*) (Figure 2). Examination of Salmon Pueblo coprolites for *Giardia* cysts was negative (Wilson et al.

Figure 2. Parasitism at Salmon Pueblo. The parasitism evidenced at this site is limited and includes only one parasitic worm, pinworm (*Enterobius vermicularis*). This parasite is transmitted by eggs through the air or by person-to-person contact. In the modern world, children are most often infected, followed by women, probably due to greater contact between women and children.

Figure 3. Parasitism at Antelope House. The parasitism evidenced at this site includes several species. Pinworm (*Enterobius vermicularis*) was transmitted as described in Figure 2. As illustrated here, dogs (*Canis familiaris*) were reservoir hosts for threadworms (*Strongyloides stercoralis*), which burrow through the skin of humans. Tapeworms (Hymenolepidae) are commonly transmitted by consumption of grain beetles (*Tribolium* spp. and *Tenebrio* spp.). An unknown strongylate worm is also present at Antelope House, but its exact species identification and therefore its life cycle is currently unknown.

2006). Of 180 coprolites studied from Antelope House, 52 (29%) contained worm eggs. Five taxa are represented: pinworm, threadworm (*Strongyloides* sp.), tapeworm (family Hymenolepidae), the giant intestinal roundworm of humans (*Ascaris lumbricoides*), and a strongylate species (Figure 3). The strongylate worm category refers to the eggs of parasites that could be in either the order Strongyloidea or the order Trichostrongyloidea. The size of these eggs is consistent with hookworms (family Ancylostomidae, *Ancylostoma duodenale*, *Necator americanus*). Other tests show that Antelope House inhabitants were infected by the amoebids that causes amoebic dysentery *G. lamblia* and *E. histolytica*.

The difference in parasitism between the sites had a dramatic impact on health. Pinworms in small numbers are essentially harmless. They are, however, an annoyance. In high numbers, pinworms can be distinct health problems. They can cause minute ulcerations of the intestine with subsequent bacterial infection. Also, the anus can become ulcerated due to scratching, with subsequent bacterial infection. Beyond these rare problems, insomnia, appetite loss, and weight loss can result from pinworm infection. The pinworm prevalence at Antelope House is very high, higher than any modern standards and higher than any other coprolite series studied in the world. Therefore, pinworm was undoubtedly a health problem for Antelope House inhabitants.

Species of threadworms (*Strongyloides*) are very pathogenic. Third-stage larvae penetrate the skin of humans, enter the bloodstream, and go to the lungs. From the lungs, they migrate up the throat and are swallowed. When they reach the intestine, they mature to the adult stage. The adults burrow through the intestinal lining and cause ulcerations. The eggs hatch in the intestine and the larvae enter the bloodstream through the ulcerations caused by the parents. They then mature in the normal way. This process is called *autoinfection*. Autoinfection can result in a massive population of worms (*hyperinfection*). The blood loss from ulcerations causes anemia. Also, because scar tissue replaces normal intestinal lining at the ulcerations, less food is absorbed through the intestinal lining. Thus, threadworm (*Strongyloides*) infection is dangerous and debilitating.

I cannot determine which species of worm laid the strongylate-type egg. It is probable that hookworm is present. Hookworm is one of the most dangerous human parasites. This possibility is under investigation using DNA within the eggs.

Two other relatively harmless worms are the hymenolepidid tapeworm and the giant intestinal roundworm. The tapeworm found in a Antelope House coprolites rarely causes disease but may cause nausea and other minor symptoms. The giant intestinal roundworm is noteworthy in the numbers of people it infects and the insignificant pathology it causes. In the world today, about 1.5 billion people are infected. Of these only 59,000 become ill, and 10,000 die (Crompton 1999; de Silva et al. 1997).

The results of the parasite analysis show a higher prevalence of parasitism at Antelope House, which undoubtedly caused disease. Fewer parasites were present in the Salmon Pueblo coprolites. As a pathoecologist, I wonder what factors led to greater disease at Antelope House. By looking at other archaeological data, this difference can be understood.

Discussion

Season of Occupation

It is likely that both villages were occupied year-round, although the concentrated habitation of Salmon Pueblo was probably more typical of the late fall, winter, and early spring, when people took refuge from the cold.

On the basis of results from the coprolite analyses (Fry and Hall 1986; Williams-Dean 1986), Morris (1986:55) concluded that Antelope House was occupied throughout the year. Williams-Dean (1986) included macrofossil and palynological data in her analysis of residential patterns. She identified two types of coprolites, designating them "spring-summer" and "four seasons." The first category included coprolites with constituents that could be gathered only in the warm months. Coprolites in the second category contained food items available year-round. Williams-Dean (1986) concluded that year-round occupation of Antelope House was probable, but that winter occupation of the site cannot be empirically

demonstrated. Winter occupation can be inferred, however, from the presence of the remains of storable foods and ethnographic analogy for the use of harvested plants. This inference is supported by another study (Sutton and Reinhard 1995), which examined associations of macroscopic plant remains through cluster analysis. This study revealed a difference between foods associated with whole maize (*Zea mays*) kernels and ground maize kernels. The whole kernels were associated with a great diversity of warm-season foods such as prickly pear (platy *Opuntia* sp.) fruits. Ground maize was associated with less variety and foods that reflect cool-season diets. It is likely therefore that Antelope House was occupied year-round. Reinhard et al. (2006a) completed a pollen concentration analysis of coprolites from both sites and concluded that the background pollen was not statistically different between the sites. Both sites were occupied partly in the warm seasons when pollination occurs.

The Salmon Pueblo fire carbonized substantial amounts of stored cultivated and wild plant foods (Bohrer 1980). These foods were harvested or collected during the warm months and stored for winter. The combined data suggest that the site was intensively occupied at least during the winter months when the stores would have been most needed. Adams (1980a; 2006a) interprets the presence of purslane (*Portulaca* sp.) and goosefoot (*Chenopodium* sp.) seeds in the Pueblo as evidence of spring and fall activity.

Resource Exploitation

Environmental parameters are important in the formation of conditions suitable for parasitism. Moist, warm conditions are optimal for the transfer of many parasite species. The analysis of the way in which people at Antelope House and Salmon Pueblo exploited local resources provides information about the ecological conditions to which they were habitually exposed. These data speak to the environments in which Salmon Pueblo and Antelope House inhabitants lived and foraged. They demonstrate that the inhabitants of Antelope House were closely tied to the wetland canyon bottom in which they lived. Conversely, the inhabitants of Salmon Pueblo utilized drier areas for habitation and food collection.

Coprolites from Antelope House indicate that residents there tended to eat plant foods from wet areas (Table 1). For example, horsetail (*Equisetum* spp.) pollen is present in 12 of 27 coprolites (Reinhard et al. 2006a), although it is apparently absent in coprolites from other Ancestral Pueblo sites (Clary 1984). Cattail (*Typha* spp.) pollen is found in 17 of 27 Antelope House coprolites. Analysis of pollen and macroscopic remains shows that the pollen and spores of these plants were eaten as a food. The terminal stems of horsetail, which occur just beneath the spore-producing bodies (strobili), are present in macroscopic remains. Cattail pollen is still aggregated in rows and is associated with the fibrous matrix of immature cattail heads in macroscopic remains. Obviously, the strobili of horsetail and the inflorescences of cattail were common food sources for Ancestral Pueblo living at Antelope House. Both plants occur in wetland habitats, often associated with standing water. Horsetail is also found in wet soils of stream beds.

Table 1. Number of Coprolites Containing Economic Pollen Types from Antelope House and Salmon Pueblo

Taxa	Antelope House	Salmon Pueblo
Parsley family (Apiaceae)	2	6
Sunflower-type (Compositae)	13	12
Mustard family (Brassicaceae)	3	8
Cactus family (Cactaceae)	3	5
Hackberry (<i>Celtis</i> spp.)	1	—
<i>Cheno-Ama</i> (<i>Chenopodium-Amaranthus</i>)	9	9
Beeweed (<i>Cleome</i> spp.)	24	28
Squash (<i>Cucurbita</i> spp.)	3	3
Horsetail (<i>Equisetum</i> spp.)	12	2
Bean family (Fabaceae)	5	4
Lily family (Liliaceae)	1	4
Prickly pear (platy <i>Opuntia</i> spp.)	—	2
Grass family* (Poaceae)	2	3
Purslane (<i>Portulaca</i> spp.)	1	—
Sumac (<i>Rhus</i> spp.)	6	3
Cattail (<i>Typha</i> spp.)	17	
Maize (<i>Zea mays</i>)	18	25

* Only percentages exceeding 5% of a 200 grain-count are included in these categories. Number of coprolites analyzed for pollen: Antelope House $N = 27$, Salmon Pueblo $N = 30$. Data from Reinhard et al. (2006a).

Salmon Pueblo data contrast sharply with those from Antelope House. Wetland-associated plants are absent in the Salmon Pueblo coprolites. In particular, cattail and horsetail were not eaten at Salmon Pueblo (Table 1); instead, there was a tendency to consume dry-adapted plants. The pollen evidence from Salmon Pueblo indicates that the flowers of prickly pear or cholla (platy *Opuntia* sp. or cylindro *Opuntia* sp.), beeweed (*Cleome* spp.), and cultivated gourd/squash (*Cucurbita* sp.) were eaten. In addition, pollen of maize, a highspine composite such as sunflower (*Helianthus* sp.), and perhaps a plant in the parsley family (Apiaceae) are also present. This evidence suggests a more maize-dependent diet for Salmon Pueblo with less diversity in wild plant foods than at Antelope House. The macrofossil remains from the coprolites contrast between the two sites (Table 2). There were more wild plant taxa eaten at Antelope House than at any other Ancestral Pueblo site (Reinhard 1992b). Compared to 21 wild plant taxa eaten at Antelope House, just 12 wild plant taxa were eaten at Salmon Pueblo. In the total of 112 coprolites from Salmon Pueblo, juniper (*Juniperus* sp.) fruits are the most common noncultivated macrobotanical component (23 of 112 coprolites). This plant grows in the juniper woodlands overlooking the San Juan River plain. Its presence signals foraging in xeric environments. Other major macrobotanical components are maize, cultivated bean (*Phaseolus vulgaris*), goosefoot, and pigweed (*Amaranthus* spp.). No evidence of wetland plants such as horsetail, hackberry (*Celtis* spp.), or chokecherry (*Prunus virginiana*) was found.

Analyses of food plants, nondietary plants, and vertebrates in noncoprolite contexts provide additional evidence that Antelope House inhabitants utilized aquatic resources to a greater degree than did the inhabitants of Salmon Pueblo

Table 2. Percentage of Coprolites Containing Macrofloral Fossil Types from Antelope House and Salmon Pueblo*

Common Name and Genus or Family	Antelope House	Salmon Pueblo
Onion (<i>Allium</i> spp.)	2	—
Pigweed or amaranth (<i>Amaranthus</i> spp.)	10	6
Saltbush (<i>Atriplex</i> spp.)	1	—
Cactus (Cactaceae)	42	—
Goosefoot (<i>Chenopodium</i> spp.)	4	21
Beeweed (<i>Cleome</i> spp.)	16	6
Gourd/squash (<i>Cucurbita</i> spp.)	29	4
Ringwing (<i>Cycloloma</i> spp.)	—	1
Tansy mustard (<i>Descurainia</i> spp.)	—	4
Wild rye (<i>Elymus</i> spp.)	1	—
Horsetail (<i>Equisetum</i> spp.)	7	—
Hedgehog cactus (<i>Echinocereus</i> spp.)	—	4
Cotton (<i>Gossypium</i> spp.)	18	—
Sunflower (<i>Helianthus</i> spp.)	4	8
Juniper (<i>Juniperus</i> spp.)	—	23
Pepperweed (<i>Lepidium</i> spp.)	1	—
Prickly pear (platy <i>Opuntia</i> spp.)	12	1
Rice grass (<i>Oryzopsis</i> spp.)	2	—
Panic grass (<i>Panicum</i> spp.)	1	—
Bean (<i>Phaseolus</i> spp.)	1	10
Groundcherry (<i>Physalis</i> spp.)	16	13
Pine (<i>Pinus</i> spp.)	29	6
Grass (Poaceae)	1	—
Purslane (<i>Portulaca</i> spp.)	21	6
Sumac (<i>Rhus</i> spp.)	7	—
Drop-seed (<i>Sporobolus</i> spp.)	1	—
Grape (<i>Vitis</i> spp.)	2	—
Yucca (<i>Yucca</i> spp.)	1	—
Maize (<i>Zea mays</i>)	91	43

* Data from Reinhard (1992b) and Reinhard et al. (2006b).

and other Ancestral Pueblo sites in general. The vast majority of bird remains from Antelope House are wading birds (Ardeidae) and ducks (Anatidae), which contrasts with other Ancestral Pueblo collections considered by McKusik (1986). Most of the wild bird species identified prefer standing, shallow pools, further demonstrating that Antelope House inhabitants hunted in moist places. Of plant remains found in noncoprolite contexts, 37% of 78 species from the Antelope House excavations were from “wet places” (Harlin and Dennis 1986). It was concluded from these data that “the canyon bottom, in general, provides more plant species suitable for food than do any of the other [ecological] areas” (Hall and Dennis 1986: 139). Other uses of wetland species, particularly woody genera, were noted as well (Morris 1986:548-549). In contrast, Durand and Durand (2006) and Harris (2006) find relatively few wetland species other than fish from the San Juan River at Salmon Pueblo. The faunal remains from Salmon Pueblo were dominated by turkey (*Meleagris gallopavo*) and animals from the desert such as jack rabbit, cottontail rabbit, deer, rodents, and lizards.

Xeric macrobotanical data from Salmon Pueblo contrast with the wetland plants and animals at Antelope House. The most common plants recovered from Salmon Pueblo were maize, cultivated beans, pinyon nut (*Pinus edulis*), gourd/squash, goosefoot, pigweed, wild onion (*Allium* spp.), yucca (*Yucca* spp.), juniper, and purslane (Adams 2006a,b,c,d; Bohrer and Doebly 2006; Doebly 2006). These plants derive from gardening and foraging in xeric areas. Thirteen other plants are listed as common, but only sedge (*Carex* sp.), spikerush (*Eleocharis* sp.), and bulrush (*Scirpus* spp.) are from wet locations (Adams 1980a,b; 2006a,b,d; Bohrer 1980).

Seven burned storerooms were excavated at Salmon Pueblo. When the burning roofs and walls of the rooms collapsed, they smothered the fire, thus preserving carbonized plant remains. Reviewing the contents of these storerooms provides a unique view of the plants harvested and stored at Salmon Pueblo. All seven of the rooms contained stores of maize. Six contained cultivated beans. Squash seeds and rinds were found in three rooms. Three rooms contained goosefoot seeds and cholla cactus stems, buds, and seeds. Two rooms contained tumble ringwing (*Cydoloma* spp.) seeds as well as prickly pear seeds and pads. Beeweed seed, Indian rice grass (*Oryzopsis hymenoides*) florets, purslane seeds, and pinyon nuts were found in one room. The area did not support pinyon pine, so these nuts were probably collected at some distance from the village. These plant foods probably represent major dietary components. None is specific to wetlands.

The consumption of chokecherry fruit bears on the relative importance of wetland-adapted plants at Salmon Pueblo. Bohrer (1980) discusses the evidence of pinyon pine nut, juniper berry, wild onion bulb, yucca pod, and chokecherry fruit consumption at the site on the basis of botanical data from 53 trash strata. Pinyon nuts and juniper berries occurred in roughly equal numbers of strata, 48 and 43, respectively. Wild onion remains were recovered from 34 trash strata and yucca remains from 26 trash strata. In contrast, chokecherry was found in only 8 strata. Bohrer notes that chokecherry should be expected to produce a reliable crop. In comparison, pinyon pine and yucca are undependable resources. With respect to chokecherry Bohrer (1980:247) states that "the heavy use of pinyon nuts runs counter to its erratic seed production and distance from Salmon Pueblo. The low frequency of chokecherry pits may indicate a lack of popularity, for they seem to be available and reliable." The contrast in utilization of chokecherry with other desert plants suggests that Salmon Pueblo inhabitants preferred foraging in xeric areas even though productive species were available in wetlands near the village.

Sanitation

The patterns of excreta disposal at the two sites reflect drastic differences in general hygiene. At Antelope House, approximately 150 separate fecal deposits were found in the excavation. All these deposits can be considered to be individual latrines. They are located throughout the site, both in plaza areas and in habitation rooms. Thus, the pattern of excreta disposal shows no organized system for segregating human waste from other activity areas.

In contrast, coprolites were recovered from specific, sequestered areas in Salmon Pueblo. Usually, rooms were set aside for the purpose of trash and feces disposal. An example of such a room is 62W, in which a trench was excavated into deep trash deposits next to a narrow masonry bench. Feces were deposited into the trench by people sitting on the bench. Several other rooms were used as latrines, and coprolites were recovered from trash strata as well. The pattern of feces disposal at Salmon Pueblo was one that resulted in the isolation of large amounts of fecal material in specific areas. These rooms were two stories deep and had walls up to 1.5 m thick, so latrines were quite effectively separated from living areas.

Personal hygiene is more difficult to reconstruct. The only information relative to this aspect of life comes from Bohrer (1980) for Salmon Pueblo. She speculates that the inhabitants of Salmon Pueblo made soap from yucca roots. This idea is based on the abundance of yucca leaves, pods, seeds, and hearts at the site, although no yucca roots have been identified. Bohrer suggests that the roots were pulverized to make soap and consequently were destroyed. Soap could have impacted parasitism, especially that of lice (*Pediculus humanus capitis*). Similar information about personal hygiene is not available for Antelope House.

One important aspect of Antelope House was that it was largely enclosed in a cave. The enclosure limited air movement and prevented removal of suspended particles from the air. Because pinworm is commonly transferred by aerial contamination, the lack of air movement at Antelope House could have aggravated pinworm infections.

The pattern of parasite infection coupled with the nature of human habitations can promote or limit infection level (Reinhard 2007). This effect is especially true for pinworms. Pinworms work the night shift. The females crawl out of the anus of the host and desiccate on the skin. Desiccation causes the worms to burst, and the eggs are showered into the air. Now, because pinworm eggs are transmitted through inhalation, areas where the air is still promote infection because the eggs remain in ambient air longer and have a better chance of infecting a new host. Therefore, airborne contamination of food is another source of pinworm infection. Caves, such as the one in which Antelope House was built, are ideal for the transmission of pinworms compared to open sites such as Salmon Pueblo. The open sites are subject to air movement (winds) that blow the tiny eggs out of the village. Therefore, the lower prevalence of pinworm eggs in Salmon Pueblo is due to the fact that it is an open site. Once the pinworms are established via air contamination, other modes of infection exacerbate the problem. When female worms lay their eggs, the eggs are laid in a viscous substance that irritates the perianal skin and causes itching (pruritus). Thus, the human scratches in his or her sleep and transfers the eggs to the hands. The eggs are easily transmitted from person to person in the morning. The eggs must be eaten or inhaled in order to cause infection. If personal hygiene is poor and the perianal folds are not cleaned, the eggs can hatch and the

worms wander back into the intestine and mature to adulthood. This process is called *retroinfection*. In addition, the eggs are very light and can be suspended in even the slightest air currents.

Environmental Collapse, Water Contamination, and Starvation

Reinhard and Bryant (2007) present a case that the Pueblo III occupation of Antelope House is the best documented example of an Ancestral Pueblo village suffering from declining health due to contamination of water with parasite eggs and cysts. Morris (1986) summarized the pathoecology of Antelope House water contamination. Towards the end of the occupation, drought affected the Canyon de Chelly region. Water sources outside of the canyon dried up, and people moved into communities such as Antelope House to take advantage of more reliable water within the canyon. Reinhard and Bryant (2007) argue that the increased population and decreased water resulted in contamination. They write "It is also probable that the long-term drought that is recorded in the Antelope House region resulted in an aggregation of human populations around the dwindling water sources. This in turn led to a proliferation of crowd diseases as well as diseases associated with contaminated water and inadequate sanitation. Bioarchaeologically, this phenomenon is commonly expressed in skeletal remains as elevated levels of porotic hyperostosis." Three parasites in Antelope House are associated with such contamination; *E. histolytica*, *G. lamblia*, and hookworm. These cause diarrhea and anemia, especially in children and mothers, which coincides with the increased prevalence of anemia during the Pueblo III occupation of Canyon de Chelly relative to other time periods (El-Naijar 1986; El-Naijar et al. 1976). Thus, there is a relationship between environmental stress, increased parasitism, and skeletal indicators of morbidity in mother and infants.

This infectious pathoecology was compounded by starvation. Early comparative analysis of Ancestral Pueblo coprolites (Reinhard 1992b) suggested that Antelope House inhabitants diversified their subsistence strategy during the Pueblo III occupation and became more reliant on wild plants than any other Ancestral Pueblo Village. Sutton and Reinhard's (1995) component analysis of 180 Antelope House coprolites showed that there was a distinct period when the variety of foods used was low and dominated by yucca and prickly pear. These studies suggested temporary food shortages were suffered at Antelope House. Reinhard and Danielson (2005) examined coprolites for phytolith evidence of reliance on starvation foods at Ancestral Pueblo communities. They discovered that starvation foods (yucca leaf bases and prickly pear pads) were present in nearly all Antelope House coprolites. Reinhard and Danielson (2005) related these starvation foods to the pathoecology of dental disease. Relative to other Anasazi sites, Salmon Pueblo has a moderate prevalence of dental caries and a low prevalence of dental abscesses. In contrast, Antelope has a high level of dental wear relative to other sites. Reinhard and Danielson (2005) hypothesize that ecological collapse in the

region of Antelope House resulted in higher reliance on starvation foods containing high levels of phytoliths which, in turn, abraded dental enamel and cause dental wear and abscesses.

Summary of Pathoecology

Several factors relevant to the pathoecology of anemia have been examined, including general environment of the sites, parasite prevalence, parasite diversity, population size, residential seasonality, resource exploitation, and general hygiene. In some aspects, no difference between the sites is apparent. The sites are essentially similar with respect to general environment. Both are built on moist soils adjacent to riparian or wetland environments. The demographic estimates suggest that the populations of the two sites were roughly similar. Both sites were probably year-round habitations.

The major differences are seen in environmental stability, resource exploitation, and hygiene. Antelope House was occupied at a time of drought and environmental collapse. The canyon population became crowded and the water sources were contaminated with protozoa cysts and hookworm eggs. The excreta disposal pattern at Antelope House was erratic in comparison to the defined, isolated latrines at Salmon Pueblo. These factors probably had a pronounced influence on parasitism.

Use of wetlands kept inhabitants of Antelope House in contact with moist soils infested with the facultative threadworm parasite *Strongyloides stercoralis* and hookworms. Dogs (*Canis familiaris*) at Antelope House served as reservoir hosts for threadworm (Reinhard 1985b) and could have maintained threadworm in the soil. Deposits of dog and human feces near and in habitations could have led to human threadworm infection as well. The human crowding throughout the site combined with poor air circulation may have contributed to higher levels of pinworm infection. The considerable difference in pinworm prevalence between the two sites suggests that the inhabitants of Antelope House lived in more crowded conditions than did residents of Salmon Pueblo. This crowding is significant with regard to other diseases. High worm infections are accompanied by high protozoal infections in the modern world, and it is almost a certainty that protozoal parasites of the order Amoebida were more common at Antelope House as well. Therefore, amoebid-caused diarrhea and anemia were probably greater problems for Antelope House inhabitants than for those at Salmon Pueblo.

The health impacts of the combined starvation and parasitism are best seen in skeletal pathology. Stuart-MacAdam and Kent (1992) present a strong case that infectious disease is the main cause of porotic hyperostosis seen in human skeletal remains. Porotic hyperostosis refers to cranial lesions on the parietal and occipital regions that develop as a response to infection-related anemia. Among Ancestral Pueblo sites that have been examined for porotic hyperostosis in crania and parasites in coprolites, Salmon Pueblo has the lowest prevalence of both. The Canyon de Chelly area, where Antelope House is located, has the highest preva-

Figure 4. Parasitism of southwestern hunter-gatherers. Parasitism in this population was limited by seasonal movement, small band size, diet, and other factors. Studies of coprolites from hunter-gatherer sites show only three parasites. Thorny-headed worm (probably *Moniliformis clarki*) became a human infection when humans ate uncooked insects. Pinworm (*Enterobius vermicularis*) existed in small numbers. An unknown tapeworm (Taeniidae) may be the result of contamination and not actual parasitism of humans. (Data from Reinhard 1988, 1992b).

lence of both (Reinhard 1992b). Further, of 33 children from Salmon Pueblo, 14 (45%) exhibit porotic hyperostosis, compared to 15 of 17 children from Canyon de Chelly (88%). Therefore, skeletal pathology at the two sites reflects the health impact of parasitic disease and poor nutrition.

Conclusion

Humans have endured parasitic disease throughout their evolution. Before plant domestication, aspects of hunting-gathering life served to limit the prevalence and diversity of parasites in human populations (Figure 4). When horticulture emerged, parasitism increased, with debilitating results (Figure 5). Only through controlling aspects of behavior could horticultural populations limit the intensity of their parasitic diseases. Through comparison of the coprolites from Salmon Pueblo and Antelope House, one begins to understand the consequences of environmental collapse, sedentism and population increase, as well as the behavioral changes that evolved to limit parasitism in settled villages.

Figure 5. Parasitism of horticulturists in the Southwest was more diverse and infections were more common than among hunter-gatherers. Pinworm (*Enterobius vermicularis*) infection increased dramatically. Fecal-borne parasitism emerged (*Trichuris trichiura* and *Ascaris lumbricoides*). Hymenolepidid tapeworms occurred in grain beetles. Threadworm (*Strongyloides* spp.) and an unknown strongylate worm are also evident.

Acknowledgments — The illustrations were drawn by Jonathan Ham and Debra K. Meir.

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