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Pollen Concentration Analysis of Ancestral Pueblo Dietary Variation

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Abstract

Previous coprolite research on the Colorado Plateau has shown that macrofossils are a useful way of statistically demonstrating prehistoric dietary variation of Ancestral Pueblos (Anasazi). Up until now, pollen concentration from human coprolites has not been used for comparative, statistical study. We present here the statistical analysis of pollen concentration values of coprolites from two Ancestral Pueblo sites, Salmon Ruin and Antelope House. The data show that although most pollen types do not show statistically significant variation, there are some types that show how different Ancestral Pueblo populations adapted to plant resources in different environments. The analysis indicates that future work should focus more on pollen concentration analysis of coprolites.

Keywords: Ancestral Pueblo; Anasazi; Palynology; Pollen concentration; Coprolites; Diet

1. Introduction

Minnis (1989) demonstrated that coprolite macrofossils from Ancestral Pueblo (Anasazi) sites were particularly important in identifying culturally-defined dietary patterns. "Ancestral Pueblo" refers to the prehistoric precursors of modern Pueblo societies such as the Hopi, Zuni, and Rio Grande Pueblos. Ancestral Pueblo societies were among several prehistoric groups that occupied the Colorado Plateau, a region that includes parts of Arizona, New Mexico, Colorado, and Utah. To date, no researcher has attempted to assess the value of pollen concentration analysis in defining different patterns of Ancestral Pueblo resource use at separate sites. We are taking this opportunity to evaluate the value of coprolite pollen concentration techniques in assessing variation in Ancestral Pueblo dietary practices between two very different Ancestral Pueblo sites: Salmon Ruin, New Mexico and Antelope House, Arizona.

Antelope House in Canyon de Chelly National Monument, Arizona, and Salmon Ruin near Bloomfield, New Mexico were excavated with particular attention paid to recovery of biological remains (Figure 1). Both sites were excavated in the "New Archaeology" period in the late sixties and seventies. The focus on the scientific recovery of biological data was pioneered in the excavations of these sites. Coprolites and other biological remains from both sites have been studied (Reinhard, 1992, 1996). With regard to other remains, both are documented by monographs (Irwin-Williams and Shelley, 1980; Morris, 1986). However, Antelope House studies are more represented in journal articles and book chapters (Fry and Hall, 1975; Re-

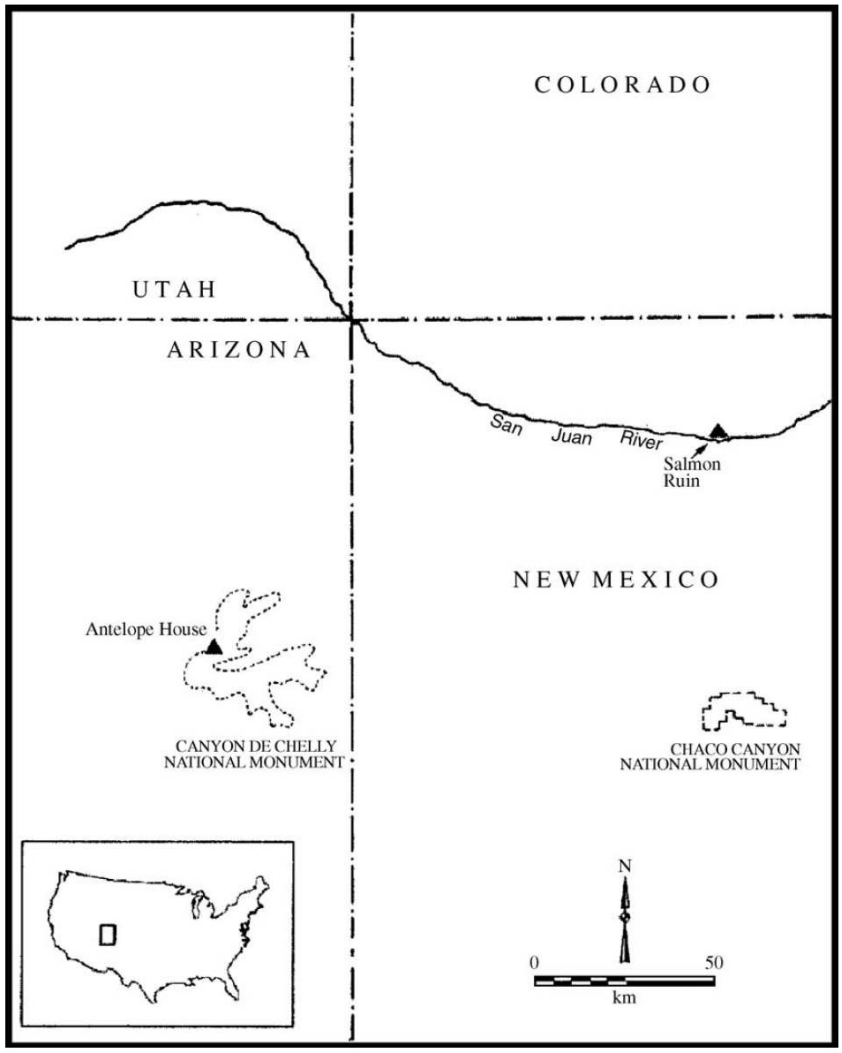

Fig. 1. Location map for Antelope House, Arizona and Salmon Ruin, New Mexico with archaeological areas mentioned in text.

inhard, 1992, 1993, for review Sutton and Reinhard, 1995; Reinhard, 1996). In 1975, volume 41 of the *Kiva* (Journal of the Arizona Archaeological and Historical Society) was committed to articles concerning Antelope House archaeology. Fewer articles appeared regarding the biological analysis of Salmon Ruin (Doebley, 1976; Burgess-Terrel, 1979; Doebley, 1981, 1983; Lentz, 1984). However, the methods used in the biological analysis were published in monograph form (Bohrer and Adams, 1977) as well as the results of the analysis of botanical remains from specific features (Adams, 1980). A comparative analysis of available published and unpublished data for the site was done by Reinhard (1996). Because these sites were critical in the development of Ancestral Pueblo paleoethnobotany, it is appropriate that coprolites from these sites continue to be used to develop new methods of analysis.

These are particularly good sites to compare. Both have Pueblo III Period (AD 1,100–1,300) occupations with coprolites. Approximately the same number of people lived in the Pueblo III occupations of each village (Reinhard, 1996). Both sites have coprolite deposits that can be sampled to diversify the number of individual defecations by separate Ancestral Pueblo people represented by the coprolites (Reinhard, 1996). Previous analyses of the coprolites and sites indicate that the sites were used year-round and that coprolites were deposited year-round (Williams-Dean, 1986; Sutton and Reinhard, 1995). Therefore, there is

no evidence of differential seasonal use of the sites or the latrines at the sites.

In other ways the sites form a contrast. Antelope House is located on the floor of Canyon de Chelly. Salmon Ruin is located overlooking the flood plain of the San Juan River in open country. The Pueblo III occupation of Antelope House is the final manifestation of indigenous occupation of the site since Pueblo I times (AD 700), and since Basket Maker times for Canyon de Chelly in general, (at least since AD 300). In contrast, Salmon Ruin was originally built by the Chacoan Ancestral Pueblo as a colony. The Pueblo III occupation of Salmon Ruin is derived from a San Juan River Ancestral Puebloans that moved into Salmon Ruin after it was abandoned by the Chacoans in the beginning of the Pueblo III Period (AD 1,130). Thus, the Salmon Ruin people were new San Juan occupants and were adapted to the San Juan River environment. The Pueblo III people of Antelope House were the descendants of a tradition that had lived in Canyon de Chelly for centuries. Importantly, the cultural traditions of the sites were distinct. Antelope House was a classic Kayenta Ancestral Pueblo village adapted to the canyon country of northeastern Arizona. The Pueblo III occupation of Salmon Ruin was of the San Juan Ancestral Pueblo adapted to drier, high mesa country of the San Juan River. Therefore, the sites represent different traditions associated with different environments.

Pollen analysis has been a central part of coprolite research from the earliest studies in North America (Martin and Sharrock, 1964). For most of the history of coprolite pollen research, pollen data have been presented as percentage expression of pollen taxa present in studied coprolites. In the last decades, a newer method of presenting pollen data was applied to coprolite pollen analysis. This is the pollen concentration method that allows one to calculate the approximate number of pollen grains per unit measure of coprolites. This method was reviewed by Maher (1981). Maher presents methods of calculating the numbers of pollen grains per gram of sediment using the following formula:

$$\text{Pollen concentration} = ((p/m) \times e) \,/\, w$$

p pollen grains counted
m marker grains counted
e number of exotic marker pollen grains added
w weight or volume of sediment

Researchers began to apply this method to human coprolites. Reinhard and colleagues (1991) used pollen concentration data to develop interpretations of medicinal use of certain plant taxa. They discovered that pollen concentration values are particularly compelling because they reveal that tremendous amounts of pollen were consumed by prehistoric Southwesterners. Pollen concentration values ranged into the millions of pollen grains per gram of coprolite. Such high quantities of pollen in human coprolites had been appreciated previously by only one researcher. Sobolik (1988) calculated pollen concentration values for coprolites from the lower Pecos region of Texas. She also found that human coprolites contained large quantities of pollen. She used pollen concentration values to interpret the passage of time between the consumption of pollen and the defecation of pollen. In essence, she interpreted coprolites with very high concentration values as evidence of recent consumption of pollen-rich foods and coprolites with low concentrations as evidence of pollen-rich food consumption many days before defecation. Most recently, Reinhard *et al.* (2002) used pollen concentration analysis in conjunction with phytolith and macroscopic analysis to reconstruct Archaic diet in the northern Sonoran Desert. They found that pollen concentration was particularly important in identifying dietary use of yucca, prickly pear, mustard family, and grass family. The pollen concentration data also demonstrate medicinal or dietary use of willow and Mormon tea.

The aim of this study is to evaluate the value of pollen concentration in defining dietary differences between two Ancestral Pueblo sites.

2. Materials and methods

The coprolite sampling strategies for the sites and determination of human origin were detailed by Reinhard (1996). The goal of the strategy was to diversify the samples so that many defecations by separate humans were sampled. At Antelope House, this was accomplished by taking single coprolites from several separate, discrete, and dated latrines. At Salmon Ruin, only one latrine was sampled. It was, however, a very large, stratified deposit of coprolites of which an estimated 10,000 were excavated and curated. One coprolite was taken from alternate 10 cm levels in alternate 1 m grids. The sampling was done by Reinhard and Meier.

Ultimately, 180 coprolites from Antelope House (Reinhard, 1992) and 112 coprolites from Salmon Ruin were selected for analysis. The macrofloral remains from all of these were analyzed (Sutton and Reinhard, 1995; Reinhard, 1996). All of these were analyzed microscopically for parasites before pollen processing (Reinhard, 1992). In the parasite analysis, differential diagnosis of *Equisetum* spores versus *Populus* pol-

len was done based on the identification of elators on spores. A subsample was analyzed for phytolith content (Reinhard and Danielson, 2005). Finally, Edwards and Reinhard analyzed the pollen from 52 coprolites, 26 from each site.

Reinhard (1993) published his comparative observations of coprolite pollen recovery from very limited chemical processing to extensive chemical processing. With regard to Ancestral Pueblo coprolites from Utah, New Mexico, and Arizona, Reinhard found that equal results were achieved with both extremes.

One gram fragments of Antelope House coprolites were selected for analysis. One gram fragments from most Salmon Ruin coprolites were available for study. However, some fragments were only 0.75 or 0.5 g. To each sample, one Lycopodium spore tablet containing 11,400 spores was added. All fragments were taken from the interior of the coprolite. The coprolites described in this paper were processed through extensive chemical treatments following Williams-Dean (1986) with one exception. The samples were rehydrated in 0.5% trisodium phosphate for 48 h. After rehydration, macroscopic remains were screened from the microscopic remains and the microscopic residues were washed three times in distilled water. The sediments were treated in approximately 40% hydrochloric acid. After three distilled water washes, the sediments were left for 24 h in approximately 70% hydrofluoric acid. The samples were then washed repeatedly in distilled water until the supernatant was clear. After water washes and one glacial acetic acid wash, the residues were treated with a 20 min acetolysis treatment at 100°C. After one glacial acetic acid wash, the samples were then washed repeatedly in distilled water until the supernatant was clear. Finally and unlike Williams-Dean (1986), the sediments were treated in 0.5% KOH for 2 min and washed in distilled water three times. This was done to facilitate staining in basic fuchsin. The samples were then transferred to 1 dram vials and stored in glycerine. At least 200 pollen grains were counted for each sample, and up to 1,000 grains were counted for some samples. Pollen types were identified with reference collections of Colorado Plateau pollen samples. Single pollen grains and pollen aggregates were counted and tabulated. We noticed that many maize pollen grains were broken, shredded, or fragmented. These grains were consistent with those described by Bryant and Morris (1986) associated with grinding stones. We counted broken maize grains separately in order to determine whether there was significance in this observation. Only maize annuli were counted for the fragmented maize grains.

For statistical analysis, SAS was used for calculation of descriptive statistics, chi square values, and Wilcoxon analysis. The NPAR1WAY procedure was used to determine Wilcoxon scores (rank sums) for pollen counts by variable site.

3. Results and analysis

Sixteen pollen categories were chosen for statistical analysis. Whole maize, broken maize, and total maize categories were chosen to determine if there was a difference between the sites in the consumption of ground grain, assuming that broken maize grains resulted from grinding (Bryant and Morris, 1986). During macroscopic analysis, the terminal nodes immediately proximal to the strobili of *Equisetum* (horsetail) were found in several Antelope House coprolites (Sutton and Reinhard, 1995). Therefore, we thought it would be of interest to compare the frequency of *Equisetum* spores between the sites. Similarly, one Antelope House coprolite was composed of fiber with thousands of *Typha latifolia* pollen grains (Sutton and Reinhard, 1995). This coprolite was so rich in pollen, that it actually appeared yellow. Therefore, *Typha* was a logical choice for comparative pollen analysis. The macroscopic analysis showed a difference in *Rhus* (sumac) and *Phaseolus vulgaris* (bean) consumption with these plants more commonly occurring in Salmon Ruin coprolites. Phytolith analysis showed that *Opuntia* was more frequently eaten at Antelope House (Reinhard and Danielson, 2005). Therefore, we chose *Rhus*, *Phaseolus*, and *Opuntia* as comparative categories. *Cleome* pollen was common in the coprolites and the high frequencies of this type begged exploration. In previous analyses of coprolites, we found high spine Asteraceae to be common and therefore, we chose this category for analysis. Finally we chose to evaluate a number of anemophilous types to gain an idea of how much pollen could be ingested from the ambient environment and if it was possible to sort out dietary use of these types from ambient contamination. The anemophilous types chosen for study were low spine Asteraceae, Cheno–Am (Chenopodiaceae/Amaranthaceae), *Juniperus* (juniper), *Pinus* (pine), and Poaceae (grass family).

The pollen concentration values for Salmon Ruin and Antelope House are presented in Tables 1 and 2 respectively. The comparative descriptive statistics for sixteen select taxa are presented in Table 3. The first stage of the analysis was comparison of the frequency of occurrence of the categories between the sites. Chi square analysis (Table 4) showed that the frequency differences were significant at the 0.05 level only for *Typha* and *Equisetum*. Both of these taxa were more

Table 1
Pollen concentration values for 26 coprolites from Salmon Ruin

Taxa	1	2	3	6	7
Apiaceae				285	
Artemisia	6270	1524	276		
Asteraceae-high spine	1425		69		7600
Asteraceae-low spine	7695	1368	622	1700	
Brassicaceae	285				
Carex	285				
Cheno–Am	7695	80,256	8291	3705	273,600
Cleome	855	9576	967	62,415	53,200
Cucurbita					
Ephedra		456			
Equisetum					
Eriogonum					
Fabaceae		456			
Juniperus	4560	456	69	570	
Ligulaflorae type	285				
Liliaceae					
Maize broken	855	1814	2902	855	5,145,200
Maize whole	1425	3192	898	855	1,725,200
Opuntia					
Pinus	3420	1368	484		
Plantago					
Poaceae	1710	912	207	1140	592,800
Polemonium					
Quercus					
Rhus					
Rosaceae					
Sarcobatus	855				
Salix					
Shepherdia		456			
Sphaeralcea					
Typha					
Unknown	7125	456			
Unidentifiable	23,085	912	1244		1520

Taxa	8	9	10	11	13
Apiaceae		3800			
Artemisia					
Asteraceae-high spine			1221		39,086
Asteraceae-low spine	1256				
Brassicaceae		30,400			
Carex					
Cheno–Am	2511		1221		19,542
Cleome	1,216,000	3,750,600			6,364,457
Cucurbita			407		
Ephedra			407		
Equisetum					
Eriogonum					
Fabaceae					
Juniperus					
Ligulaflorae type					
Liliaceae		7600			
Maize broken	11,300		814	589,650	39,086
Maize whole	25,111		407	711,511	45,600
Opuntia	7533		401,850		
Pinus			407		
Plantago	2511	3800			
Poaceae					

Table 1 (*continued*)

Taxa	8	9	10	11	13
Polemonium					
Quercus	1256				
Rhus					
Rosaceae				1310	
Sarcobatus					
Salix					
Shepherdia					
Sphaeralcea					
Typha					
Unknown			407		
Unidentifiable		3800			6514

Taxa	15	16	17	18	19
Apiaceae				224	
Artemisia			1382	224	570
Asteraceae-high spine	200,018	814		2235	570
Asteraceae-low spine		2443	1382	5141	1140
Brassicaceae					950
Carex					
Cheno–Am	5182	4071	6909	7153	2850
Cleome	29,018	56,593	1,355,561	5365	78,470
Cucurbita					
Ephedra					
Equisetum					190
Eriogonum				447	
Fabaceae					2470
Juniperus	1036			671	190
Ligulaflorae type					
Liliaceae					190
Maize broken	133,691	6921		3129	8852
Maize whole	664,309	1629		10,059	48,590
Opuntia			8291		40,280
Pinus		2036		2459	190
Plantago					
Poaceae	2073	1221	9673	5812	1520
Polemonium					
Quercus				447	
Rhus		2443		224	
Rosaceae					
Sarcobatus	1036			447	570
Salix					
Shepherdia					
Sphaeralcea					
Typha		407			
Unknown				2235	950
Unidentifiable		3257	1382	2012	3420

Taxa	20	32	33	34	35
Apiaceae					156
Artemisia	283				156
Asteraceae-high spine	50,122	80	1322	3257	312
Asteraceae-low spine	2073	400	330		937
Brassicaceae	188	240			
Carex					
Cheno–Am	5276	2720	1487	8686	1249
Cleome	4522		133,165	1,060,743	11,556
Cucurbita	660	320		1086	2811

(*continued on next page*)

Table 1 (*continued*)

Taxa	20	32	33	34	35
Ephedra					
Equisetum					312
Eriogonum					
Fabaceae				1086	
Juniperus	94				
Ligulaflorae type					
Liliaceae		240			312
Maize broken	471	6640		1086	5153
Maize whole	565	5280		1086	937
Opuntia					156
Pinus	848	80	330	1086	156
Plantago					
Poaceae	848	80	165		156
Polemonium					
Quercus					
Rhus	188				
Rosaceae					
Sarcobatus	94	634	496	5429	468
Salix	94				
Shepherdia	94				
Sphaeralcea					
Typha				2171	
Unknown			330		
Unidentifiable	565	480	496	1086	2342

Taxa	37	38	39	40	41	42
Apiaceae				442		
Artemisia			2974	442		
Asteraceae-high spine		633	3635			
Asteraceae-low spine		1267	11,896	2209		950
Brassicaceae				442		1900
Carex						
Cheno–Am		4433	8922	5744	80,108	9500
Cleome	2,926,000	20,266	42,296	412,251	1,472,757	931,000
Cucurbita						
Ephedra		633	1322			
Equisetum						
Eriogonum						
Fabaceae		633				
Juniperus		1267	8261			
Ligulaflorae type						
Liliaceae			330			
Maize broken	9500	51,933	661	5744		950
Maize whole		53,200	6278	6186		
Opuntia						
Pinus			18,835	1326		1900
Plantago						
Poaceae	76,000	633	12,557	3977		1900
Polemonium			330			
Quercus			661			
Rhus				442		
Rosaceae						
Sarcobatus			2643	3535	6162	950
Salix			330			
Shepherdia						
Sphaeralcea						
Typha						
Unknown			5948			
Unidentifiable	4433		8591	5744	3081	1900

The values are number of pollen grains per gram of coprolite (pg/gc).

Table 2
Pollen concentration values for 26 coprolites from Antelope House

Taxa	1-11	1-17	1-18	2-5	2-14
Apiaceae					4366
Artemisia	78	24		1090	1213
Asteraceae-high spine	26	264	1572		243
Asteraceae-Low spine	26	120	376,200	99	485
Brassicaceae			786		728
Celtis					
Cheno Am	312	528	1966	10,706	7519
Cleome	364	240		2974	18,434
Cucurbita	52				
Ephedra					
Equisetum	104		393		2426
Fabaceae	26	24			485
Fraxinus	26			198	
Juglans					
Juniperus			393		1213
Liliaceae					
Maize broken		24		99	
Maize whole		72	393		243
Opuntia					
Pinus	208	336		1685	2668
Poaceae		48		397	
Polemonium					
Quercus		24			
Rhus				694	243
Ribes		576			
Rosaceae					
Sarcobatus					
Salix					
Shepherdia					
Sphaeralcea					
Typha	3921	3552	11,400	397	8489
Unknown	338	216		1487	1213
Unidentifiable					

Taxa	2-18	3-8	3-12	3-16	3-18
Apiaceae		301			
Artemisia	45	226		666	
Asteraceae-high spine		150	2850	83	402
Asteraceae-low spine	91	188		166	492
Brassicaceae		38			
Celtis	273				179
Cheno–Am	409	677	138,225	14,063	1520
Cleome	136	4440	8550	1331	2146
Cucurbita					1252
Ephedra	91				
Equisetum	45	75			179
Fabaceae	45	113			
Fraxinus					
Juniperus		38			
Liliaceae					
Maize broken	363	150			134
Maize whole	3815	226	2850	83	134
Opuntia					
Pinus	2135	451		250	894
Poaceae	182	376	128,250		134
Polemonium					

(continued on next page)

Table 2 (*continued*)

Taxa	5-19	6-6	6-8	6-13	7-5
Quercus			1425		
Rhus	227				
Ribes	182				179
Rosaceae					
Sarcobatus	45	75			
Salix	136				
Shepherdia		38			
Sphaeralcea					
Typha					
Unknown	500	301		250	447
Unidentifiable	681				224

Taxa	5-2	5-8	5-9	5-11	5-16
Apiaceae					
Artemisia				760	
Asteraceae-high spine	518	438		380	
Asteraceae-low spine	4145	2631		17,480	
Brassicaceae					
Celtis					
Cheno–Am	367,909	1754			
Cleome	71,509	415,662	12,129,600	366,700	
Cucurbita	518				
Ephedra					
Equisetum	518			18,240	3800
Fabaceae	6218				
Fraxinus					
Juniperus					
Liliaceae	518				
Maize broken	1036			380	858,800
Maize whole	1036			380	2,945,000
Opuntia					
Pinus	518			760	
Poaceae	22,800			1140	
Polemonium					
Quercus					
Rhus			11,400		
Ribes					
Rosaceae	1036				
Sarcobatus		438			
Salix					
Shepherdia					
Sphaeralcea					
Typha		7015	11,400		
Unknown	15,545				
Unidentifiable					

Taxa	5-19	6-6	6-8	6-13	7-5
Apiaceae					
Artemisia		1200		356	
Asteraceae-high spine	3353		600		
Asteraceae-low spine	671			178	
Brassicaceae	2682				
Celtis					
Cheno–Am	41,912	1500	3000	3028	34,200
Cleome		24,450	2600	23,513	
Cucurbita					11,400
Ephedra			200		
Equisetum		300	159,000	713	

Table 2 (*continued*)

Taxa	5-19	6-6	6-8	6-13	7-5
Fabaceae		600			
Fraxinus					
Juniperus			400	178	
Liliaceae					
Maize broken	8718		2400	48,984	
Maize whole	8382		11,400	52,013	
Opuntia			600		114,000
Pinus	671	150		1069	22,800
Poaceae	335	300	1600		
Polemonium					
Quercus					
Rhus		150			
Ribes					
Rosaceae					
Sarcobatus			200		
Salix	335				
Shepherdia			200		
Sphaeralcea					
Typha	1006	300	16,000	178	100,810,200
Unknown		1350	200	178	
Unidentifiable					

Taxa	7-13	7-14	8-2	8-13	9-13	9-10
Apiaceae						
Artemisia		903				
Asteraceae-high spine		903		1565		713
Asteraceae-low spine	760	1693	386	447	570	356
Brassicaceae				224		356
Celtis						
Cheno–Am	2280	2257	386	1565	570	11,044
Cleome	139,080	3048	72,844	15,871	37,620	326,325
Cucurbita		113	386			356
Ephedra						
Equisetum				4247		1069
Fabaceae						
Fraxinus						
Juniperus				224		713
Liliaceae				671		
Maize broken		1129		6259	1710	3563
Maize whole		9707		5588	14,250	10,331
Opuntia	3800	113		224		
Pinus	760	564	580	3129	570	713
Poaceae	760	451		1565		713
Polemonium						
Quercus						
Rhus		226			570	
Ribes						
Rosaceae						
Sarcobatus						
Salix		113				
Shepherdia				224		
Sphaeralcea						
Typha			193		129,960	
Unknown	3040	1242	773	3129	2280	
Unidentifiable						

The values are number of pollen grains per gram of coprolite (pg/gc).

Table 3
Descriptive statistics for taxa by site

Taxa and site	Mean	Standard deviation	#/ 26	Maximum concentration
Artemisia Salmon Ruin	552.3	1349.0	10	6270
Artemisia Antelope House	252.4	422.7	11	1213
Broken maize Salmon Ruin	231,815.7	1,008,883.4	22	5,145,200
Broken maize Antelope House	35,913.4	168,112.1	15	858,800
Whole maize Salmon Ruin	127,396.9	374,700.8	20	1,725,200
Whole maize Antelope House	117,919.4	576,710.0	19	2,945,000
Total maize Salmon Ruin	336,925.3	1,348,019.0	22	6,870,400
Total maize Antelope House	153,832.8	744,715.7	19	3,803,800
Cheno–Am Salmon Ruin	21,196.6	55,516.6	23	273,600
Cheno–Am Antelope House	24,897.3	75,314.7	23	367,909
Cleome Salmon Ruin	769,139.7	1,489,134.7	23	6,364,457
Cleome Antelope House	525,670.7	2,369,720.7	22	12,129,600
Cucurbita Salmon Ruin	203.2	590.1	5	2814
Cucurbita Antelope House	541.4	2231.3	7	11,400
Equisetum Salmon Ruin	0	0	0	0
Equisetum Antelope House	7350.4	31,144.5	14	159,000
High spine Asteraceae Salmon Ruin	12,015.4	40,193.0	16	20,0018
High spine Asteraceae Antelope House	540.8	878.4	16	3353
Juniperus Salmon Ruin	660.5	1804.5	10	8261
Juniperus Antelope House	121.5	282.4	7	1213
Low spine Asteraceae Salmon Ruin	1646.5	2723.3	17	11,896
Low spine Asteraceae Antelope House	15,660.9	73,616.4	20	376,200
Opuntia Salmon Ruin	17,619.6	78,780.6	5	401,850
Opuntia Antelope House	4566.8	22,332.6	5	114,000
Pinus Salmon Ruin	1343.3	3684.8	15	18,835
Pinus Antelope House	1573.5	4406.9	20	22,800
Poaceae Salmon Ruin	27,437.9	116,264.0	19	592,800
Poaceae Antelope House	6117.4	25,300.7	15	128,250
Rhus Salmon Ruin	126.8	483.0	4	2443
Rhus Antelope House	519.6	2226.5	8	11,400
Typha Salmon Ruin	99.2	430.0	2	2171
Typha Antelope House	3,884,769.7	19,769,002.7	18	101,000,000

#/26 refers to the number of coprolites from each sample of 26 positive for the specified taxon and site.

common at Antelope House. Broken maize is more common at Salmon Ruin, and the difference between the sites is almost statistically significant with a p (Z) value of 0.0663. Therefore, simple examination of the frequency data reveals three interesting differences between the sites with regard to dietary use of mesic taxa and ground maize.

To determine which taxa showed significant differences between the two sites, we ran the Wilcoxon procedure through SAS for each of the pollen categories. This is a 1 way non-parametric procedure which assumes a non-normal distribution of events. The resulting Z-values of this test are presented in Table 5. Five total taxa showed significant difference at the 10%

Table 4
Chi square values for taxa of interest

Taxa	Chi square	p value	Significant?
Artemisia	0.080	0.7775	No
Broken maize	3.373	0.0663	No
Whole maize	0.103	0.7488	No
Total maize	0.461	0.4971	No
Cheno–Am	0	1	No
Cleome	0.165	0.6845	No
Cucurbita	0.108	0.7420	No
Equisetum	8.739	0.0031	Yes
High spine Asteraceae	0	1	No
Juniperus	0.35	0.5544	No
Low spine Asteraceae	0.375	0.5404	No
Opuntia	0	1	No
Pinus	1.398	0.2370	No
Poaceae	0.765	0.3819	No
Rhus	0.975	0.3234	No
Typha	18.281	Less than 0.0001	Yes

Table 5
Wilcoxon scores for taxa of interest

Taxa	Wilcoxon score	Significant at 0.01 level	Significant at 0.05 level	Significant at 0.10 level
Artemisia	1.000	No	No	No
Broken maize	0.0067	Yes	Yes	Yes
Whole maize	0.1746	No	No	No
Cheno–Am	0.1696	No	No	No
Cleome	0.0462	No	Yes	Yes
Cucurbita	0.6049	No	No	No
Equisetum	0.0019	Yes	Yes	Yes
High spine Asteraceae	0.3181	No	No	No
Juniperus	0.2824	No	No	No
Low spine Asteraceae	0.4348	No	No	No
Opuntia	0.8947	No	No	No
Pinus	0.3061	No	No	No
Poaceae	0.0742	No	No	Yes
Rhus	0.3042	No	No	No
Typha	0.0007	Yes	Yes	Yes

confidence level. Poaceae showed a relative significance of difference with *Z*-value of 0.0742. *Cleome* was significant at the 5% confidence interval with a *Z*-value of 0.0462. The other three taxa, *Typha*, *Equisetum*, and broken maize showed very significant differences between sites with *Z*-values less than .01. Thus, the statistical analysis shows significant variation in five of the 16 taxa of interest and shows dietary variation in the use of wild and domesticated plants.

The real power of pollen concentration data is its ability to document the magnitude of pollen ingestion. The concentration value ranges of many taxa ran into hundreds of thousands to millions of pollen grains per gram of coprolite (pg/gc). The maximum values for each taxon and site are presented in Table 3. The highest total concentration of maize, including broken grains and whole grains, was 6,870,400 pollen grains per gram of coprolite (pg/gc) at Salmon Ruin compared to 3,803,800 pg/gc for Antelope House. In general, pollen grains from maize are more common in Salmon Ruin coprolites as seen in the higher mean (336,925.3 pg/gc) relative to the mean of 153,832.8 pg/gc for Antelope House. The means of whole maize pollen abundance are very similar for the sites (Table 3). However, there are four coprolites from Salmon Ruin that exceed 100,000 pg/gc as opposed to one for Antelope House. The statistically significant chi square value (p = 0.1 to 0.05) for the difference in broken maize pollen (Table 4) is amplified by the pollen concentration data. Both the mean and maximum pg/gc values are higher for Salmon Ruin (Tables 1–3). In general, we can assume that broken pollen was consumed with pollen-bearing, maize-based foods such as stews (Sutton and Reinhard, 1995) while the highest concentrations of whole maize probably were ingested with corn silk as suggested by Williams-Dean (1986) and Williams-Dean and Bryant (1975).

The mesic taxa, *Typha* and *Equisetum*, are very important in documenting dietary differences in the coprolite samples. The data strongly indicate that *Typha* was part of Antelope House diet. The mean value of 3,884,875 pg/gc and maximum value of 101,000,000 pg/ gc clearly show that *Typha* pollen was eaten at Antelope House. The lower mean of 99.1 pg/gc maximum of 2,171 pg/gc for Salmon Ruin possibly reflects ambient consumption of pollen with drinking water. *Typha* pollen was so abundant in some coprolites, that the coprolites actually have a yellow color and examination of the macrofloral component of such coprolites revealed clumps of pollen held together by spongy fibers. Clearly, the Antelope House Ancestral Puebloans collected and ate *Typha* male spikes. The mean concentration values of *Equisetum* spores (7354.7 pg/gc for Antelope House versus 0 pg/gc for Salmon Ruin) and maximum concentration values (159,000 pg/gc for Antelope House versus 0 pg/gc for Salmon Ruin) support the significant chi square analysis. These data verify the macrofloral analysis which indicated that *Equisetum* strobili were a part of Antelope House diet.

After maize, *Cleome* is the most ubiquitous dietary pollen type found in Ancestral Pueblo coprolites (Martin and Sharrock, 1964; Aasen, 1984; Williams-Dean, 1986). *Cleome* is an insect pollinated genus that should not occur in coprolites as part of natural contamination from the ambient environment. Although the frequency of occurrence is almost the same among Salmon Ruin and Antelope House coprolites, and although the highest maximum pg/gc occurs in an Antelope House coprolite, it appears that *Cleome* is

a greater dietary pollen source at Salmon Ruin. The mean pg/gc value is greater at Salmon Ruin and, when the data are plotted (Figure 2). It is clear that there are more *Cleome* values above 100,000 pg/gc for Salmon Ruin. Therefore, it is nearly ubiquitous in coprolites from both sites, but has greater concentrations at Salmon Ruin.

Cucurbita and *Opuntia* were prehistoric Ancestral Pueblo foods and were perhaps exploited to different degrees in different environments. Also, both types are insect pollinated and therefore should not occur as ambient contamination from the natural environment. In this analysis, neither type was ubiquitous. The difference in *Cucurbita* means looks important (Table 3), but it is influenced by one relatively high value of 11,400 pg/gc for one coprolite. The *Opuntia* values are more interesting. Each site has relatively high concentrations of this pollen type. In one Salmon Ruin coprolite, a very high value indicates the use of buds or flowers as food.

The data indicate that both high spine Asteraceae and low spine Asteraceae were background and dietary pollen sources (Table 3). With regard to pollination, low spine grains are primarily anemophilous

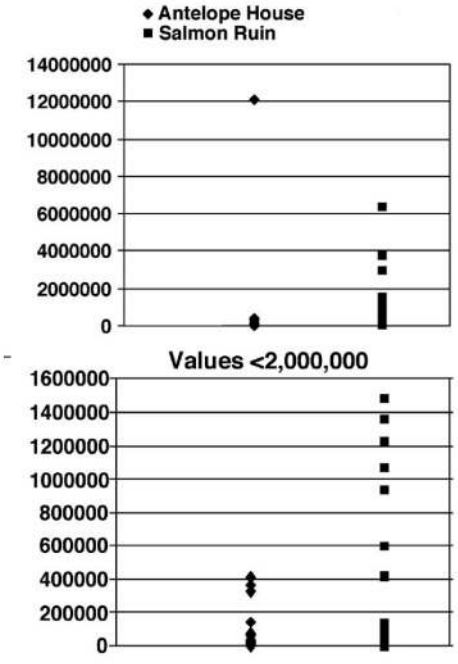

Fig. 2. Pollen concentrations for *Cleome* compared between Antelope House and Salmon Ruin. Although Antelope House has one very high spike, high concentration values are more ubiquitous at Salmon Ruin.

while high spine grains tend to be entomophilous. Both types occur in a majority of the samples. Usually, the concentrations for these types are under 20,000 grains per gram. However, at Salmon Ruin there are high numbers of high spine Asteraceae pollen at 40,000, 50,000, and 200,000 gp/gc. These higher values suggest that Asteraceae pollen-rich foods were eaten. At Antelope House there is one high value for low spine Asteraceae at 376,200 pg/gc. This high value also suggests that Asteraceae pollen-rich foods were eaten.

Chenopodium and *Amaranthus* seeds were eaten at both sites as shown by macrofloral analysis (Reinhard, 1992). *Chenopodium* or *Amaranthus* greens were eaten at Antelope House but not at Salmon Ruin as shown by phytolith analysis (Reinhard and Danielson, 2005). The high concentrations of Cheno–Am pollen in a minority of coprolites from both sites show that Cheno–Am pollen-rich foods were part of the diet at both sites. However, the majority of coprolites have lower concentrations of less than 10,000 pg/gc. These lower values are probably the result of ingestion of ambient pollen in air, drinking water, or food contaminated with anemophilous pollen.

Rhus seeds were a common food at Salmon Ruin as shown by macrofloral analysis of coprolites (Reinhard, 1996). The pollen data show no evidence of high concentration values (Table 3). Therefore, *Rhus* pollen-rich foods such as flowers were apparently not eaten at the sites.

Poaceae macrofossils, excluding maize, were found in Antelope House and Salmon Ruin coprolites. These included seeds of non-cultivated grasses, and glumes from grass spikelets. Most of the pollen concentration values of wild Poaceae were low and consistent with what might be ingested with water, air, or contaminated food. However, there are high values at both sites (Table 3) that signal the consumption of Poaceae pollen-rich foods.

The anemophilous types *Artemisia*, *Juniperus*, and *Pinus* occurred in low concentrations of less than 25,000 pg/gc (Table 3). In the field, juniper bark was noted in association with Salmon Ruin coprolites, but was not incorporated in the coprolites. There is no evidence that *Artemisia* was eaten at either site. Pinyon pine nuts were eaten at both sites. Harvesting nuts from sticky pine cones may result in transfer of ambient pollen from the pine cones to hands and harvested nuts. Thus, some *Pinus* pollen may have been eaten inadvertently as part of collected food. However, for the most part the pollen from these types appears to be non-dietary.

In general, there was a relationship between the total pollen content of the coprolites and the number of

plant taxa represented in the coprolites. Those coprolites with the highest over-all pollen concentration values had the fewest number of plant taxa represented by the pollen. Those coprolites that had relatively low pollen concentrations tended to have the largest number of pollen types. This is best seen in the data from Salmon Ruin. The coprolites that contained in excess of 1,000,000 grains per gram generally had an average of 5.2 taxa identified in the pollen counts. Coprolites with less than 10,000 grains per gram had an average of 11.9 taxa identified in the counts. The trend is also present in the Antelope House counts. The coprolites that contained in excess of 1,000,000 grains per gram had an average of 3.7 taxa identified in the pollen counts. Coprolites with less than 10,000 grains per gram had an average of 13.8 taxa identified in the counts. The types that are less likely to appear in higher counts are wind pollinated, non-dietary types. Therefore, it appears that when large amounts of pollen-rich foods are eaten, the ambient pollen becomes infrequent relative to dietary types. This is identical to the pattern previously reported by Reinhard *et al.* (2002). Therefore, the likelihood of finding the more dilute ambient types is lessened in pollen-rich coprolites.

We believe that the range of values for the taxa is striking and indicates that some taxa are more sensitive to differences in prehistoric behavior than others. The general Ancestral Pueblo reliance on maize and sporadic use of squash and prickly pear, for example, makes these taxa poor indicators of prehistoric differences in resource use. However, *Typha*, *Equisetum*, *Cleome*, wild grass, and broken maize exhibit significant variation which characterizes these taxa as a more interesting taxa for comparison. With regard to environmental taxa such as *Juniperus*, *Pinus*, and *Rhus*, there is no detectable difference.

4. Discussion

We believe that the pollen concentration values do provide exciting comparative data. The data are strongly influenced by the prehistoric practice of eating pollen-rich food. Past and current research shows some of the sources of this pollen. Bohrer (1981) demonstrated that some wild seeds commonly eaten in prehistory carry pollen from the source plant. Therefore, the consumption of certain seeds is a source of dietary pollen. This study shows that other pollen-rich foods included florets, buds and/or flowers, strobili, and male floral spikes. With regard to the Ancestral Pueblo, wild grass florets were eaten. The buds and/or flowers of Asteraceae, *Cleome*, *Opuntia*, and possibly *Cucurbita* were eaten. The strobili of *Equisetum* and the male floral spikes of *Typha* were eaten. It is likely that eating the greens of certain species could also be a source of dietary pollen. Phytolith analysis shows that wild grasses, *Cleome*, *Chenopodium* and/or *Amaranthus* were sources of greens for the Ancestral Pueblo at Antelope House. Therefore, some pollen could have been introduced from pollen contaminated greens. Maize pollen is abundant in the coprolites. The high concentration values which range into the millions indicate that the male florets and tassels were harvested and eaten. Another source of maize pollen could have been from ground grain as indicated by the higher amounts of broken grains at Salmon Ruin.

This study shows that pollen-rich foods were a common aspect of Ancestral Pueblo cuisine. Of the 51 coprolites studied here, 33 (63%) had over 100,000 pg/gc. Eighteen (35%) had between 100,000 and 1,000,000 pg/gc. Thirteen (25%) had between 1,000,000 and 10,000,000 pg/gc. Two coprolites (4%) had over 10,000,000 pg/gc. With regard to the dietary behavior represented by these coprolites, it appears that pollen-rich foods were more important at Salmon Ruin than Antelope House. Eighteen (69%) of Salmon Ruin coprolites have values over 100,000 pg/gc in contrast to 13 (50%) of Antelope House coprolites. However, the Antelope House Ancestral Pueblo targeted pollen or spore producing plant organs for harvest, specifically *Equisetum* and *Typha*.

The next logical question is what was the nutritional benefit of pollen-rich foods? The nutritional value of pollen has been evaluated in several studies (Herbert and Shimanuki, 1978; Schmidt and Schmidt, 1984). Pollen is 44% carbohydrate, 24% protein, and is a source of fat, sodium, vitamin C, calcium, iron, and potassium. Therefore, pollen-rich foods augmented the Ancestral Pueblo dietary sources of these nutrients. The contribution of pollen-rich foods to Ancestral Pueblo diet supports Cummings (1994) assertion that Ancestral Pueblo diet was essentially healthy.

Future research needs to be done to quantify the amount of pollen present in purported food sources. There is a need to harvest wild inflorescences, seeds, and other potential pollen-rich foods to determine how many pollen grains are produced per flower or are present per gram of greens and seeds. Once these types of baseline data are collected, we can then determine how much pollen-rich food originally consumed is represented by pollen grain per gram of coprolite values. This will further elucidate the prehistoric Ancestral Pueblo dietary use of pollen. Also, further analysis of many more coprolites from these sites must be done to assess potential differences in consumption of less common types such as Apiaceae, Brassicaceae, and Liliaceae.

The value of holistic coprolite analysis and pollen concentration can be demonstrated by contrasting past and current study. Antelope House human coprolites had been extensively analyzed decades ago. This provides us with an opportunity to show what can be learned through pollen concentration analysis in contrast to previous studies. Also, we can address the advantage of doing pollen concentration analysis as part of a holistic analysis of coprolites which includes macro-floral and phytolith analyses as well as observations of simple fecal smears made directly from rehydrated coprolites. Previous pollen analysis of Antelope House Ancestral Pueblo coprolites was done by Williams-Dean and Bryant (Williams-Dean, 1975; Williams-Dean and Bryant, 1975; Williams-Dean, 1986). The macrofloral analysis of the coprolites was done by Fry and Hall (1975, 1986).

The past pollen analysis and macrofloral analysis of Antelope House coprolites were done independently by separate researchers who were apparently not in communication. This resulted in misidentification of spores and a failure to recognize the dietary value of pollen and spores. Williams-Dean (1986) in her final report correctly recognized that *Typha* pollen was consumed by Antelope House Ancestral Pueblo. However, she confused *Equisetum* with *Populus*.It may seem outrageous that confusion of spores from a "primitive" vascular plant with pollen grains from a tree could occur. However, the spores of *Equisetum* and the pollen grains of *Populus* are very similar after acetolysis. After acetolysis, the elators which are diagnostic of *Equisetum* spores are destroyed (Kapp, 1969:65,67). Therefore, *Equisetum* spores look like *Populus* pollen grains after processing.

The first hint that *Equisetum* and not *Populus* was eaten comes from the macrofloral analysis. Fry and Hall found the terminal nodes immediately proximal to the strobili of *Equisetum* (horsetail) in 7% of 91 coprolites (Fry and Hall, 1986). However, Fry and Hall (1986) identified the remains as "horsebrush stem" which did not indicate clearly that the strobili were eaten. Thus, the palynologists were not alerted to the presence of *Equisetum strobili* and consequently misidentified these structures as *Populus*. Had the palynologists been directly aware of the macrofloral remains, they would probably have considered the differential diagnosis of *Equisetum* versus *Populus*. A second hint that *Populus* might not be the correct identification could have come from Bryant and Wier's (1986) analysis of pollen from Antelope House floors. They did not find that ambient *Populus* pollen was abundant in any of their samples. When we began this analysis, we had the benefit of reading Fry and Hall (1975, 1986). Also, Reinhard (1992, 1996) had done an independent macrofloral and parasite analysis of 112 coprolites from Salmon Ruins (Reinhard, 1996) and 180 coprolites from Antelope House (Sutton and Reinhard, 1995). We also had the advantage of having 180 parasite preparations from Antelope House coprolites and 112 from Salmon Ruin coprolites. These were not processed with acetolysis solution.

Reinhard found macrofloral *Equisetum* remains in 10 of 180 coprolites from Antelope House but not in any Salmon Ruin coprolite. Harlan and Dennis (1986) report three species of *Equisetum* from the area near Antelope House, *E. arvense*, *E. hyemale*, and *E. laevigatum*. Reinhard compared the macrofloral *Equisetum* remains with modern *Equisetum* and discovered that these were not just stem fragments as described by Fry and Hall (1986). These modern Antelope House species noted by Harlan and Dennis (1986), like other *Equisetum* species, have jointed aerial stems. For these species, nodes proximal to the terminal node connect two stem sections. Therefore, stem fragments have nodes attached to two distinct stem sections. The Antelope House *Equisetum* nodes were definitely terminal nodes. There was no distal stem section at the node. Also, the stems proximal to the nodes were cleanly cut. This shows that the Antelope Ancestral Puebloans used sharp implements, probably stone knives to cut the plant stems just at the terminal nodes and strobili.

Another hint that the Antelope House Ancestral Puebloans ate *Equisetum* spores came from the fecal preparations for parasite analysis. For parasite preparations, no chemical processing beyond rehydration is done. Therefore, it was possible to examine *Equisetum*/*Populus*-like structures for elators that occur on *Equisetum* but not *Populus*. At Antelope House, we could identify the elators on some of spores in the parasite preparations but not in the Salmon Ruin preparations. We are certain that the *Equisetum*/*Populus*-like structures in the Antelope House coprolites are spores of *Equisetum*.

Finally, there is negative evidence from the phytolith analysis that indicates that *Equisetum* stems were not eaten. *Equisetum* stems contain phytoliths. Had stems been eaten as identified by Fry and Hall (1986), we would have found *Equisetum* phytoliths in the coprolites. Although phytoliths were abundant in Antelope House coprolites, no *Equisetum* phytoliths were found (Reinhard and Danielson, 2005).

The error by Williams-Dean (1975, 1986) and Williams-Dean and Bryant (1975) was probably also made by Bryant and Morris (1986). Bryant and Morris analyzed pollen samples from grinding stones and ceramic jars in comparison to several control samples. They identified *Populus* pollen in 28 samples from ce-

ramic vessels, but did not encounter this type in any samples from grinding stones. The percentage of *Populus* pollen in the vessels ranged from 1% to 39.5% with a mean of 7.6%. Of seven control samples, only two contained *Populus* pollen in percentages of 2% and 5%. In the light of the discovery of *Equisetum* spores in the coprolites, it is probable that some or most of the "*Populus*" pollen found in the Antelope House ceramic vessels were actually *Equisetum* spores. It is interesting that the *Populus* pollen and *Typha* pollen was found in ceramic cemetery offerings (Bryant and Morris, 1986). Apparently, pollen and spore food sources were sufficiently valued to be included as burial offerings.

These comments are not intended to demean the work of Bryant, Wier, and Williams-Dean. Their combined Antelope House work is a milestone in the development of archaeological methods. We present this critique only to highlight that even the best palynologists can make errors when working independently of other investigators, especially analysts working with macrofossils. Because of the independence of macrofossil and pollen analysis done previously, and because of the identification of *Equisetum* terminal nodes as "horsebrush stem," the palynologists were not aware that a differential diagnosis of *Equisetum* spores and *Populus* pollen grains was necessary for true reconstruction of Antelope House diet. We recommend that palynologists work directly with macrofloral remains to avoid such errors. Also, we recommend that palynologists examine simple fecal smears from rehydrated coprolites to aid in differential diagnosis. Although Kapp (1969) asserts that *Equisetum* elators are lost in the process of fossilization, we were able to identify a few of these on spores before pollen processing. This indicates that fossilization of desiccated coprolites does not destroy the elators.

In the future, pollen concentration should be done with human coprolites from all cultural contexts especially hunter–gatherers. Hunter–gatherers probably ate pollen and spore producing organs. Heizer and Napton (1969) found this to be true of hunter–gatherers from the Great Basin. They note (1969:566), "dozens of the Lovelock coprolites are composed almost entirely of cattail pollen." Our analysis shows that such qualitative observations can be quantified with application of the pollen concentration technique. Only when this method is widely applied, will the anthropological community become aware of how widespread prehistoric people relied on pollen and spore producing plant organs for dietary use.

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The two archaeologists who excavated Antelope House and Salmon Ruin are paragons of scientific archaeology. Don Morris excavated Antelope House with the goal of collecting all biological remains. Therefore, his excavations produced an unprecedented collection of Pueblo cave biological materials. He fostered new technology and new applications, as exemplified by this study. For those of us who worked with Cynthia Irwin-Williams in the Salmon Ruin excavations, there is universal appreciation for her scientific zeal. As a mentor in field archaeology and research design, she was an inspiration that drove many young careers. Like Morris, Irwin-Williams was an excellent scientist with a vision of the future of archaeology and the skills and tools that would come as archaeology developed as a scientific field. Both Morris and Irwin-Williams took a direct interest in the analysis of coprolites.

In the first stage of laboratory analysis, Dr. Richard Hevly of the Department of Biological Sciences, Northern Arizona University played an important role. He was a product of a unique period in Arizona archaeology when botanists were trained in the archeological and geological sciences and went on to train a generation of environmental archaeologists. He was a pioneering coprolite analyst. As a master's major professor, he gave generously of his time to teach Colorado Plateau archaeobotany. In Hevly's case, his department never fully appreciated his work in geology and archeology because it fell out of the bioscience mainstream. Therefore, his efforts in training geoscientists and archaeobotanists were largely unrewarded.

In the second stage of analysis, Vaughn Bryant, Jr. of the Department of Anthropology at Texas A&M University played the key role. Vaughn worked with Texas archaeologists in developing research designs for the recovery of biological remains from cave sites. Trained as a botanist, Vaughn became the chair of the A&M Anthropology Department. In that position, he developed a center for training environmental archaeologists working in a diversity of places, including the Colorado Plateau. Vaughn directed the first palynological studies of Antelope House artifacts and coprolites. He provided the expertise, laboratory, and graduate student colleagues that contributed to the success of research projects. As graduate students, two other people contributed directly to this research. John Jones helped Reinhard master Colorado Plateau palynology. Richard Holloway encouraged the use of pollen concentration in the analysis of Antelope House.

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