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Earliest evidence for human use of tobacco in the Pleistocene Americas

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Current archaeological research on cultigens emphasizes the protracted and intimate human interactions with wild species that defined paths to domestication and, with certain plants, profoundly impacted humanity. Tobacco arguably has had more impact on global patterns in history than any other psychoactive substance, but how deep its cultural ties extend has been widely debated. Excavations at the Wishbone site, directed at the hearth-side activities of the early inhabitants of North America's desert west, have uncovered evidence for human tobacco use approximately 12,300 years ago, 9,000 years earlier than previously documented. Here we detail the preservation context of the site, discuss its cultural affiliation and suggest ways that the tobacco may have been used. The find has implications for our understanding of deep-time human use of intoxicants and its sociocultural intersection with food crop domestication.

Among the intoxicant plants preferred by humans, tobacco (*Nicotiana*) has arguably had the most critical social and economic impact. Its historical rise as a globally important domesticate is directly tied to Western expansion and commerce, beginning with humble interactions between Spanish explorers and indigenous peoples in the Americas. Tobacco now contributes to the enjoyment, traditional practice and detriment of hundreds of millions of people worldwide[1]. Within indigenous North American culture, ethnographic and historical accounts indicate tobacco's use in all manner of ritual, medicinal and social settings, and its power is richly ensconced in oral traditions[2–7]. Of North America's desert west, the late tobacco specialist Joseph Winter[8] wrote, "Of all the native [sic] groups…the Paiute, Goshute, Shoshone, Washo, Kawaiisu, and Ute of the Great Basin best represent the ancient substratum of tobacco-using shamanism that evolved elsewhere into… complex tobacco-using religious systems." This relationship implies deep time, but how deep remains a vital question[8–14].

Exploring deep-time use involves age control for identifying how human behaviour intersected with plant biology, distribution and evolutionary history. These aspects are essential to understanding how certain plants proceeded through long-term human fostering and traditional practice to eventual domestication[15–18]. Until recently, a key issue was whether people themselves expanded tobacco's geographic range into North America (from South America and southern Mexico) or whether they found it distributed much as it is today[9,11]. Phylogenetic studies now strongly establish the latter, on the order of hundreds of thousands to millions of years[19–24]. Current estimates for peoples' arrival in the Americas place them south of the continental ice sheets in coastal and neighbouring inland areas by about 16,000 calibrated years before present (cal BP)[25,26]. The phylogenetic data thus nullify the question of human ties to tobacco's natural distribution at a large scale, but lesser shifts through time brought by cultural mechanisms cannot be excluded and may be anticipated[17,18,27,28]. Winter[14] argued that people would have quickly recognized tobacco's intoxicant properties on their arrival and, having antecedent knowledge of other psychoactive plants, purposefully altered its distribution by various means of transport, ground disturbance and tending. When that happened, an inextricable human–plant relationship began. In Winter's view, people pushed the distribution of tobacco northwards from southern regions, but if the primary distribution of tobacco was already in place, then these secondary aspects, entailing numerous wild tobacco species and regional cultural traditions, represent the essence of his hypothesis and pivotal benchmarks in the trajectory of human utilization. Physical evidence from the archaeological record is needed to identify these benchmarks.

Archaeologists have worked back from established tobacco use in the precontact agrarian economies of North America to find deeper associations[29–31]. Recent finds of nicotine residue on pipes now demonstrate tobacco smoking in a pre-agricultural context at about 3,300 cal BP (ref. [9]). This is in the southeastern United States, where the archaeological record of pipes, for tobacco or otherwise, extends back to about 5,000 cal BP. Residues on smoking pipes in the Pacific Northwest date to about 1,200 cal BP or more[12,13]. In the Great Basin and adjacent areas, where agriculture was never fully adopted, tobacco seeds have been found in cultural contexts dating as early as about 1,750 cal BP (ref. [32]), and ceramic pipe fragments are known as early as about 4,800 cal BP (ref. [33]). Tobacco use in South America has a demonstrated age profile within the past 3,000 years[34]. If tobacco was available in the Americas when humans arrived in the Pleistocene, then, per Winter's hypothesis, archaeological associations should keep extending further back towards this time, shortly after people familiarized themselves with American flora. This familiarization probably extends more broadly to a complex of weedy plant species of dietary and medicinal significance to North America's indigenous cultures[3,17,18,35,36].

Results

Archaeological excavations at the Wishbone site (42TO6384) have yielded evidence for human use of tobacco at approximately 12,300 cal BP. Four charred *Nicotiana* seeds (Fig. 1) were found among the contents of an intact cultural hearth. The site is a hunter–gatherer

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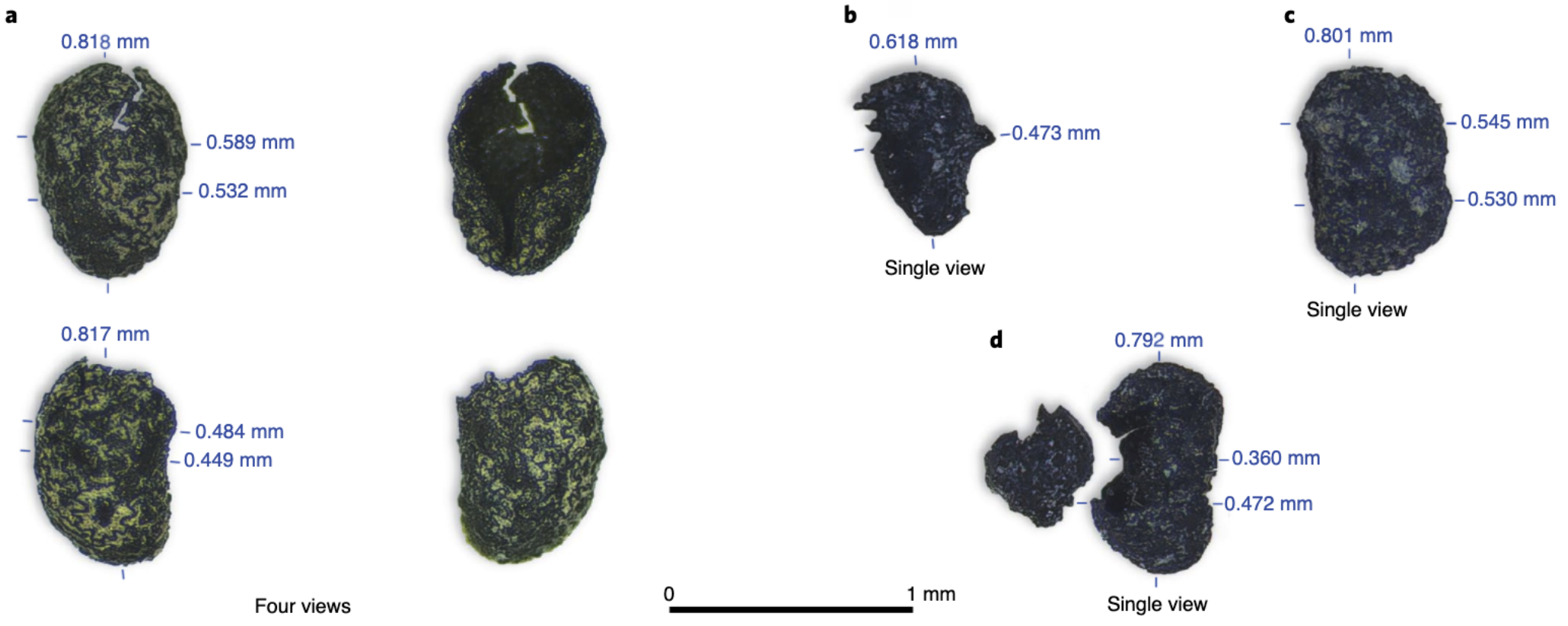

Fig. 1 | *Nicotiana* seeds and measurements from the Wishbone site. a, Specimen 1-35-98-1. **b**, Specimen 1-40-98-2. **c**, Specimen 1-40-98-1. **d**, Specimen 2-40-98-1.

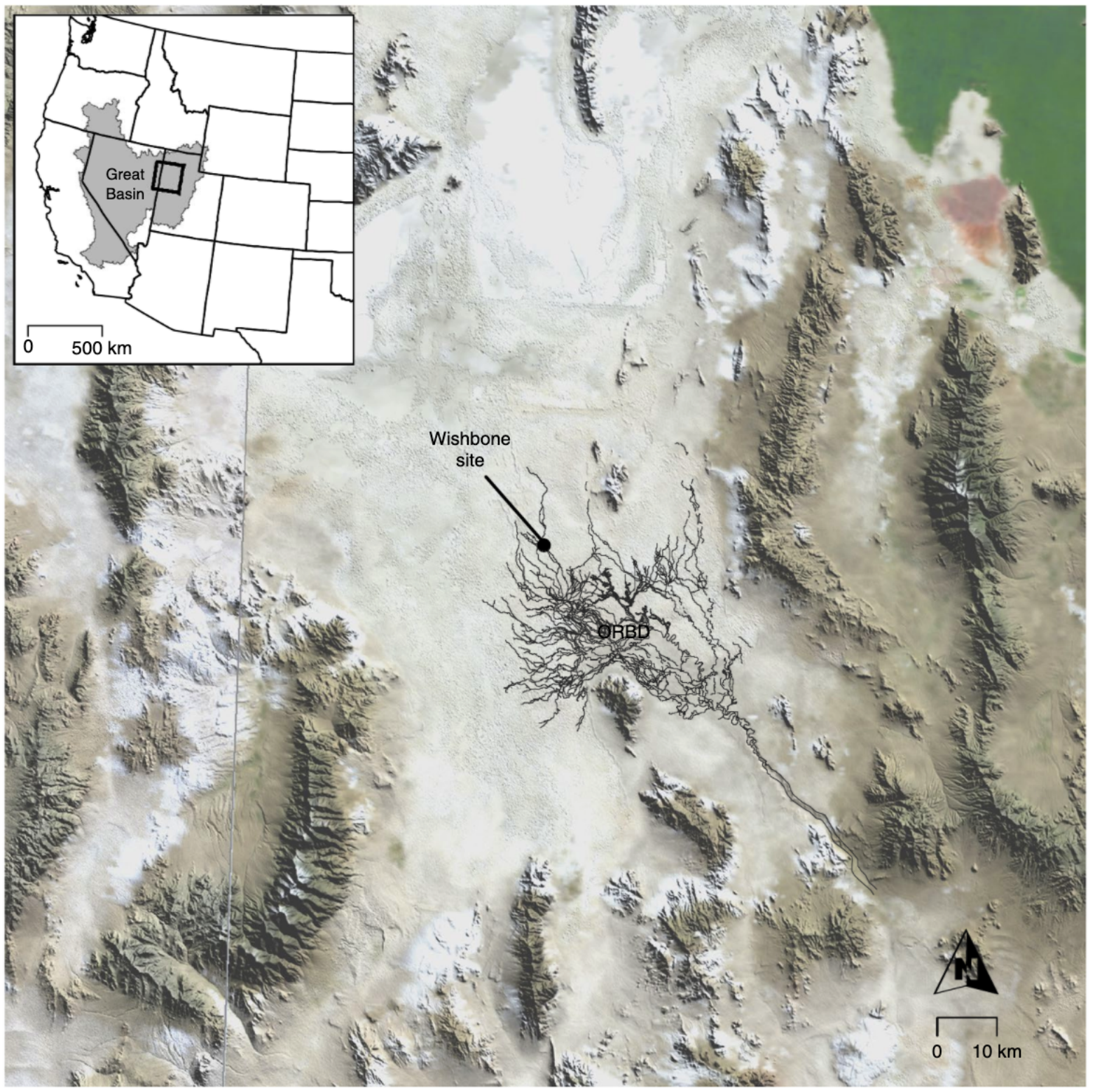

Fig. 2 | Location of the Wishbone site and important physiographic features. The ORBD channels are based on GIS mapping of extant landforms using aerial imagery (courtesy US Army Dugway Proving Ground).

Table 1 | Radiocarbon age estimates from Feature 1 at the Wishbone site and palaeoenvironmental controls

Site	Geo-locality	Laboratory number	Material	$^{13}C/^{12}C$ ratio	Conventional radiocarbon age (BP)	Median probability (cal BP)	Age range (cal BP, 95% confidence)	Comments
42TO6384	To64-1	Beta-428728	Charcoal—*Salix* (twig)	−26	10,370 ± 30	12,250	12,470–12,000	–
42TO6384	To64-1	Beta-428729	Charcoal—*Salix* (bark)	−26.9	10,430 ± 40	12,320	12,610–12,090	–
42TO6384	To64-1	Beta-428730	Charcoal—*Salix* (bark)	−27.3	10,370 ± 40	12,240	12,470–12,000	–
42TO6384	To64-1	–	–	–	10,390 ± 20	12,270	12,470–12,060	Above three dates combined
–	To27-1	Beta-479064	Organic sediment	−26.4	10,820 ± 30	12,750	12,830–12,720	–
–	To35-2	Beta-479058	Organic sediment	−20.2	10,720 ± 30	12,720	12,750–12,680	–
–	To35-2	Beta-479059	Organic sediment	−19.4	10,660 ± 30	12,700	12,740–12,620	Representative for To35-1, To35-3, To35-4 and To35-5
–	To65-1	Beta-428734	Organic sediment	−25.8	9,590 ± 30	10,930	11,150–10,760	–
–	To66-1	Beta-432288	Organic sediment	−18	10,350 ± 30	12,190	12,470–11,970	–
–	To81-4	Beta-479056	Organic sediment	−22.3	10,270 ± 30	11,970	12,430–11,820	–
–	To85-8	Beta-479061	Organic sediment	−26.8	10,710 ± 30	12,720	12,750–12,680	–
–	To85-8	Beta-479071	Charcoal specimen	−23.5	10,580 ± 40	12,630	12,710–12,480	Individual piece from To85-8 sediment

IntCal20 calibrations using OxCal v.4.4. Ages are rounded to the nearest ten years.

camp consisting of stone and bone artefacts surrounding the hearth and eroding from the mud flats of the Great Salt Lake Desert (GSLD). The area is now an open playa, but the site is situated alongside relict landforms of the Old River Bed delta (ORBD) (Fig. 2), a once-sprawling distributary marshland (>1,000 km^2) that existed between approximately 13,000 and 9,500 cal BP (refs. [37,38]). During this time, the ORBD served as a primary habitat draw for people in the region, who camped on the intervening dry landforms between wetland water bodies. The dating of the site is based on three radiocarbon age estimates on pieces of charred *Salix* sp. (willow) wood from the hearth fill (Methods). These provide a combined radiocarbon age estimate for the hearth of 10,390 ± 20 BP, which calibrates to a median probability age of 12,270 cal BP with a 95% confidence range of 12,480–12,060 cal BP (Table 1). Willow was probably the best marshland fuelwood option on the ORBD, as it commonly is now in wetlands throughout the Great Basin.

The site is culturally affiliated with an archaeological complex known as the Western Stemmed Tradition within indigenous Shoshonean-speaking Goshute territory[39]. This tradition is largely restricted to western North America at the Pleistocene–Holocene transition and is recognized by a series of stemmed projectile point styles. The oldest of these in the Great Basin, Haskett, was identified among the hearth-associated artefacts at the Wishbone site. Haskett points are lanceolate-shaped spear tips[40,41] that may date as early as about 13,000 cal BP (ref. [42]). This date is contemporaneous with the Clovis style, of the fluted point tradition, which is widely recognized across the continent[43], but Haskett is unique to the Intermountain West. Haskett points in dry cave and rockshelter sites at the GSLD margins demonstrate use in the area beginning sometime between about 12,900 and 12,500 cal BP (refs. [44,45]). Both Haskett and Clovis are specialized large-game hunting technologies used by highly mobile hunter–gatherers who ranged on the order of several hundred kilometres annually[46,47]. These technologies are thought by some to represent distinctive cultural traditions converging on waning megafaunal populations at the end of the Pleistocene in North America's sparsely populated interior[26,41,48].

A diverse cultural assemblage was associated with the hearth, providing behavioural context for the find. Within the hearth fill, the recovered artefacts include one half of a broken Haskett point made from Wildhorse Canyon obsidian (about 200 km south) (Fig. 3a), 2,062 bones and bone fragments (burned) weighing 24.0 g, at least one definitive avian gastrolith (Methods), one eggshell fragment, and 41 pieces of stone toolmaking debris. Among the macrobotanical remains, alongside the *Nicotiana* were three other small-seed genera (all charred) commonly tied to human dietary use when found in hearths: *Chenopodium berlandieri* (pitseed goosefoot), *Chenopodium* spp. (goosefoot), *Calandrinia* spp. (red maids) and *Deschampsia* spp. (hairgrass). Seeds common to wetland plants were also found (Table 2). Surrounding the hearth, the excavation and surface collection yielded the other half of the Haskett point from the hearth fill (Fig. 3b) and a complete Haskett specimen made from Flat Hills A dacite (about 60 km southeast) (Fig. 3d), 19,071 bones and bone fragments (unburned) weighing 355.5 g, 23 eggshell fragments, 577 pieces of stone toolmaking debris, seven cutting and scraping tools, and a human-made incised mammal bone object (possibly representing bead production[49,50]) (Fig. 3e). The distribution of burned versus unburned bone in and around the hearth, respectively, represents common food discard behaviour. A plan view map of the excavated area is provided in Fig. 4.

A sample of 2,066 identifiable bones and bone fragments weighing 110.7 g were subjected to detailed faunal analysis. This represents 15% of the assemblage count and 35% of the assemblage weight. Waterfowl bones (n = 1,782) dominate the sample and are easily recognizable throughout the assemblage. Taxonomic classification was impractical because of the fragmentary nature of the bone, but the assemblage overwhelmingly indicates small to large species of ducks (Anatidae). At least six individuals are present in the sample: three large (for example, canvasbacks, mallards, pintails and wigeons), two medium (for example, gadwalls, ruddys, scaups and woods) and one small (for example, shovellers and teals). Unfused limb bones from three individuals, one from each size category, indicate subadults and summertime seasonality.

Fig. 3 | Position of hearth (circled) relative to selected artefacts at the Wishbone site. a, Haskett fragment, field specimen (FS) 247, refits with FS 59. **b**, Haskett point fragment, FS 59, refits with FS 247. **c**, Unburned Anatidae humerus, FS 230. **d**, Haskett point, FS 220. **e**, Incised mammal bone, FS 761. **f**, Burned Anatidae furculum, FS 246.

Six bones, five from the thorax region (two furculae, two coracoids and one scapula) and one unspecified, exhibit tool cutmarks. Mammal bones ($n=120$) represent at least one individual (Antilocapridae or Cervidae), and the remaining bones from the sample are indeterminate vertebrate ($n=182$). The examined sample, as well as the remaining bone assemblage, was largely contained within a 3-m radius of the hearth but decreased substantially outside of 1 m.

The *Nicotiana* seeds were identified in 0.5-mm grade and 0.4-mm flotation residues from the central hearth fill (Fig. 5). That these seeds were preserved at all in such an early site is attributed to the distinctive subsurface context of the GSLD. Geomorphological investigations suggest that the hearth had been buried by persistent ORBD sediment deposition after the Pleistocene habitation but before the desiccation of the wetlands in the Early Holocene (about 9,500 cal BP). Aeolian and alluvial processes have been peeling away sediment layers since that time, just now reaching the hearth. On the basis of the extent of the oxidized ring surrounding the remaining feature (which must have been heated from above and near the hearth margins), we estimate that perhaps a substantial portion has already eroded away. Beneath the ground surface, cultural deposits remain largely undisturbed and sealed in a fine silty clay matrix. This matrix represents a waterlogged and nearly anaerobic substrate[51] that remains intact except at the deflating surface where wet–dry cycles and seasonal water affect and destroy archaeological materials and the wind carries away the lightweight fragments. The hearth was being exposed at this erosional interface. The sediments surrounding the hearth and similarly aged palaeoenvironmental control samples from the site vicinity were also examined; no tobacco seeds were found, only the seeds of wetland plants (Table 2).

Nicotiana seeds are readily identifiable at the genus level, but species identification is challenging given overlapping morphological attributes[29,52–55]. Because tobacco seeds ripen inside stiff-walled capsules, individual seed shape is affected to some extent by being packed up against other seeds during development, contributing to minor variability. The seeds from the Wishbone site hearth closely resemble *N. attenuata* Torr. Ex S. Wats., which is common in the Great Basin[29,56], and its use by indigenous peoples has been well documented in this region[5,8,57–60]. *N. attenuata* seeds average 0.7–1.0 mm long by 0.5–0.8 mm wide and have a reniform to angular-reniform shape, dark grey-brown colour, prominent hilum and reticulate to fluted-reticulate surface ornamentation with wavy walls[11,52,61]. The Wishbone site seeds (Fig. 1) are charred and discoloured, but they are otherwise consistent on each attribute with *N. attenuata* and compare favourably with published microphotos[29,52]. The other relevant western species are *N. quadrivalvis* Pursh and *N. obtusifolia* M. Martens & Galeotti (formerly *N. trigonophylla*). (There are several varieties of *N. quadrivalvis*, a few of which are indehiscent, suggesting domestication[29,62–64].) Charred seeds from either of these may be confused with *N. attenuata* if found in shared geography, but the Wishbone site is located in

Table 2 | Charred plant materials from the Wishbone site and palaeoenvironmental control samples

Site			**42TO6384**	**42TO6384**	**42TO6384**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Geo-locality			**To64-1**	**NA**	**NA**	**To27-1**	**To35-1, To35-2, To35-3, To35-4 and To35-5**	**To65-1**	**To66-1**	**To81-4**	**To85-8**	**To114-1**
Sediment context			**Within hearth (fill)**	**Beneath hearth**	**Outside hearth**	**Organic sediment**	**Organic sediment**	**Organic sediment**	**Organic sediment**	**Organic sediment**	**Organic sediment**	**Organic sediment**
Volume (l)			**12.1**	**23.3**	**327.9**	**2.3**	**35.2**	**0.15**	**0.5**	**1.8**	**19.5**	**2.5**
Scientific name	**Common name**											
Calandrinia spp.	Red maids	ct	1	–	–	–	–	–	–	–	–	–
Chenopodium berlandieri	Pitseed goosefoot	ct	5	–	–	–	–	–	–	–	–	–
Chenopodium spp.	Goosefoot	ct	–	–	–	–	–	–	–	–	–	–
Deschampsia spp.	Hairgrass	ct	3	–	–	–	–	–	–	–	2	–
Juncus spp.	Rush	ct	4	1	–	–	–	–	–	–	1	–
Nicotiana spp.	Tobacco	ct	4	–	–	–	–	–	–	–	–	–
Potamogeton spp.	Pondweed	ct	44	–	20	–	3	–	–	–	–	–
Rumex spp.	Dock	ct	–	–	–	1	–	–	–	–	1	–
Schoenoplectus spp.	Tule	ct	75	6	67	99	94	2	4	2	133	57
Typha spp.	Cattail	ct	–	–	1	4	–	–	–	–	23	–
Chenopodiaceae	Goosefoot family	ct	1	–	3	1	–	–	–	8	66	9
Poaceae fragments	Grass family	ct	11	1	4	2	1	–	2	–	–	1
Unidentifiable seeds		ct	33	9	60	5	21	5	4	3	16	2
Total identified to genus		ct	136	7	88	104	108	2	4	160	104	57
Total identified to family		ct	149	8	95	107	109	2	6	226	107	67
Salix sp. wood charcoal		mg	830.8	–	–	–	–	–	–	–	–	–
Unidentified wood charcoal		mg	247.2	0.6	–	2.3	5.7	–	–	–	275.0	–

NA, not applicable; ct, count.

the eastern Great Basin, away from their common ranges[11,29,56]. *N. attenuata* is a cold-adapted, drought-tolerant species well suited to the higher-latitude Great Basin[56]. *N. quadrivalvis* is intolerant to frost, high temperatures and dry conditions and is most abundant in California, west of the Sierra Nevada and the Great Basin Desert[62,63,65]. *N. obtusifolia* is likewise frost-intolerant but favours high temperatures and dry conditions; it is most abundant in the southern deserts of the United States and Mexico[56,63]. Colder terminal Pleistocene conditions—on the order of 6–7 °C in the eastern Great Basin[66]—would have exaggerated these distinctions, favouring *N. attenuata* habitat range at the expense of the other two species. The geographic probability combined with the observable seed characteristics supports a classification of the Wishbone site seeds as *N. attenuata*.

Cultural versus natural deposition. Seeds identified in prehistoric hearths usually represent human use unless attributable to natural factors. We considered two alternative hypotheses to the interpretation that the *Nicotiana* seeds were culturally deposited: (1) they represent the stomach contents of waterfowl cooked in the hearth; and/or (2) they were included as a fire fuel source or were introduced naturally and burned. Regarding the first alternative, *Nicotiana* is not part of the avian diet. Nicotine and other alkaloids are variably unpalatable and/or toxic to many vertebrate animal species[67]. Also, regional *Nicotiana* is found upland in rocky outcrops and adjacent areas[56,68], in stark contrast to the open marshland context—that is, waterfowl food supply—of the ORBD and immediate site vicinity. Nevertheless, we surmise that the internal organs of the cooked birds were present in the hearth, so the possibility of incidental inclusion was addressed. Whole-bird cooking, a favoured method by indigenous peoples in the region[69], is suggested by the presence of gastroliths and bones from the lower legs and feet, which were probably deposited from discarded entrails and body parts. The hearth also contained *Potamogeton* spp. (pondweed) seeds, a subaqueous dietary staple for many Anatidae species and an unlikely food target for people, in relative abundance compared with our palaeoenvironmental control samples (Table 2).

Regarding the second alternative, *Nicotiana*'s use by people as fuel is improbable because tobacco is an annual or biennial plant lacking woody tissue; it burns quickly and cannot generate a fire of enough strength or duration for most cooking. Another incidental possibility is from wildland fires, which presumes the presence of *Nicotiana* in the site vicinity at the time of human use. The local range of desert species of *Nicotiana* within its modern distribution can increase quickly after wildfires, a fact exploited by indigenous people who sometimes used controlled burns to enhance its yield[5,8,57,63,65,70], but, human-induced or not, the plants would be expected to expand only within their normal habitat, not across the ORBD marshes. The intervening landforms between waterways would consist of poorly drained sediments much like those at the Wishbone site; the GSLD at large remains the muddy bottom of pluvial Lake Bonneville. Desert tobacco species require well-drained

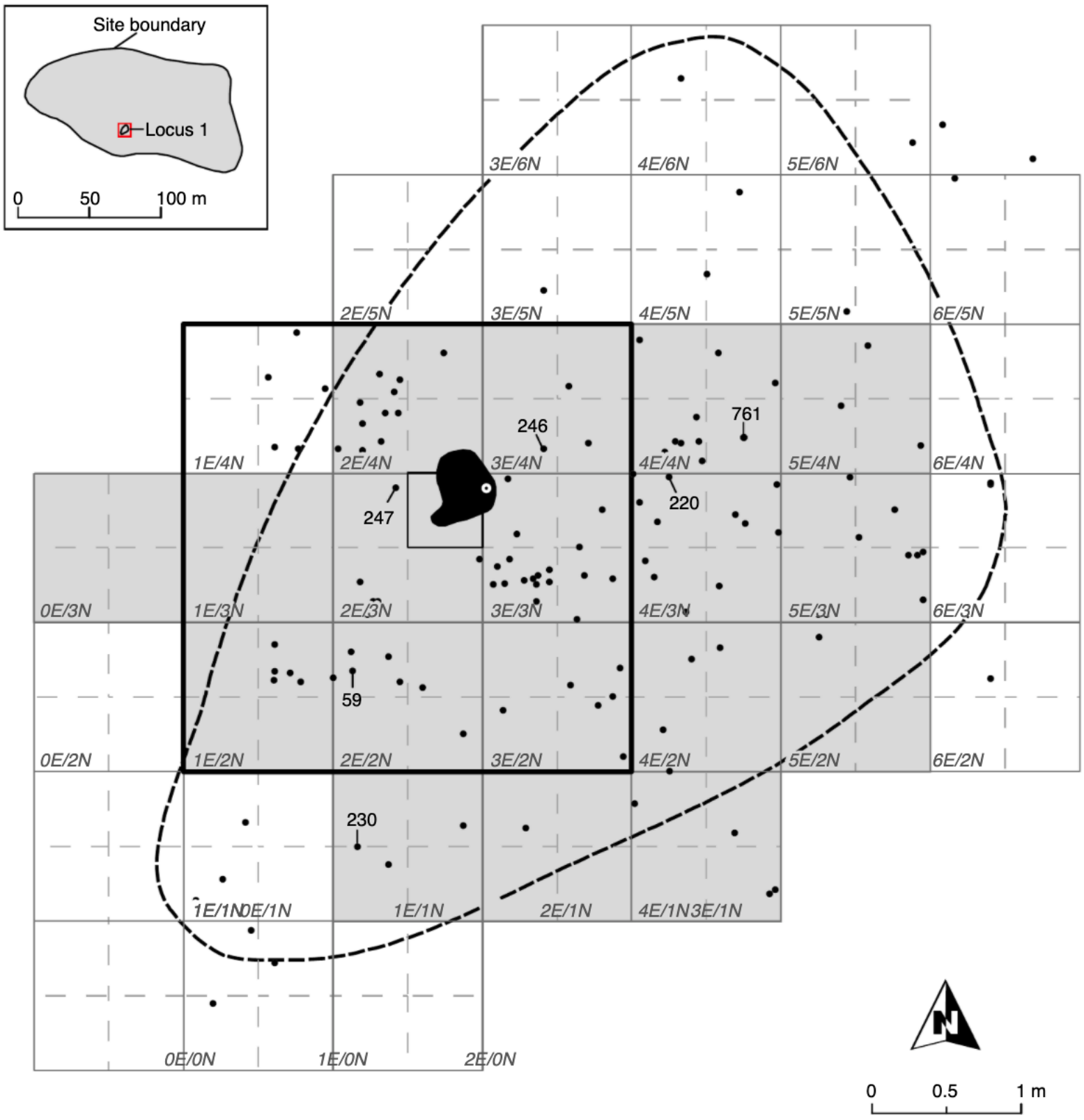

Fig. 4 | Plan view map of the excavated area at the Wishbone site (Locus 1). The Locus 1 boundary (bold dashed line) represents the concentrated region of piece-plotted surface- and subsurface-encountered artefacts (dots). Selected items corresponding with those shown in Fig. 5 are indicated by FS number. The total gridded area represents the planned maximum possible extent of excavations using 1-m units and 0.50-m-by-0.50-m quadrants (grey dashed lines). The shaded region shows the final extent of excavations. The bold 3-m-by-3-m box shows where all sediments were extracted and taken to the laboratory for manual flotation (the exception, 1E/4N, was eroded below the level of the adjacent units and the human living surface). Sediments from other units were screened on site using 64-mm mesh. The hearth area is shown in black and can be seen in detail in Fig. 5.

gravelly and sandy sediment for growth[56]. Current tobacco habitat lies 13 km to the northeast on Wildcat Mountain, a small, isolated mountain protruding from the GSLD mud flats (Fig. 2); otherwise, 24 km separate the site from the nearest habitat along the mountain fans and foothills at the basin margin. We examined the macrobotanical remains from our palaeoenvironmental control samples and found only seeds from plants common to Great Basin wetlands (Table 2). *Potamogeton* is more abundant in the hearth than the controls, supporting the case for duck entrail contents, but there is no evidence of *Nicotiana*.

On the basis of these lines of evidence, the introduction of *Nicotiana* by cultural agents is the most parsimonious explanation for its presence at the Wishbone site. This interpretation is strengthened by the general lack within the control samples of the other plant species found in the hearth (*Chenopodium berlandieri*, *Calandrinia* spp. and *Deschampsia* spp.), although some *Chenopodium* spp. seeds were identified (Table 2). Taken together, the evidence represents a common archaeological profile for human-introduced small seed components in the intact hearths of the Great Basin and California dating throughout the Holocene[71–76].

Manner of human use. We cannot determine for certain the manner of human use for the tobacco at the site, but a few considerations are useful for narrowing the range of possibilities. The data suggest use as a fireside activity along with food preparation, food consumption and tool use among mobile hunter–gatherers at a distance from natural tobacco habitat. The finding of seeds implies emphasis on leaves and flowering stems, the parts with the intoxicant effect. Seeds are the tobacco parts preserved most often in the archaeobotanical record, but non-germinated seeds carry no nicotine[77]. Because the seeds are small and easily caught up by the sticky hairs of the plant, they could be incidentally included when leaves and stems with attached flowering parts are harvested. This is consistent with the archaeological record and preparation methods by indigenous groups in the Great Basin[78,79].

The growing dataset of nicotine residues from precontact pipes indicates that tobacco smoking was common[2,9,12,13,31], but the chewing and/or sucking of plugs, pinches and quids was also practiced[52,80]. Smoking might introduce seeds by the discard of unused portions of undesired dry remnants. Quids—wads of plant fibre to be chewed and/or sucked—have been found in regional dry caves

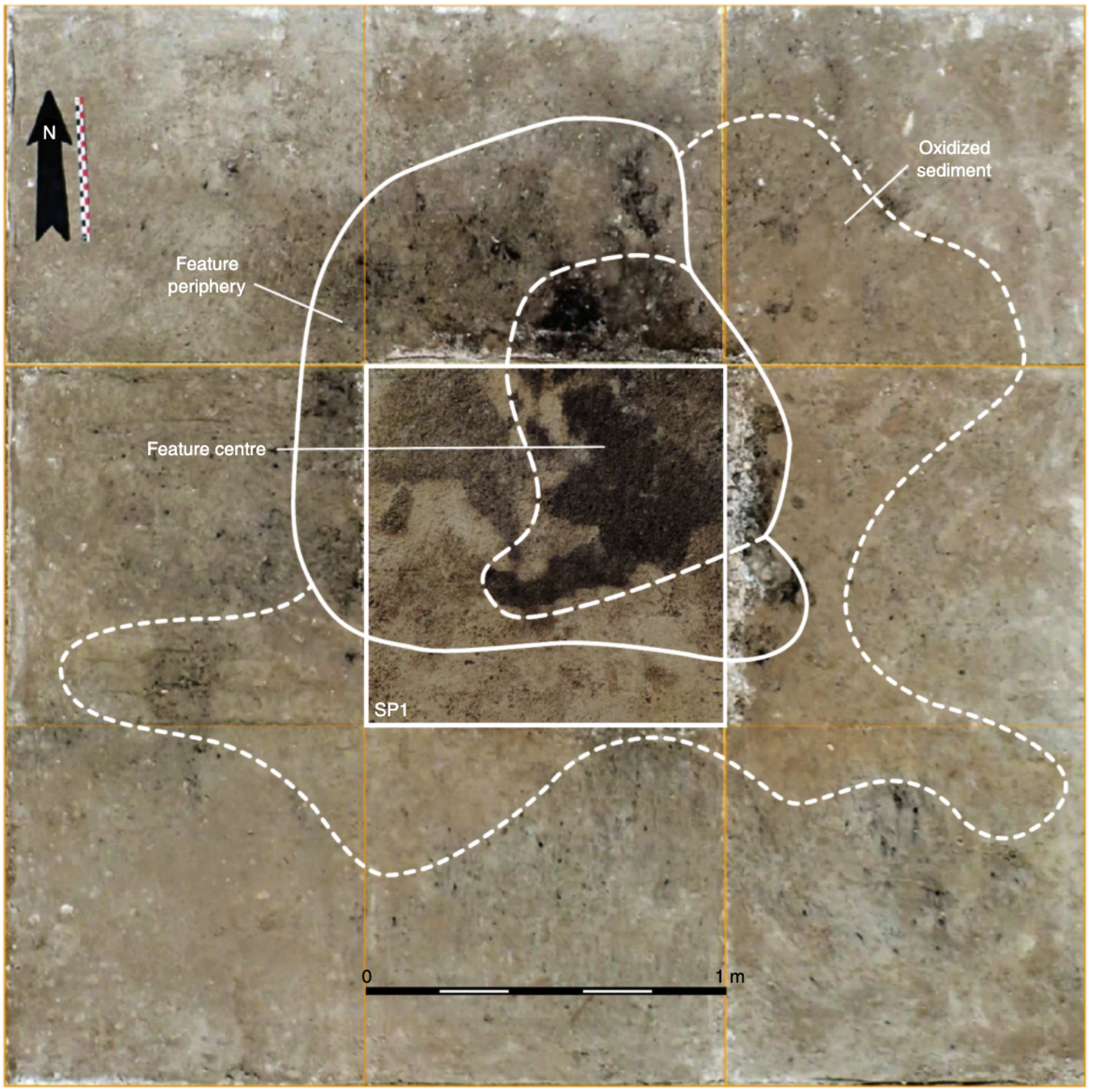

Fig. 5 | Plan view of the Wishbone site hearth (Feature 1). View is at 2 cm below the ground surface (162 cm below datum). The central square represents the 0.5-m-by-0.5-m shovel probe (SP1) excavated and photographed in 2015. The *Nicotiana* seeds were found in the flotation-processed feature centre fill from SP1. The remaining area was excavated to the same level and photographed in 2016. The charcoal flecks outside the defined hearth boundary probably represent windblown pieces from the time of use.

and shelters containing tobacco and other intoxicant substances, such as *Datura*[81]. In one regional example, Arizona's Antelope Cave, seeds and fragments of tobacco capsules, calyxes, pedicels, stems and leaves were found in 90% of the quids examined[80]. Nearer to the Wishbone site, over 1,900 discarded quids were found in Danger Cave[82], just 65 km to the northwest at the basin margin near Wendover, Utah. Their contents have not been examined, but the quids were found throughout the Holocene cultural profile. Seeds from quid use could have been deposited by being spat or by expended quids being tossed into the fire. Researchers might consider the potential for *Nicotiana* residues, such as phytoliths, being retained in well-preserved contexts.

Discussion

In the Great Basin, people lived as hunter–gatherers through Euroamerican contact, and their most common foray into plant cultivation was with tobacco. At the Wishbone site, this plant was brought from its upland habitat into the centre of a large wetland early in human experience in the Americas. The limitations of this work include the presence of non-intoxicant seeds representing human tobacco use and the potential that these seeds were deposited by non-cultural means. Archaeological examples show that the small seeds are readily included in quids used for intoxicant effect. Habitat considerations and palaeoenvironmental control samples are consistent with the expectation that tobacco plants would not have been growing in the ORBD wetlands. The data confirm that wild tobacco was available in the continental interior during the Pleistocene and support the conclusion that its intoxicant properties were soon recognized by people upon their arrival.

The latter is consistent with Winter's[14] hypothesis for early tobacco adoption and provides information for future studies. Regarding *N. attenuata* in particular, its frost-tolerant dryland ecology would be expected to facilitate an expanded range in the colder, dryer terminal Pleistocene, especially to the south at the expense of *N. obtusifolia*. This was a threshold time in the human settlement of the Americas. If people in the earliest-settled coastal and near-coastal regions between about 16,000 and 13,000 years ago already had experience with local species such as *N. quadrivalvis*, then *N. attenuata* should have figured into the traditional practices of human populations moving into the western North American interior shortly thereafter.

The find recalibrates research on tobacco as a domesticate, putting some 8,000 to 10,000 years of human use before the great efflorescence of agriculture in North America and the domestication of *N. tabacum* and *N. rustica* at some point alongside a host of food crops. This has implications for examining how long-term

cultural relationships with plants shape and respond to further developments. Tobacco's early use lends to the interpretation that there is nothing inevitable about domestication. Rather, it is one result of a feedback process between humans and plants that is best understood as mutually beneficial at any given time, then moves forwards according to local refinements from a base of traditional ecological knowledge[17,18,28]. The place of tobacco among other disturbance-pioneering weedy species (a few found in the Wishbone site hearth and in other North American sites from its time[83–85]) suggests that it was part of a complex of early successional small seed plants known to people in the terminal Pleistocene. These could have helped underwrite hunter–gatherer diet and nutrition[86–88] alongside the high-calorie food packages, usually hunted, that drove broader land use priorities. Although not a food plant, tobacco's long heritage with humans, entailing both use and abuse, represents one view from the sociocultural side of a broader plant intensification process that manifested itself differently according to local socioeconomic incentives and pressures. With its rich history in Western commerce, influence and cross-cultural impact, tobacco is uniquely suited to examining this process through a connection to many societal facies since the Pleistocene.

Methods

The Wishbone site (42TO6384) was initially identified in 2015 during a cultural resource management survey conducted by Far Western Anthropological Research Group on US Air Force, Hill Air Force Base (Hill AFB)-managed lands of the Utah Test and Training Range under Section 110 of the National Historic Preservation Act. Excavations took place in 2016 to address the potential loss of important information to ongoing erosion. The study protocol, an archaeological Historic Properties Treatment Plan, was submitted by Far Western Anthropological Research Group to the Hill AFB Cultural Resource Program and the Center for Integrated Research on the Environment (CIRE) at the University of Montana. The plan was approved by the Hill AFB Cultural Resource Program consistent with US regulations and government-to-government consultation with 20 indigenous tribes who claim ancestral ties to Utah Test and Training Range lands—the Confederated Tribes of the Goshute, the Blackfeet Tribe of the Blackfeet Indian Reservation of Montana, the Crow Tribe of Montana, the Eastern Shoshone Tribe, the Hopi Tribe, the Navajo Nation, the Northern Arapaho Tribe, the Northwestern Band of the Shoshone Nation, the Paiute Indian Tribe of Utah, the Pueblo of Zuni, the San Juan Southern Paiute Tribe, the Shoshone-Bannock Tribes of the Fort Hall Reservation, the Shoshone-Paiute Tribes of the Duck Valley Reservation, the Skull Valley Band of the Goshute Indians, the Te-Moak Tribe of Western Shoshone Indians, the Ute Indian Tribe, the Ute Mountain Ute Tribe, the Duckwater Shoshone Tribe of the Duckwater Reservation, the Ely Shoshone Tribe and the Wells Band of the Western Shoshone. Compliance with the Archaeological Resources Protection Act was met through the approval of the treatment plan by the Hill AFB, per Air Force Manual 32–7003, Section 2.11.4.2. As approved in the Historic Properties Treatment Plan, collections from the Wishbone site consisted of all archaeological materials—flaked stone, faunal material, botanical remains, hearth contents and sediment samples—observed on the ground surface and from excavations, to be curated at the Natural History Museum of Utah under a standing agreement with Hill AFB.

The total dimensions of the Wishbone site represent the distribution threshold of artefacts found on the ground surface according to Hill AFB site definition policy, which is at least ten items within an area measuring 10 m in diameter. The current study focuses on a distinctive subarea of the site defined as Locus 1 (Fig. 4). Outside of Locus 1, the site assemblage is a common array of artefacts for the area already eroded out of their primary context and moved by geomorphological processes. The context and associations in Locus 1, however, indicated that erosion had not yet proceeded through the cultural deposits. This area was the focus of excavations (Fig. 4). The archaeology of Locus 1 and its central hearth are the subject of the current study, and no direct association is made with the assemblage found elsewhere in the site. A full report on the Wishbone site was provided to the US Air Force[89].

Macrobotanical specimens were identified in the laboratory from sediment fill collected during site excavations (Table 2). The hearth extended variably 2–4 cm down from the ground surface. All excavated sediment within a 3-m-by-3-m gridded area inclusive of and surrounding the hearth was bagged by each 0.5-m-by-0.5-m subunit for comprehensive analysis in the laboratory (Fig. 4). The other excavated areas were screened using 64-mm wire mesh. Sizeable or otherwise noticeable artefacts found during the excavation (as opposed to found while screening sediments or during manual flotation in the laboratory) were piece plotted when encountered to document their spatial association with the hearth.

Palaeoenvironmental control samples from seven geo-localities in the vicinity (<3 km) of the site were collected for comparison with the hearth contents. These are of similar age to the site and are intended to represent the macrobotanically identifiable plant profile of the ORBD wetlands at the Pleistocene–Holocene transition. The sediments, often referred to as 'black mats', are extant shallow-marsh, organic-rich sediment layers that retain a black-to-grey colour[90]. While bulk organic sediments can represent only an average of time, their deposition on the ORBD tended to occur in short-lived oscillations of wetland waterways. They have proven useful in radiocarbon dating of the ORBD system[37,38], and their age resolution is sufficient for the current purposes.

The sediment samples were flotation-processed using a manual technique utilized for thousands of soil samples throughout the Great Basin and California[91,92]. Three iterations of filling, skimming and decanting from the slurry in a washtub ensured thorough recovery and collection of charred plant remains in the buoyant light fraction collected using 0.4-mm screen. The approximately 1.0-mm tobacco seeds and other small plant specimens would be caught in this mesh. The non-buoyant heavy fraction was washed through 3-mm and 0.7-mm mesh to retrieve other fine-grained site constituents as well as the rare non-buoyant plant remains. Thorough washing of all equipment, before and upon completion of flotation, ensured that no inter-sample contamination occurred. The light fraction was size-sorted using 2-mm, 1-mm, 0.7-mm and 0.5-mm mesh. The sorting of light fractions for charred seeds and other recognizable plant material was then completed. Each size grade, including the 0.4-mm residue, was examined under a microscope at ×10–30 magnifications. Soil volume (l) and weight (kg) were recorded for each flotation sample.

Radiocarbon dating by accelerator mass spectrometry was conducted on charred woody material from the hearth contents, retrieved during manual flotation, and on six of the seven the palaeoenvironmental control localities (Table 1). The *Nicotiana* seeds were judged too small (<0.1 mg) and fragile for direct dating by current methods. The charred wood samples were submitted to the Paleoscapes Archaeobotanical Services Team for plant identification before submission to Beta Analytic for accelerator mass spectrometry dating. The age calibrations are based on the IntCal20 curve[93] via OxCal v.4.4 (ref. [94]). The calibrated median probability age for the site was generated using the OxCal combining tool.

Gastroliths, commonly referred to as gizzard stones, can be challenging to identify archaeologically unless their context can be restricted to no similar other kinds of stones and substantiated by further evidence of avian entrails having been present. Both requirements are met at the Wishbone site, where the only pebble input could have come from an ORBD palaeochannel 70 m away and there is clear evidence from the faunal assemblage for waterfowl entrails in the hearth; there is no other evidence of such pebbles in the site vicinity, which is otherwise a nearly barren silt-clay mudflat. In total, nine subrounded to subangular pebbles were found measuring about 1.0–3.0 cm at maximum. Three of these are from the hearth fill, and five others are from the surrounding area within Locus 1. One pebble, FS 74, is not a rock but rather a concretion of very coarse sand and translucent filaments, the latter visibly consistent with fragmented feather parts but not otherwise tested as such. Concretions of this sort are consistent with some gastroliths[95]. We examined this specimen's chemistry by X-ray fluorescence and found it to be calcic, as would be expected if concreted biologically. The other rocks are conspicuous because they are not typical of the playa surface and are not known to otherwise be of any value to people. We did not notice any additional coarse or very coarse sand in the sediment that might further represent gizzard contents. Taken with the one concreted item and proximity to the hearth, the other eight rocks are tentatively interpreted as gastroliths. Nevertheless, only specimen FS 74 can be demonstrated as such by our analysis.

The authors affirm that the human research participants provided informed consent for the publication of the images in Fig. 3.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The data analysed in this study are currently being processed by Far Western Anthropological Research Group for curation at the Natural History Museum of Utah, Salt Lake City, under accession number UMNH.A.2016.18, by the end of 2021. The Natural History Museum of Utah serves as the repository for all archaeological collections from military lands managed by Hill AFB, including archaeological artefacts and related field notes, files, databases and reporting.

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Author contributions

D.D. directed the project and wrote the main text with assistance from E.W., K.R.A. and S.K.R. E.W. supervised the archaeobotanical laboratory and assisted D.D. with the Methods. K.R.A. provided specialized knowledge of *Nicotiana* morphology and human use. A.A.-I. initially identified and photographed the *Nicotiana* seeds in the laboratory. D.D. and S.K.R. directed the excavations. D.C.Y. conducted the geomorphological investigations and directed the palaeoenvironmental control sampling with D.D.

Competing interests

The authors declare no competing interests.

Additional information

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