Pollen analysis of sediment cores recovered from the Sand Creek Massacre National Historic Site.

Final Report
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EXECUTIVE SUMMARY

A series of sediment cores were recovered from two sites within the Sand Creek Massacre National Historic Site, one within Sand Creek and another from a nearby spring-fed pool. Pollen was analyzed from each core. The Creek Site cores record a series of deposits of silts and gravels indicating periodic flood events within the channel. About 30 cm of organic silty sediment are preserved in a pool above the last gravel deposit, representing the period from about 1850 to the present.

A chronology developed using radiometric dating (lead 210) gave an age of about 1850 for the sediment directly above the last gravel deposit. Around 1864, at the time of the Sand Creek Massacre, the vegetation at the site primarily consisted of small shrubs from the goosefoot family (*Chenopodium* and *Amaranthus*), commonly associated with dry environments. Grasses were also abundant, although sagebrush was uncommon. There is no evidence that willows were ever an important part of the riparian system at this site, thus their absence today is consistent with the landscape in 1864.

Since 1864, *Chenopodium* and *Amaranthus* have declined somewhat and sagebrush has increased in abundance, possibly in response to changes in disturbance such as fire and agriculture. A survey of the native vs. non-native species within this family (primarily *Chenopodium* and *Amaranthus*) would be worth pursuing to determine if most of the plants present today are natives.

Grasses have been present throughout the record, and appear to have been fairly abundant in the mid 19th century. Efforts to maintain grasslands associated with shrubs (primarily goosefoot) would be consistent with the vegetation history reconstructed from the pollen record.

PROJECT DESCRIPTION (from original task agreement)

The Sand Creek Massacre National Historic Site was authorized on November 7, 2000, encompassing 12,500 acres in the short-grass prairie region of southeastern Colorado. The park commemorates the 1864 massacre of Cheyenne and Arapaho people by the United States Army Volunteers. Among other mandates, the authorizing legislation calls for the NPS to protect “the cultural landscape of the site in a manner that preserves, as closely as practicable, the cultural landscape of the site as it appeared at the time of the Sand Creek Massacre.” In order to gain a better understanding of the site’s environmental history, current conditions, changes that have occurred over time, and possible causes of those changes, the park is working closely with several partners including the USDA Natural Resources Conservation Service, the NPS Southern Plains Inventory and Monitoring Network and the CESU.

Through the CESU network, environmental historians at Colorado State University have initiated a literature research project designed to collect as much information relevant to reconstructing the 1864 Sand Creek environment as possible. The literature research is providing a framework for understanding a century and a half of environmental changes at Sand Creek within a regional context. This valuable historical information may be greatly enhanced by the addition of information from the analysis of site-specific environmental indicators, including the record of pollen deposition at the site over time. By analyzing pollen data and tree ring data (a separately proposed project) and triangulating the results with the historical literature review, it may be possible to gain a comprehensive and reliable understanding of the 1864 Sand Creek Massacre site within its larger southern plains context.

This project is to extract and analyze pollen cores from the Sand Creek Massacre National Historic Site as a portion of a larger effort to reconstruct the historic environment of the site, to meet legislative requirements for managing the site for its 1864 conditions.

DESCRIPTION OF THE STUDY AREA AND FIELD RESULTS

On August 16 2005 I recovered sediment cores from the Sand Creek Massacre National Historic Site in Eads, Colorado with the assistance of Karl Zimmermann and Craig Moore, park rangers with the National Park Service.

We recovered a total of nine cores from seven different attempts at two different sites – a creek site and a spring site (Fig. 1). At the creek site, we initially cored in the deepest pool along the creek, east of the house off of County Road W. The initial coring at the creek site found that there was course sands and gravels not far below the organic rich sediments of the surface, so the many attempts were to try and recover the longest organic rich sediment core possible above the sands, as well as to then push through the sands to see if more organic rich sediments were below. Below is a description from the coring field notes.

Creek Sites:

Site A
I assumed that the deepest sediments would be in the center of pools along the creek. Our first attempt, Site A, was in a pool approximately 7 m wide and 33 m long with a water depth of 140 cm. We were able to push the Livingstone corer 90 cm into the sediment. (Visit http://lrc.geo.umn.edu/livingstone-bolivia.pdf to see a picture of the coring device). The surface sediments were organic but graded rapidly into coarse gravel that was nearly impossible to extrude. We probed the sediments with long metal rods to find where the bottom was softest. After testing with the rods and probing all through the pond we eventually gave up on coring in the center and went to the edges where we had better but not ideal results.

Site B
Based on the results of our probing, we moved to the edge of the creek channel to Site B. We cored right next to a stand of cattails within about 3 m of the edge of the stream channel and in a small side channel that appears to have retained the organic upper sediments better than the ponds. This channel did not reconnect with the main stream channel, but was like a cul de sac about 8 m long ending in a solid stand of cattails.

The water depth was 50 cm. Three cores were taken with the Livingstone. I stood in the water and the other two worked from the raft.

Core 1 – The first core recovered the surface sediments from 0-25 cm (75 cm total depth from the water surface to the base of the first core). There was complete recovery of the surface organic material down to the beginning of the gravel layer. The sediment was black and anoxic, with a strong sulfur smell.

Core 2 – The second core recovered ~47 cm of sediment and gravel from 25 – 72 cm (112 cm total depth from the water surface to the base of the second core). The sediments were gray at the top and brown at the base. It appears that the surface organic material has worked down into the gravels. The gravel lens which is very coarse and difficult to core is at least 25 cm and may be as deep as 50 cm. Depths were difficult to measure because the core is intended to go back down the same hole with each push and the gravel collapsed the hole to a certain extent.

Core 3. The third core recovered ~30cm of sediment below the sandy gravels, from 112 – 142 cm (142 cm total depth from the water surface to the base of the third core). This material appears to be a compact light brown silty clay with a lens of tan sand. The sediment appears to be fairly inorganic and is strikingly different from the surface samples.

The stratigraphy of Site B includes three distinct sediment layers; organic rich surface, gravelly lens, then inorganic clay/silt/fine sand layer below the gravel. Although my measurements are not crisp because the gravel was so difficult to work with, these three layers stand out as distinct and represent at least 3 different periods of deposition.

Site C – Plastic tube core #1

Using a large diameter plastic tube (~3" diameter) we pushed the tube directly into the mud to obtain a core. The purpose of using a plastic tube is to preserve the uppermost sediments which could be verified by viewing through the tube. The core was taken in about 70 cm of water and we began the push at 50 cm (20 cm above the sediment/water interface) to ensure that we recovered the surface sediments. The surface sediments were unconsolidated and the water really stirred them up. We recovered 50-60 cm of sediment. The top was quite fluid and the bottom was gravelly. I tried to put the Livingston down the same hole for a deeper core, but the gravels were so loose that they kept collapsing back into the hole. I took two cores with the Livingstone into the gravels to see if I could clean the hole and go deeper, but each time it refilled with gravel so we abandoned this effort.

August 17 we returned to the Creek Site

Site D – Plastic tube core #2

It was clear from the previous days coring that the stratigraphy at sites B and C had upper sediments that were organic rich silts and there was a sandy gravel layer at 30 cm depth that was preventing deeper coring. The goal the second day was to recover duplicate cores so that the most complete cores could be used for analysis. Site D was located several feet over from Site C, in water that was 78 cm deep. We pushed from 70 cm depth (beginning the push 8 cm above the sediment/water interface) and again got a good surface core recovery. We drilled holes in the tube to drain the water and the core settled down to a length of about 50 cm again with the upper layers very loose and watery and the bottom gravelly. The cores were transported in an upright position after cutting tubes to length and draining most excess water.

Site E – Colinveaux corer

Sands and gravels do not preserve pollen, so we were not interested in a duplicate core from the gravel section, but we wanted to obtain a duplicate core of the silty inorganic sediments below the gravel layer that we discovered in Core 3 from Site B. We pounded a Colinveaux corer in near where site D was taken to try and get through the coarse sands and gravels to the inorganic sediments beneath. (A Colinveaux corer is similar to a Livingstone corer but us built stronger for pounding with a hammer). We pushed the corer through the upper soft sediments (~ 40 cm) until we hit the gravels and then pounded it about another meter. The basal material was a sandy organic silt, but there was no way to tell in the field what the rest of the sediments looked like since with this system, we leave the material in the aluminum barrel until we return to the lab. The top of the core was coarse sands and gravels. We transported the barrel in an upright position with a rag inside to minimize shifting of the core where there was a gap at the top.

Spring Site

After finishing coring at the creek site, we explored further and found a spring site about ½ mile from the first coring location (Fig. 1). The pool has no apparent inlets or outlets. In hindsight this may have been the best site for pollen coring. Since we found this site late in the day on our second and last field day, we did not set up the raft but cored standing in the pond in about 50 cm of water. The pond was filled with dead tumbleweeds which made it difficult to determine the sediment water interface. We were able to obtain two cores by pushing in plastic tubes.

Core 1 – Plastic tube core #3
Many submerged tumbleweeds in the pond made it very difficult to be certain where the sediment/water interface was, but we measured a water depth of ~30 cm. Again the sediment was very loose so the surface core began where the sediment was a bit firmer, with less loose water in the top. I am not certain that the top is the true sediment water interface, but the resulting core had much less surface disturbance. We recovered 55 cm of organic rich black sediment. We attempted to core to the sandy base but for whatever reason could not push any deeper. We assumed that this core represented the top 50 cm.

Core 2 – Livingstone core
We moved over about 2 m south, parallel to the shoreline and took another core with the Livingstone corer. We let the corer settle into the sediments 40 cm. Water depth here was 30 cm so I think this core begins 40 cm below the sediment water interface, but again, the exact interface was difficult to determine. We recovered 42 cm, which represents the sediment from 40 – 82 cm depth. I assume that this then has about a 15 cm overlap with the surface core, but depth here is probably not a perfect 1:1 correlation so these will have to be matched with pollen stratigraphy if possible. The Livingstone core went to the sandy bottom, but I could not penetrate deeper. It is possible that some of the sand slipped out of the bottom of the corer when I pulled it up since I pushed 53 cm. It was tricky holding the piston cable in place so we could have lost the bottom 10 cm back out the barrel on the recovery.

All cores were stored in a 4º C cold storage facility at the University of Nevada, Reno.

Core descriptions and analysis

Core descriptions

Three different cores were analyzed. From the Creek site, I analyzed cores D and E. From the Spring Site, I analyzed Core #1.

At the creek site, core D was selected as the longest and best preserved continuous sediment core. This core was ~50 cm in length, with the upper 29 cm being a black, organic rich silt. From 29 – 32 cm the sediment increased in percent sand, and below 32 cm the sediments consisted entirely of coarse sands and gravels. No pollen analysis was done on the gravelly sediments.

Core E was analyzed since it was the best preserved core that extended below the gravel layer. From ~ 32 cm depth to 90 cm depth the sediments consisted of coarse granitic sands and gravels. Beginning at 90 cm and extending to 105 cm the sediments changed to inorganic silt with fine sand. Below 105 cm the sediments again became coarse sands and gravels.

From the spring site, only Core 1 was analyzed since it contained the surface sediments and it was difficult to determine where Core 2 overlapped with Core 1. Similar procedures for sediment and pollen analysis were conducted on all cores.

Sediment analysis

Percent water, percent organic material, percent carbonate and percent non-carbonate inorganic material was measured for each core. Percent water was obtained by weighing a 1.25 cc sample of wet material and placing it in a crucible into a 100º C oven for 24 hours, then reweighing to obtain the dry weight. Samples were then combusted at 600º C in an oven (loss on ignition) to obtain the percent organic matter and finally combusted at 1000 º C to determine percentage of carbonate and inorganic carbonate (Dean, 1974).

Sixteen samples (taken every two cm) were taken from Core D and three from core E at the Creek site (Table 1). Twenty-five samples (taken every two cm) were taken from Core 1 at the Spring site (Table 2)

Pollen analysis

A total of sixteen samples were analyzed for pollen from the Creek Site. Thirteen samples were taken from core D, above the gravels, and three samples from Core E below the gravels. The sands and gravels held no pollen. Eleven samples were taken from Core 1 at the Spring Site for pollen analysis. Pollen preparation followed standard procedures outlined in Faegri and Iverson (1985). A known quantity of *Lycopodium* (clubmoss) spore tracers were introduced into each sample for calibrating pollen concentration (Stockmarr 1971).

Between 190 and 280 terrestrial pollen grains were counted for each sample (mean = 227), excluding aquatic types, such as *Typha* (cattails), Cyperaceae (sedges) and

Potamogeton (pondweed). *Lycopodium* spore tracers were counted in addition to pollen grains to calculate pollen concentration.

Pollen was identified to the lowest possible taxonomic level using reference material in the UNR Palynology laboratory and published pollen keys (Kapp et al. 2000, Moore and Webb 1978). In some cases, pollen can only be identified to family groups, such as TCT which includes members of the Taxodiaceae (bald cypress) family, including species such as redwood, the Cupressaceae (cypress) family including various juniper species, and the Taxaceae (yew) family, including yews. The pollen was assumed to be *Juniperus* (juniper) since no other member of these families occur in the region.

RESULTS

Creek Site

Chronology

Only core D was dated due to budgetary constraints. No dates were obtained until after the pollen analysis was largely completed in the hopes that the pollen might provide guidance on what dating method to use and where to obtain dates.

The initial pollen results, combined with the short length of the core and the knowledge that this is an active fluvial system suggested that the sediments may have been deposited over a fairly short period of time. To test this, I chose to use the Pb-210 (lead 210) dating technique rather than ^{14}C radiocarbon analysis. Pb-210 is used to determine the accumulation rate of sediments in lakes and other bodies of water over a period of 100-200 years. An assumption in this dating technique is that a constant amount of Pb-210 is accumulating in the site. Pb-210 measures decay to a background level. Background is generally considered to be about 100 years and age models can be fit within this approximate period of time. Once sediments have reached background, the age model falls off quickly and dating below that level is not reliable. Below the range of Pb-210, it is advisable to use ^{14}C dating. Radiocarbon is unreliable within the last 200 years, so the time period from about 1800 – 1900 A.D. is difficult to date precisely and often inferred from dating methods and potential ecologic changes.

Continuous 1-cm thick samples were sent to Flett Research Ltd., Canada for Pb-210 analysis. Those results were then interpreted for dating by Alan Haeyvert of the Desert Research Institute, a research institute of the Nevada system of Higher Education, in Reno, Nevada. The age model indicated that Pb-210 reached background levels at 29 cm depth (Fig 2). Haeyvert assigned a date of 1910 to the depth of 28.5 cm and 1860 to the depth of 29.5 cm. Below this depth, it is difficult to assign accurate dates since the age model changes rapidly (Fig. 2), but reasonable to conclude that these sediments represent the pre-historic period. Since pollen samples were from 28 cm (~1925 AD) and 30 cm (~1850 AD) the pollen record has no data between 1850 and 1925.

Sediments

The sediments are relatively inorganic, (1-3% organic) between 105 and 90 cm depth (undated sediments below the gravel), and only 2-3% organic at the sediment depth of 29-32 cm, just above the sands and gravels (Table 1, Fig. 3). This sand and gravel layer is likely a flood deposit laid down over what was probably a small pool (similar to what we cored) that had previously been collecting sediments (and pollen). The flood deposits may or may not be one event or a number of events. I did not date materials from below the gravels, so the true age of that deposit is unknown, although it is reasonable to conclude that it is pre-historic in age. There are no sands or gravels in the upper 30 cm (deposited since 1850) to indicate floods that deposited sediment in this pool during the historic period. The sediments steadily increase in organic content to about 10-11% at the surface.

Pollen

The percent pollen of plants in the Chenopodiaceae family and genus of *Amaranthus* (ChenoAm) are the dominant pollen types at the creek site (Figs. 4 & 5). Cheno Am pollen could represent native species within the Chenopodiaceae family (i.e. *Chenopodium glaucum* ssp. *salinum*– Rocky Mountain goosefoot) and genus *Amaranthus* (*Amaranthus arenicola* – sandhills pigweed), or introduced species such as *Bassia hyssopifolia* – fivehorn smotherweed, *Chenopodium botrys* – Jerusalem oak goosefoot, *Chenopodium album* - lambsquarters, and *Amaranthus albus* – prostrate pigweed. There are several trends in the ChenoAm pollen worth noting. First, ChenoAm pollen comprises 64% of all terrestrial pollen in the pre-historic sediments below the coarse sand layer, is at 50% in the sediments about the turn of the century, and has declined to only 32% today.

Another trend seen in the pollen record is the increase in *Artemisia* (sagebrush) pollen in recent time. In the pre-historic period, sagebrush pollen was only 2-4%, and this was true at the turn of the century as well, but since that time it has increased to about 10%. This is confirmed in the pollen concentration data.

Grass pollen (Poaceae) has also increased since the pre-historic period. This trend is not confirmed at the spring site. It is possible that the preservation of grass pollen was poor in the sandy sediments of the creek site; however this is worth exploring further.

What is of interest for its absence is the lack of any significant riparian tree pollen, particularly *Salix* (willow). Of all the pollen analyzed, I found only one Salix pollen grain, at the1984 depth in the creek site core. Willow pollen is typically common in sediments fed by streams lined with willow, and while it is not always abundant, it is typical to find grains in most levels examined. Cottonwood (*Populus*) pollen was also absent from the core, however this is not unusual since this pollen type is not typically preserved and even in sites dominated by cottonwoods, the pollen is commonly absent. *Alnus* (alder) pollen was found in very small quantities in three samples from the 20th century. This pollen type is very resistant and is common in sediments along riparian corridors. The low abundance suggests that it is from a distant source, either through fluvial transport, or possibly wind transport.

Typha (cattail) pollen only appears after 1950 (Fig. 3), suggesting that the cattail thickets along the creek appear to be a fairly recent change to the system. Cyperaceae (sedges) are present in all levels, suggesting that the creek system has always at least had sufficient soil moisture to support these water-loving plants.

Spring Site

Chronology
No radiometric dates were obtained for this core. Without obtaining dates on the spring core, we cannot confirm a chronology, but the pattern of change in the pollen record with depth is very similar to that at the creek site, suggesting that the spring site also holds a record of sediments extending back at least a few centuries. Since the Creek Site sediments show no clear evidence for flood deposits within the last century, I assume that for both the Spring and Creek sites, most deposition is from windblown deposits or organic material formed in place, and that the sedimentation rates are similar. If this assumption is true, then the Spring site should hold at least two centuries of sediments and the base of the core analyzed should represent the pre-historic period.

Sediments
The spring site does not contain layers of gravel and sand associated with the creek environment (Fig 6). Percent organic matter (Table 2) is comparable with the creek site averaging 6% throughout the core with a maximum of 11.4%. Although a grain size analysis was not done, these sediments still had large amounts of sand, most likely blown into the pond.

Pollen
Trends in pollen percentages at the Spring Site are generally similar to those found at the Creek Site, however there are some differences. The decrease in ChenoAm pollen towards the present is not as strong at the Spring Site. At the Spring Site I identified two different forms of ChenoAm pollen based on the number of pores (<20 pores and > 20 pores, with *Chenopodium* typically having <20 and *Amaranthus* having >20 pores, typically 30 or more). In Figure 7 I have plotted the trends of one type versus another and there is a very clear trend that *Chenopodium* pollen (<20 pores) were much more common in the lower part of the core, and *Amaranthus* (>20 pores) have increased in importance in recent times.

Artemisia (sagebrush) pollen increases towards the present similar to the Creek Site, but Poaceae (grass) pollen does not. Typha (cattail) pollen is rare, only occurring near the surface, but Cyperaceae (sedges) are again present at all depths, suggesting that there has always been the presence of moist soil, but possibly not standing water, preferred by cattails.

No *Salix* (willow) pollen was found at the spring site.

DISCUSSION

The age model developed from Pb-210 indicates that the cores analyzed span the historic and reach into the pre-historic period. At the Creek Site, the sediments at a depth of about 29 – 30 cm appear to most closely align with the time period of 1864 AD. Below this depth there is a thick (~30-50 cm) layer of gravel and coarse sands. It is interesting to note that age structure studies conducted on plains cottonwood (*Populus deltoids* ssp. *monilifera*) identified a germination cohort between 1865 and 1875 AD (Lukas and Woodhouse, 2006). One hypothesis concerning cottonwood establishment is that successful germination is often associated with flood events. Although the Pb-210 dating cannot be identified with specific annual events, there is some chance that the gravels deposited immediately below the 30 cm depth (ca 1860) are associated with a flood ~1864 AD. Coarse sands and gravels require fast flowing water to move and deposit. Assuming that the Pb-210 age model is correct, the gravels at the Creek Site were deposited during the mid to late 19th century. Since that time, the bare gravels began collecting organic material, cattails arrived and have continued to increase in abundance, resulting in the wetland seen at the site today. There is no evidence that willows have ever been important at the site, and the absence of willows at the site today is consistent with the paleoecologic record.

The terrestrial pollen suggests that the plants growing beyond the riparian zone have changed remarkably little over time. About 1860, the dominant plants on the plains would have been from the Chenopodiaceae (goosefoot) family. Plants in this family typically thrive in dry environments. Sagebrush would have been fairly limited. About 1860, grasses also appear to have been fairly common. There is no evidence for willows within the creek channel and no evidence of other trees in the landscape. While the pollen record has some pollen of pine and juniper, pine pollen is known for traveling long distances and this is undoubtedly wind transport from the Rocky Mountains, not local populations.

Prior to 1860, Chenopodiaceae appear to have been even more abundant and grass less common. Although there is no chronology for the pre-historic sediments below the gravel layer at the Creek Site, the pollen record suggests that at times in the past, the region of the Sand Creek Massacre National Historic Site were even drier than today. The evidence points to a dry and barren landscape.

Since 1860, sagebrush appears to have increased and Chenopodiaceae has decreased somewhat. Evidence from the ChenoAm pollen at the spring site suggests that there has been a shift in the types of Chenopodiaceae species at the site over the last century. It is possible that this shift is away from native species towards introduced species, but further work with the pollen record, as well as other ecological studies are needed to confirm this. It is unclear to what would favor an expansion of sagebrush in relation to saltbush Chenopodiaceae. Within the last century, there have been changes in fire frequency, and well as increased disturbance associated with agriculture. Changes in disturbance regime may have favored sagebrush in recent decades. This is worth examining.

CONCLUSIONS, MANAGEMENT IMPLICATIONS AND FURTHER RESEARCH

Since 1860, there have been few changes in the terrestrial vegetation within the Sand Creek Massacre National Historic Site. The area appears to have been dominated by drought tolerant members of the goosefoot family since pre-historic time. In recent decades, goosefoot have declined some and sagebrush have increased. There are many non-native invasive members of the goosefoot family that may have been introduced to the site within the past century. A survey of the native vs. non-native species within this family (primarily *Chenopodium* and *Amaranthus*) would be worth pursuing to determine if most of the plants present today are natives. The pollen record suggests that during the pre-historic period the site was dominated by native Chenopodiaceae, and that in 1864, this would have still been the case. The recent increase in sagebrush may be the result of changes in disturbance within the recent century.

I was able to identify some differences in pollen between Chenopodiaceae, and it might be worth pursuing this line of study further if there is a relationship between the number of pores in pollen of non-native species vs. native species. This would help us understand when invasive species became important at the site.

Grasses have been present throughout the record, and appear to have been fairly abundant in the mid 19th century. Efforts to maintain grasslands associated with shrubs (primarily goosefoot) would be consistent with the vegetation history reconstructed from the pollen record.

There is no evidence that willows were ever an important part of the riparian system at this site, thus their absence today is consistent with the landscape in 1864. Willows are most common in continuously wet cool environments, associated with montane environments, and the dry wash system on the plains may simply be too dry to support these trees.

REFERENCES

Dean, W.E. Jr. 1974. Determination of carbonate and organic matter in calcareous sediments by loss on ignition comparison to other methods. Journal of Sedimentary Petrology 44:242-248.

Faegri, K., and J. Iversen. 1985. "Textbook of Pollen Analysis," 4th edition. Hafner Press, New York.

Kapp, R.O., O.K. Davis, and J.E. King. 2000. Ronald O. Kapp's Pollen and Spores: 2nd edition. American Association of Stratigraphic Palynologists, College Station, TX.

Lukas, J. and Woodhouse, C. 2006. Riparian forest age structure and past hydroclimatic variability, Sand Creek Massacre National Historic Site and Bent's Old Fort National Historic Site. Draft Final Report, July, 2006.

Moore, P.D. and J.A. Webb. 1978. An Illustrated Guide to Pollen Analysis. Wiley and Sons, New York. 133 pp.

Stockmarr, J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13, 615-621.

Table 1. Sediment Analysis - Creek Site, Cores D (0-30 cm) & E (92-104 cm). Core E is undated.

Depth cm	Year AD	Water %	Organic %	Carbonate %	Non-carbonate inorganic %
0	2005	62.0	10.5	8.6	80.9
2	2001	63.1	11.1	13.2	75.7
4	1997	61.0	11.0	9.1	79.9
6	1993	63.4	11.1	4.9	84.0
8	1988	45.4	5.0	9.2	85.8
10	1984	52.5	8.2	7.3	84.5
12	1981	58.5	9.4	8.7	81.9
14	1978	51.1	6.2	7.0	86.7
16	1972	30.8	3.0	2.5	94.6
18	1967	35.2	3.7	3.7	92.6
20	1960	33.3	3.2	3.8	93.0
22	1954	34.1	3.6	3.9	92.5
24	1946	22.6	1.9	1.8	96.2
26	1936	24.5	2.2	1.4	96.4
28	1922	35.1	3.4	2.0	94.6
30	1850	18.0	2.0	1.7	96.4
		No analysis - gravels			
92		17.6	2.2	0.8	96.9
96		14.9	1.3	0.8	97.9
104		20.2	3.4	1.2	95.4

Table 2. Sediment Analysis - Spring Site, Core 1

Depth cm	H2O %	Organic %	Carbonate %	Non-Carbonate inorganic %
0	43.5	6.2	4.6	89.2
2	43.5	6.2	4.6	89.2
4	56.7	9.3	6.0	84.7
6	62.6	11.4	9.0	79.6
8	60.2	10.7	9.0	80.4
10	54.5	9.0	4.3	86.6
12	49.4	6.8	3.6	89.6
14	36.3	4.3	4.2	91.5
16	29.3	4.0	1.9	94.1
18	40.9	5.7	2.7	91.6
20	45.1	7.6	2.4	90.0
22	27.1	3.8	1.4	94.8
24	28.6	4.2	1.8	94.0
26	31.9	4.8	1.7	93.5
28	30.2	4.7	1.8	93.4
30	31.3	4.8	1.7	93.4
32	36.7	5.9	1.6	92.5
34	30.5	3.8	1.5	94.6
36	27.8	5.2	2.5	92.3
38	25.0	4.2	2.7	93.1
40	33.2	5.8	1.6	92.6
42	28.5	4.5	1.4	94.1
44	27.8	4.3	1.6	94.1
46	26.5	4.6	2.4	93.0
48	29.9	5.4	1.5	93.1

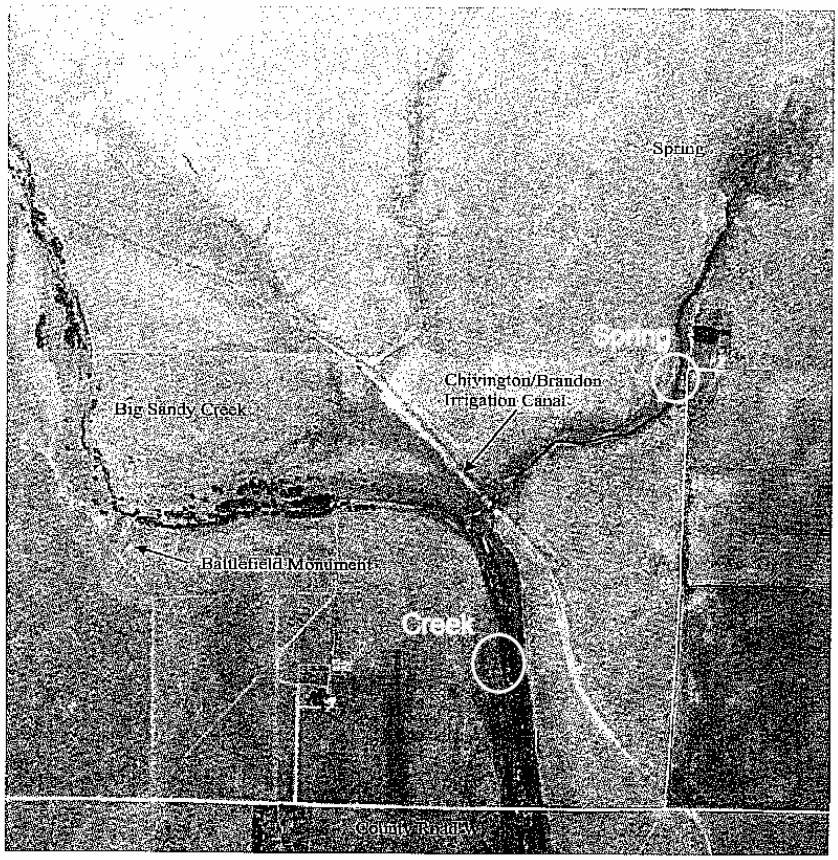

Fig. 1. Location of the coring sites within the Sand Creek Massacre National Historic Site. Figure represents the southern portion of the current park area along County Road W.

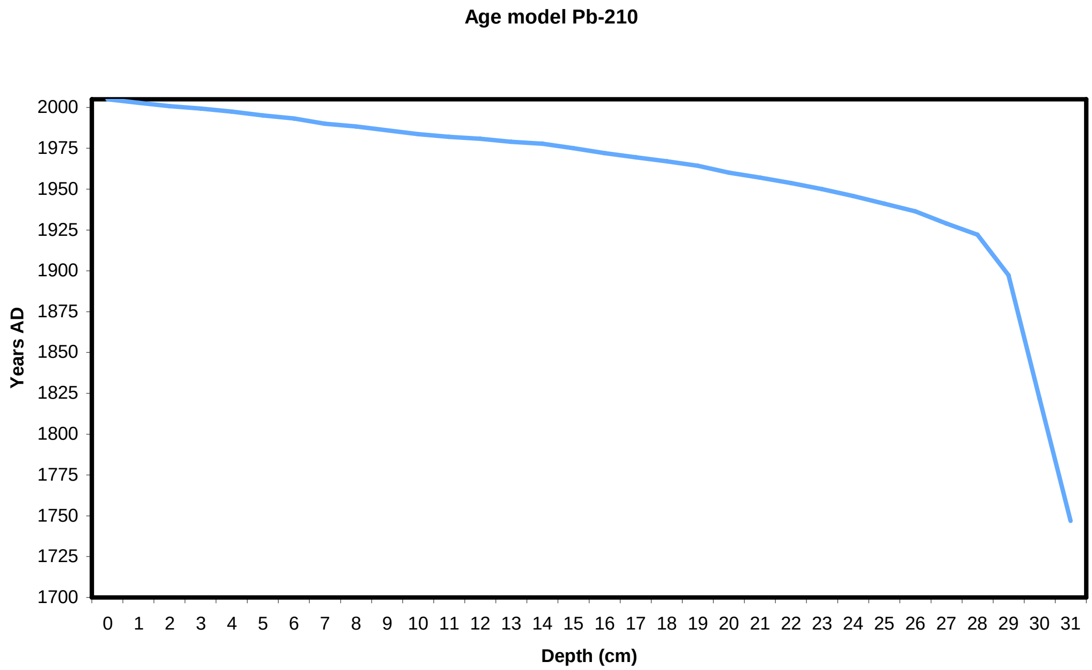

Fig. 2. Age model for the Creek Site core developed from Pb-210 analysis. Pb-210 reaches background levels at 29 cm depth at an age of about 1880 AD, after which depth the dating becomes less reliable, indicated by the sharp change in the curve.

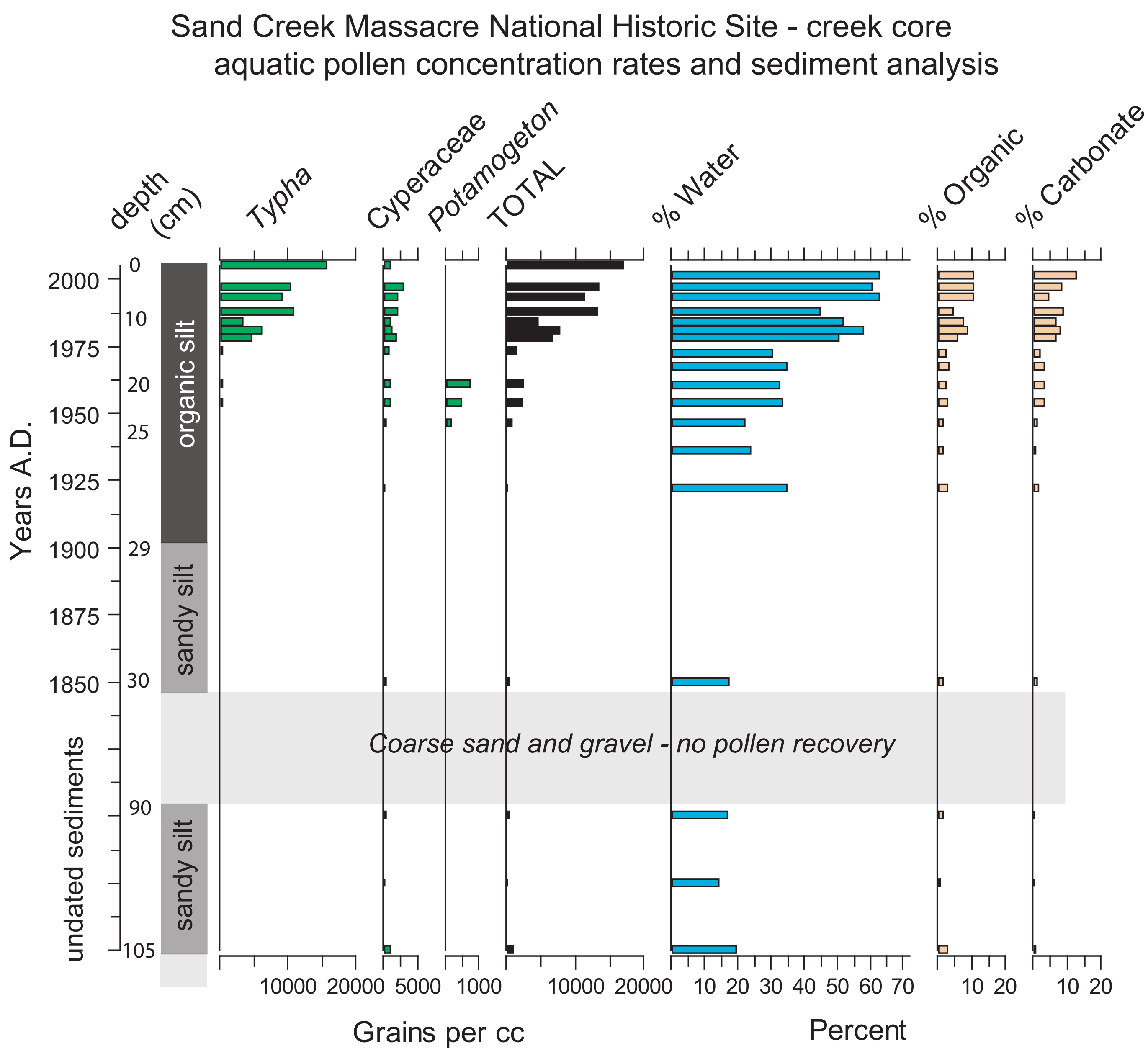

Fig. 3. Aquatic pollen type concentration rates and sediment analysis for Cores D & E from the Creek Site, Sand Creek Massacre National Histroic Site. Pollen types include *Typha* (cattails), Cyperaceae (sedges), and *Potamogeton* (pondweed).

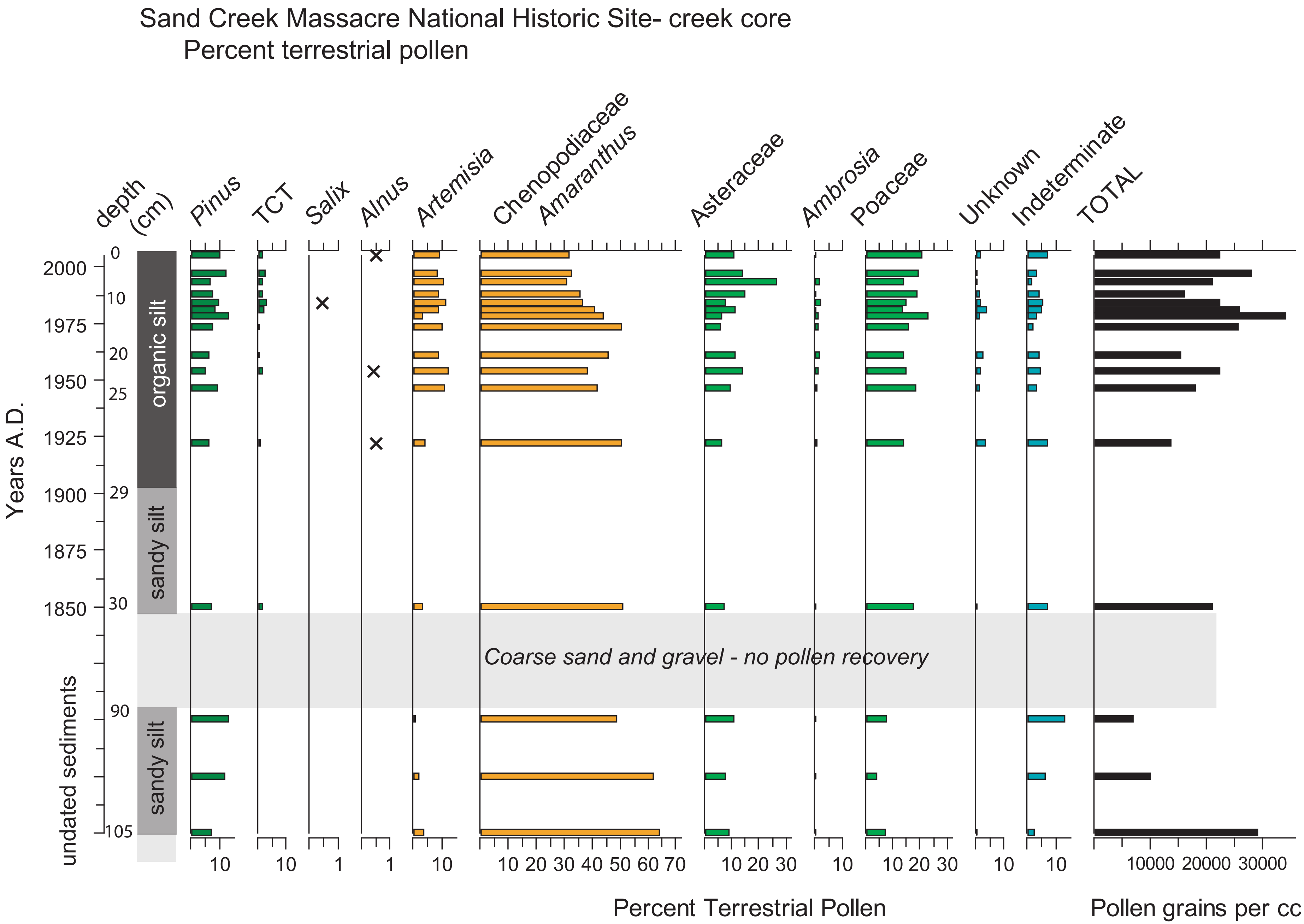

Fig. 4. Percent pollen for major terrestrial pollen types from the Creek Site at Sand Creek Massacre National Historic Site. Common names for pollen types are given in the text. Total represents the total pollen concentration per sample. X marks samples with <1% abundance.

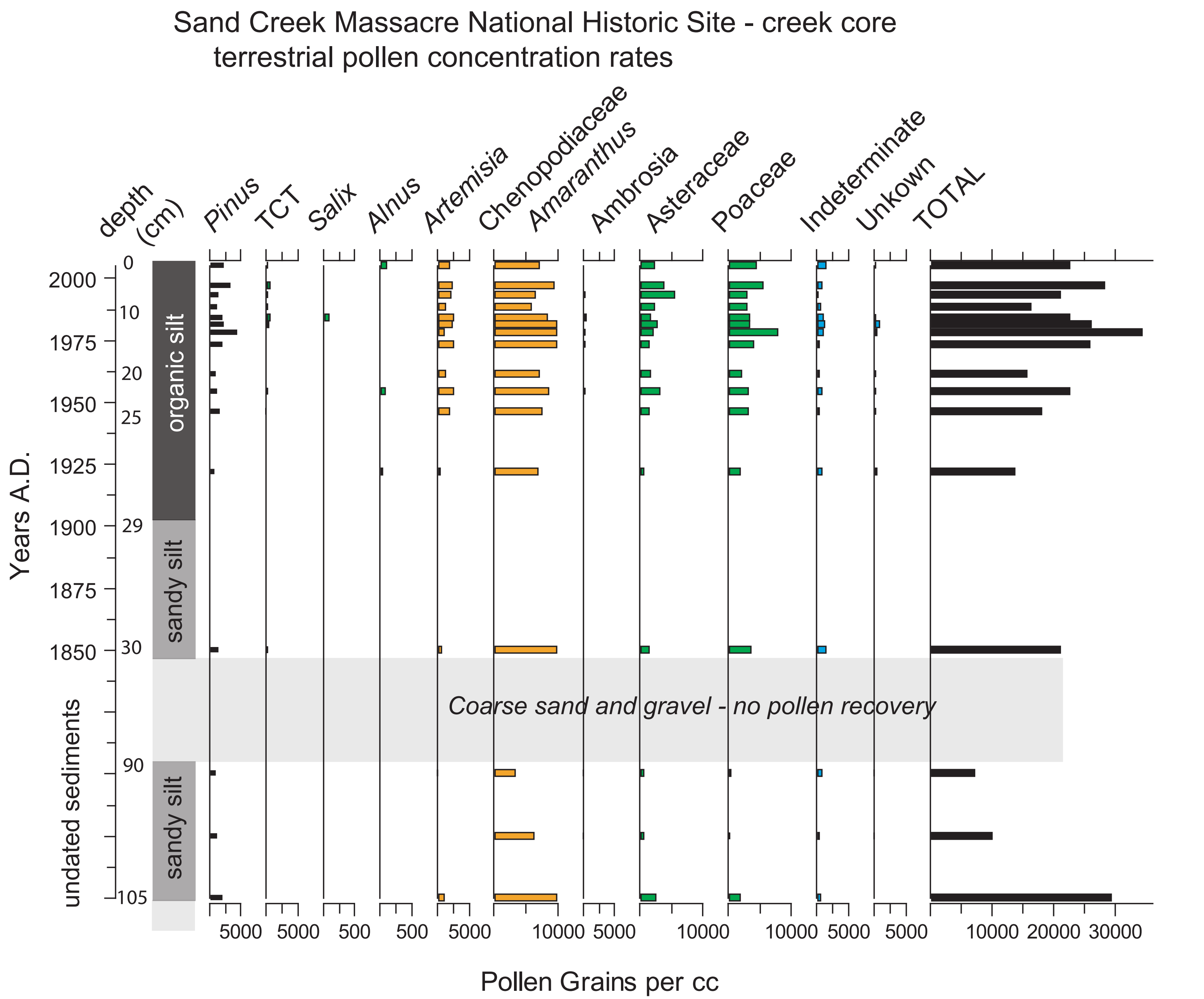

Fig. 5. Terrestrial pollen concentration rates from the Creek Site, Sand Creek Massacre Histroic Site. Pollen taxa are explained in the text. TCT is assumed to be juniper pollen.

Sand Creek National Historic Site - spring site
aquatic pollen concetration rates and sediment analysis

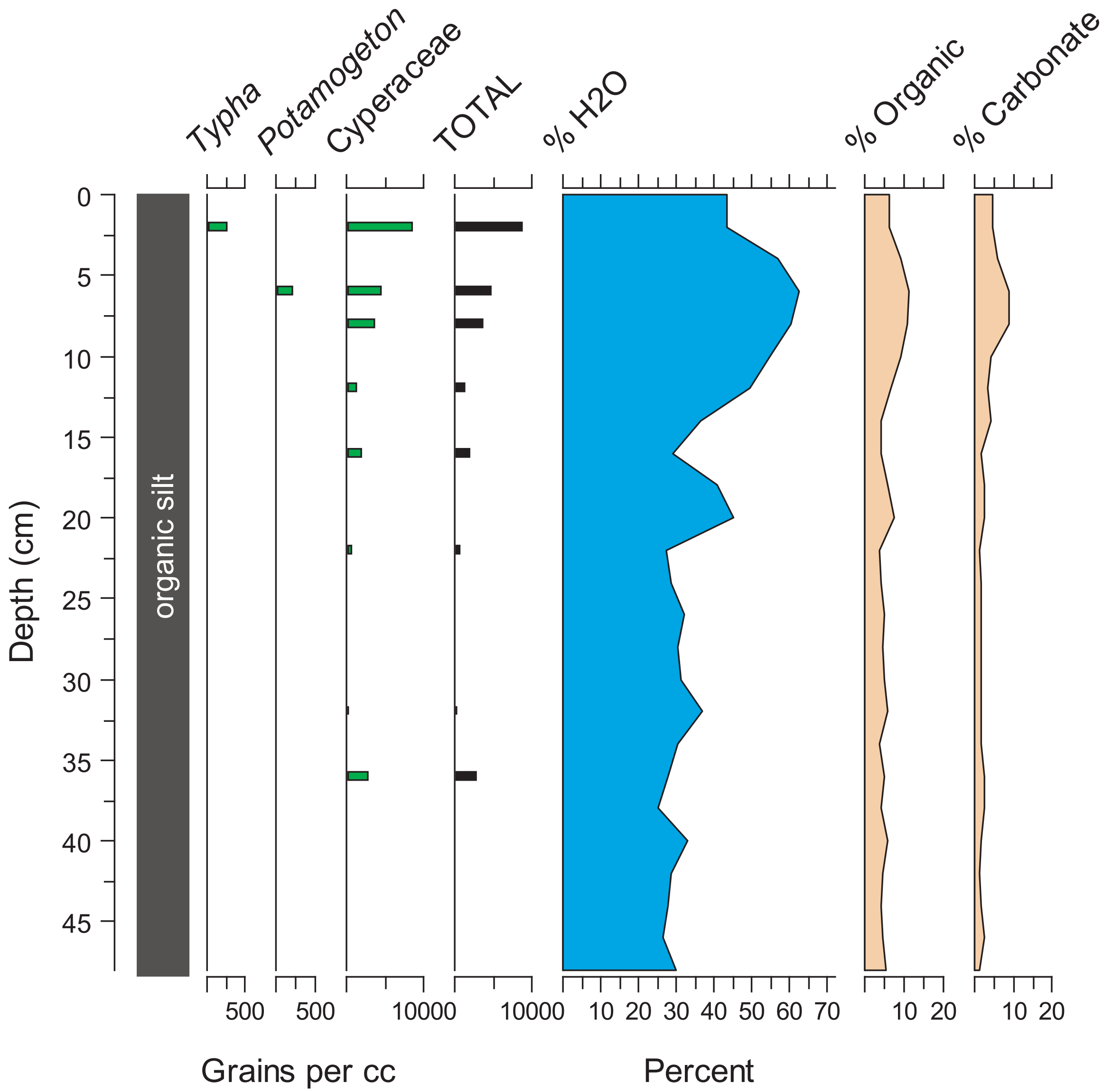

Fig. 6. Aquatic pollen concentration rates and sediment analysis from the Spring Site, Sand Creek National Historic Site. Pollen taxa common names are given in the text.

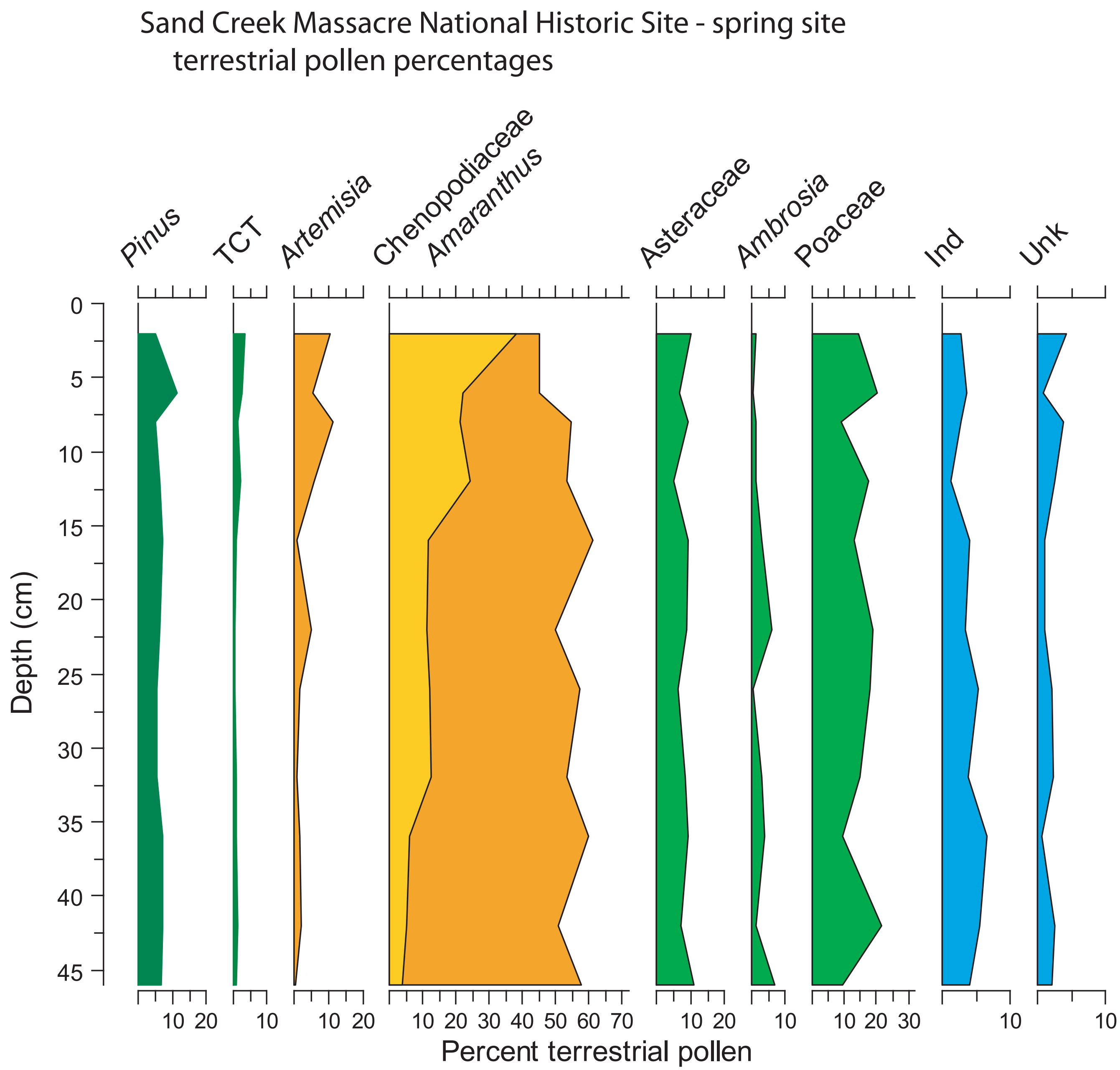

Fig. 7. Terestial pollen percentages from the Spring Site, Sand Creek Massacre Historic Site. Yellow fill in the Chenopodiaceae/*Amaranthus* graph represents percent *Amaranthus* pollen, identified by having >20 pores per grain. TCT is assumed to represent juniper pollen. See text for common names for all pollen types.

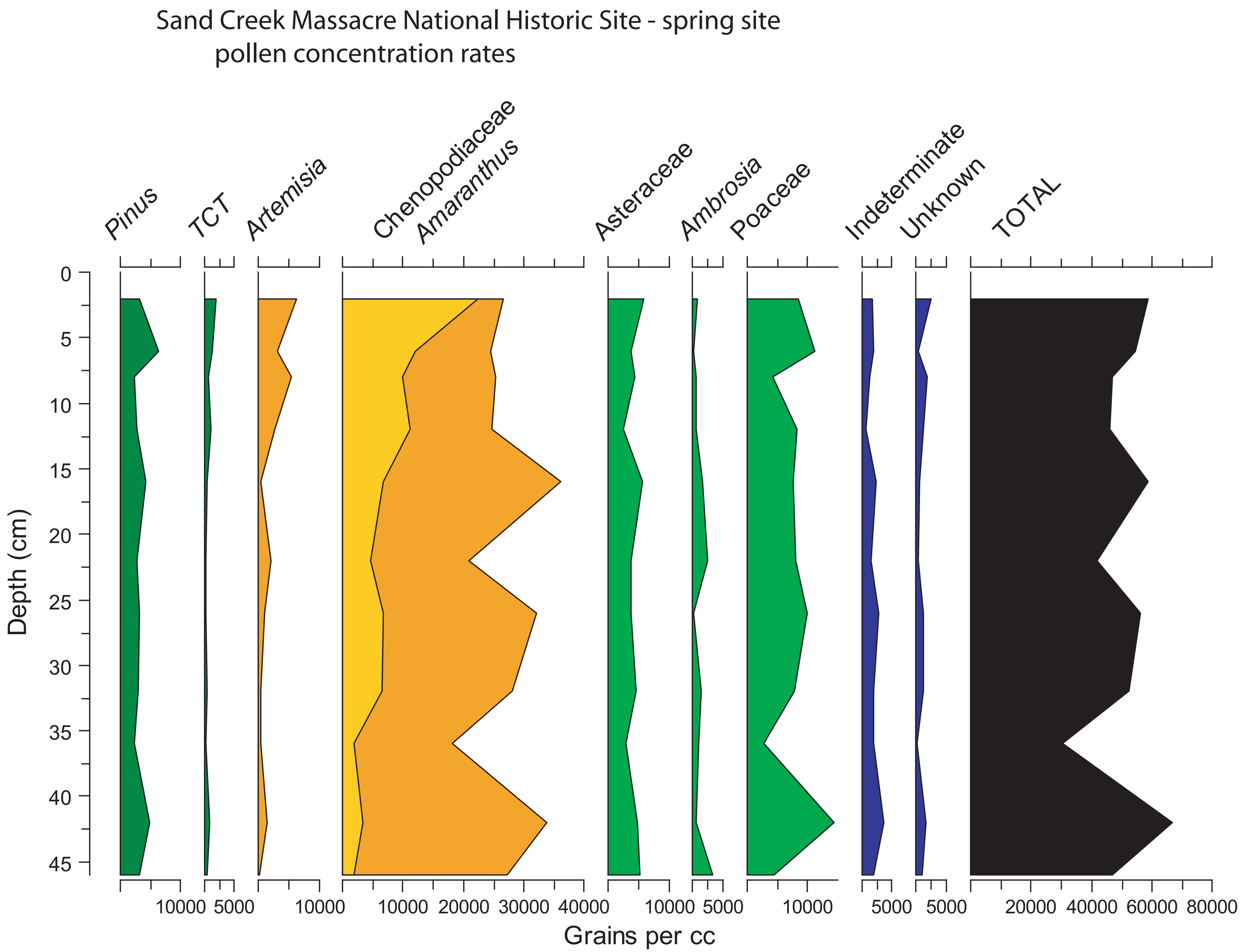

Fig. 8. Terrestial pollen concentration from the Spring Site, Sand Creek Massacre Historic Site. Yellow fill in the Chenopodiaceae/*Amaranthus* graph represents percent *Amaranthus* pollen, identified by having >20 pores per grain. TCT is assumed to represent juniper pollen. See text for common names for all pollen types.