American Antiquity (2025), **90**, 200–216
doi:10.1017/aaq.2024.42

SOCIETY FOR AMERICAN ARCHAEOLOGY

ARTICLE

Starch Granule Evidence for Biscuitroot (*Lomatium* spp.) Processing at Upland Rock Art Sites in Warner Valley, Oregon

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(Received 1 September 2023; revised 6 May 2024; accepted 27 May 2024)

Abstract

Geophytes are hardy, resilient plants that are tolerant of cold temperatures and drought and are well documented as a reliable food source for hunter-gatherers worldwide. Human settlement patterns and foraging behaviors have long been associated with the use of nutrient-dense geophytes rich in carbohydrates, fiber, vitamins, and minerals. Indigenous communities in the northern Great Basin developed cultural practices centered around gathering, preparing, and consuming important geophytic plants. These practices became deeply embedded in their cultural identity, forming rituals, stories, and traditions that persist today. Although there is strong ethnographic precedent for the significance of geophytes, finding evidence of their use in the archaeological record remains a challenge. This study analyzed archaeological starch residue extracted from bedrock metates in the uplands of Warner Valley, Oregon. Systematic studies of starch granules collected from extant plant communities growing near archaeological sites were applied to the identification of archaeological granules. Starch granules from geophytes, specifically *Lomatium* spp. (biscuitroot), were identified on metate surfaces at all sites, thus providing direct evidence for the collection and processing of geophyte vegetables. Evidence of geophyte plant processing on bedrock metates contributes to archaeological theories about subsistence strategies, food-processing technologies, social organization, and cultural practices in past human societies.

Resumen

Se conoce a las geófitas por ser fuertes y resistentes, tolerantes a las bajas temperaturas y a la sequía, y se han considerado como fuente de alimento confiable para los cazadores y recolectores en todo el mundo. Así mismo se les ha relacionado durante mucho tiempo, por estar presentes en los asentamientos humanos y la búsqueda de alimento, por considerarse ricas en nutrientes, carbohidratos, fibra, vitaminas y minerales. Las comunidades nativas indígenas del Norte de la Gran Cuenca desarrollaron usos y costumbres centradas en la recolección, preparación y consumo de estas importantes plantas geófitas. Estas prácticas han formado parte esencial en su identidad cultural a través de rituales, relatos y tradiciones que sobreviven hoy en día. Aunque existen estudios etnográficos significativos sobre la importancia de las geófitas, el hallar evidencia arqueológica sobre su uso sigue siendo un desafío. Este estudio consistió en analizar residuos arqueológicos de almidón extraídos de metates de piedra madre en los altos de Warner Valley, Oregón. Durante el proceso de búsqueda de gránulos arqueológicos, se condujeron estudios sistemáticos basándose en la identificación de partículas de almidón recolectadas cerca de sitios arqueológicos donde crecen ciertos grupos de plantas. Se identificaron gránulos de almidón de plantas geófitas, específicamente de múltiples especies de *Lomatium* spp. (raíz de Lomatium) en las superficies de los metates de todos los sitios analizados, lo que muestra evidencia directa de la recolección y procesamiento de plantas geófitas. El descubrimiento del procesamiento de plantas geófitas en los metates de piedra madre es de gran aportación a las teorías arqueológicas sobre la subsistencia de los humanos, la tecnología aplicada en el proceso de alimentos, la organización social y las prácticas culturales en las sociedades pasadas.

Keywords: starch granule analysis; northern Great Basin; Paleoindians; geophytes; ground stone; bedrock metate; Warner Valley; Oregon

Palabras clave: análisis de gránulos de almidón; norte de la Gran Cuenca; Paleoindios; geófitas; piedra para moler; metate de piedra madre; Warner Valley; Oregón

Geophytes are perennial, herbaceous plants that store their energy in underground organs, such as roots, tubers, corms, and rhizomes (Raunkiaer 1934). They are nutrient-dense vegetables, rich in carbohydrates, fiber, vitamins, and minerals, with caloric return rates as high as 3,500 cal/hr (comparable to those of avian and small mammal resources; Botha et al. 2022; Carney et al. 2021; Fowler and Rhode 2006; Madsen and Schmitt 1998; McGuire and Stevens 2017; Smith and McNees 2005, 2011; Trammell et al. 2008). Geophytes are hardy, resilient plants that are tolerant of cold temperatures and drought and are well documented as a reliable food source for hunter-gatherers worldwide (Hawkes and O'Connell 1992; Hurtado and Hill 1987; Pontzer and Wood 2021; Pontzer et al. 2018). Over hundreds of generations, Indigenous communities in the northern Great Basin developed cultural practices centered around the gathering, preparation, and consumption of geophytes. These practices became deeply embedded in their cultural identity, forming rituals, stories, and traditions around the harvesting and use of these plants (Carney et al. 2021; Couture et al. 1986; Fowler 1989; Fowler and Lepofsky 2011; Fulkerson and Tushingham 2021; Kelly 1932; Steward 1933; Stewart 1939). However, finding evidence of geophyte use in the archaeological record remains a challenge (Copeland and Hardy 2018; Fulkerson and Tushingham 2021; Mercader et al. 2018).

Archaeologists in the northern Great Basin—a region encompassing the intersection of the High Lava Plains of the Columbia Plateau and the northernmost Great Basin interior drainage—have long hypothesized that human settlement patterns and foraging behaviors during the Late Pleistocene/Early Holocene were tethered to rich lacustrine environments that included wetlands, marshes, and extensive sand dunes (Bedwell 1973; Duke and King 2014; Madsen 2007; Weide 1968). As regional human population densities increased, and aridity desiccated wetland resources, people were forced upslope to exploit a more diverse array of plants, including geophytes (Aikens and Jenkins 1994; Brashear 1994; Helmer and Tushingham 2021; Jenkins 1994; O'Connell 1975). Although some research from early Holocene archaeological sites in the region alludes to the use of upland geophytes (e.g., Blong et al. 2019; Bradley et al. 2022; Kennedy 2018; Kennedy and Smith 2016; Kingrey 2022; McDonough et al. 2022), it has been assumed that geophyte use is a Late Holocene phenomenon based on the establishment of large village sites located in upland environments across Fort Rock Basin (Brashear 1994; Housley 1994; Prouty 1994, 1995). For example, at Boulder Village, rock art sites are aggregated near upland playas containing rock ring features, abundant ground-stone tools, and numerous storage pits; the latter two were presumably used to process and store geophytes (Brashear 1994). Botanical surveys conducted around Boulder Village revealed that most sites are associated with occurrences of ethnographically important geophytes, including biscuitroot (*Lomatium* Raf.), yampa (*Perideridia* Rchb.), camas (*Camassia* Lindl.), sego lily (*Calochortus* Pursh.), and bitterroot (*Lewisia* Pursh.); these findings led investigators to conclude that root gathering was the primary subsistence focus in this area (Housley 1994; Jenkins 1994; Prouty 1994, 1995).

The Warner Valley uplands in southern Oregon (southeast of Fort Rock Basin) also support large populations of ethnographically important geophytes. Embedded within many of these populations are lava outcrops with thousands of rock art panels. As with Boulder Village, rock ring structures, ground-stone tools, and bedrock grinding surfaces are also documented (Figure 1; Cannon and Ricks 1986, 2007; Louderback, Wilks, and Simper 2022; Ricks 1995). It has been proposed that rock art sites in Warner Valley are intentionally located near ethnographically significant plant communities and are associated with the processing of those plant foods (Cannon et al. 1990; Cannon and Ricks 1986; Ricks 1995; Ricks and Cannon 1993). The current project tests the assumption that geophytes were collected and processed at these upland areas by sampling 58 bedrock metates at three rock art sites east of Warner Valley. Our research tests whether starch granules extracted from open-air bedrock metate surfaces can be identified as originating from *Lomatium* spp., an ethnographically significant plant that grows abundantly on the landscape near our study sites. The approach to archaeological

https://doi.org/10.1017/aaq.2024.42 Published online by Cambridge University Press

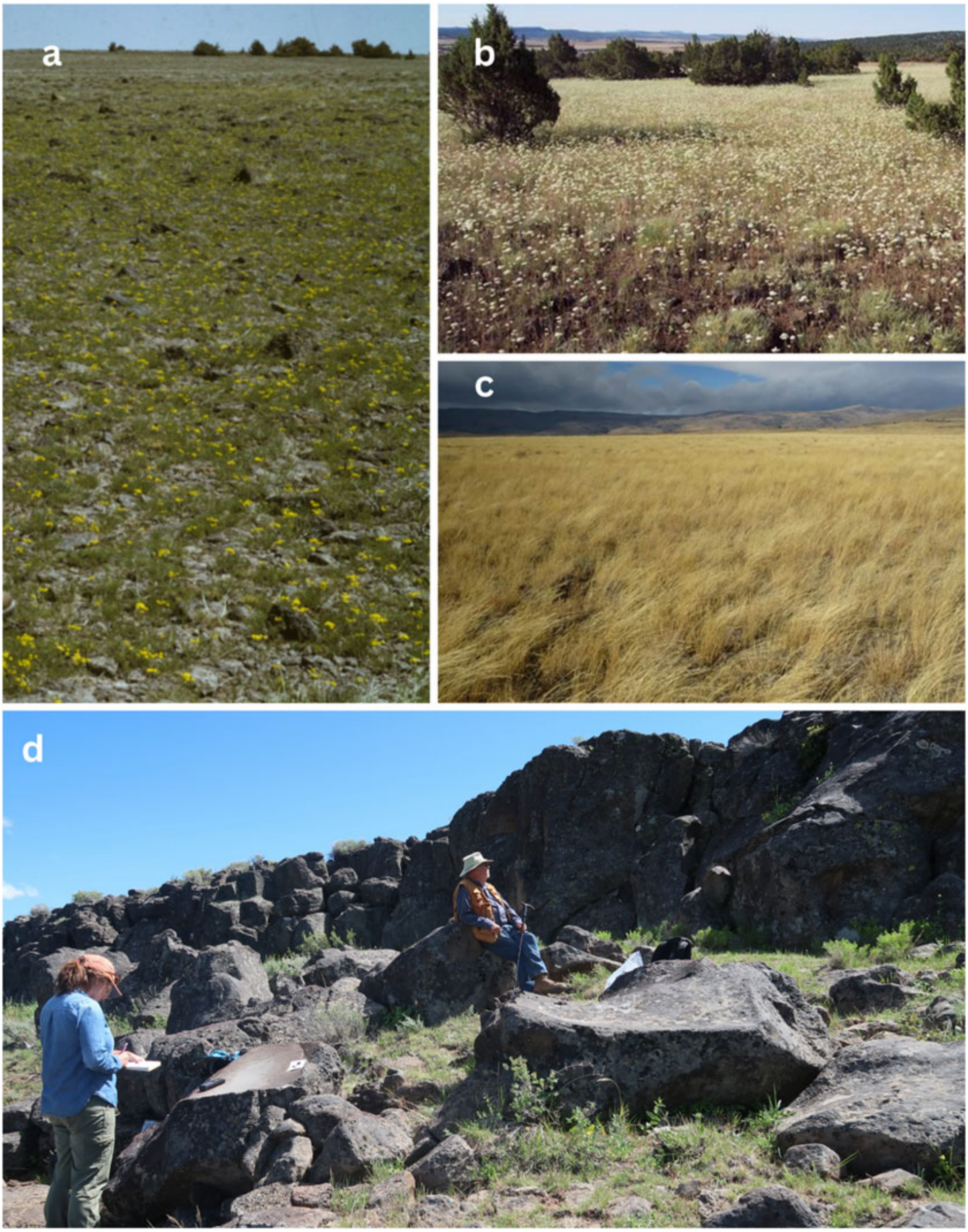

Figure 1. Upland habitats east of Warner Valley Oregon, support large populations of ethnographically important plant communities: (a) biscuitroot, (b) yampa, and (c) wild rye (photos by William J. Cannon). Embedded within many of these plant communities are (d) lava outcrops with hundreds of rock art panels and bedrock metates (photo by Stefania L. Wilks).

starch research, used herein, begins with a focused examination of specific plant taxa that are members of the local flora. Systematic studies are then conducted on reference granules from that subset so that observed morphological characteristics could be applied to the identification of starch granules recovered from archaeological contexts (Louderback, Wilks, et al. 2022). This project focuses on *Lomatium* because it grows abundantly in the uplands near the sites examined, it has a rich ethnographic record of use in the region, and it is shown to be highly nutritious.

Ethnographic Evidence of *Lomatium*

Lomatium is a genus in the carrot family (Apiaceae) that comprises more than 100 native species and subspecies distributed across western North America (Constance and Wetherwax 2023). These species and subspecies are typically associated with foothills and lower montane slopes, but some occur at higher elevations among alpine plant communities. They are perennially herbaceous forbs whose deep taproots prefer shallow, rocky soils (lithosols). *Lomatium* spp. flower after snow melt in early spring and produce seed before entering dormancy as summer daytime temperatures increase. Traditional ecological knowledge (TEK) describes at least 14 *Lomatium* species to be among the most important foraged plant foods in the Pacific Northwest: they may represent more than 30% of all ethnographically significant geophyte species harvested (Hunn 1981, 1990; Hunn and French 1981). All parts of the plant can be eaten fresh, but their fleshy taproots are preferred and prepared by pounding and grinding into dried cakes to be stored as winter reserves (Couture 1978; Couture et al. 1986; Hunn and French 1981; Prouty 1995).

According to ethnographic accounts, *Lomatium* was traditionally harvested with digging sticks in the spring as part of the systematic exploitation of seasonally available food resources. Harvesting began when flower stalks were still visible and had well-developed umbels, indicating larger taproots (Figure 2).

Recent experimental studies propose that past Indigenous management practices may have had a positive impact on geophyte growth and production (Botha et al. 2022; Carney et al. 2021; Thoms 1989; Trammell et al. 2008). Digging was restricted to zones of dense plant concentrations, which increased plot productivity by aerating soils and reducing competition for seeds dispersed during the digging process. When found in sufficient quantities and harvested according to traditional practices, *Lomatium* can provide substantial calories. Preliminary studies of densities and harvest rates suggest these geophyte resources could provide the bulk of the annual calorie requirement (Hunn 1981, 1990; Hunn and French 1981). Harvest rate estimates indicate that one forager could harvest a year's supply of *Lomatium* taproots for four people in 400 hours (Hunn and French 1981:92). When this TEK became established or how it may have changed over time is unknown. However, ethnobotanical data provided by the Indigenous people whose traditional lands are represented in the northwestern Great Basin clearly indicate that *Lomatium* was a resilient, primary food source with strong cultural affiliations (Couture 1978; Couture et al. 1986; Housley 1994; Hunn 1981; Prouty 1995; Stewart 1939).

Bedrock Metates and Starch Granule Analysis

Bedrock metates are shallow, often highly polished depressions created on the bedrock's surface through grinding or milling activities. They are ubiquitous throughout North America and are largely understood through their contextual relationship with landscape and ethnographic models (Burton et al. 2017; Lynch 2021; Lynch et al. 2017; Wilks et al. 2024). For example, in central Nevada, oval grinding slicks or depressions on boulders and rockshelter ledges were used to process pine nuts from nearby pinyon woodlands (Tinsley et al. 2021). In contrast to analyses of ground-stone tools preserved in a buried context, very limited starch research has been conducted on bedrock mortars and metates exposed to natural erosional elements (but see Wilks et al. 2024). Nevertheless, bedrock milling features have the potential to provide evidence of past human lifeways, including foods collected and processed, settlement patterns and land investment, and the frameworks for social identity (Buonasera 2012, 2015; Burton et al. 2017; Fulkerson and Tushingham 2021; Lynch 2021; Lynch et al. 2017; Shoemaker et al. 2017; Stevens et al. 2019; Tinsley et al. 2021).

The study of starch granules preserved in archaeological contexts can refine our understanding of which plant taxa people were processing. Carbohydrates produced during photosynthesis are stored as starchy reserves in seeds, fruits, and underground organs. Grinding processes related to human cultural activities release the starches that become deeply lodged in the surface cracks and crevices of stone artifacts. Due to their semi-crystalline structure, starch granules can remain preserved in archaeological

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Figure 2. (a) Flowering individual of *Lomatium* in late spring/early summer (photo by Stefania L. Wilks). Inset showing bulbous taproot, the underground storage organ; (b) *Lomatium* was traditionally harvested with digging sticks in the spring as part of the systematic exploitation of seasonally available food resources (photo courtesy of Washington State Digital Archives).

contexts for millennia, thus providing direct evidence of plant exploitation. Systematic morphometric studies of modern plant starches, including granule size, shape, and 3D-surficial structuring, provide useful taxonomic references through which archaeological identifications can be made with reliable accuracy (Henry 2020; ICSN 2011; Liu et al. 2014; Louderback et al. 2017; Louderback, Wilks, et al. 2022; Mercader et al. 2018; Reichert 1913; Wang et al. 2019).

Recent starch analysis on excavated ground stone tools has revealed evidence of geophyte use by Late Pleistocene / Early Holocene hunter-gatherer populations in western North America (Herzog and Lawlor 2016; Joyce et al. 2022; Louderback and Pavlik 2017; Rankin 2016; Rhode and Rankin 2020). On the Colorado Plateau in southern Utah, residues found on ground-stone tools buried in North Creek Shelter indicate the use of a native potato, *Solanum jamesii*, as early as 10,900 years ago (Louderback and Pavlik 2017). Geophyte starch was also identified on early Holocene tools from Hogup Cave in Utah (Herzog and Lawlor 2016). Evidence for the processing of spring parsley (*Cymopterus* spp.) at Early and Middle Holocene sites (around 9400–4400 cal BP) in the Wyoming Basin was documented on ground-stone tools (Joyce et al. 2022). And ground stone from high elevations (around 8300–1400 cal BP) as far ranging as the White Mountains of California and Wyoming's Wind River Range (Rankin 2016; Rhode and Rankin 2020) supports the dietary importance of geophytes throughout the Holocene.

Methods and Materials

Bedrock Metates

Starch residues were extracted from 58 open-air bedrock metates at the three upland rock art sites in southern Oregon: six from Corral Lake (35LK500), 28 from Barry Spring (35LK502), and 24 from

https://doi.org/10.1017/aaq.2024.42 Published online by Cambridge University Press

Long Lake (35LK514) (Figure 3; supplemental data archived in DRYAD, https://datadryad.org/stash/dataset/doi:10.5061/dryad.tqjq2bw52). The bedrock metate features occur on fine-grained, basalt outcrops containing hundreds of petroglyphs and pictographs and are situated along the edges of upland playa lakes and springs (Cannon and Ricks 1986; Ricks 1995; Ricks and Cannon 1993).

Rock art and bedrock metates from all three sites show evidence of patination, a geochemical process thought to develop a varnish on inorganic surfaces over time caused by weathering. Some of the patinated grinding surfaces showed evidence of more recent reuse occurring on top of the patina surface (Figure 4). A subset of bedrock metates in this study were sampled based on the presence of patina ($n = 12$) or patination with reuse ($n = 8$) on their surface. The remaining bedrock metates sampled ($n = 38$) were associated with rock art panels but did not exhibit patina on their surface.

Starch Granule Analysis

Reference Materials. Plant lists were compiled and specimens collected in the field to document site floras with particular focus on *Lomatium* spp. because of its importance to Indigenous communities as well as its abundance and ubiquity across the landscape (Louderback, Wilks, and Simper 2022). Vouchered specimens were mounted, labeled, and reposited in the Garrett Herbarium, Natural History Museum of Utah (NHMU), as well as on the Intermountain Regional Herbarium Network. The collection is titled "Flora of Warner Valley, Oregon-Geophyte Study" (http://intermountainbiota.org/portal/collections/index.php?catid=1) to document site floras (Louderback, Wilks, and Simper 2022).

Our approach to identifying archaeological starch granules from bedrock metates began with a systematic study of *Lomatium* granules extracted from extant plant populations within the vicinity of each site (Louderback, Wilks, and Simper 2022). Three *Lomatium* species (*L. donnellii*, *L. macrocarpum*, and *L. triternatum*) were collected, and each taproot (three per species) was sampled for starch. Using randomly generated x–y coordinates on the microscope stage, we described and measured morphological characteristics, such as size, shape, and surface features, of 100 starch granules from each taproot ($n = 900$ granules total; for descriptions of morphological characteristics, see Louderback, Wilks, et al. 2022). The frequency of characteristics occurring on granules was calculated and expressed as a number between 0.0 and 1.0. This approach allowed us to develop a set of

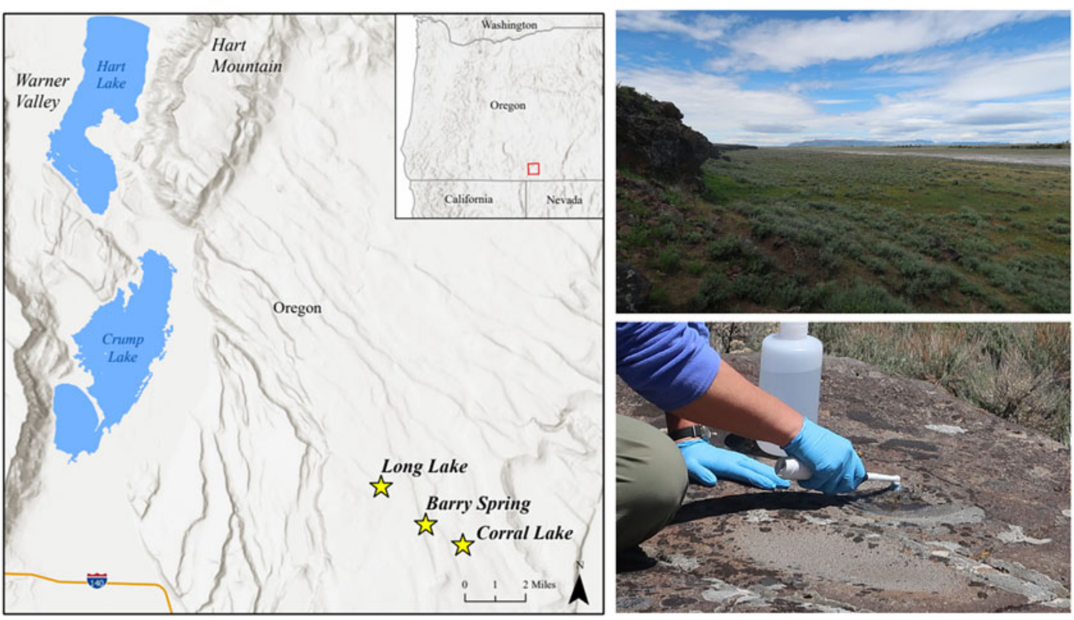

Figure 3. Starch residues were extracted from bedrock metates at Corral Lake, Barry Spring, and Long Lake. Bedrock metate features occur on fine-grained volcanic basalt outcrops containing hundreds of petroglyphs and pictographs situated along the edges of upland playa lakes and springs (photos by Stefania L. Wilks).

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Figure 4. (*Upper panel*) Rock art panels identified as Great Basin Carved Abstract (GBCA) were found buried beneath a Mt. Mazama ash layer in association with Western Stemmed projectile points. (*Lower panel*) A subset of bedrock metates was sampled based on the presence of patina (*left*) or reuse over surface patination (*right*) (photos by Stefania L. Wilks).

statistically defined characteristics frequently observed in *Lomatium* granules, which could then be applied to the identification of archaeological granules (Figure 5).

Sample Collection in the Field. After collecting starch samples from the surfaces of 58 bedrock metates from all three sites, we assessed environmental contamination by collecting separate metate surface and noncultural control samples. These samples were analyzed in conjunction with the samples extracted from deeper within the bedrock metate's geologic matrix (for the expanded protocol, see Wilks et al. 2024). All consumable supplies were used only once to prevent cross-contamination during sampling in the field. Loose sediment was brushed from metate surfaces before sampling. Approximately 50 mL of distilled water (DH_20) was then added to the stone surface and cleaned with an ultrasonic toothbrush. A sterile syringe was used to transfer the DH_20 and sediment to a sterile test tube labeled "surface extract." This was repeated until the DH_20 wash was clear.

Next, 50 mL of a 2.5% solution of sodium hexametaphosphate (Na-Hex) was added to the cleaned bedrock surfaces to deflocculate residue that was more deeply embedded in the stone's interstitial matrix. After about an hour, approximately 50 mL of DH_20 was added, and a sterile ultrasonic toothbrush was used to vigorously clean the surface for five minutes. A sterile syringe was then used to transfer the resultant serum to a 50 mL test tube labeled "interstitial extract."

Control Samples. Thirteen control samples (Barry Spring, $n = 6$; Corral Lake, $n = 1$; and Long Lake, $n = 6$) were also collected from nonworked or noncultural stone surfaces about 5–10 m from the sampled archaeological bedrock metates. These control samples were collected at each site and treated in

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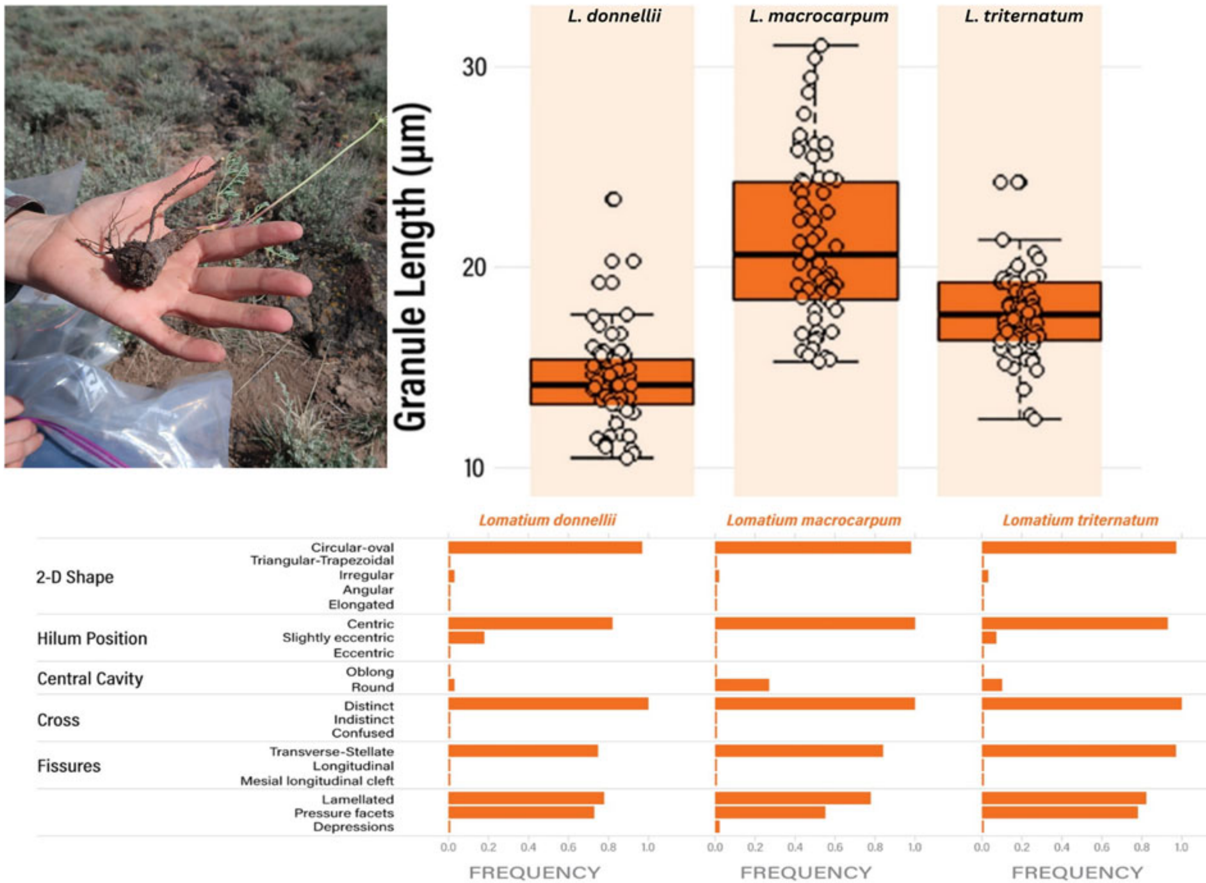

Figure 5. (*Upper left*) Three *Lomatium* species (*L. donnellii*, *L. macrocarpum*, and *L. triternatum*) were collected near the three study sites and sampled as starch reference material (photo by Lisbeth A. Louderback). (*Upper right and lower panel*) Diagnostic characteristics of more than 900 starch granules were quantified and used to identify archaeological starch residues (adapted from Louderback, Wilks, and Simper 2022).

the same way as the surface and interstitial starch samples. Control samples were labeled as “control” and numbered consecutively as they were collected in the field. The aim was to compare the control sample residue to the residue extracted from the bedrock metate. Although noncultural stone surfaces in the vicinity of bedrock metates may have been contaminated with starch from associated plant materials, this source would yield insignificant levels of starch granules when compared to starch granules ground into the stone matrix of bedrock cultural features and artifacts.

Laboratory Analysis. All samples were processed in the Archaeobotany Laboratory at the Natural History Museum of Utah (NHMU). Each residue serum was sieved through a 125 µm mesh Endecotts sieve into a beaker using deionized water (DiH_20). Sample water greater than 125 µm was discarded, while the sampled portion under 125 µm was retained and transferred to a 50 mL test tube and centrifuged for 3 minutes at 3000 RPM. The supernatant was then discarded and the sample pellet transferred to a new 15 mL test tube, resuspended with about 10 mL of DiH_20, mixed with a vortex, and centrifuged for 3 minutes at 3000 RPM. Approximately 7 mL of Lithium heteropolytungstate (LST: specific gravity 2.2) was added, resuspended with a vortex mixer, and then centrifuged for 15 minutes at 1000 RPM. The starch samples were extracted from the surface of the heavy liquid using a pipette and transferred to a freshly labeled 15 mL test tube. To remove any residual heavy liquid, each sample was rinsed two to three times with about 10 mL of DiH_20, vortexed, and centrifuged for 3 minutes at 3000 RPM. The sample was then decanted and resuspended with about 7 mL of acetone, mixed with a vortex, and centrifuged for 3 minutes at 3000 RPM. The acetone was decanted, and samples were covered and left to dry overnight. Individual samples were reconstituted with 50% DiH_20 and 50% glycerol and mounted on a glass slide for observation. Each slide was scanned in its entirety using a transmitted brightfield microscope fitted with polarizing filters and Nomarski optics (Zeiss Axioscope 2, Zeiss International, Göttingen). Starch granules were photographed under 400× magnification with a digital camera (Zeiss HRc) and measured with Zeiss Zen software.

Results

Bedrock Metates

Twelve bedrock metates displayed visible patina, seven of which yielded a total of 101 starch granules. Of these, five granules (5%) were attributed to *Lomatium* and six (6%) to Apiaceae. Eight bedrock metates were patinated with evidence of reuse; seven of these surfaces yielded a total of 130 granules, of which nine (7%) were attributed to *Lomatium* spp. and 18 (14%) to Apiaceae. There is a difference in mean starch yield between patina versus reused surfaces (reused surfaces produced higher yields), although it was not quite statistically significant ($t = 1.73$, $df = 18$, $p = 0.10$).

Starch Granule Analysis

Reference Materials. Granule size distributions for each of the species were pooled ($n = 300$ per species) and their distributions were plotted. Morphological characteristics occurred more frequently in the top 20% size range of starch granules, and therefore, we report frequencies for those granules (Liu et al. 2014; Louderback et al. 2017; see Figure 5).

Seven diagnostic characteristics were used to identify archaeological granules of *Lomatium* spp. (Louderback, Wilks, et al. 2022): size range of 10.7–31.0 µm, circular to oval shape, centric hilum, distinct extinction cross, fissure (transverse/stellate), visible lamellae, and pressure facets. Archaeological starch granules exhibiting six or seven of these characteristics are considered *Lomatium* spp. (Figure 6). Granules displaying four or five are attributed to their family, Apiaceae. Starches with fewer than three characteristics remain unidentifiable.

Laboratory Analysis. Interstitial residues extracted from 43 of the 58 metate surfaces yielded a total of 644 starch granules. Of those 644 starch granules, 81 (13%) were assigned to *Lomatium* spp., and 107 (17%) were identified as belonging to Apiaceae (Figure 6; Table 1). Control and surface samples associated with each site yielded significantly fewer starch granules than the interstitial samples overall. Control samples yielded four starch granules, whereas surface samples yielded a total of two granules (Wilks et al. 2024).

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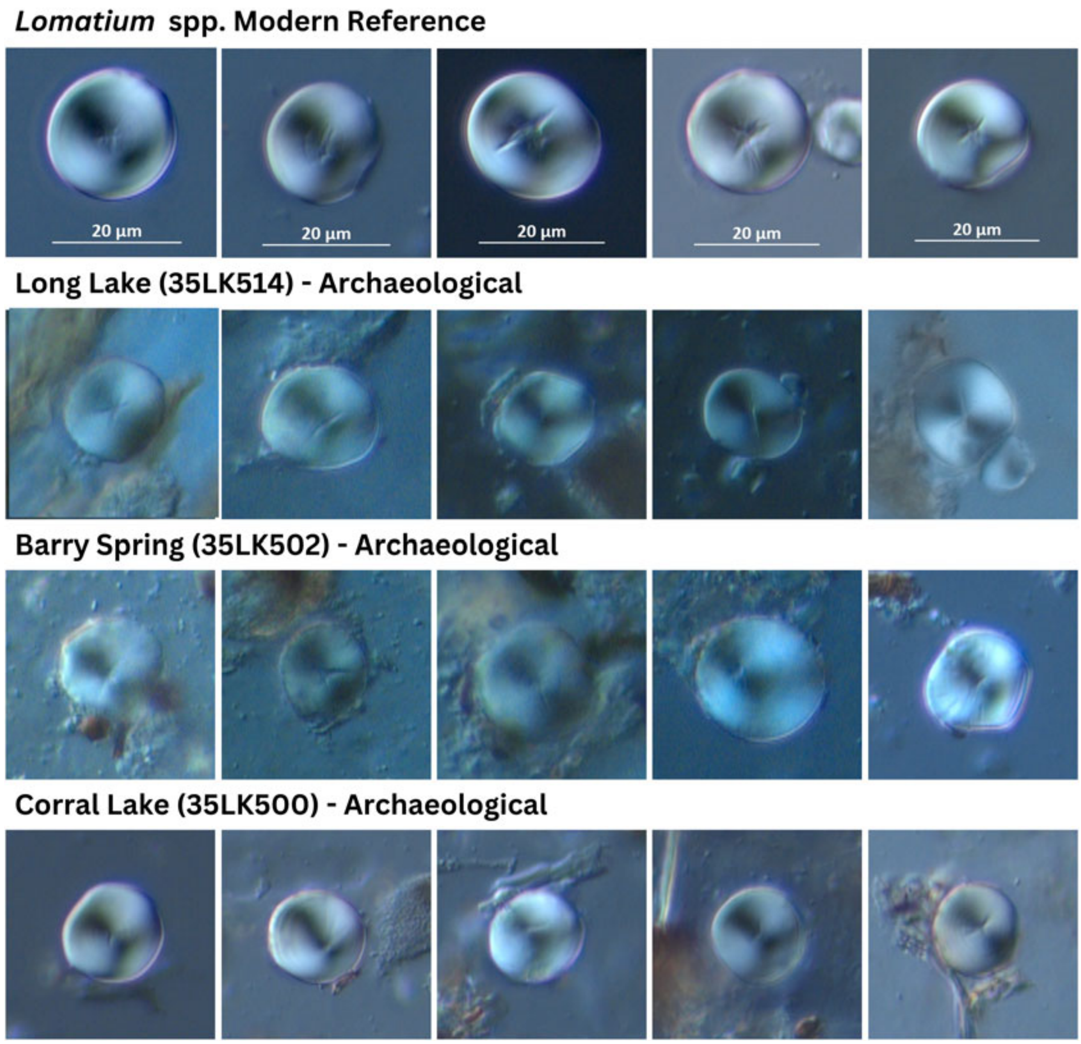

Figure 6. Micrographs of *Lomatium* spp. starch granules shown in differential interference contrast (DIC). (*Top row*) Reference granules from *Lomatium* spp. harvested from boundaries within each site. (*Bottom rows*) Archaeological granules extracted from bedrock metates at Long Lake, Barry Spring, and Corral Lake attributed to *Lomatium* spp (see reference photos for scale).

Although the current study focuses on the presence of *Lomatium* spp., starch granules from other plant species were also present on the bedrock metates from Corral Lake, Barry Spring, and Long Lake. Granules of Triticeae, the grass tribe that includes wild rye, barley, and wheat, occurred frequently (6%) on the metate surfaces. Two species of wild rye (*Leymus cinereus* and *Elymus elymoides*) grow at the sites today, so it is conceivable that people in the past also collected and processed these grasses. Despite our attempts to identify archaeological starch granules, a large number of granules (80%) extracted from the bedrock metates remain unidentified due to enzymatic damage. Nevertheless, every granule observed in this study was photographed and measured to enable future identification (https://doi.org/10.5061/dryad.tqjq2bw52).

Discussion

Despite the historical and contemporary significance of geophytes to Indigenous groups across the globe, archaeological evidence for their use is difficult to reveal. Starch granule analysis is a novel technique used by archaeologists to assess the significance of plants in ancient human diets and expose which plant species were collected and how they were processed. Recent starch granule analyses

Table 1. Interstitial (Archaeological) and Surface Starch Granules Recovered from Bedrock Metates at Corral Lake ($n = 6$), Barry Spring ($n = 28$), Long Lake ($n = 24$), and All Control Samples ($n = 13$).

		Total Starch Granules	Size Range (µm)	Granules Assigned *Lomatium* spp.	Granules Assigned Apiaceae
Corral Lake:	Interstitial	126	7.26–37.69	24	46
	Surface	0	—	—	—
	Control	0	—	—	—
Barry Spring:	Interstitial	346	5.10–39.46	16	27
	Surface	0	—	—	—
	Control	2	28.03–36.57	0	0
Long Lake:	Interstitial	172	1.32–42.66	40	34
	Surface	2	13.37–22.47	0	0
	Control	4	12.44–18.60	0	3

have shed light on the importance of plants in ancient human diet (Henry 2020; Herzog and Lawlor 2016; Joyce et al. 2022; Louderback and Pavlik 2017; Rankin 2016; Rhode and Rankin 2020).

The present study identified starch granules, including biscuitroot (*Lomatium* spp.), on bedrock metate surfaces at all three rock art sites (Corral Lake, Barry Spring, and Long Lake), thus providing direct evidence for the processing of an ethnographically significant geophyte growing nearby. Some of these bedrock metates had a patina, suggesting older grinding surfaces, whereas others showed evidence of reused surfaces embedded within the patination (Cannon and Ricks 1999; Middleton et al. 2014). Our results indicate that archaeological starch residues can be extracted from the interstitial matrices of grinding surfaces, regardless of patination and its effects on bedrock metate features.

Rock art sites and bedrock metates in the uplands east of Warner Valley are associated with Late Pleistocene / Early Holocene archaeology (Benson et al. 2013; Cannon and Ricks 1999; Middleton 2013; Middleton et al. 2014; Ricks 1995; Smith and Barker 2017). Rock art panels identified as Great Basin Carved Abstract (GBCA) were found buried beneath a layer of Mt. Mazama ash (eruption around 7,560 ybp) and in association with Western Stemmed projectile points (Middleton et al. 2014; Smith and Barker 2017). Western Stemmed projectiles are chronologically associated with Late Pleistocene / Early Holocene archaeological contexts (Brown et al. 2019; Jenkins et al. 2012; Smith et al. 2020) and are frequently used as regional measures of relative dating (Rosencrance et al. 2022). In addition to being associated with Western Stemmed projectile points, the rock art panels and bedrock metates are also embedded within extant populations of ethnographically significant geophytes. These geophyte plant communities would have been a reliable source of carbohydrates to people living in the region (Carney et al. 2021; Couture et al. 1986; Madsen 2007; McGuire and Stevens 2017; Prouty 1995; Steward 1933). Therefore, it is possible that the collecting and processing of upland geophytes were important parts of subsistence lifeways since the transition from the last Ice Age. Whether the bedrock metates in this study were created and used by people living on the landscape during the Late Pleistocene / Early Holocene remains unclear, however. Given the open-air nature of these features, it is possible they were used repeatedly to process geophytes throughout the Holocene.

Although archaeological features such as rock art and bedrock metates are difficult to date, they are contextually and functionally tied to our understanding of past people's relationships with their environment (Buonasera 2012, 2015; Fulkerson and Tushingham 2021; Lynch 2021; Lynch et al. 2017; Shoemaker et al. 2017; Stevens et al. 2019; Tinsley et al. 2021). Bulk resource processing at fixed locations is often done in large family groups or at community-level events (Adams 1999; Helmer and Tushingham 2021; Lynch 2017; Lynch et al. 2021; Madsen and Schmitt 1998; McCarthy et al. 1985; O'Connell et al. 1991). In Warner Valley, all the largest rock art sites recorded—Long Lake, MC Reservoir, Portrait Rim, Point Juniper Reservoir, North of Point Juniper, Barry Spring, Hidden Lake, 44 Lake, and Corral Lake—contain bedrock metates (Cannon and Ricks 1986; Ricks 1995). The presence of geophyte starch granules, specifically *Lomatium* spp., a plant found growing near the sites today, supports the hypothesis that rock art sites with bedrock metate grinding features are intentionally located near ethnographically significant plant communities and that they are associated with the processing of those plant foods (Cannon and Ricks 1986, 2007; Cannon et al. 1990; Ricks 1995).

Indigenous people of the northern Great Basin possess a rich cultural identity with geophytes as essential components of their nutritional subsistence strategies (Couture et al. 1986; Fulkerson and Tushingham 2021; Helmer and Tushingham 2021; Housley 1994; Hunn 1981; Kelly 1932; Prouty 1995; Steward 1933; Stewart 1939). The gathering of native geophytes, such as biscuitroot, yampa, bitterroot, camas, and sego lily, remains important in traditional cultural practices. Ethnohistoric accounts describe starchy, edible geophytes such as *Lomatium* as highly valued root crops that were traditionally harvested in the spring, when groups or families migrated to "root-digging" camps in the mountains. Seasonal harvesting campgrounds were social places that brought extended families together, facilitating the exchange of knowledge and trade goods, the arrangement of intertribal marriages, important regional gambling competitions, and strengthening bonds of cooperation required for survival in semiarid landscapes (Couture et al. 1986; Fowler 1989; Wewa and Gardner 2017). Wilson Wewa, a member of the Warm Springs Paiute and a keeper of traditional knowledge, recalls learning the stories of his people while harvesting geophytes as a young boy with his extended family in the mountains of southeast Oregon (Wewa and Gardner 2017).

TEK evolves through generations of holistic practices aimed at increasing the quantity or quality of culturally preferred plants (Anderson 2005; Berkes 2018; Fowler and Leland 1967; Fowler and Lepofsky 2011; Fowler and Rhode 2006; Hunn 1981; Hunn and French 1981; Nabhan 2000). Hunter-gatherer societies have often been portrayed as passively existing within their environments, but ethnobotanical researchers have demonstrated that these groups actively managed landscapes through sophisticated practices. A growing body of research argues that Indigenous peoples were managing their landscapes long before the arrival of European-based colonists (Anderson 1997, 2005; Carney et al. 2021; Deur 2009; Deur and Turner 2005; Fowler 1982; Pavlik et al. 2021; Peacock and Turner 2000; Stewart 2002; Turner 2014, 2020a, 2020b). Low-intensity land management practices as strategic burning, tilling, and seed dispersal may have contributed to long-term stable economies and social organizations very distinct from traditional agrarian societies (Lightfoot et al. 2013). Sustainable Indigenous ecological practices, such as controlled burning to promote the growth of edible plants and enhance animal habitats, the cultivation of "semi-domesticated" plants, such as berry patches, and the management of shellfish beds, ensured long-term productivity and resilience in resource systems (Deur 2009; Lepofsky et al. 2005; Lightfoot et al. 2013). In the northwestern Great Basin, Klamath and Modoc communities intentionally modify the landscape to meet their dietary, social, and spiritual needs by managing culturally preferred plant species and their habitats. Likewise, Paiute communities develop cultural practices centered around the gathering, preparation, and consumption of geophytes (Brashear 1994; Couture 1978; Couture et al. 1986; Deur 2009; Deur and Turner 2005; Housley 1994; Kelly 1932; Prouty 1995; Steward 1933). Connecting past human foodways with the present exemplifies TEK empowers Indigenous food sovereignty and can be used to inform public land management policy.

Conclusion

Plant communities rich in geophyte species are essential to the traditional lifeways of many Indigenous groups across the globe. These species are closely associated with archaeological features in the northern Great Basin, suggesting their cultural and dietary significance throughout time. Starch granule analysis can assess that significance by revealing which plant species were collected and how they were processed. Furthermore, this novel technique often corroborates ethnohistoric and contemporary accounts of traditional plant use.

Geophytes are recognized for their multifaceted roles in Indigenous cultures, serving not only as food resources but also as catalysts for social cohesion, cultural exchange, and cooperative endeavors. Their importance extends beyond mere sustenance to encompass broader aspects of community well-being and identity. Understanding the cultural and ecological significance of geophytes can inform public land management policy, fostering more inclusive and sustainable approaches to natural resource management. Incorporating Indigenous perspectives and traditional ecological knowledge into decision-making processes supports the conservation and stewardship of geophyte habitats.

Acknowledgments. The bedrock grinding surfaces and rock art features described in this research exist on sacred ground that has been respected, cared for, cherished, and protected over the ages and to this day by the Klamath, Modoc, and Paiute Peoples. We commit to follow their lead in the conservation and stewardship of these habitats. We are grateful to the BLM Lakeview Office, especially Carolyn Temple for funding our cooperative agreement, and Grace Haskins, Shelli Timmons, and Cynthia Brown for executing the funding. Kathy Stewardson joined us in the field and helped choose the bedrock metates for sampling: we appreciate her time and advice throughout the project. Thank you to Samantha Paredes for assisting with starch samples in the lab and mounting plant specimens on herbarium sheets. Thank you to Allison Izaksonas for repositing the herbarium collection into the NHMU Garrett Herbarium and imaging them for online access. We also thank Phoebe McNally at the DigitLab (University of Utah) for making the maps, and Fanny Blauer for translating our abstract into Spanish.

Funding Availability Statement. Funding for this project came from the Department of the Interior Bureau of Land Management (Lakeview District Office) Cooperative Agreement (L20AC00050) awarded to Lisbeth A. Louderback.

Data Availability Statement. Starch granule measurements, descriptions, and images are available at https://doi.org/10.5061/dryad.tqjq2bw52.

Competing Interests. The authors declare none.

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Cite this article: Wilks, Stefania L., Lisbeth A. Louderback, Heidi M. Simper, and William J. Cannon. 2025. Starch Granule Evidence for Biscuitroot (*Lomatium* spp.) Processing at Upland Rock Art Sites in Warner Valley, Oregon. *American Antiquity* **90**(1):200–216. https://doi.org/10.1017/aaq.2024.42.