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Chemical characterization of Arctic soils: activity area analysis in contemporary Yup'ik fish camps using ICP-AES

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Abstract

Despite the vital role of seasonal fish camps in hunter–gatherer subsistence activities in the Arctic, little archaeological or ethnographic research on fish camps has been conducted. This ethnoarchaeological study uses the chemical composition of soil samples collected at two modern fish camps in the Yukon–Kuskokwim Delta of western Alaska to elucidate chemical soil signatures associated with seasonal subsistence fish camps and the activities performed there. Concentrations of Al, Ba, Ca, Fe, K, Mg, Mn, P, Sr, Ti, and Zn were determined using an inductively coupled plasma-atomic emission spectrometer (ICP-AES). Both camps showed distinct anthropogenic soil signatures, even though one camp had a 30-year occupation history and one camp had only been occupied for 1 year. In addition, some activity areas within the camps have distinct anthropogenic signatures. In the future, this research can be used to identify ephemeral camps and their activities in the archaeological record.

Keywords: Ethnoarchaeology; Western Alaska; Soil analysis; Seasonal camps; ICP-AES

1. Introduction

Prehistorically and historically, fish have been a critical resource in the Americas [11,30,48,51] and world-wide [32,53]. In addition to its elemental role in many indigenous diets, fish are also key trade and ceremonial items, and can play a pivotal role in emergent social inequalities [4,21,25,60]. However, even with its paramount social and economic importance to hunter–gatherers, relatively little is understood of the production sequence of fish processing or the archaeological signatures of ephemeral sites such as fish camps.

In the Arctic, where a 'season of plenty' is followed by a long, dark and cold 'season of scarcity' [21,57], a family's health and well-being depends on their ability to procure, process and store large quantities of food during the short summer season. In the Yukon–Kuskokwim Delta of western Alaska, like much of the Arctic, fish caught and processed at summer subsistence camps provide community inhabitants with food for the remainder of the year. Recent archaeological, ethnoarchaeological, ethnographic and oral historic research with the Eskimo community of Chevak has elucidated the vital role of fish camps [23,24]. However, despite the clear significance of fish camps in Arctic hunter–gatherer subsistence, such sites are difficult to identify in the archaeological record. This ethnoarchaeological study utilizes chemical characterization of soils from two modern fish camps in order to elucidate chemical soil signatures associated with seasonal fish camps and camp activities.

2. Environmental background: The Yukon–Kuskokwim Delta

The alluvium-based Delta is framed by the Yukon and Kuskokwim Rivers in the north and south, respectively (Fig. 1). The Yukon River is responsible for

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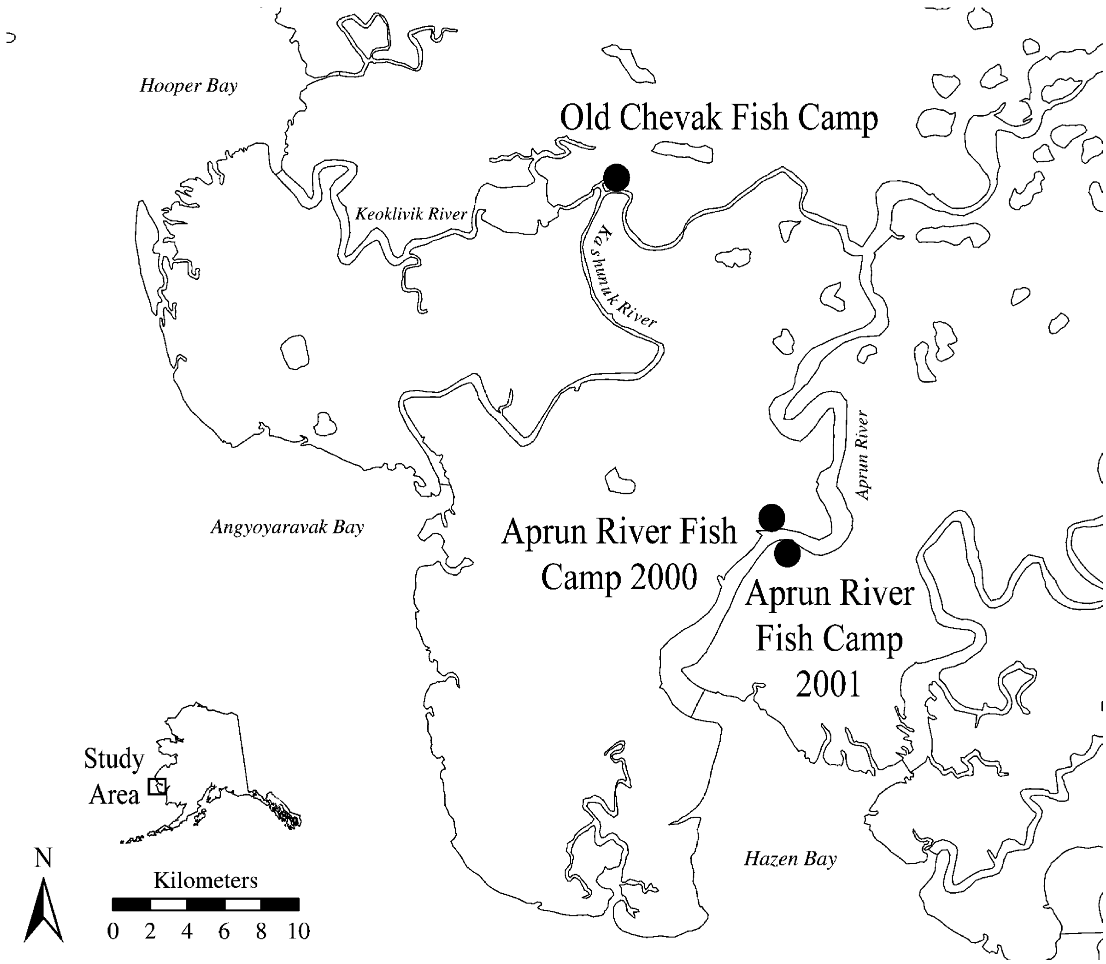

Fig. 1. Map of the study area in western Alaska with sites discussed in the text [1,2].

90% of the sediment introduced into the Bering Sea, and is part of a lobate delta with low wave action, an extremely shallow sea shelf, and low clay content in the sediment load [3]. The Yukon–Kuskokwim Delta, however, is not a single large alluvial fan, but rather the accumulation of several fans formed by the rivers fed by the Yukon, such as the Black and Kashunak Rivers [56]. The composition of the undulating coastline is a varied environment of graveled and steep cliff lined beaches, sandy and muddy flat beaches, and eroding tundra bluffs that line much of the coast.

Much older Mesozoic topographic features frame the unglaciated Delta [3]. To the northeast are the low-rising Nulato Hills and Askinuk Mountains, which are composed of late Cretaceous rocks such as granodiorite [16,38]. The southern boundary of the Yukon–Kuskokwim Delta is the southern range of the Kilbuck Mountains, which are composed of Mesozoic sedimentary rocks such as shale, siltstone, and sandstone [38,54]. The Delta has numerous small Cenozoic cinder cones and basalt flows including the centrally located Ingakslugwat Hills, which are likely 1,000,000–700,000 years old [3,38,54]. However, most of the Delta is underlain by Quaternary sands and silts, with Cenozoic sedimentary rocks [38].

The Delta itself is up to 50% water, and thousands of lakes, rivers and sloughs, or partially abandoned and brackish river courses, amble across the boggy wetlands [54]. The stratified loams, silts, and sands from the old coastal deposits, marine sediments, and fine-grained fluvial deposits allow for poor drainage in most of the region. Most soils are Histic Pergelic Cryaquepts and Pergelic Cryofibrists [38]. The Delta soils are shallow over a discontinuous permafrost layer which varies in content and thickness and can be up to 200 m deep. The poorly drained soils are strongly affected by the sometimes violent storms that occur in the late summer and early fall and that can cause extensive flooding with much erosion and sediment deposition [3].

Although the Delta has been described as “monstrous and dreary” [59], it supports a wide variety of animals and edible plants. While caribou disappeared from the Delta in the late 1800s [45], smaller terrestrial mammals are plentiful, and mink (*Mustela vison*) and beaver

Fig. 2. The Old Chevak fish camp in 2001. Two canvas living and storage tents are visible behind a covered drying rack, and a smokehouse is visible in the far left of the photograph. (Photograph by Lisa Frink).

(*Castor canadensis*) are hunted and trapped in the uplands. Migrating waterfowl make the Delta their seasonal nesting and breeding grounds, and exist in extremely high densities. Native residents also continue to utilize marine resources including the Northern (*Clorhinus usrsinus*), ringed (*Phoc hispida*), harbor (*P. vitulina*), spotted (*P. largha*), and ribbon (*P. fasciata*) seals, and the most economically and socially important marine mammal, the Pacific bearded seal (*Erignathus barbatus*), which can reach weights of 600 to 800 pounds [3,21,22]. Also available in the salty waters are migrating Pacific walrus (*Odobenus rosmarus*) and the beluga whale (*Delphinapterus leucas*), all of which are captured along the coast while ascending the larger rivers. Finally, edible plants in the Delta include ferns (*Dryopteris dilatat*), wild potato (*Claytonia tuberosa*), marsh marigold (*Caltha palustris*), sourdock (*Rumex arica*), and several species of berries including blueberry (*Vaccinium uliginosum*) and salmonberry (*Rubus chamaemorus*).

However, the most abundant Delta subsistence source is fish. Salmon begin to run in late June or early July after the initial run of herring (*Clupea harengus*) in mid-June and continue to run into September [33]. In addition, whitefish and freshwater fish like the blackfish (*Dallia pectoralis*) are each part of a year-round subsistence base harvest [21].

3. Cultural background: indigenous subsistence activities

For this study, soil samples were collected from two modern fish camps associated with the community of Chevak, located 48 km east of the Bering Sea on the Yukon–Kuskokwim Delta (Fig. 1). Today Chevak is inhabited by approximately 800 Cupiit Eskimos [42,63] who live on a bluff above the Ninglikfak River. Chevak families attempt to catch and process from 150 to more than 300 salmon every summer [24] in order to survive the long winter. Since all aspects of fish processing are completed at the seasonal fish camps, each extended family that builds and maintains a camp has processing equipment such as butchery areas, drying racks, smokehouses, and domestic stations containing sleeping tents and cooking areas (Fig. 2).

Fish and other coastal resources were equally important historically and prehistorically [25,40,49,50, 52,55,60–62]. In the Yukon–Kuskokwim Delta, which may have initially been inhabited 3000 years ago [43], subsistence activities included catching fish, hunting seal, caribou, walrus, and birds, and gathering greens and berries [10,19–21,44,46,47]. In addition, fish processing technology has undergone few changes during the historic and modern periods. Most archaeologists agree that the ground slate ulu, a multi-purpose tool used also for fish processing and strongly associated with women, was introduced into the Delta approximately 1000 years ago with the Western Thule expansion into the region [17,24,55]. Fish continued to be important during the Early Historic and Historic Eras when Zagoskin, an early explorer in what was then Russian America, dubbed chum salmon the “bread of all coastal dwellers of the Eastern Ocean and Bering Sea” [40,49,50]. Therefore, there is substantial evidence for prehistoric, historic and modern continuity in both subsistence and processing activities in the Arctic.

4. Fish camps: an introduction

Fish camp complexes contain both fish processing equipment and general living structures [10,14,15,21, 60,62]. Most living and storage tents sit directly on a plywood base on the ground (Fig. 2). All living tents have a raised platform within the tent for sleeping and

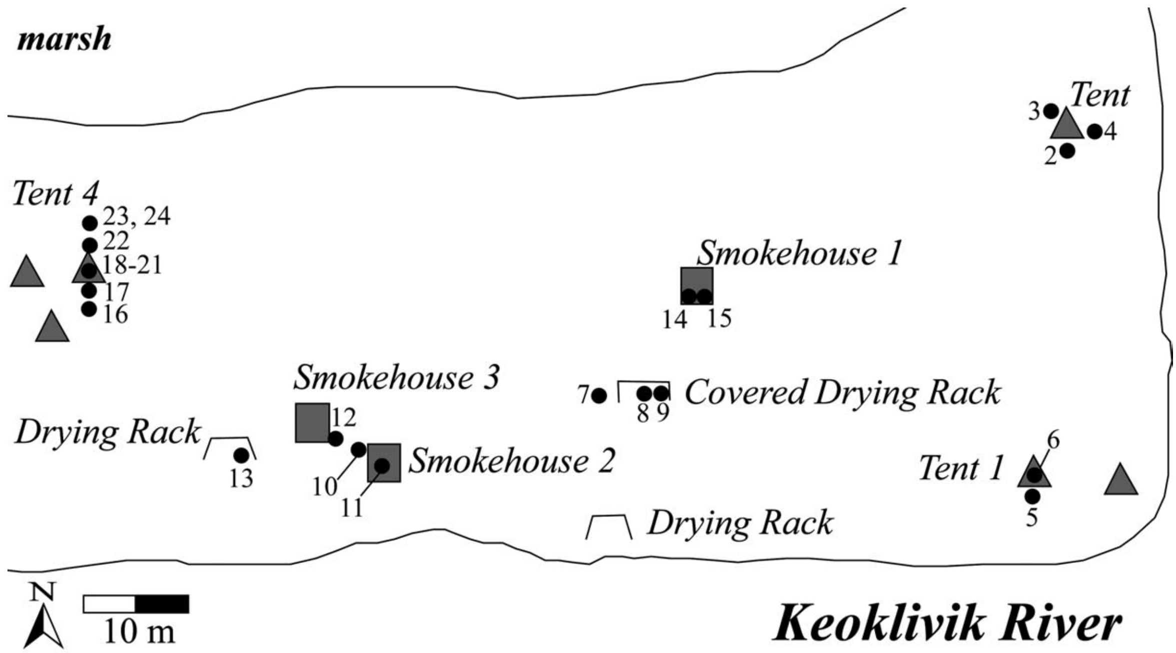

Fig. 3. Sketch map of the Old Chevak fish camp in 2001. The camp had been occupied every summer for 30 years by the same extended family. However, at the time of sampling, the camp had not yet been occupied for the summer.

general family use. Most families have a Coleman-type stove for cooking and a steel drum of variable size attached to a stove pipe that sticks out from the canvas covering for interior heating.

The fish cutting station used by the women is typically located near the river or slough shoreline, and consists of a plywood board upon which the fish are cut. Once removed, the viscera, spine, and head of the fish are conveniently tossed out on to the muddy river bank where the ravenous seagulls await. The fish processing area contains refuse such as blood and fish scales. This pattern of refuse results from the mid-twentieth century introduction of snowmobiles and airplanes [36]. Prior to these technological introductions, families owned five to ten dogs, which were essential to a family's survival and were fed at least half of a salmon each day when traveling [49]. Native interviewees consistently expressed the sentiment that, unlike today, nothing went to waste when they were younger [23].

After the fish are cut, cleaned and, sometimes, soaked in a salt solution, they are dried on fish racks which are placed under a canvas or plastic tarp to prevent rain from spoiling the drying process (Fig. 2). The salmon, whitefish and herring each dry on the racks for days or weeks depending on the type of fish being processed and the weather conditions. The freshly processed fish drip directly on to the tundra upon which the fish rack rests; rib bones and, occasionally, whole fish are also discarded on the soil under the drying rack.

After the fish have dried, many are then smoked within the smokehouse facility, which is constructed of plywood with a tin or tarp roof (Fig. 2). Inside the smokehouse, smoldering willow branches within the round base of a 55-gallon drum produce the drying smoke. Other storage facilities at fish camps include rectangular pits near the fish cutting station that hold fish before processing, and small, round pits for stored fish heads, which are a gelatinous, fermented delicacy stored for enjoyment in the fall [39,40]. Eventually, all of the fish are taken to Chevak for storage, where the women of the family are responsible for appropriate management of the fish throughout the winter [23].

5. Ethnoarchaeological field methods: soil sample collection

In order to determine soil signatures of seasonal fish camps and the activities performed there, soil samples were collected from two modern Arctic fish camp complexes, the Old Chevak fish camp and the Aprun River fish camp (Figs. 2–5, Appendix A). The two main fish camp complexes were both used by an extended family for fish procurement and processing, but differ in length of occupation. Therefore, a comparison of results from the two camps will reveal the effect of length of occupation on soil chemical signatures. In addition, because the two camps are located in different natural environments, as will be discussed below, the two data sets can be compared to give information on the effects of Arctic environment on soil signatures.

More specifically, this analysis is based on 52 soil samples (Appendix A, Tables 1 and 2). Soil Sample 1

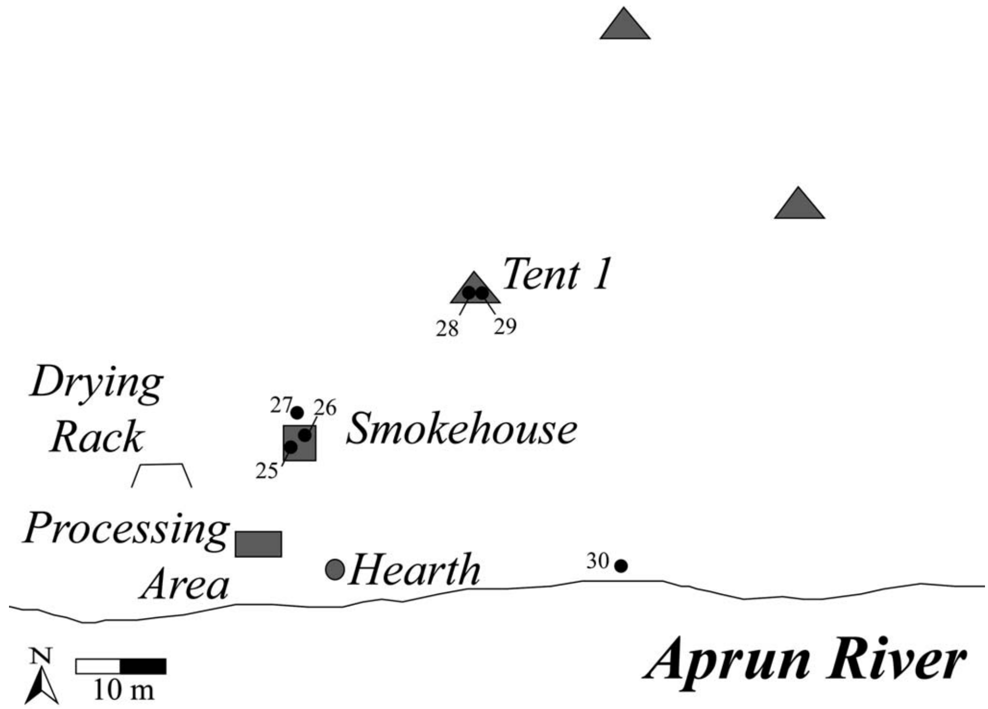

Fig. 4. Sketch map of the 2000 occupation of the Aprun River fish camp with locations of soil samples (see also Appendix A and Tables 1 and 2). During soil sampling, this camp was abandoned and had been moved across the river to the 2001 occupation site.

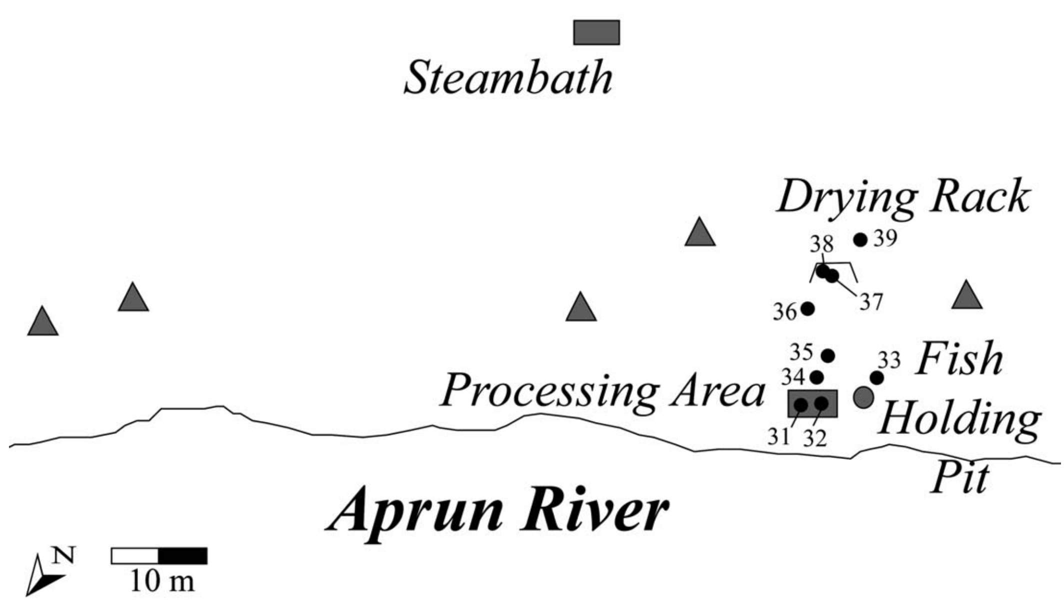

Fig. 5. Sketch map of the 2001 occupation of the Aprun River fish camp with locations of soil samples (see also Appendix A and Tables 1 and 2). This fish camp was in active use during sampling.

(SS1) was collected from a modern seal processing camp. Although it was analyzed, it was not included in this study because it was not taken from a modern fish camp. Thirty-eight samples were collected from activity areas and features associated with the two fish camps. The remaining 14 samples were collected from "offsite" locations in order to determine natural background levels of the analyzed elements in the soils. Samples were typically collected from immediately beneath the surface vegetation (less than 10 cm below the surface), especially

Table 1
Fish camp (Old Chevak) and offsite soil samples from crowberry tundra environmental setting

Sample	Location	log Al	log Ba	log Ca	log Fe	log K	log Mg	log Mn	log Na	log P	log Sr	log Ti	log Zn
1	Atchak's	3.907	1.654	3.616	4.282	3.123	3.755	2.438	3.578	2.999	1.596	2.373	1.852
2	Old Chevak	3.279	1.544	3.534	3.861	2.668	3.193	1.867	2.685	2.827	1.600	1.639	1.643
3	Old Chevak	3.157	1.649	3.621	3.824	2.981	3.067	1.702	2.980	3.017	1.649	1.504	1.567
4	Old Chevak	3.119	1.468	3.432	4.077	2.584	3.097	1.567	2.428	2.983	1.569	1.491	1.513
5	Old Chevak	3.470	1.562	3.372	4.252	2.560	3.151	1.666	3.319	2.826	1.489	1.968	1.661
6	Old Chevak	3.574	1.647	3.439	4.610	2.657	3.139	1.377	3.122	3.190	1.547	2.186	1.635
7	Old Chevak	3.805	1.630	3.427	4.188	2.766	3.573	1.970	2.691	2.887	1.440	2.293	1.679
8	Old Chevak	4.052	2.389	4.032	4.903	3.215	3.559	3.083	3.184	3.798	2.135	2.078	2.972
9	Old Chevak	3.791	1.753	3.445	4.788	2.957	3.583	2.360	2.713	3.009	1.341	2.310	2.081
10	Old Chevak	3.985	2.117	3.960	4.527	3.121	3.906	2.868	2.768	3.199	1.821	2.496	2.385
11	Old Chevak	3.414	1.759	3.786	4.537	2.745	3.486	2.700	2.677	3.278	1.799	1.889	2.578
12	Old Chevak	3.316	1.696	3.856	4.290	2.770	3.525	2.484	3.056	3.211	1.862	1.731	2.650
13	Old Chevak	3.278	1.563	3.313	4.591	2.943	3.028	2.080	2.816	3.575	1.477	1.876	1.727
14	Old Chevak	3.788	1.800	3.732	4.268	2.861	3.676	2.438	2.805	2.982	1.590	2.223	1.701
15	Old Chevak	3.911	1.830	3.772	4.281	2.936	3.787	2.502	2.707	2.916	1.520	2.443	1.866
16	Old Chevak	3.369	1.789	3.653	4.685	2.714	3.346	2.314	3.441	3.305	1.693	2.007	2.152
17	Old Chevak	3.821	1.587	2.967	4.056	2.671	3.325	1.706	2.741	2.638	1.142	2.487	1.412
18	Old Chevak	3.750	1.743	3.407	3.960	2.792	3.320	1.881	2.985	2.829	1.489	2.251	1.639
19	Old Chevak	3.955	1.765	3.111	4.194	2.692	3.502	1.902	2.669	2.632	1.256	2.516	1.531
20	Old Chevak	3.732	1.650	2.969	4.016	2.458	2.779	1.232	2.695	2.952	1.288	2.119	1.180
21	Old Chevak	3.536	1.611	3.350	3.721	2.673	3.123	1.757	2.661	2.975	1.481	1.927	1.417
22	Old Chevak	3.425	1.711	3.260	4.394	2.574	2.968	1.818	2.645	2.971	1.367	1.774	1.432
23	Old Chevak	3.715	1.588	3.198	4.055	2.263	3.004	1.428	2.581	2.812	1.341	2.075	1.393
24	Old Chevak	3.051	1.680	3.659	3.781	2.675	3.278	2.038	2.545	2.942	1.678	1.255	1.880
44	Offsite	3.752	1.628	3.403	4.090	2.756	3.471	1.950	2.594	2.751	1.524	2.236	1.644
49	Offsite	3.877	1.625	3.361	4.288	2.811	3.529	1.918	2.725	2.796	1.485	2.414	1.617
51	Offsite	3.906	1.697	3.122	4.275	2.526	3.177	1.520	2.673	2.868	1.279	2.293	1.389
52	Offsite	3.970	1.746	3.245	4.236	2.597	3.392	1.742	2.623	2.800	1.318	2.415	1.508
53	Offsite	3.943	1.883	3.548	4.165	2.575	3.673	2.047	2.600	2.914	1.469	2.521	1.892

Table 2
Fish camp (Aprun River) and offsite soil samples from sedge meadow environmental setting

Sample	Location	log Al	log Ba	log Ca	log Fe	log K	log Mg	log Mn	log Na	log P	log Sr	log Ti	log Zn
25	Aprun 2000	0.592	0.273	0.568	0.633	0.465	0.576	0.386	0.390	0.502	0.471	0.288	0.186
26	Aprun 2000	0.593	0.269	0.564	0.634	0.464	0.574	0.384	0.415	0.491	0.468	0.290	0.197
27	Aprun 2000	0.596	0.279	0.573	0.637	0.474	0.580	0.391	0.413	0.516	0.477	0.281	0.211
28	Aprun 2000	0.593	0.266	0.568	0.636	0.467	0.577	0.386	0.413	0.506	0.470	0.272	0.202
29	Aprun 2000	0.595	0.274	0.574	0.638	0.472	0.583	0.391	0.420	0.521	0.477	0.297	0.212
30	Aprun 2000	0.599	0.247	0.555	0.632	0.482	0.577	0.402	0.362	0.481	0.470	0.276	0.197
31	Aprun 2001	0.587	0.277	0.566	0.626	0.468	0.568	0.371	0.407	0.488	0.482	0.254	0.178
32	Aprun 2001	0.589	0.279	0.565	0.629	0.482	0.569	0.372	0.409	0.490	0.492	0.262	0.182
33	Aprun 2001	0.592	0.283	0.556	0.641	0.457	0.569	0.389	0.416	0.484	0.471	0.267	0.178
34	Aprun 2001	0.585	0.273	0.559	0.622	0.445	0.561	0.363	0.369	0.486	0.475	0.241	0.166
35	Aprun 2001	0.587	0.268	0.561	0.629	0.455	0.567	0.374	0.390	0.482	0.475	0.256	0.181
36	Aprun 2001	0.589	0.262	0.562	0.629	0.462	0.570	0.376	0.393	0.519	0.470	0.265	0.189
37	Aprun 2001	0.595	0.272	0.566	0.636	0.481	0.580	0.394	0.414	0.529	0.475	0.279	0.209
38	Aprun 2001	0.594	0.258	0.563	0.636	0.495	0.578	0.392	0.417	0.524	0.485	0.282	0.209
39	Aprun 2001	0.592	0.255	0.556	0.636	0.467	0.572	0.382	0.409	0.508	0.470	0.269	0.198
40	Offsite	0.590	0.256	0.569	0.631	0.469	0.576	0.378	0.409	0.531	0.469	0.263	0.203
41	Offsite	0.607	0.271	0.565	0.635	0.505	0.589	0.404	0.333	0.559	0.467	0.293	0.241
42	Offsite	0.598	0.288	0.566	0.690	0.491	0.583	0.397	0.427	0.527	0.501	0.293	0.271
43	Offsite	0.597	0.268	0.555	0.638	0.485	0.574	0.396	0.374	0.520	0.466	0.281	0.187
45	Offsite	0.592	0.267	0.560	0.645	0.478	0.573	0.386	0.431	0.504	0.480	0.274	0.217
46	Offsite	0.601	0.250	0.562	0.641	0.499	0.584	0.403	0.393	0.548	0.472	0.286	0.235
47	Offsite	0.599	0.241	0.563	0.627	0.493	0.582	0.392	0.331	0.559	0.461	0.263	0.240
48	Offsite	0.608	0.274	0.566	0.659	0.501	0.588	0.414	0.373	0.554	0.455	0.317	0.236
50	Offsite	0.603	0.249	0.565	0.633	0.509	0.589	0.406	0.367	0.592	0.467	0.292	0.214

in the crowberry tundra where permafrost conditions made it impossible to penetrate the ground with a trowel or soil probe. Soils from different stratigraphic levels are represented by the offsite profiles taken from the eroding river and slough banks; this was generally the only situation where soils were collected from different stratigraphic levels.

6. Laboratory methods: ICP-AES analysis of fish camp and offsite soil samples

In the Laboratory for Archaeological Chemistry at the University of Wisconsin at Madison each soil sample was first oven-dried at 120 °C for 48 h, pulverized with a Coors porcelain mortar and pestle and screened with a 2 mm screen to remove all particles larger than sand-sized. Two mg of each sample were then extracted in 1 M HCl at room temperature for 14 days. The sample extract was analyzed at the Laboratory for Archaeological Chemistry using an inductively coupled plasma-atomic emission spectrometer (ICP-AES). For each sample, concentrations of the following elements were recorded in parts per million (ppm): Al, Ba, Ca, Fe, K, Mg, Mn, Na, P, Sr, Ti, and Zn. All sample preparation and analysis was performed by the first author under the direction of James H. Burton. Using this well-established methodology [13,28,29,41], reproducibility of the technique is better than $\pm 5\%$ (1σ) variation on all of the elements analyzed here. In this study, laboratory standards were analyzed every 5–10 samples. Elemental concentrations of standard solutions of Laboratory for Archaeological Chemistry reference 9511 were as follows: log Al=4.059 ± 0.006 (n=7, 2σ), log Ba=2.318 ± 0.011 (n=7, 2σ), log Ca=4.499 ± 0.001 (n=7, 2σ), log Fe=4.017 ± 0.003 (n=7, 2σ), log K=3.725 ± 0.002 (n=7, 2σ), log Mg=3.945 ± 0.002 (n=7, 2σ), log Mn=2.479 ± 0.001 (n=7, 2σ), log Na=3.451 ± 0.004 (n=7, 2σ), log P=3.743 ± 0.003 (n=7, 2σ), log Sr=2.166 ± 0.003 (n=7, 2σ), log Ti=2.272 ± 0.009 (n=7, 2σ), and log Zn=1.939 ± 0.003 (n=7, 2σ). Finally, when using this procedure, the elemental concentrations in blanks are below the detection limit of the machine.

Until relatively recently, the use of soil chemistry in archaeology has been limited to the identification and delineation of archaeological site boundaries using soil phosphate analysis and the identification of certain archaeological features [5,31,34,35,58]. Chemical analysis of activity areas using a variety of elements shows much promise and has become increasingly useful at archaeological sites [6–9,18,34,37,41]. While there are a variety of techniques that can be used to analyze soils for activity area analysis [6–9,18,34,37,41], using ICP-AES enables the rapid and inexpensive detection of a variety of elements in a large number of samples. Analysis of a large number of samples is necessary if changes in activities across a surface are being investigated [41]. In addition, this technique allows examination of the concentration of mobile elements in the soil. More mobile elements are deposited in the soil through human activity or natural processes such as weathering, while the less mobile elements that are tightly bound within mineral lattices more generally reflect the parent material in which the soil developed [41].

7. Results and discussion

7.1. Predictions and expectations

The Yukon–Kuskokwim Delta is an ideal environment for a chemical analysis of soils because the cold climate reduces the rate of chemical weathering in the soil and the permafrost layer ensures that the soil is poorly drained and permanently moist or saturated [26]. Therefore, relatively high concentrations of all elements in the soil and strong anthropogenic soil signatures were expected for this study.

Various researchers have shown that human activity areas can be elevated in Ca, K, Mg, Na, and P because of the incorporation of human waste, decaying plant and animal materials, and ash from fires into the soil [18,27,41]. Specific activity areas that have been identified in other ethnoarchaeological projects include hearths, which have elevated K, Mg and P concentrations, and areas that contained food preparation or consumption waste such as small bones, which have elevated Ca and Sr concentrations [41]. We hypothesized that the smokehouses, drying racks and fish processing areas would retain these signatures in the soil. In addition, it was predicted that the presence of seawater and marine materials could result in elevated Sr and Ca concentrations but low Ba concentrations, because of the low solubility of barium sulfate in seawater [12].

In general, the actual results were similar to the expected results, and will be discussed in detail below. As predicted, the elemental concentrations in the poorly drained Delta soils were quite high, and even camps with only 1 year of occupation retained anthropogenic signatures in the soil (Appendix A, Tables 1 and 2). This suggests that this type of analysis can identify ephemeral occupations in areas where the soils are poorly drained.

7.2. Old Chevak fish camp and the offsite crowberry tundra soil samples

The Old Chevak fish camp has been used by the same extended family for fish procurement and processing every summer for at least 30 years, and is located in crowberry tundra (Figs. 1–3). Crowberry tundra is found at a slightly higher elevation than the lower sedge meadow, and is a moist tundra environment with nearly continuous stands of cotton grass tussocks (*Eriophorum*

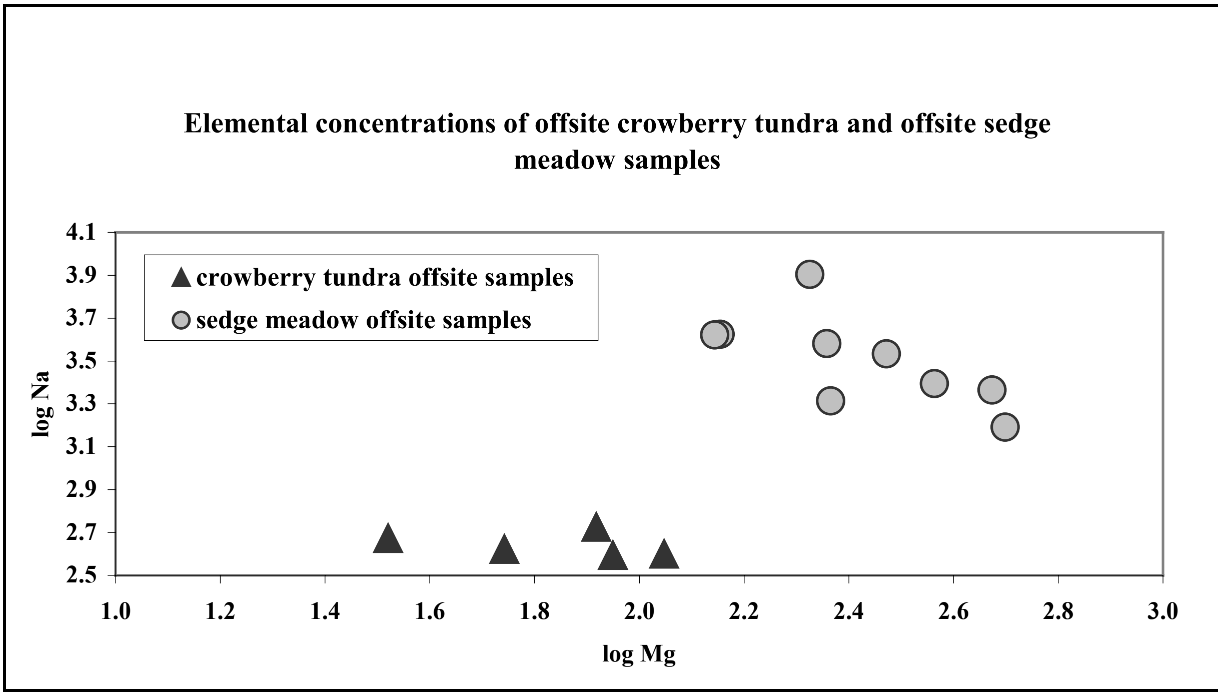

Fig. 6. Log Na versus log Mg for the crowberry tundra offsite samples and the offsite sedge meadow samples.

spp.) and sparse growth of sedges and dwarf shrubs like the willow (*Salix* spp.) and herbs such as fireweed (*Epilobium angustifolium*) commonly found in disturbed contexts such as archaeological sites. The crowberry tundra soils are poorly drained as the permafrost is 8–10 inches below the soil surface. Although storm surges and flooding could greatly affect the poorly drained crowberry tundra soils, the Old Chevak fish camp is well protected and has not been significantly affected by flooding and erosion in its 30-year occupation.

When compared to the sedge meadow soils of the Yukon–Kuskokwim Delta, it is apparent that the crowberry tundra soils are characterized by lower levels of most elements, including Na and Mg (Fig. 6, Table 1). It is not surprising that the concentrations of soluble elements such as Na are low in the crowberry tundra, as it is better drained than the sedge meadow environments. Discriminant function analysis also supports this conclusion; the discriminant function differentiated between the crowberry tundra samples (both offsite and onsite) and the sedge meadow samples (both offsite and onsite) with a high degree of accuracy, correctly identifying 98% of the samples. The discriminant function was determined using the computer program SPSS and is $f(x)=(0.76054*\log \mathrm{Al})-(0.01067*\log \mathrm{Ba})-(0.80160*\log \mathrm{Ca})-(0.29291*\log \mathrm{Fe})-(0.47905*\log \mathrm{K})+(1.84656*\log \mathrm{Mg})+(1.09710*\log \mathrm{Mn})+(1.24020*\log \mathrm{Na})+(0.85097*\log \mathrm{P})-(0.21788*\log \mathrm{Sr})-(1.45046*\log \mathrm{Ti})-(1.73768*\log \mathrm{Zn})$.

Although the offsite soil samples from crowberry tundra environments were readily distinguishable, the onsite samples from the Old Chevak fish camp were highly variable (Fig. 7). This variability was investigated with both a multi-element analysis using principal components analysis and single element analysis of each sample. However, the factors identified as sources of variability in the principal components analysis were translated into more accessible equations using elemental concentrations (Fig. 7). More specifically, log ((Sr)(P)/(Al)(Ti)) is an approximation of principal component factor 2, which accounted for the most significant variability in the sample set.

When compared with soil samples from outside of the covered drying rack, samples taken from underneath the drying rack were elevated by an order of magnitude in Mn, P, and Sr, and were elevated to a slightly lesser extent in Ba, Ca, K, and Na (Appendix A, Table 1). This most likely results from drippings from the drying fish and from unwanted fish left to decay over the winter, although droppings left from scavenging foxes have also affected the soil chemical signatures. The covered drying rack may also have elevated soil signatures because there is less rainfall to wash away the fish drippings, compared to the uncovered fish racks. Finally, the sheltered area underneath the drying rack would be less susceptible to soil leaching. This explains the elevated levels of highly soluble elements such as Na. High levels of Na can also be explained by the fish processing production sequence; after being cleaned in water, the fish are dunked in a bucket of salt water and then placed on the racks to dry.

Although elevated K, Mg, and P levels would be expected in soils from the two smokehouses at the Old

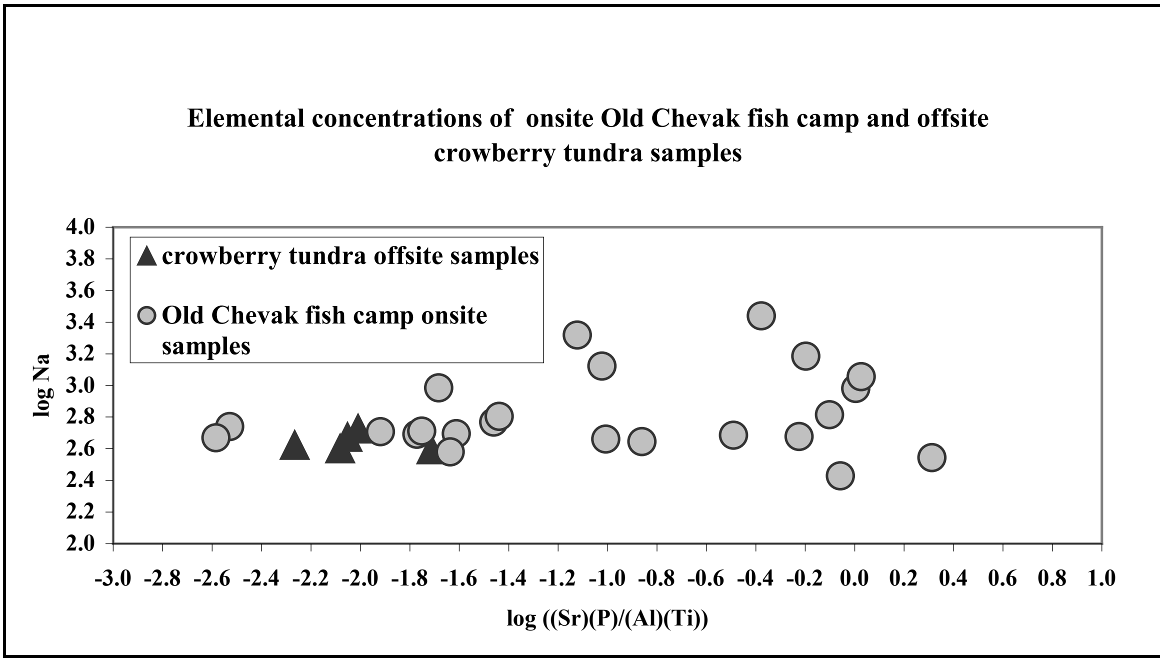

Fig. 7. Log Na versus log ((Sr)(P)/(Al)(Ti)) for the crowberry tundra offsite samples and the Old Chevak fish camp samples. Log ((Sr)(P)/(Al)(Ti)) is an approximation of principal component factor 2, which accounted for the most significant variability in the sample set. While Sr and P are likely to be anthropogenic signatures, the elements Al and Ti are derived from minerals in the soil.

Chevak fish camp, the smokehouse soil samples did not show this typical ash or hearth signature. It is possible that the mud floor was replaced often enough to mask the anthropogenic signature. In addition, the soil samples taken from three different tents at Old Chevak did not show clear anthropogenic signatures. The tent interiors were elevated in Al and Ti, which implies a high mineral content of the soil but not an anthropogenic signature. Although elevated Al and Ti levels can imply that soil was brought in to make a floor, in this case it is likely that the tent platform prevented any significant anthropogenic inputs into the soil.

7.3. Aprun River fish camp and the offsite soil samples from sedge meadow environments

Unlike the Old Chevak fish camp, the Aprun River fish camp had been occupied for a relatively short time. Although the camp had been utilized by the same extended family for 2 years, the 2001 camp was moved across the river from the 2000 camp so each activity area at the camp had only been in use for one season of fish procurement and processing (Figs. 1, 4 and 5). In addition, the natural environment of the Aprun River fish camp is sedge meadow, not crowberry tundra. The sedge meadow is at a slightly lower elevation than the crowberry tundra, and is composed of grasses (*Festuca* spp.) and sedges (*Carex* spp.) which are rooted in mosses (*Sphagnum* spp.) and lichens [3]. As previously discussed, the chemical signature of the sedge meadow is characterized by higher mean concentrations of the elements analyzed, which is consistent with its description as more poorly drained when compared to the crowberry tundra (Fig. 6, Tables 1 and 2).

Even though the Aprun River fish camp had been occupied for a relatively short time, its soil signature was different from the sedge meadow samples, which suggests that the soil at the camp had been anthropogenically altered (Fig. 8, Table 2). More specifically, the overall concentrations of Na and Sr were lower at the Aprun River camp. Although activity areas in the Aprun River camp do show distinct chemical signatures, the anthropogenic signature is not as strong as the Old Chevak camp signature. Even though the anthropogenic concentrations of elements are not very elevated, it is possible to delineate activity areas based on their chemical signatures. For example, the fish processing areas are elevated in Ca, K, Mg, Na and P compared to soils samples taken outside of these activity areas (Fig. 9). In addition, samples taken from beneath the covered drying rack were elevated in Ca, Fe, K, Mg, Na, P, and Sr when compared to samples taken 2 m from the drying rack (Fig. 10). Finally, hearths usually cause elevated K, Mg and P levels in the soil. However, the soil samples taken from inside and outside of the smokehouse do not exhibit elevated K and P levels, though Mg is elevated. This is most likely because the fires in the smokehouses are contained in steel drums; an archaeological smokehouse would likely leave a distinct soil signature.

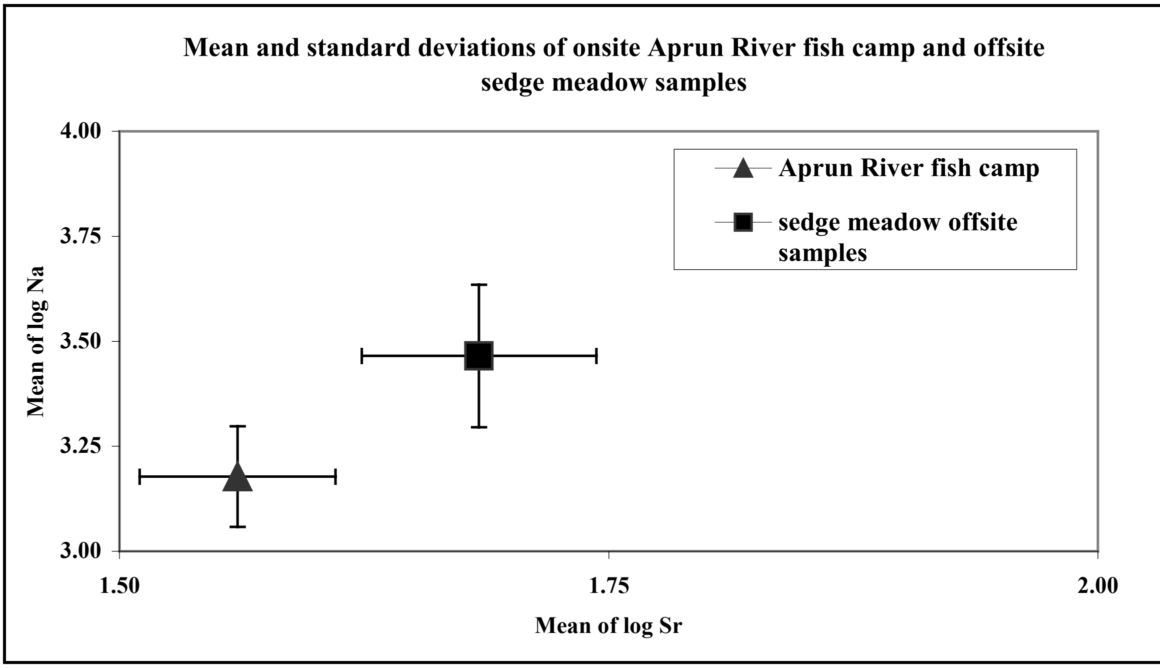

Fig. 8. Mean log Na versus mean log Sr with 1 standard deviation for the Aprun River fish camp and the offsite sedge meadow samples.

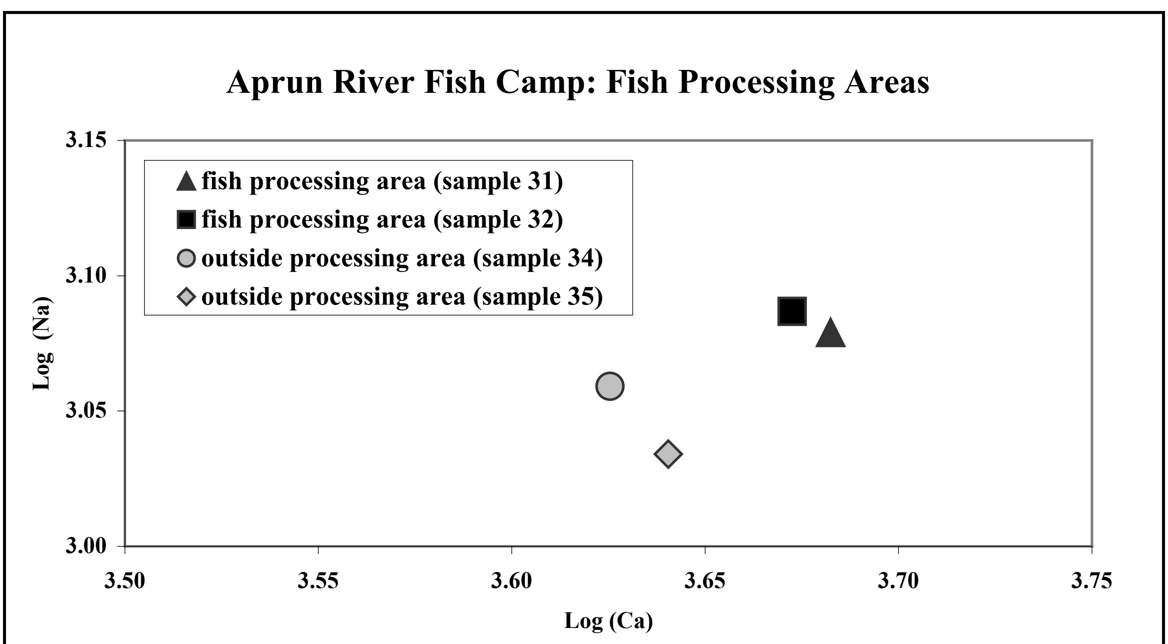

Fig. 9. Log Ca versus log Na for samples taken from the Aprun River fish processing areas as well as samples taken from locations 2 m outside of the fish processing areas.

7.4. General discussion of results

In this study it is vital to distinguish between changes in the soil's chemical signature that were caused by humans and those caused by biological processes. In the Delta, for example, animal droppings could dramatically alter the chemical signature of soils by elevating P and Ca concentrations. Migratory waterfowl in particular are abundant during the summer months. However, the soils of fish camps included in this study were not

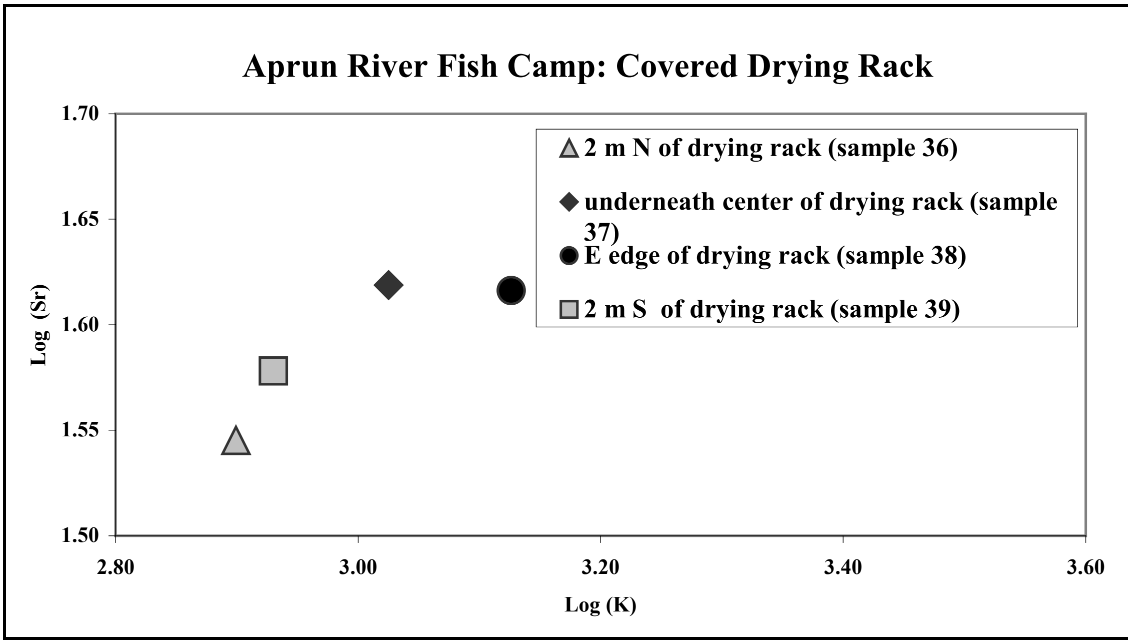

Fig. 10. Log K versus log Sr for samples taken from the Aprun River covered drying rack as well as samples taken from locations 1 and 2 m outside of the covered drying rack.

dramatically affected by goose droppings. For example, the Old Chevak fish camp is on a well-traveled route and is across the river from the archaeological village of Old Chevak and the US Fish and Wildlife summer research camp. The high level of human activity in the area repels large quantities of geese, and, during several years of visiting the Old Chevak fish camp, goose waste was not noticed in the large quantities typically found in other, less populated, regions. The Aprun River fish camp is located in a less-populated area, where geese may be present in larger numbers when the camps are unoccupied. However, the clear differences between the activity areas at the Aprun River camp and the offsite soil samples makes it highly unlikely that nonanthropogenic activities caused the soil signatures seen at the camps.

8. Suggestions for further research and conclusions

The data presented here demonstrate that the chemical characterization of soils has great utility in identifying and understanding archaeological and modern fish camps. In addition, this preliminary research has generated more general questions regarding the chemical signatures of Arctic soils and their formation processes. While the research presented here demonstrates that length of camp occupation is associated with the strength of and variability in anthropogenic soil signatures, more research on the relationship between length of camp occupation and soil chemical signature is necessary. In addition, it would be highly useful to compare the soil signatures of fish camps with other ephemeral camps, such as seal processing camps. While it is highly unlikely that soil chemical signatures alone will differentiate between, for example, fish and seal processing, chemical characterization of soils used in conjunction with other types of high resolution analysis such as microdebitage and soil micromorphology may be useful.

In conclusion, this study has demonstrated the feasibility of chemical characterization of soils in the Arctic, where slow-forming and poorly drained soils have especially strong chemical signatures [28,29]. Future research will elucidate the complex geologic and anthropogenic processes involved in soil formation, including the effect of length of camp occupation on soil signatures. As the chemical characterization of Arctic soils continues, archaeologists can begin to create data sets that can be used to identify seasonal camps in the archaeological record, and perhaps even to distinguish different camp activities and types of seasonal occupations.

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Appendix A. Soil sample collection

A.1. Offsite soil sample collection

The offsite samples came from the following three locations: (1) Old Chevak Slough near the Old Chevak fish camp, (2) along the Aprun River, and (3) near the Kashunak Slough. Fourteen offsite samples were collected, including six samples from sedge meadow settings, three samples from crowberry tundra settings, and four additional samples from stratigraphic profiles. At Old Chevak three stratigraphic samples were collected from a portion of the eroding slough bank underneath the crowberry tundra approximately 300 m north of the fish camp. The slough bank here was badly slumped and still frozen except for the upper 20 to 30 cm of soil. The first of these slough bank samples (soil sample 51, or SS 51) came from an organic-rich dark brown silty sand immediately beneath the tundra and is grouped with the crowberry offsite samples. This sample most closely matches the stratigraphic setting for the Old Chevak fish camp samples. The second Old Chevak offsite sample (SS 52) came from a homogenous brown silty sand about 15 to 20 cm below the surface. The third Old Chevak offsite sample (SS 53) came from the gray very fine sand or "river mud" which seems to characterize the basal soil throughout the study area.

At Aprun River four samples were collected from a stratigraphic profile of the eroding river bank approximately 400 m upstream (east) of the fish camp (Fig. 2). The first of these samples (SS 40) came from a dark brown loamy silt immediately beneath the sedge meadow vegetation. This sample most closely matches the stratigraphic setting for the Aprun River fish camp samples and is grouped with the sedge meadow offsite samples. The second sample (SS 41) came from a layer of mottled brown silt between 15 and 30 cm below the surface. This second layer was interspersed with bands of what appeared to be iron concretions, which were collected as SS 42. Beneath the mottled layer, another sample of the gray very fine silty sand or "river mud" was obtained (SS 43). Additional offsite samples collected at Aprun River include sedge meadow samples from 300 m west of camp (SS 44) and 75 m south of camp (SS 46), and a crowberry tundra sample from 400 m south of camp (SS 45).

The remaining four offsite samples came from locations near the Kashunak Slough. Here three additional sedge meadow samples were collected (SS 47, 48, 50) and one additional crowberry tundra sample (SS 49). One of the sedge meadow samples (SS 50) was in a location heavily impacted by waterfowl (primarily Canada and Brant geese). This sample allows an assessment of the possible effects the organic input from these birds has had on the soils in the study area.

A.2. Old Chevak fish camp

Seven features were sampled at the Old Chevak camp including three tent areas, two smoke houses, an open-air drying rack, and a covered drying rack. The three samples collected from outside of Tent 3 were taken from behind the structure (SS 3), in front of the doorway (SS 2), and near a "honey bucket", or latrine, adjacent to this tent (SS 4). Two samples were collected from the main tent including one underneath the rear sleeping platform (SS 6), and one from just outside the tent doorway (SS 5). Tent 4 was the most extensively sampled feature. Here nine samples were collected at 1-m intervals along a transect through this area. This transect included two samples south of the tent area (SS 16, 17), four samples inside the tent area (SS 18–21), and three samples north of the structure (SS 22–24). Samples 23 and 24 were both taken 2 m north of Tent 4; one was collected from just beneath the tundra vegetation (SS 23) and the other was collected 10 cm below the surface (SS 24). These two samples are the only occasion where soil from different depths was collected except for the previously discussed offsite profiles.

In the smokehouses both exterior and interior samples were collected. The floor in Smokehouse 1 had a fresh layer of river mud. This "fresh floor" (SS 15) was sampled as was the original floor beneath the mud (SS 14). In Smokehouse 2 soil from the interior (SS 11) and from just outside its doorway (SS 10) was collected. Smokehouse 3 was used for storage at the time of field sampling, so only the area outside its doorway was sampled (SS 12). The remaining samples obtained at Old Chevak include a sample from underneath an open-air drying rack (SS 13) and three samples from a covered drying rack—one sample from the center (SS 8), one sample from just inside the covered area (SS 9), and one sample from 1 m west of this structure (SS 7).

A.3. Aprun River fish camp

At the Aprun River Camp samples were collected from both the 2000 and 2001 fish camp locations. From the 2000 camp, the following six samples were collected: two interior smokehouse samples (SS 25, 26), one exterior smokehouse sample (SS 27), two samples from inside the tent area (SS 28, 29), and one sample from near the river bank (SS 30). An additional nine samples were collected from the 2001 camp including five samples from the fish processing area and four samples from the covered drying rack. The fish processing area included two samples from where the fish were butchered (SS 31, 32), one sample from the fish holding pit (SS 33), and two samples from just outside the work area (SS 34, 35). The samples from the drying rack include two from underneath the covered area (SS 37, 38), and two samples from outside the rack (SS 36, 39).

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